SY-01 SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER STUDY REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT FERC NO. 553

Seattle City Light

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Updated Study Report

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List of Acronyms and Abbreviations

AFS ....American Fisheries Society
CFS ....Cramer Fish Sciences
City Light...................Seattle City Light
DFC............................desired future conditions
Ecology ....Washington State Department of Ecology
EDT............................ecosystem diagnosis treatment
EEM ....estuarine emergent marsh
ESA ....Environmental Science Associates
ESRP ....Estuary and Salmon Restoration Program
ESU ....evolutionary significant unit
FERC..........................Federal Energy Regulatory Commission
FL...............................fork length
FRT ....forested riverine tidal
GUI ....graphical user interface
HGMP ....hatchery and genetic management plans
HU..............................hydrologic unit
ILP..............................Integrated Licensing Process
ISR ....Initial Study Report
LWD ....large woody debris
LP...............................licensing participant
LSF.............................life stage factor
MHHW ....mean higher high water
MMPA ....Marine Mammal Protection Act
MPG...........................major population group
MPN...........................most probable unit
NMFS.........................National Marine Fisheries Service
NWFSC......................Northwest Fisheries Science Center
NWRFC ....Northwest River Forecast Center
NWS...........................National Weather Service
PME ....protection, mitigation, and enhancement
Project ....Skagit River Hydroelectric Project

PFC ....properly functioning conditions
RM ....river mile
RSP ....Revised Study Plan
SDM...........................structured decision making
SLR ....sea level rise
SPD ....Study Plan Determination
SS ....scrub shrub
SSL.............................suspended sediment load
SSM............................size selective mortality
SWE ....snow water equivalent
USACE .......................U.S. Army Corps of Engineers
USFWS .......................U.S. Fish and Wildlife Service
USGS ..........................U.S. Geological Survey
USR............................Updated Study Report
WDFW.......................Washington Department of Fish and Wildlife
WRIA.........................Water Resource Inventory Area

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1.0 INTRODUCTION

The SY-01 Synthesis and Integration of Information on Resources in the Lower Skagit River (Synthesis Study) is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021). On June 9, 2021, City Light filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the RSP agreed to between City Light and supporting licensing participants (LP) (which include the Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service [NMFS], National Park Service, U.S. Fish and Wildlife Service [USFWS], Washington State Department of Ecology [Ecology], and Washington Department of Fish and Wildlife). The June 9, 2021 Notice included agreed to modifications to the Synthesis Study.

In its July 16, 2021 Study Plan Determination (SPD), FERC approved the Synthesis Study without modification. On March 8, 2022, City Light filed its Initial Study Report (ISR). Skagit County filed a request for study modification. In the August 8, 2022 Determination of Requests for Study Modification, FERC did not recommend adopting City Light's proposal in the ISR to include in the Synthesis Study the Swinomish and Stillaguamish river deltas or nearshore habitats in Padilla Bay. Notwithstanding, City Light is implementing the Synthesis Study as proposed with the agreed to modifications described in the June 9, 2021 Notice and further described in the Synthesis Study Interim Report (City Light 2022a).

This study is complete and a report of the study efforts is being filed with FERC as part of City Light's Updated Study Report (USR).

[1] Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

2.0 STUDY GOALS AND OBJECTIVES

The goal of the study is to compile, analyze, and summarize available data and studies on anadromous fish resources using the Skagit River watershed, characterize factors affecting these populations, develop conceptual life history models of each population, and develop hypotheses to understand potential impacts of the Project and other contributing factors in the watershed. Existing information on watershed-wide contributing factors will then be updated and integrated with the results of studies being conducted as part of the Integrated Licensing Process (ILP) to determine the major factors affecting each target species, which may further inform preferred watershed-based measures and/or longer-term adaptive management processes for protecting and enhancing target anadromous salmonid populations in the Skagit River. The recommended target species are Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch*), Sockeye Salmon (*Oncorhynchus nerka*), Chum Salmon (*Oncorhynchus keta*), Pink Salmon (*Oncorhynchus gorbuscha*), Bull Trout (*Salvelinus confluentus*), and steelhead (*Oncorhynchus mykiss irideus*). Based on the preliminary data review and consultation with LPs in the December 2021 Synthesis Study Work Group Meeting, the target species for the Synthesis Study has been clarified to include Pacific Lamprey (*Lampetra tridentata*).

Study requests raise hypotheses that Project operations may detrimentally affect conditions in the lower Skagit River downstream of the Sauk River and in the estuary related to water quality, habitat availability, wood and sediment transport, riparian and floodplain conditions, and other factors that may impact the life stages of anadromous fish resources using the lower river, delta, and estuary. As noted in the RSP, quantification of Project-related effects on anadromous fish resources in the lower Skagit River represents a significant scientific challenge given the multitude of factors interacting with resources and processes in the lower Skagit River. This study is intended to summarize and synthesize available data and existing analyses by others (e.g., recovery plans, peer-reviewed and gray literature) that have investigated the conditions of these resources in the study area to date. Some of these factors are listed as potential topics of interest below:

- Geomorphology (e.g., geomorphic change, channel migration and incision; aquatic habitat; side channel/off channel connection; floodplain connectivity; substrate and sediment; wetlands; sediment transport; and large wood inventories);
- Landforms;
- Water quality;
- Aquatic primary and secondary productivity;
- Fish and aquatic habitat (e.g., species limiting factors; habitat quality and quantity; salmonid population trends);
- Riparian vegetation and wetlands;
- Available modeling tools (e.g., hydraulic, biological, geomorphologic); and
- Other watershed and regional activities and land uses (e.g., forestry/logging, agriculture, commercial/industrial, shoreline development, levees, shoreline hardening, floodplain development and encroachment, irrigation/diking, urban landscapes).

Per the June 9, 2021 Notice, additional commitments related to the goals and objectives of the Synthesis Study include:

- City Light will perform additional field studies in 2022 to fill data gaps that are unaddressed in the Synthesis Study or other studies below the Sauk River confluence.
- City Light will consolidate the results of the Synthesis Study and baseline data collected in other studies that extend below the Sauk River confluence in the USR in an attempt to identify Project effects below the Sauk River confluence.

A full list of City Light's commitments from the June 9, 2021 Notice with respect to the Synthesis Study is included in Section 6.2 of this study report.

The Synthesis Study is subdivided into four steps: (1) data compilation; (2) data analysis; (3) identification of factors affecting the target species by reach and life stage; and (4) identification of Key Uncertainties for each of these factors and the data/information needed to address/reduce these uncertainties. Each step is briefly described below and expanded upon in the Methodologies Section of this study report. The review and synthesis of existing information and available information from other studies being undertaken under the ILP will be used to identify any additional field data collection needs related to investigating the Project's effects on anadromous salmonids in the reach below the Sauk River. The results of this study will help establish a broader understanding of potential preferred protection, mitigation, and enhancement (PME) measures to protect and improve the target species and/or initiate consensus-based studies to increase the understanding of specific Key Factors.

Step 1: Data Compilation

The first step of the Synthesis Study is to assemble and review relevant and available information to characterize the status of each target species and physical and ecological attributes of important habitats for individual salmonid life stages of these target species in the lower Skagit River system.

Step 2: Data Analysis

Data inventories will be developed to summarize the information available for the study area, target species, and topics of interest. Relevant information collected during data compilation will be reviewed to develop life-history-based conceptual models of each of the Skagit River target anadromous fish species using the lower river, delta, and estuary. To the extent possible and practical, linkages will be explored between species abundance/productivity and land and water uses, physical and ecological watershed processes, habitat conditions in the lower Skagit River and delta/estuary, hatchery operations, ocean conditions, and the effects of these factors on anadromous fish resources. For example, information from the literature on resource conditions, life stage factors (LSF), drivers and stressors, and data gaps identified in the literature will be analyzed and synthesized to support Steps 3-4, which includes an initial assessment of relative importance as described in Step 3.

Step 3: Life Stage Factors Affecting Target Species

Using a life-history framework, key in-river and delta/estuary factors thought to be of greatest importance to each of the target anadromous fish populations in the Skagit River watershed will be identified based on the work conducted in the data compilation and data analysis steps. Factors considered would include those identified above in the Topics of Interest. Potential relationships between these Key Factors affecting anadromous fish resources in the Skagit River below the Sauk River confluence and Project operations will be identified from the synthesized literature.

Step 4: Identification of Key Uncertainties

Based on the information and data developed in the first three steps, this step includes identifying areas where further data are necessary to understand the key mechanisms and Project operations affecting species and their respective in-river, delta, and estuary life stages. Where large uncertainties and/or data gaps exist related to analyzing Project effects on Key Factors affecting anadromous fish resources, specific studies to reduce uncertainties and/or fill data gaps will be identified.

2.1 Key Questions

As noted in the study plan, the goals of this study are to compile, summarize, and analyze available data and studies on anadromous fish resources using the Skagit River watershed, characterize factors affecting these populations, develop conceptual life history models of each population, and develop hypotheses to understand potential impacts of the Project and other contributing factors in the watershed. The preliminary approach described in this study report is designed to address several key questions that address the goals of the Synthesis Study, including:

- What is the condition of resources in the lower Skagit River?
- What are the contributing factors to resource conditions in the lower Skagit River?
- What data gaps and research or monitoring needs might limit our ability to describe how Project operations influence conditions in the lower Skagit River?

To understand the condition of resources in the lower Skagit River, the Synthesis Study will directly address this question by developing an inventory and archive of available data for the lower Skagit River study area. This information will be used to describe the condition of resources in the lower Skagit River study area based on the best available information. This information will then support identifying the contributing factors to resource conditions in the lower Skagit River through development of conceptual life history models for anadromous salmonids that integrate factors affecting survival from one life stage to another.

As noted in the study plan, quantification of Project-related effects on anadromous fish resources in the lower Skagit River represents a significant scientific challenge given the multitude of factors interacting with resources and processes in the lower Skagit River. The data inventory and conceptual life history models developed by this study intend to support identification of data gaps and monitoring needs that currently limit the ability to describe how Project operations influence resource conditions in the lower Skagit River in the context of other factors that influence resources. In addition, this study will support the identification of Key Uncertainties for hypotheses related to potential Project-related impacts or contributing factors and their influence on resource conditions or life stage transitions that could be addressed by additional research or monitoring.

3.0 STUDY AREA

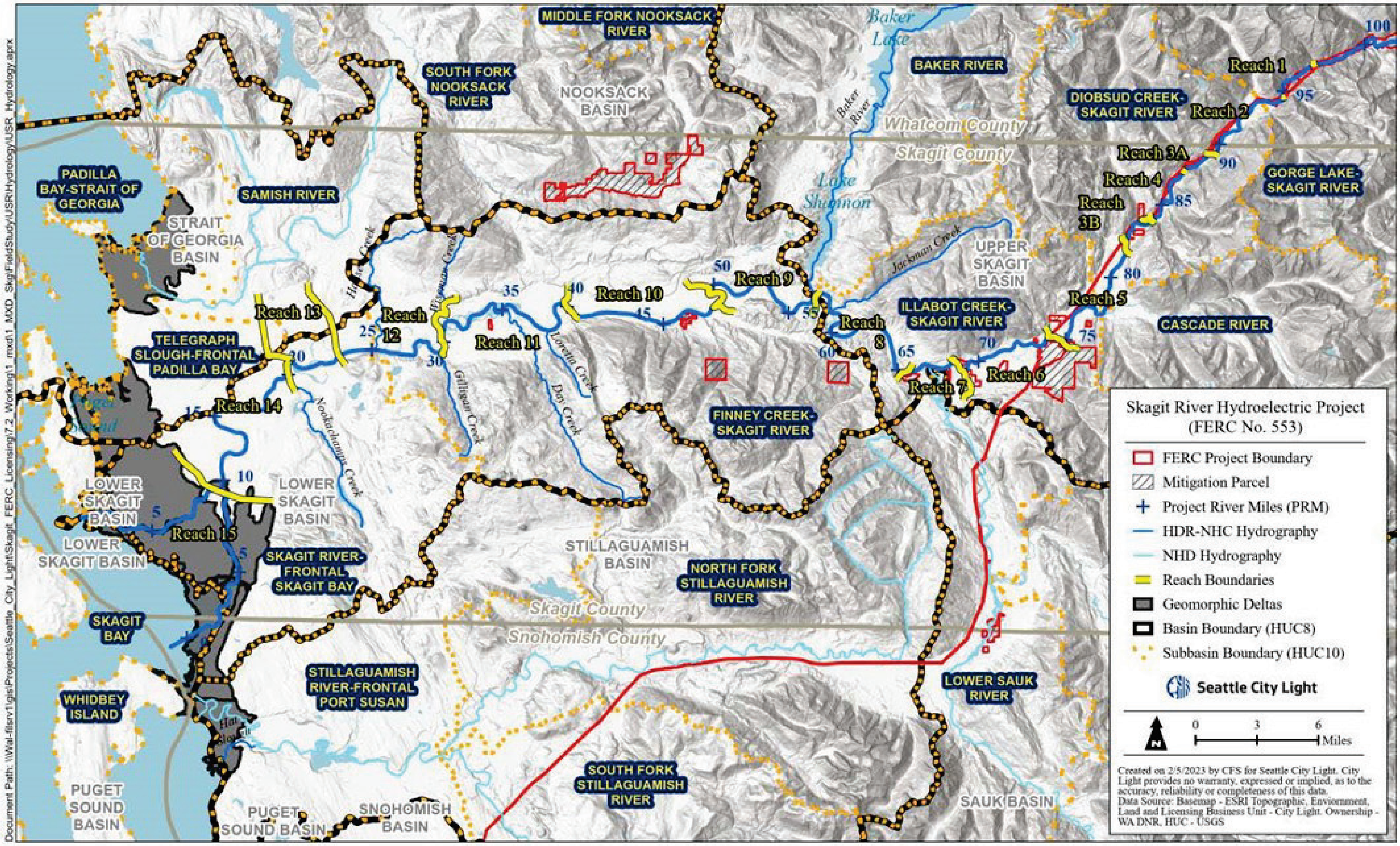
The study area for the Synthesis Study is the Skagit River from the Sauk River confluence to the Skagit delta and estuary (City Light 2021). Several large tributaries that flow into the lower Skagit River study area were also identified in the study plan, including the Baker River, Jackman Creek, Day Creek, Gilligan Creek, Loretta Creek, Hansen Creek, Wiseman Creek, and Nookachamps Creek. Based on the preliminary data review and consultation with LPs in the December 2021 Synthesis Study Work Group meeting (see Attachment K), the study area for the Synthesis Study has been clarified to include the following extent:

- The lower mainstem Skagit River from the Sauk River confluence to Skagit Bay;
- Large tributaries to the lower Skagit River including Baker River, Jackman Creek, Day Creek, Gilligan Creek, Loretta Creek, Hansen Creek, Wiseman Creek, and Nookachamps Creek;
- The Sauk River and its confluence reach with the mainstem Skagit River;
- The geomorphic Skagit River delta including the Swinomish delta, North and South Fork Skagit River deltas, and the northern portion of the Stillaguamish River delta; and
- Skagit Bay and Padilla Bay.

This study area is shown in Figure 3.0-1 and is described in more detail here. Details on how the geographic information was used in the Synthesis Study are provided in Section 4.0 of this study report. Within the mainstem Skagit River, reaches will be consistent with the geomorphic reaches delineated by Riedel et al. (2020), and later updated by Riedel et al. (TBD),[2] and will include Reach R7-14 and the Skagit estuary (Reach R15) (Figure 3.0-1). Large tributaries considered were identified in the study plan and potentially provide unregulated inputs to the lower Skagit River that can attenuate potential Project impacts in the study area (e.g., see Connor and Pflug 2004). The Sauk River also provides a source of unregulated flow and inputs to the lower Skagit River study area and was included in this study area based on feedback from the December 2021 Synthesis Study Work Group Meeting.

For the Skagit River delta and its estuary, the delta is considered to include the geomorphic deltas of the North Fork and South Fork Skagit River distributaries, the Swinomish Channel delta, the northern portion of the Stillaguamish River delta, and the southern portion of the Samish delta associated with the Swinomish Channel. This extent is consistent with the Skagit River System Cooperative's delta extent for the Skagit River Chinook Recovery Plan (Beamer et al. 2005) and the boundaries adopted by the National Oceanic and Atmospheric Administration's Salmon Habitat Status and Trends Monitoring Program (Beechie et al. 2017; Stefankiv et al. 2019) and Puget Sound Partnership's Common Indicators and Vital Sign reporting boundaries for the Skagit River delta (Hall et al. 2019). For the estuary, the Skagit Bay and Padilla Bay and associated nearshore and neritic habitats are considered to be the freshwater mixing and transition zone for the Skagit River and its distributaries.

2 Preliminary reach boundaries were used to inform the Synthesis Study, but the final reports have not been released.



Note: Labeled reaches are based on Riedel et al. (2020) and Riedel et al. (TBD), and geomorphic delta boundaries are based on Northwest Fisheries Science Center (NWFSC) Salmon Habitat Status and Trend Monitoring Program delta boundaries and Skagit River System Cooperative's delta boundary.

Figure 3.0-1. Study area for the Synthesis Study that includes the lower mainstem Skagit River from the confluence of the Sauk River (Reach 7) downstream to the geomorphic Skagit delta, large tributaries that flow into the lower Skagit River including the Sauk River, and Skagit Bay and Padilla Bay.

4.0 METHODS

4.1 Step 1: Data Compilation

A preliminary approach was developed to complete Step 1: Data Compilation and was presented to LPs in a work group meeting convened on December 15, 2021. Comments from LPs were requested by January 15, 2022 to support refinement of the proposed approach to meeting the study objectives and are integrated into the approach described in this study report (see Attachment K).

Step 1 consisted of identification, screening, and summarizing relevant data sources as well as extraction of quantitative data to summarize resource conditions. Identified sources were screened for relevant information, and annotated bibliographies and data inventories were developed for the sources that were determined to be most relevant. The most relevant sources were categorized as:

- Tier 1 Sources – sources that provide extensive information and data that are directly relevant to the Synthesis Study topics of interest, target species, and study area; and
- Tier 2 Sources – sources that provide some information relevant to the Synthesis Study objectives that included regional studies with the Skagit as one component or are studies that focus on one particular site within the study area for the Synthesis Study, e.g., a restoration site.

The following subsections describe the steps outlined above for Step 1: Data Compilation.

4.1.1 Identifying and Compiling Sources

A combination of sources identified in comments to and outlined in the RSP, data sources from previous synthesis studies conducted by Cramer Fish Sciences (CFS; Roni et al. 2008; Roni et al. 2014; Hillman et al. 2016; CFS 2019; Hall et al. 2019), direct communication with relevant co-managers and data stewards, web searches, and references cited in identified sources were used to discover potentially relevant information for the Synthesis Study.

A preliminary list of sources was developed based on sources identified in the RSP and previous CFS syntheses studies as noted above. This list was provided to LPs during the December 2021 Synthesis Study Work Group Meeting to support discovery of additional sources not included in this preliminary list, and to support acquisition of hard or digital copies of references for which only citations were found (see Attachment K). After sources from the RSP and previous syntheses studies were compiled, five web searches using Google Scholar were performed in December 2021 and January 2022, using a combination of geographic, topical, and species search terms:

(1) Skagit AND (Chinook OR Pink OR Sockeye OR Chum OR Coho OR steelhead OR Bull Trout) AND (river OR estuary or floodplain) AND (habitat OR riparian OR geomorphology OR sediment OR water quality OR restoration OR flow OR flow management OR flow regulation OR hydrology OR climate change OR model OR land use OR limiting factors OR status and trends).

(2) Sauk River OR Baker River OR Jackman Creek OR Day Creek OR Gilligan Creek OR Loretta Creek OR Hansen Creek OR Wiseman Creek OR Nookachamps Creek AND (Chinook OR Pink OR Sockeye OR Chum OR Coho OR steelhead OR Bull Trout) AND

(river OR estuary or floodplain) AND (habitat OR riparian OR geomorphology OR sediment OR water quality OR restoration OR flow OR flow management OR flow regulation OR hydrology OR climate change OR model OR land use OR limiting factors OR status and trends).

(3) Sauk River OR Skagit River AND lamprey AND (river OR estuary or floodplain) AND (habitat OR riparian OR geomorphology OR sediment OR water quality OR restoration OR flow OR flow management OR flow regulation OR hydrology OR climate change OR model OR land.

(4) (Sauk River OR Baker River OR Jackman Creek OR Day Creek OR Gilligan Creek OR Loretta Creek OR Hansen Creek OR Wiseman Creek OR Nookachamps Creek) AND (lamprey OR Pacific lamprey OR *Entosphenus tridentatus*) AND (river OR estuary or floodplain) AND (habitat OR riparian OR geomorphology OR sediment OR water quality OR restoration OR flow OR flow management OR flow regulation OR hydrology OR climate change OR model OR land use OR limiting factors OR status and trends).

(5) (Sauk River OR Baker River OR Jackman Creek OR Day Creek OR Gilligan Creek OR Loretta Creek OR Hansen Creek OR Wiseman Creek OR Nookachamps Creek) AND (lamprey OR Pacific lamprey) AND (river OR estuary or floodplain) AND (habitat OR riparian OR geomorphology OR sediment OR water quality OR restoration OR flow OR flow management OR flow regulation OR hydrology OR climate change OR model OR land use OR limiting factors OR status and trends).

The first search focused on the mainstem Skagit River, while the second search focused on large tributaries and the Sauk River. During the first search, the first 20 pages of results were compared against the sources already identified to discover additional, potentially relevant, sources. The first 10 pages of results from the second search were reviewed and compared to previously identified sources to discover additional relevant sources. The third, fourth, and fifth searches were focused on Pacific Lamprey. During the third and fifth searches, only five pages were returned with results and were reviewed and compared to previously identified sources to discover additional relevant sources. The fourth search only returned one result.

Additional sources were discovered during screening of references cited within the identified sources as described below. All identified sources were compiled into a reference database and attributed with information on the source as described below, with digital copies (if available) archived for screening. The archive of digital copies supported this study and will be a resource for future studies by making references readily available in a central location. The full reference list of sources identified during Step 1: Data Compilation is provided in Attachment A.

4.1.2 Screening and Attributing Sources

A workbook database was developed to inventory sources and the information they provide to support the Synthesis Study objectives and Steps 2-4. This database contains a table with information on the sources (tbl_Source), a table to inventory data or information provided by the source (tbl_Data), lookup tables for values that can be attributed to the sources (lkp_Source), and the data identified during screening of the source (lkp_Topics, lkp_Species, and lkp_Reaches). A graphical user interface (GUI) was also developed to support review of sources and compiled information, with search features for key words, source type, publication year, topics of interest, publication year, target species, life stages, and other data flags. This application can be accessed via request made to City Light.

4.1.3 Source Table and Source Information

The values used to attribute sources in the source table (tbl_Source) are briefly described here and a full list of fields and values is provided in Attachment B. The source table includes the following fields:

- SourceID (sequential numeric value based on order of entry into database)
- Citation (American Fisheries Society [AFS] style citation for source)
- CitationID (unique ID for source that concatenates SourceID and Citation)
- PubYear (publication year)
- Type (source type like journal, report, book, future study)
- Status (e.g., draft, final)
- Reference (full reference for source in AFS format)
- Permissions (e.g., public, restricted)
- ReviewStatus (status of screening and data inventory)
- Format (e.g., PDF, website, dataset)
- Category (e.g., Tier 1, Tier 2, Out of Study Area, etc.)
- Notes (general notes for source or review status)

This information serves as an inventory of potential sources, with CitationID linking the source to the inventory of data contained within it and supporting the ability to filter information based on a number of potentially useful attributes. For example, data can be filtered to only journal or peer-reviewed publications or filtered to identify data from more recent studies based on the year of publication.

4.1.4 Data Inventory Table and Screening

Identified sources were screened for information relevant to the Synthesis Study topics of interest, target species and life stages, study area, and whether the source provides quantitative, spatial, or Project impact data. Given that each source may contain a range of potentially relevant information, the data table was designed to allow multiple records for each source in the data inventory table (tbl_Data). The data inventory table contains the following fields:

- CitationID (unique ID for source in source table)
- KeyWord (concatenated value of topics and key words)
- Species (species or NA if not related to species)
- LifeStage (life stage[s] or NA if not related to species)
- Reach (geomorphic reach or spatial extent)

- QuantData (Yes/No; provides quantitative data)
- SpatialData (Yes/No; provides spatial data)
- Project Related (Yes/No; Project related is specific to the Skagit Project)
- HydroLinks_Keyword (keyword(s) related to flow regulation or NA)
- HydroLinks_Species (species related to flow regulation or NA)
- HydroLinks_LifeStage (life stage(s) related to flow regulation or NA)
- HydroLinks_Reach (reaches related to flow regulation or NA)
- Notes (general notes field used to describe the data or findings)

Topic and key words used to identify information provided by sources are described in Attachment B. Topics were used as a high-level category to classify information and group key words and included the following values:

- Geomorphology and Landforms
- Water Quality and Productivity
- Modeling Tools
- Project Operations
- Land Use and Cover
- Fish and Habitat

A list of key words, or subtopics, was developed within each topic that provided a higher resolution classification of information available from each source. For example, the Fish and Habitat topic includes key words for habitat (e.g., riparian, limiting factors, barriers), fish (e.g., periodicity, abundance, survival), and monitoring (e.g., restoration, abundance, biotelemetry). A total of 115 key words were developed for the data inventory, and these are described in Attachment B.

4.1.5 Data Flags and Screening

Data flags were also used to identify which target species, life stages, and reaches the information is related to. The data flags are described in more detail in Attachment B but are described briefly here. The following target species were included as data flags:

- Chinook Salmon
- Coho Salmon
- Sockeye Salmon
- Chum Salmon
- Pink Salmon
- Bull Trout
- steelhead

- Pacific Lamprey
- All anadromous species (when information was generic to anadromous species)
- Other species (data flag to indicate that information on non-target species is provided)

For sources with data for target species, separate fields were used to indicate what life stages of each species were included in the source. For example, if a source contained data on the abundance of Chinook and Coho salmon during freshwater rearing, both species fields ([Chinook] and [Coho]) would be populated with "rearing and outmigration" and the [KeyWord] field would include "Fish, abundance." If the source does not contain information on target species or the data are not related to target species (e.g., water quality data), the [Species] field will be populated as "NA" to indicate that the data are not associated with a particular target species. In addition, life stages may not be specified, and these are populated as "Not specified." The following values were used in the species fields with respect to life stages described in the sources, and multiple values were possible for sources that provided information on multiple life stages:

- Migration (adult migration upriver, including holding)
- Spawning (adult spawning)
- Adult outmigration (for iteroparous species)
- Incubation (egg incubation in substrate)
- Rearing (juvenile rearing in freshwater habitats)
- Overwintering (juvenile overwintering in freshwater habitats)
- Outmigration (juvenile outmigration downstream from freshwater habitats)
- Estuary rearing and emigration (juvenile rearing, transition, and migration through estuary habitats)
- Nearshore rearing and emigration (juvenile rearing and migration through nearshore habitats, including pocket estuaries)
- Ocean (adult maturation in ocean habitats)

Spatial information was also recorded for each source using data flags, and the reach information was based on the study area defined in this study report, which will include the following extents:

- Reaches 7-14 (geomorphic reaches as defined in Riedel et al. (2020) and Riedel et al. (TBD)[3] that include the lower mainstem Skagit River)
- Reach 15 or Skagit estuary (the geomorphic delta for the Skagit River including the North and South Fork Skagit River distributaries, Swinomish Channel, and the northern portion of the Stillaguamish River delta)
- Skagit Bay and Padilla Bay (nearshore habitats including pocket estuaries, beach, and neritic habitats)

3 Reach delineations based on preliminary spatial data provided from this study as final reports were not available at this time.

- Sauk River (data specific to the Sauk River tributary to the Skagit River)
- Upstream Reach 7 (data specific to the Skagit River watershed but only available for reaches upstream of the study area)

Many previous, ongoing, or future studies related to target fish species in the reaches and reservoirs upstream of the study area could be linked to abundance and demographic patterns of target species in the study area. For example, steelhead and Bull Trout are capable of expressing resident, adfluvial, and anadromous life histories with plasticity in expression of these life histories given the absence of fish passage barriers (Kendall et al. 2014). Therefore, studies of potential distribution, abundance, or genetics (e.g., FA-04 Fish Passage Technical Studies Program [City Light 2023b], FA-06 Reservoir Native Fish Genetics Baseline Study [City Light 2023d], FA-07 Reservoir Tributary Habitat Assessment [City Light 2023e]) could be related to downstream abundance and demographic patterns for these species. Similarly, studies of water quality or hydrological parameters in the upper basin can be related to patterns and conditions in the study area or used to define boundary conditions for the lower Skagit River study area. However, sources that were screened and then determined to not provide information on the Skagit River but not the Synthesis Study area were flagged as “Out of Study Area” in the [Category] field in the source table and were archived as “Other Sources.”

Sources that were screened and then determined to not provide information specific to the Skagit River or Synthesis Study area were flagged as “Out of System” in the [Category] field in the source table and were archived as “Other Sources.” This includes general ecology or biology references that synthesize information from many systems and are not specific to the Skagit River.

Sources that represent previous reports or publications that are covered by the most recent publication were flagged as “Previous Reports” and archived as “Other Sources.” These sources may provide additional detail that are not represented in the most recent reports. These reports were screened to determine if substantially different information was presented in previous reports, and when additional information was found, these sources were reviewed.

Data flags were used to identify whether quantitative or spatial data are provided by the source, or if the source provides information on Project related effects. The quantitative data flag will be used to specifically identify information that can be used to support future data extraction and analysis. The spatial data flag identifies if the data are available in a format that can be used in spatial analyses (e.g., spatial outputs from a hydrodynamic model or distribution of large woody debris). For the Project Related field, records were flagged if the source provides data that were linked to potential Project effects (e.g., flow regulation and aquatic habitat) and may include studies with a pre- or post-impact design (e.g., changes in conditions with pre and post agreement flows), modeling (e.g., simulated conditions with flow regulation scenarios), or correlative analyses (e.g., trends in abundance correlated with trends in flow regulation metrics) that were linked to Project operations in the study or were the focus of the study.

4.1.6 Summarizing Available Information

An annotated bibliography was also developed for each Tier 1 and Tier 2 Source that provides a high-level summary table for the source (full reference, source type, topics of interest, key words, species, life stages, and whether the source provides quantitative, spatial, or Project Related data), a summary paragraph describing the overall study or data, and a paragraph summarizing the information relevant to the Synthesis Study objectives (not included for Tier 2 Sources). This summary of relevant information includes descriptions of quantitative data that are provided by the source, which can be used to support future analyses. Other Sources are found in Attachment H.

4.2 Step 2: Data Analysis

Step 2: Data Analysis included three components: (1) development of conceptual life cycle diagrams and conceptual life history models based on the information compiled in Step 1 and in coordination with LPs though Workgroup Meetings (see Attachment K), (2) summaries of data inventory results from Tier 1 and Tier 2 Sources, and (3) analysis and synthesis of quantitative information on resources conditions and LSF.

4.2.1 Conceptual Models

The conceptual life stage diagrams and conceptual life history models were developed to support identification and interpretation of LSF information in Step 3. In coordination with LPs, the conceptual life cycle diagrams were developed at a species group level (salmon, trout, and lamprey) and for aggregated life stages and transitions (generally grouped as adult migration, holding and spawning; incubation and emergence; rearing and outmigration; estuary rearing and emigration; and nearshore rearing and emigration) (see Attachment K). The review included identification of sources that provide information on periodicity, but periodicities were not summarized across these sources in the conceptual models. City Light coordinated with the technical sub-group coordinating the development of periodicity tables as part of the FA-02 Instream Flow Model Development Study (City Light 2023a) to ensure that periodicities are consistent among studies (Table 4.2-1).

Table 4.2-1. Life-history periodicities for key fish species in the Project vicinity.

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead	Adult												
	Spawning			Eval	License Req'd Spawning Period		Eval						
	Juvenile												
Chinook Salmon	Spawning									License Required	Eval		
	Fry			Salmon Fry Protection Period									
	Juvenile												
Skagit Pink Salmon	Spawning								Evaluate		License Req'd		
Chum Salmon	Spawning									Evaluate		License Req'd	
	Fry			Salmon Fry Protection Period									
Coho Salmon	Spawning												
	Fry			Salmon Fry Protection Period									
	Juvenile												
Sockeye Salmon	Spawning												
Rainbow Trout	Adult												
	Spawning												
	Fry												
	Juvenile												
Bull Trout/Dolly Varden	Spawning												
	Fry												
	Juvenile												
Sea-Run Bull Trout	Spawning												
Cutthroat Trout	Adult												
	Spawning												
	Fry												
	Juvenile												
Sea-run Cutthroat Trout	Spawning												

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mountain Whitefish	Adult												
	Spawning												
	Fry												
	Juvenile												
Pacific Lamprey	Spawning												
Lamprey (generic)	Juvenile												
Western Brook Lamprey	Spawning												
Western River Lamprey	Spawning												
Salish Sucker	Spawning												
Salish Sucker	Juvenile												
White Sturgeon	Spawning												

Note: Evaluate (or Eval) indicates lower Skagit observations and carcass recoveries and/or technical group interest in evaluating the information as it relates to the portion of the Skagit River where the effects of flow management can be actualized.

4.2.2 Data Inventory

A data inventory was developed from the topics of interest, sub-topics, target species and life stages, spatial extents, and data flags. These were summarized graphically to highlight the number of sources that were identified as providing information on each of these topics, sub-topics, target species and life stages, spatial extents, and data flags. The literature database was also populated with this information to support search and filtering of information based on these sub-topics, target species and life stages, spatial extents, and data flags.

4.2.3 Quantitative Information

Relevant quantitative information from Tier 1 sources was extracted and summarized to describe resource conditions and LSF. This information was used to develop the life stage factors narratives, LSF tables, and initial assessment of relative importance as described for Step 3.

4.3 Step 3: Life Stage Factors Affecting Target Species

Step 3 included the compilation of LSF information into narratives and development of LSF Tables and an initial assessment of relative importance to support identification of Key Factors.

4.3.1 LSF Compilation and Summary

Potential factors influencing life stages, or life stage factors, were identified in coordination with LPs during Step 1 and Step 2 (see Attachment K), and information on LSFs were compiled from the annotated bibliographies developed from Tier 1 and Tier 2 Sources. Information on LSFs were summarized in narrative form based on the information found in reviewed sources only, and were organized by categories (bold) and factors (italicized):

(1) **Instream flow:** *General flow, peak flow, minimum flow, downramping, tidal inundation*.

(2) **Sediment supply and transport:** *Supply and transport, deposition and substrate*.

(3) **Habitat availability and connectivity:** *Habitat extent, habitat connectivity*.

(4) **Large woody debris (LWD) and bank condition:** *LWD recruitment/retention, hydromodified banks and channel edge*.

(5) **Riparian condition:** *Condition and composition, extent and continuity, shade and canopy*.

(6) **Water quality:** *Instream temp general, instream temp maximum, instream temp minimum, dissolved oxygen, organic matter and nutrients, pH, turbidity, salinity, bacteria and pathogens, contaminants*.

(7) **Competition and predation:** *Predation avian and mammal, predation fish, competition spawning, competition rearing*.

(8) **Food availability:** *Primary productivity, secondary productivity*.

(9) **Other anthropogenic factors:** *Climate change, hatcheries, fisheries, aquaculture, beaver management*.

For each factor, relevant information from the literature was included describing the drivers and stressors that influence the factor, and the species and life stages that are influenced by the factor.

More information on the compilation and summary of life stage factor information is provided in the life stage factors narratives (Attachment C).

4.3.2 LSF Table Summaries

Information compiled and summarized in the LSF narratives was synthesized into LSF Tables. The information presented in the LSF Tables was based in part on the Key Factor criteria that were developed in coordination with LPs (see Attachment K). These criteria were intended to support identification of Key Factors and included the following questions:

Key Factor Criteria:

(1) Is the factor relevant to one or more of the Synthesis Study target species or life stages?

(2) Is the factor a limiting factor to one or more of the Synthesis Study target species and life stages?

(3) Is the factor relevant to one or more of the strata in the study area for the Synthesis Study?

(4) Can the factor be influenced by one or more flow or non-flow management actions?

(5) Can the factor be influenced by Project operations?

(6) Is the factor sensitive to climate change or water year type?

Based on these criteria, a summary table was developed for each of the identified factors that synthesized information on sensitivities of factors to management actions and climate, and biological responses of target species and life stages to factors, the spatial extent of the influence, whether the factor was identified as limiting to a species or life stage, and if the factor was related to Project operations. These components are described briefly here, with more detail provided in the LSF Table Attachment (Attachment D). Scoring components for the initial assessment of relative importance (see Section 4.3.3 below and Attachment D) were also included for each factor in each LSF Table.

For each factor, sensitivities to management actions were identified from the reviewed literature that included six categories of management actions and two aspects of climate. Management actions included non-flow and flow actions, including flow regulation, water uses, restoration and protection, land uses and cover, hatcheries, and fisheries; and climate included climate change and water year type. Sensitivities of factors to these management actions or climate regimes were categorized as sensitive, indirectly sensitive, or not sensitive to the management action or climate.

For each factor, biological responses were identified for the species groups (salmon, trout, or lamprey) and life stages (spawning to migration, incubation to emergence, rearing to outmigration, and estuary rearing and emigration to nearshore rearing and emigration) developed during Step 2: Data Analysis. The spatial extent of the factor's influence on the species groups and life stages were summarized by primary spatial strata for the study area, which included the mainstem of the lower Skagit River habitats downstream of the Sauk River confluence (mainstem), tributaries to the lower Skagit River (tributary), Skagit estuary (estuary), and nearshore habitats of Skagit Bay and Padilla Bay (nearshore). Biological responses were identified for the species groups and life stages that were categorized based on whether the factor influences movement (e.g., movement between habitats or migration), periodicity (e.g., the timing or duration of habitat uses), habitat use (e.g., influences habitat capacity or the types of habitat(s) used), growth, or survival (including direct and indirect mortality). Limiting factors identified in the reviewed literature and linkages to Project operations were also summarized in the LSF Tables. Limiting factors were those identified in the literature as limiting the productivity of a species, life history, or life stage. Project operations summaries were used to identify where literature described linkages between operation of the Skagit Project and the factor, which is different than the flow regulation management action identified in the sensitivities section above (which may include both Baker River and upper Skagit River facilities).

4.3.3 Initial Assessment of Relative Importance

A scoring framework was developed for the initial assessment of relative importance based on the Key Factor criteria. The scoring framework included three scoring components: (1) biological score, (2) management score, and (3) climate score. Each of these scoring components address aspects of the Key Factor criteria and included weighting for elements of the scoring component, and the scoring components were summed to develop an aggregate score for each factor. The scoring components and aggregate scores are described briefly here with the LSF Tables (Attachment D) providing more details on the scoring framework.

4.3.3.1 Biological Score

The biological score (S_B) addresses Key Factor criteria questions (1) and (2) and includes three components; (A) number of target species groups that the factor influences, (B) the number of life stages the factor influences, and (C) the number of species and life stages for which the factor limits productivity (Equation 1). Both target species and life stage scores were weighted based on the number of target species groups and life stages (as whole integers) divided by the possible number of target species groups (n = 3) and life stages (n = 4). The number of species groups and life stages identified as limiting factors were added to the weighted species group and life stage scoring elements.

Equation 1. Biological score equation

$$S_B = \frac{A}{3} + \frac{B}{4} + C$$

4.3.3.2 Management Score

The management score (S_M) addresses Key Factor criteria questions three through five, and includes three components; (A) number of study area strata that the factor operates at when influencing target species groups and life stages, (B) the number of management actions that were linked to the factor, and (C) the number spatial strata that the factor was identified as being linked to Project operations (Equation 2). Both the study area strata and management actions components were weighted based on the number of strata (n = 4) and management actions (n = 6). Study area strata were scored using whole integers, while the management actions included sensitivities that could be identified as directly or indirectly influenced. For management actions that have an indirect influence, a value of 0.5 was added to the management action element of the management score. Similar to limiting factors in the biological score, the number of spatial strata that were linked to Project operations were summed and both direct and indirect linkages were scored as 1.0 and 0.5, respectively (Equation 2).

Equation 2. Management score equation

$$S_M = \frac{A}{4} + \frac{B}{6} + C$$

4.3.3.3 Climate Score

The climate score (S_C) addresses Key Factor criteria question (6) and includes one component that was weighted to a half-scale compared to the other scoring components (Equation 3). A value of one was added for each climate change (A) and water year type (B) sensitivity identified. Climate change and water year type sensitivities also included indirect sensitivities, and these were added as 0.5 for each indirect sensitivity. The sum was then divided by four to reduce the weight of the climate scoring component relative to the biological and management scoring components (Equation 3).

Equation 3. Climate score equation

$$S_C = \frac{A + B}{4}$$

4.3.3.4 Aggregate Score

The aggregate score was derived by summing each scoring component including the biological score (S_B), management score (S_M), and climate score (S_C) (Equation 4). This scoring framework results in a minimum score of 1.0 assuming that the factor was relevant to at least one target species group, life stage, spatial strata, and management action. Assuming a factor is relevant to all three target species groups, all four life stages, all four spatial strata, all six management actions, and both climate sensitivities, the aggregate score would equal 4.5. Factors that were identified as limiting factors or potentially linked to Project operations would additively increase the maximum score based on the sum of these and the values of the scoring elements in each scoring component.

Equation 4. Aggregate score equation

$$S_T = S_B + S_M + S_C$$

4.3.4 Identification of Key Factors

The aggregate score (S_T) from the scoring framework and initial assessment of relative importance were used to identify Key Factors based on the distribution of scores and the baseline score (S_T = 4.5). Factors were classified based on relative importance into three categories: (1) high relative importance, (2) moderate relative importance, and (3) low relative importance. The baseline score, which represents a factor that was relevant to all three target species groups, all four life stages, all four spatial strata, all six management actions, and both climate sensitivities, was used to categorize factors based on aggregate scores as having a low relative importance ($S_T < 4.5$). The 75th percentile of the aggregate scores were used to categorize factors as having a high relative importance ($S_T \geq 75^{th}$ percentile) or moderate relative importance ($4.5 \leq S_T < 75^{th}$ percentile).

4.4 Step 4: Identification of Key Uncertainties

Uncertainties and potential data gaps were identified through a combination of the information synthesized from the literature in Step 1 and Step 3, the results of the data inventory from Step 2, and LP feedback from the December 19, 2022 workgroup meeting (see Attachment K).

During Step 1, sources that described or reported data gaps were flagged with the "data gaps" keyword for the topic or subtopic to support identification of data gaps described in the reviewed literature. This information was also extracted and compiled into an attachment to support identification of Key Uncertainties during Step 1 (Attachment I). The results of the data inventory in Step 2 were used to highlight the relative number of sources that provide information on topics, species or life stages, and spatial extents. This was intended to support the identification of Key Uncertainties but was not intended to directly identify data gaps.

The synthesis of information on life stage factors and the initial assessment of relative importance results from Step 3 were used to focus on high priority areas of uncertainty that were related to Key Factors. This information was used to support identification of Key Uncertainties, which were uncertainties associated with Key Factors that were identified in Step 3. Therefore, Key Uncertainties represent areas where further data are needed to understand the key mechanisms and Project operations affecting species and their respective in-river, delta, and estuary life stages. Collectively, this step will support the identification and prioritization of near or long-term research or monitoring needs to address Key Uncertainties.

5.0 RESULTS

The following results represent the outcomes of Steps 1-4 of the Synthesis Study that include Step 1: Data Compilation, Step 2: Data Analysis, Step 3: Life Stage Factors Affecting Target Species, and Step 4: Identification of Key Uncertainties. The results section is organized by these steps with supporting information provided in attachments as indicated in the results.

5.1 Step 1: Data Compilation Results

A total of 523 potentially relevant sources were identified from a combination of references identified in the Synthesis Study RSP and other relicensing documents, previous CFS synthesis studies, references provided by LPs after review of initial reference lists during Synthesis Study Workgroup Meetings (see Attachment K), and web searches completed during the study. See Attachment A for the full reference list of sources identified by the Synthesis Study. This includes sources identified from the above steps, sources found within reviewed sources, and sources found in preliminary internet and database searches. Of these potential sources, digital or hard copies were obtained for 477 sources, which were screened to identify relevant sources and information for the Synthesis Study. Most (59 percent, 310/523) sources identified were reports, or white and gray literature, with 18 percent (96/523) of the potential sources being journal articles (Figure 5.1-1).

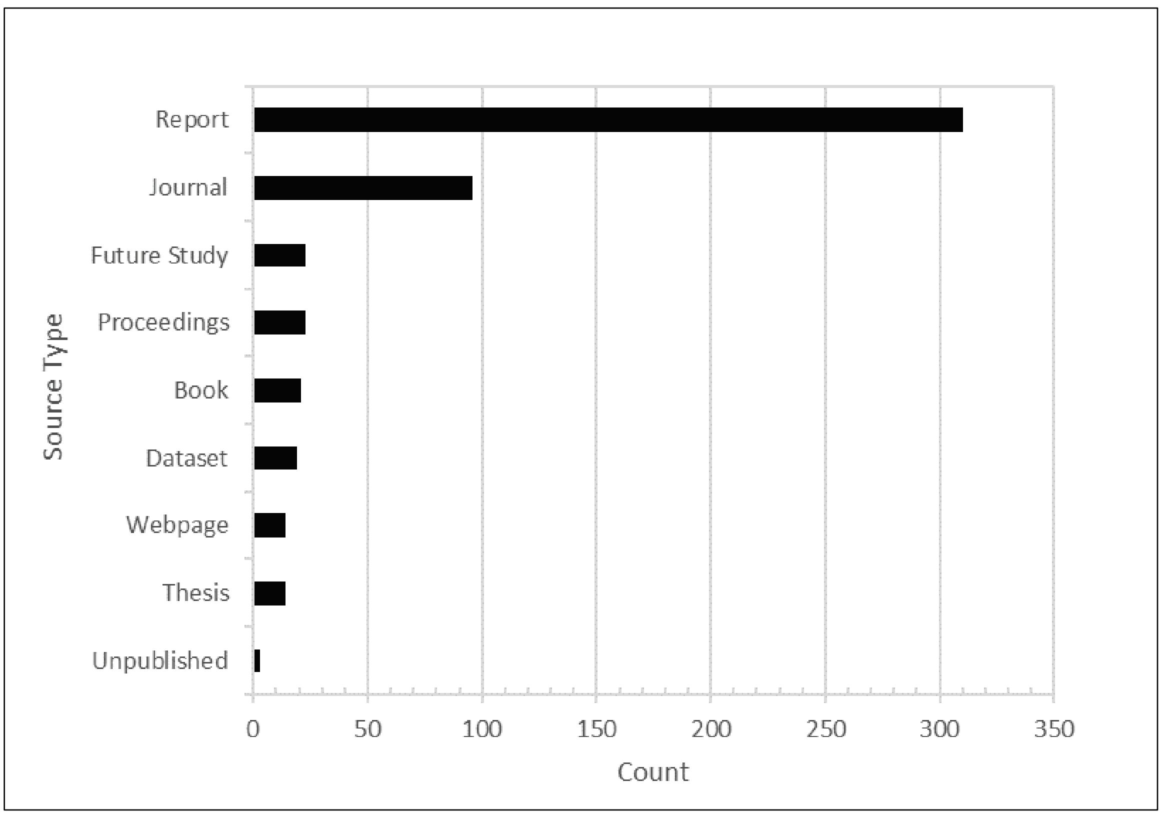


Figure 5.1-1. Count of sources identified during Step 1: Data Compilation by source type.

From the identified sources, a total of 119 sources were identified as Tier 1 sources, which provided information directly relevant to the study area, target species, or topics of interest (Figure 5.1-2). Within these Tier 1 sources, 23 sources were reviewed by the GE-04 Skagit River Geomorphology Between Gorge Dam and the Sauk River Study (Geomorphology Study; City Light 2023f) team (Figure 5.1-2). For all 119 Tier 1 sources, annotated bibliographies and data inventories were developed (Step 2).

A total of 195 sources were identified as Tier 2 Sources (Figure 5.1-2), which were also used to develop annotated bibliographies and data inventories. These Tier 2 Sources provide information on the Skagit River that was either (A) part of a larger regional study of which the Skagit River was one component of the study or results, or (B) provides information on a specific site or location with the study area (e.g., a particular restoration site).

The remaining sources include sources that were identified as previous reports (n=59, with only the most recent report being considered), studies that did not provide information for the Skagit River (n=47, Out of Basin), studies that provided information for the Skagit River but only outside of the study area (n=10, Out of Study Area), were websites or datasets (n=25), are future or ongoing studies (n=23), or were sources that were determined to not be relevant to the Synthesis Study objectives (n=6) or for which hard copies or digital copies could not be found to review (n=39, Citation Only) (Figure 5.1-2).

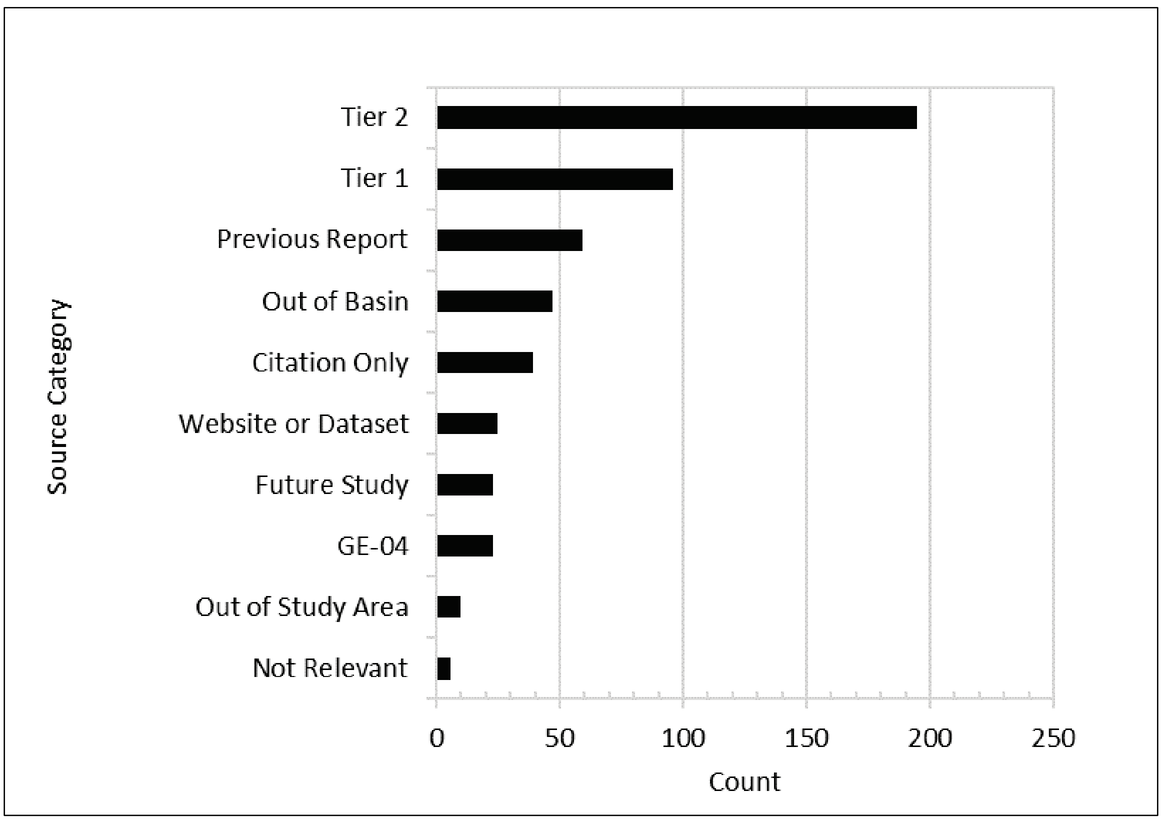


Figure 5.1-2. Count of sources identified during Step 1: Data Compilation by source category. Only sources categorized as Tier 1 (including GE-04 Geomorphology Study references) and Tier 2 were reviewed and used to develop annotated bibliographies and data inventories.

A total of 23 future and ongoing studies were identified that could provide information relevant to the Synthesis Study objectives (Attachment J). These include multiple estuary and Salmon Restoration Program Learning Projects and other relicensing studies identified in the RSP (City Light 2021) and June 9, 2021 Notice that specifically include overlaps in study area extent or objectives with the Synthesis Study.

5.2 Step 2: Data Analysis Results

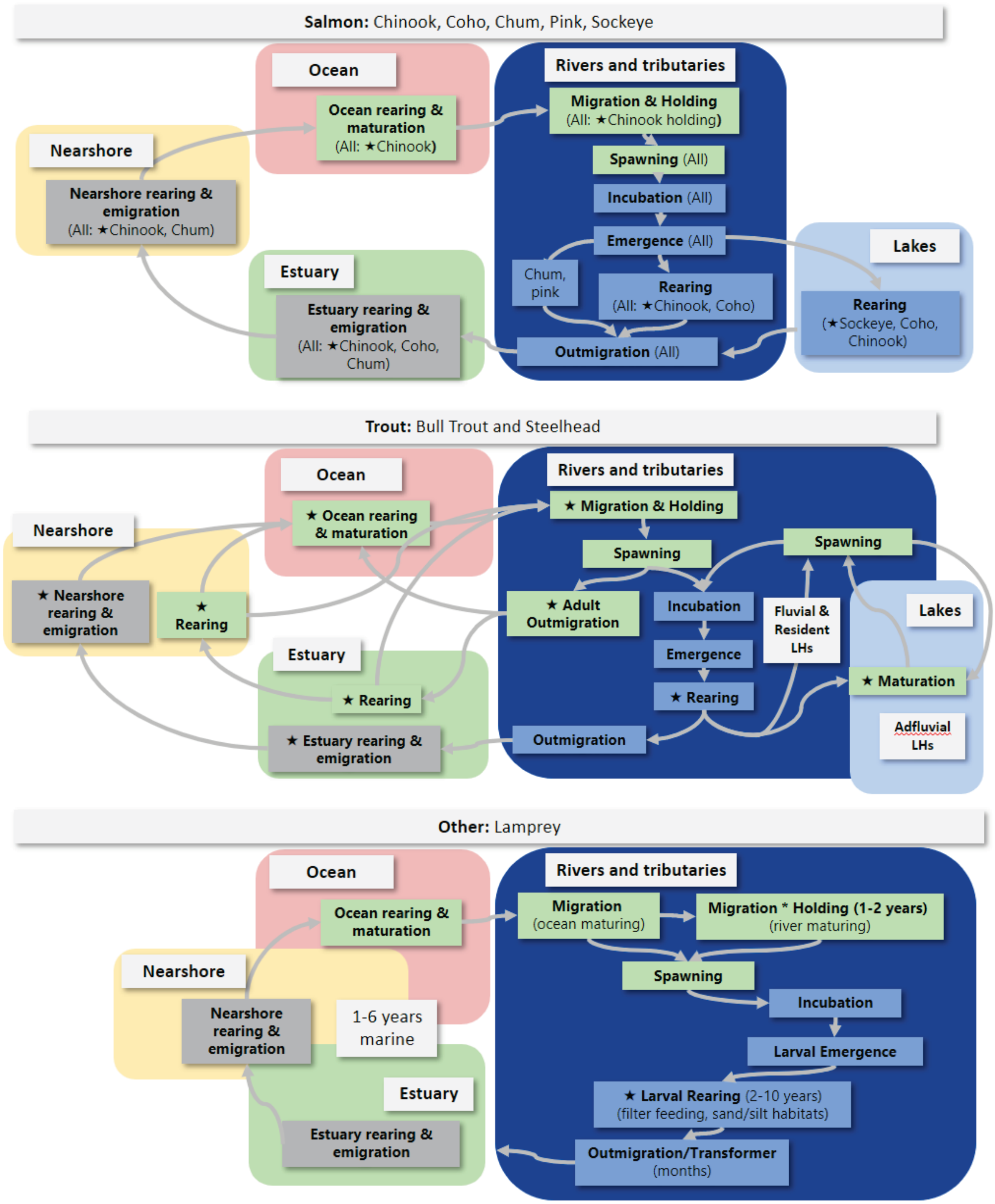
Conceptual life cycle diagrams and conceptual life history models, and data inventories were developed as part of Step 2: Data Analysis.

5.2.1 Conceptual Models

Conceptual life cycle diagrams were developed in coordination with LPs (see Attachment K) for three species groups that included:

- **Salmon** – Chinook, Coho, Chum, Pink, and Sockeye salmon;
- **Trout** – Bull Trout and steelhead; and
- **Other** – Pacific Lamprey.

These conceptual life cycle diagrams show the key life stages and habitats used by target species, which support the identification of Key Factors influencing anadromous resources (Figure 5.2-1). Conceptual life history models were developed for key life stages that describe the drivers and stressors and factors and processes that could potentially influence the target species group and life stages. Separate conceptual life history models were developed for each species group and key life stage and were developed based on information from the literature review and development of annotated bibliographies and integrated LP feedback from Synthesis Study Workgroup Meetings and review (see Attachment K). These conceptual life history models are provided in Attachment E. Collectively, the conceptual life history diagrams and conceptual life history models were intended to support Steps 3-4 by providing context for contributing factors to resource conditions.

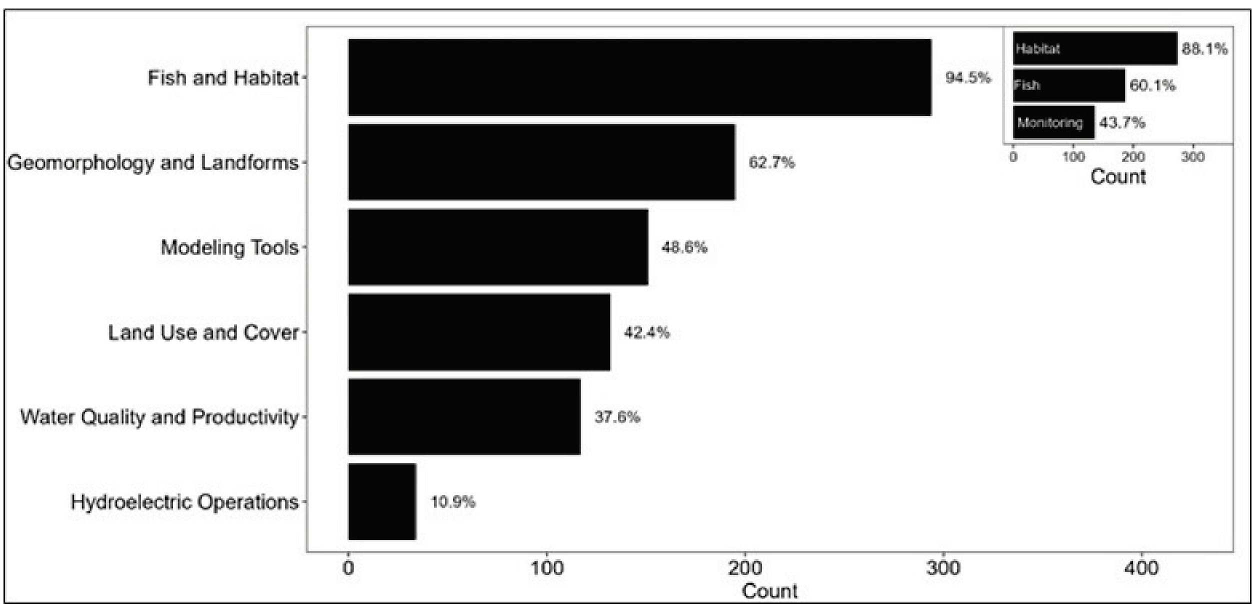


Note: Habitat strata are indicated by colored boxes with rounded edges, and life stages and transitions are identified by rectangular boxes with connecting arrows. Where applicable, specific species with the potential for extended residency are identified (★), or pathways specific to a species are identified as separate boxes. LH indicates a specific life history.

Figure 5.2-1. Conceptual life cycle diagram for salmon species group (top), trout species group (middle), and other (lamprey, bottom).

5.2.2 Data Inventory

Most of the reviewed sources provided information on fish and habitat topics (94.5 percent) and geology and landforms (62.7 percent) (Figure 5.2-2). Many sources also provided information on modeling tools (48.6 percent), land use and cover (42.4 percent), and water quality and productivity (37.6 percent) topics, while only 10.9 percent of the sources provided information on hydroelectric operations topics (Figure 5.2-2). Counts of sources that provided information on subtopics of the primary topics of interest are shown in Figure 5.2-3. Among the species of interest, most sources provided information on Chinook (59.2 percent), then information on Coho and Chum (≈29 percent) and steelhead (20.3 percent) were most prevalent (Figure 5.2-4). Fewer than 20 percent of the sources provided information on Pink (18.3 percent), Bull Trout (11.3 percent), Sockeye (6.8 percent), and Pacific Lamprey (2.3 percent) (Figure 5.2-4). Counts of sources that provided information on different life stages for each target species are shown in Figure 5.2-5. Among the spatial strata for the study area, most sources provided information on the Skagit estuary (39.2 percent) and Skagit bay (31.8 percent) (Figure 5.2-6). Sources also provided information at the Skagit watershed scale (24.8 percent), while about 9-13 percent of the sources provided information specific to Skagit River reaches within the study area (Figure 5.2-6). Many sources provided information on the Sauk River (20.3 percent), which was a tributary of interest identified for the study area, while information on other tributaries of interest were provided by 0.3-10.6 percent the sources (Figure 5.2-6). Most of the sources reviewed provided quantitative data (91 percent) and spatial data (69.5 percent), while only 14.8 percent of the sources provided information that linked Project operations to factors or resource conditions in the study area (Figure 5.2-7).



Note: the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics.

Figure 5.2-2. Count of sources by primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. The inset shows the breakdown of information on the fish and habitat topic.

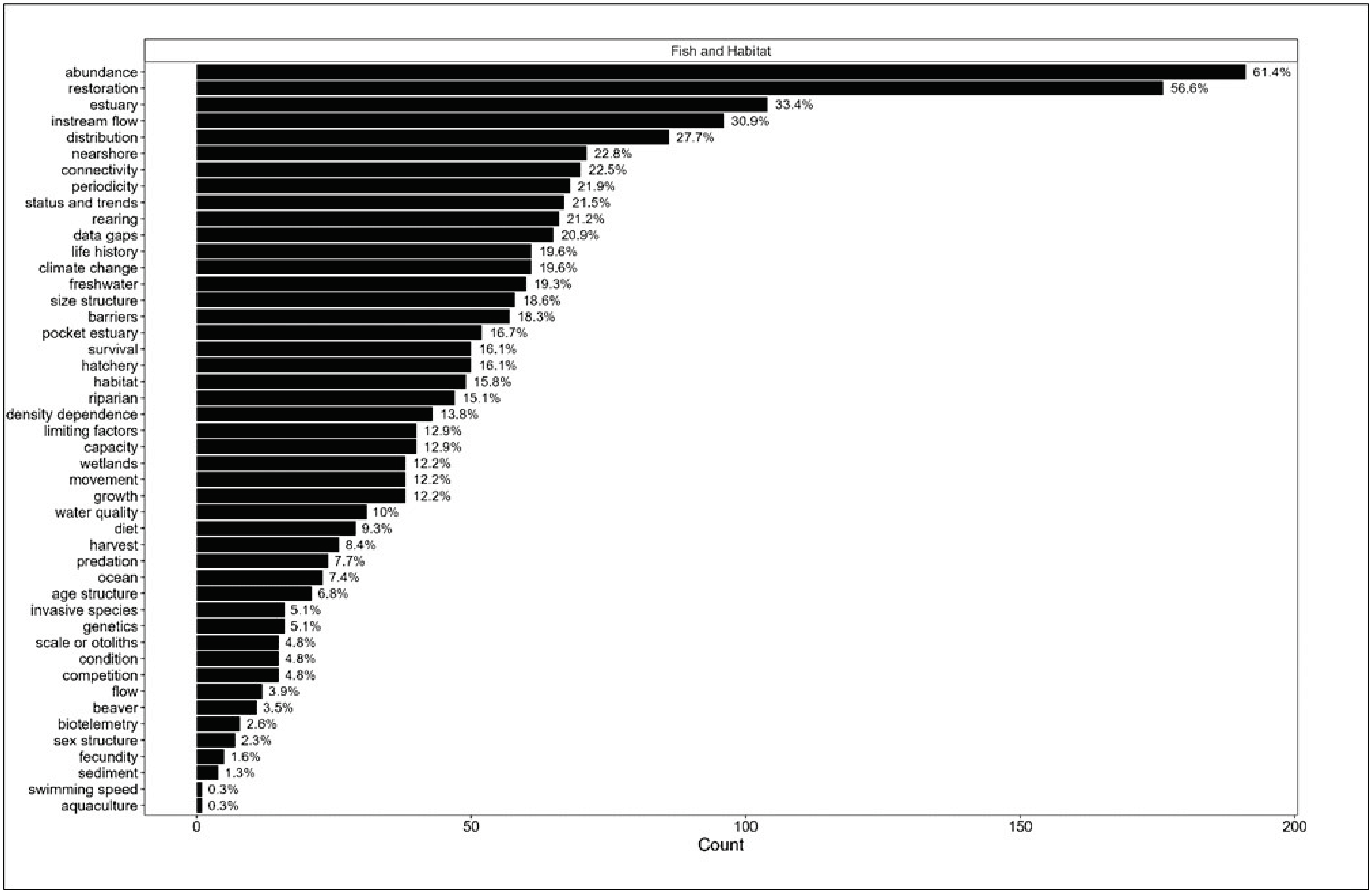


Figure 5.2-3. **Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 1 of 6).**

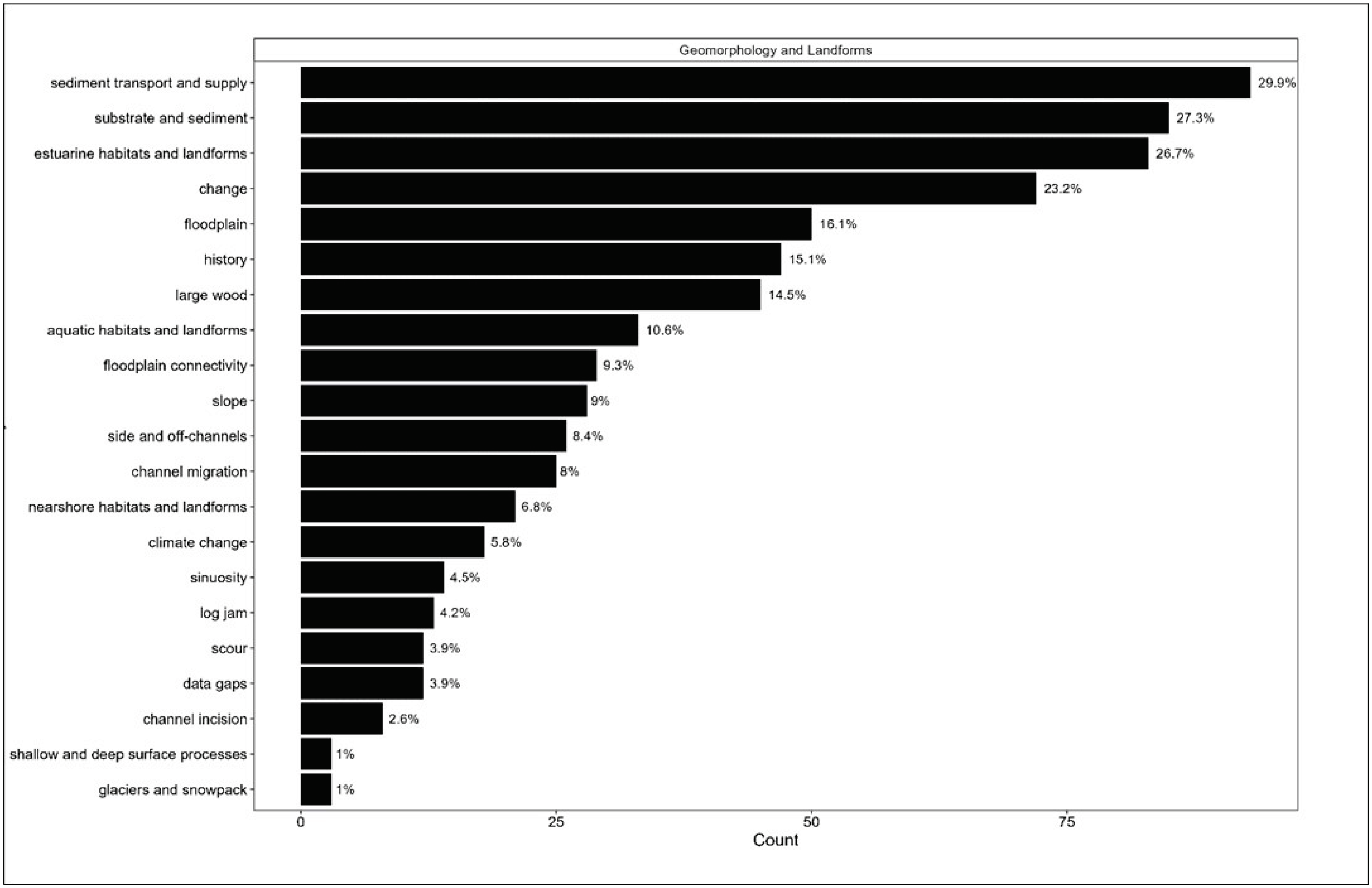


Figure 5.2-3. Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 2 of 6).

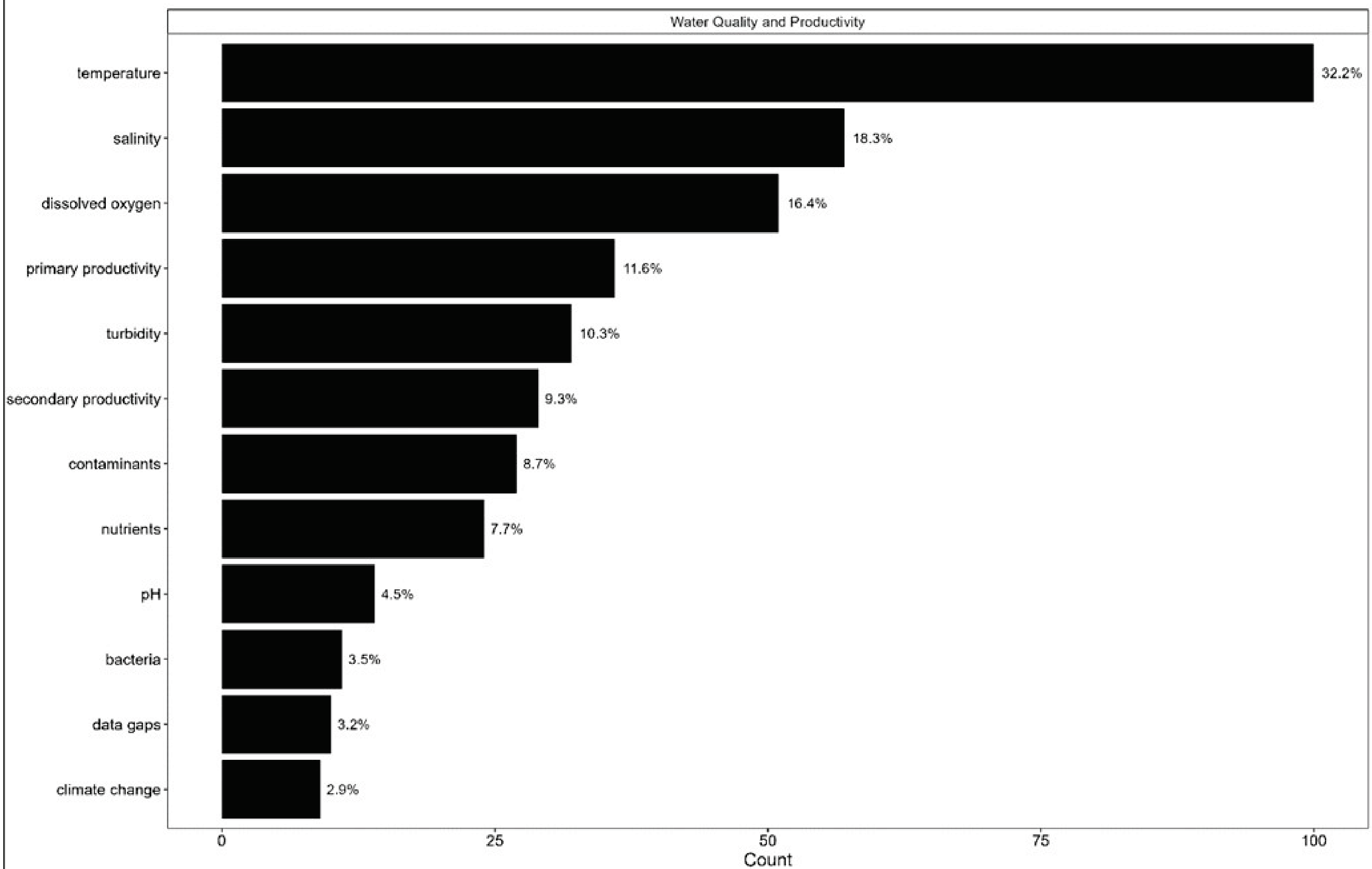


Figure 5.2-3. Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 3 of 6).

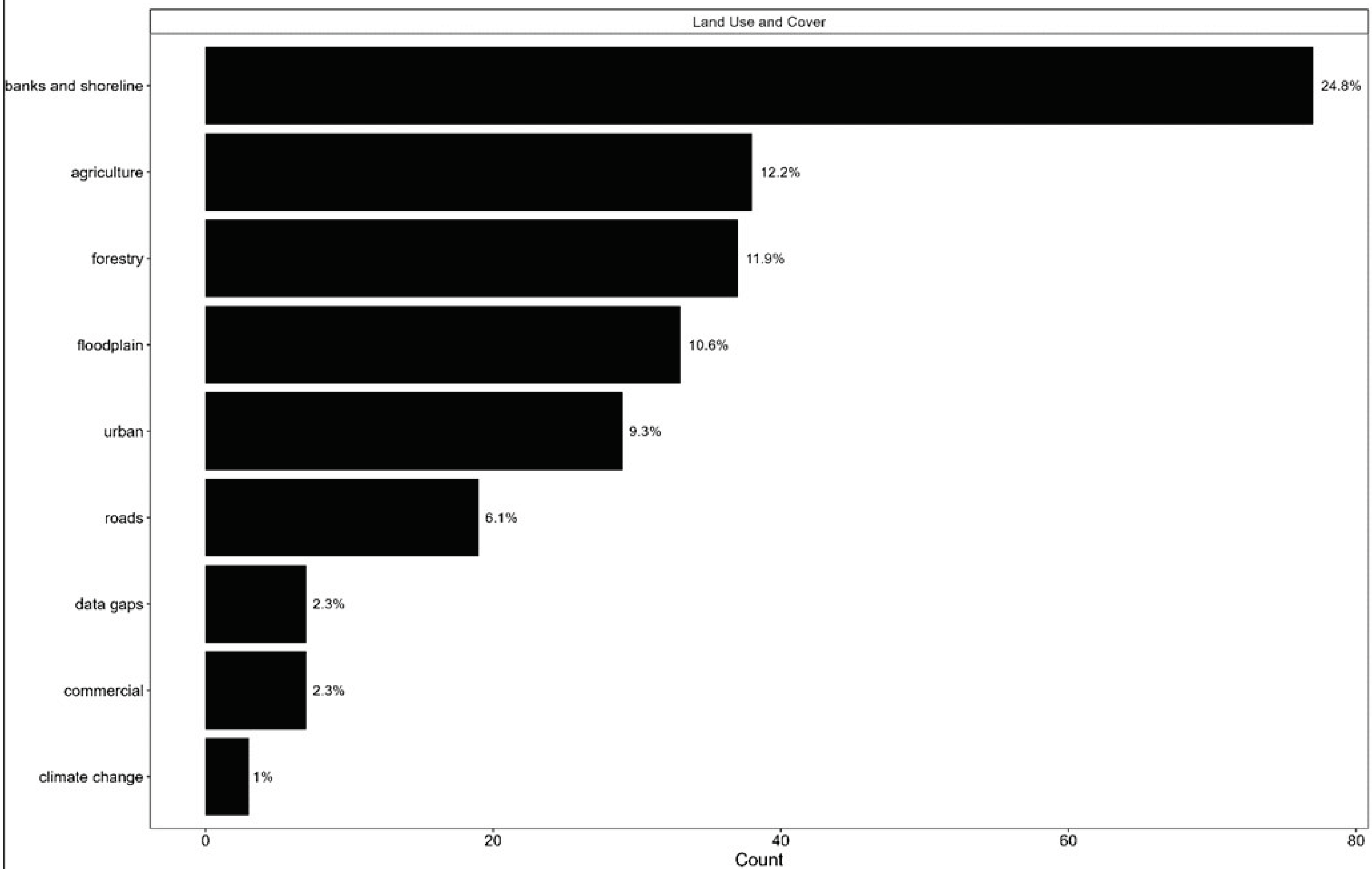


Figure 5.2-3. Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 4 of 6).

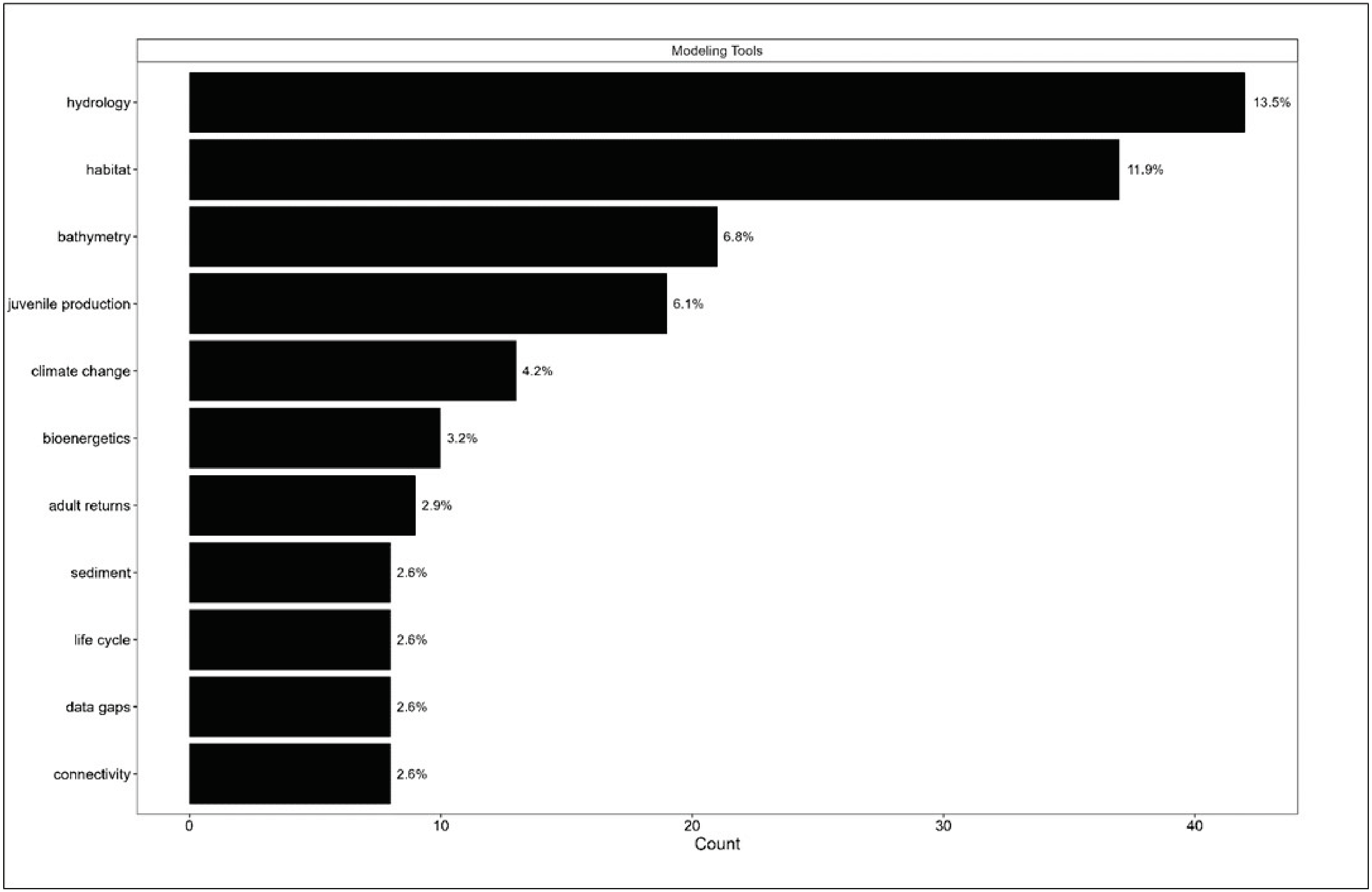


Figure 5.2-3. Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 5 of 6).

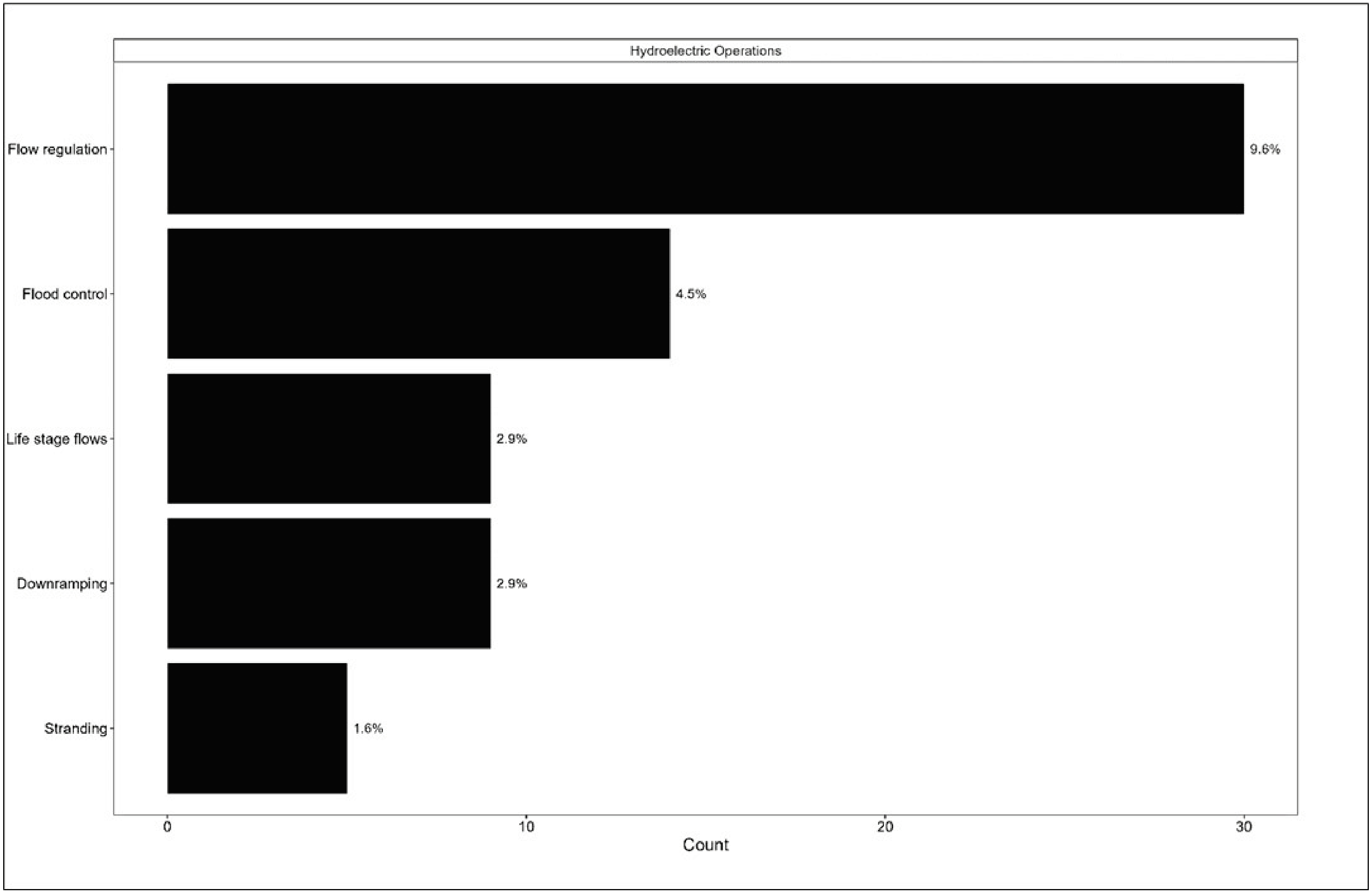


Figure 5.2-3. **Count of sources by subtopic within each primary topic of interest. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple topics (Page 6 of 6).**

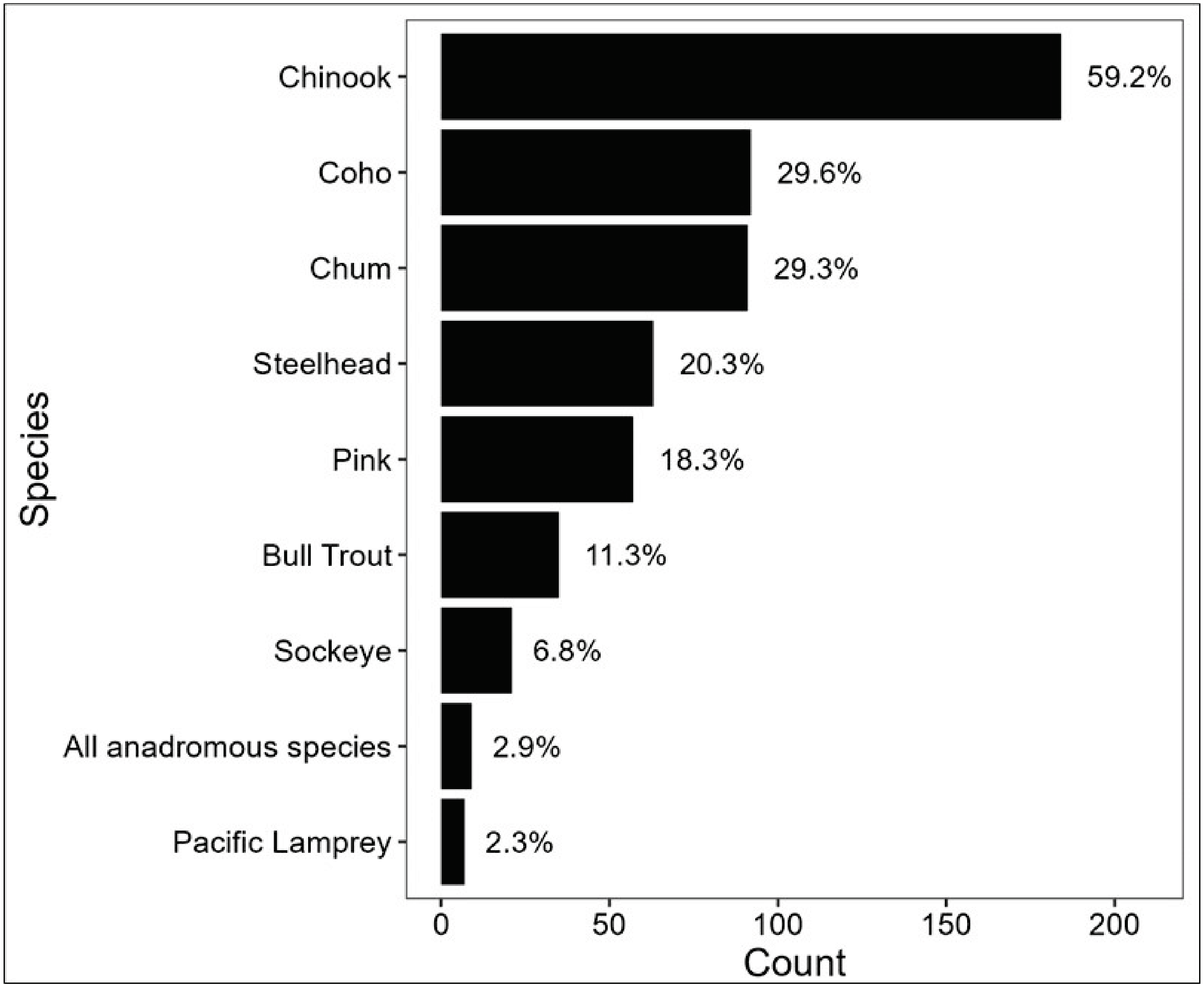


Figure 5.2-4. **Count of sources by target species. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple target species.**

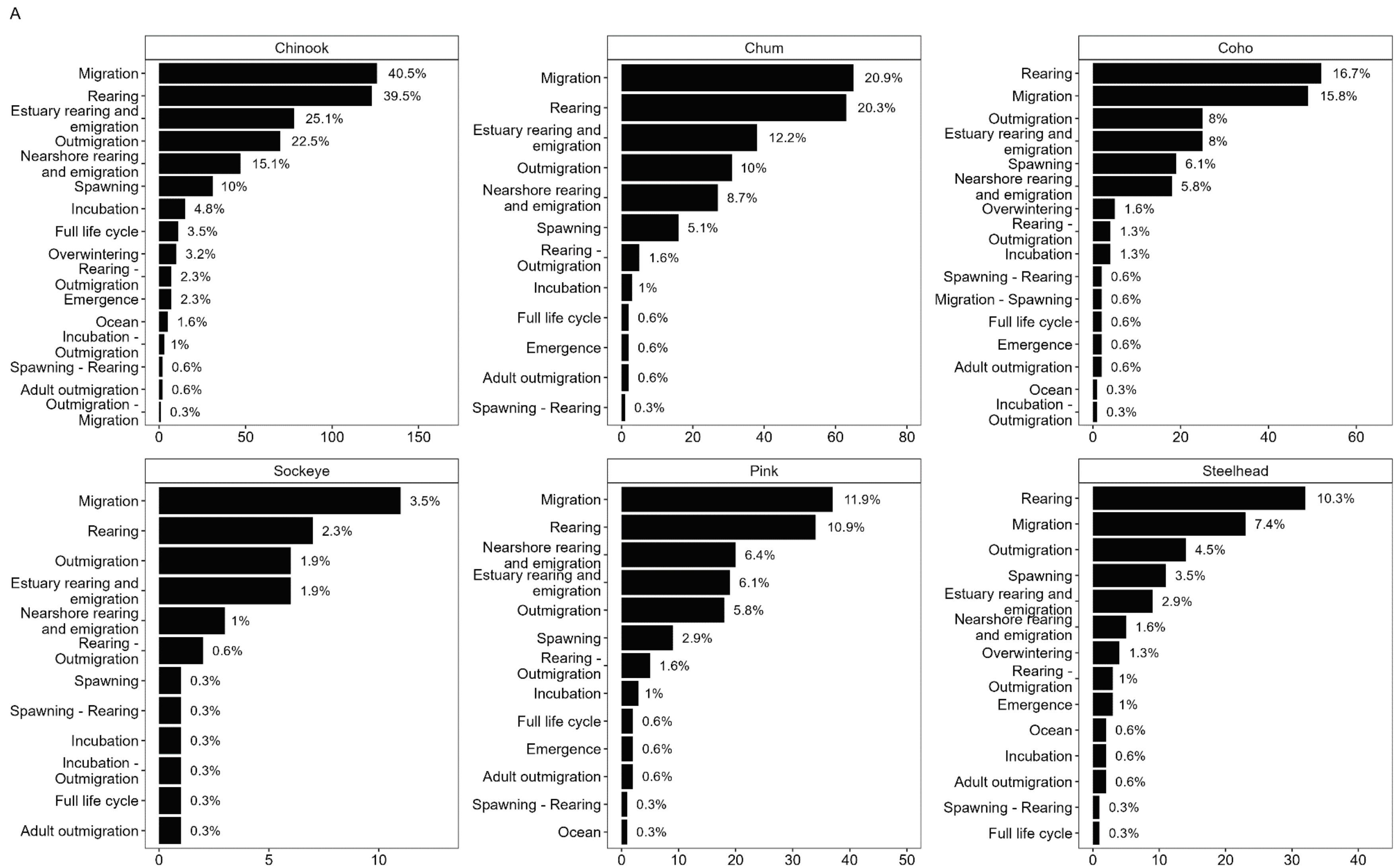


Figure 5.2-5. Count of sources that provide information on life stages by target species (Panel A). Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple target species and life stages.

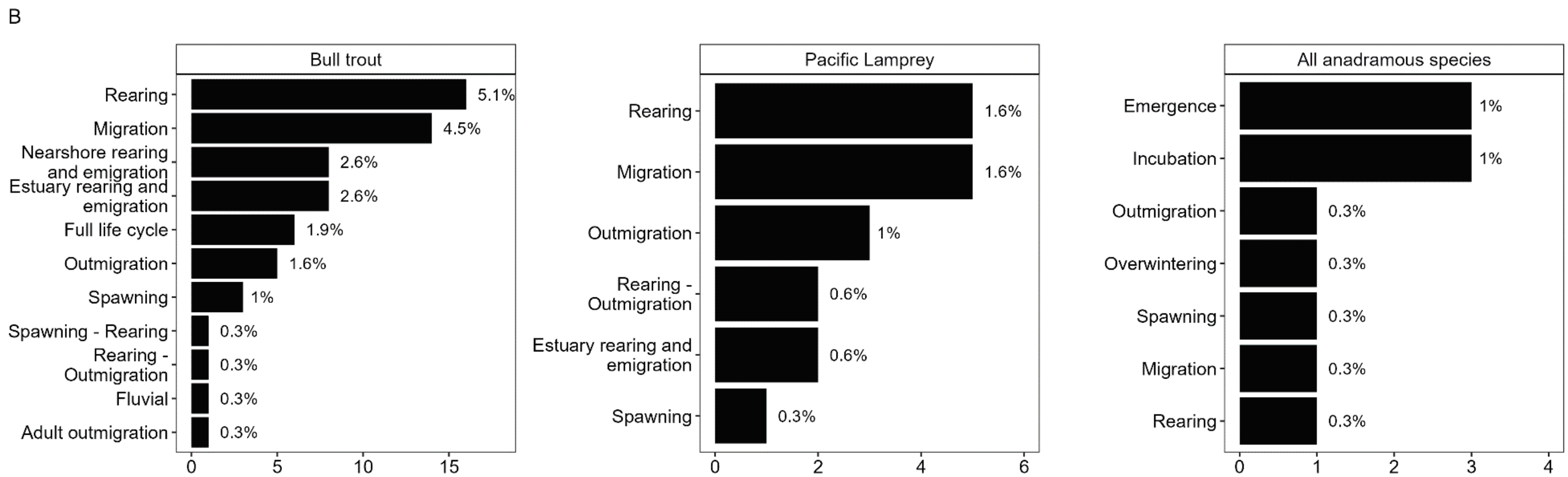


Figure 5.2-5. Count of sources that provide information on life stages by target species (Panel B). Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple target species and life stages.

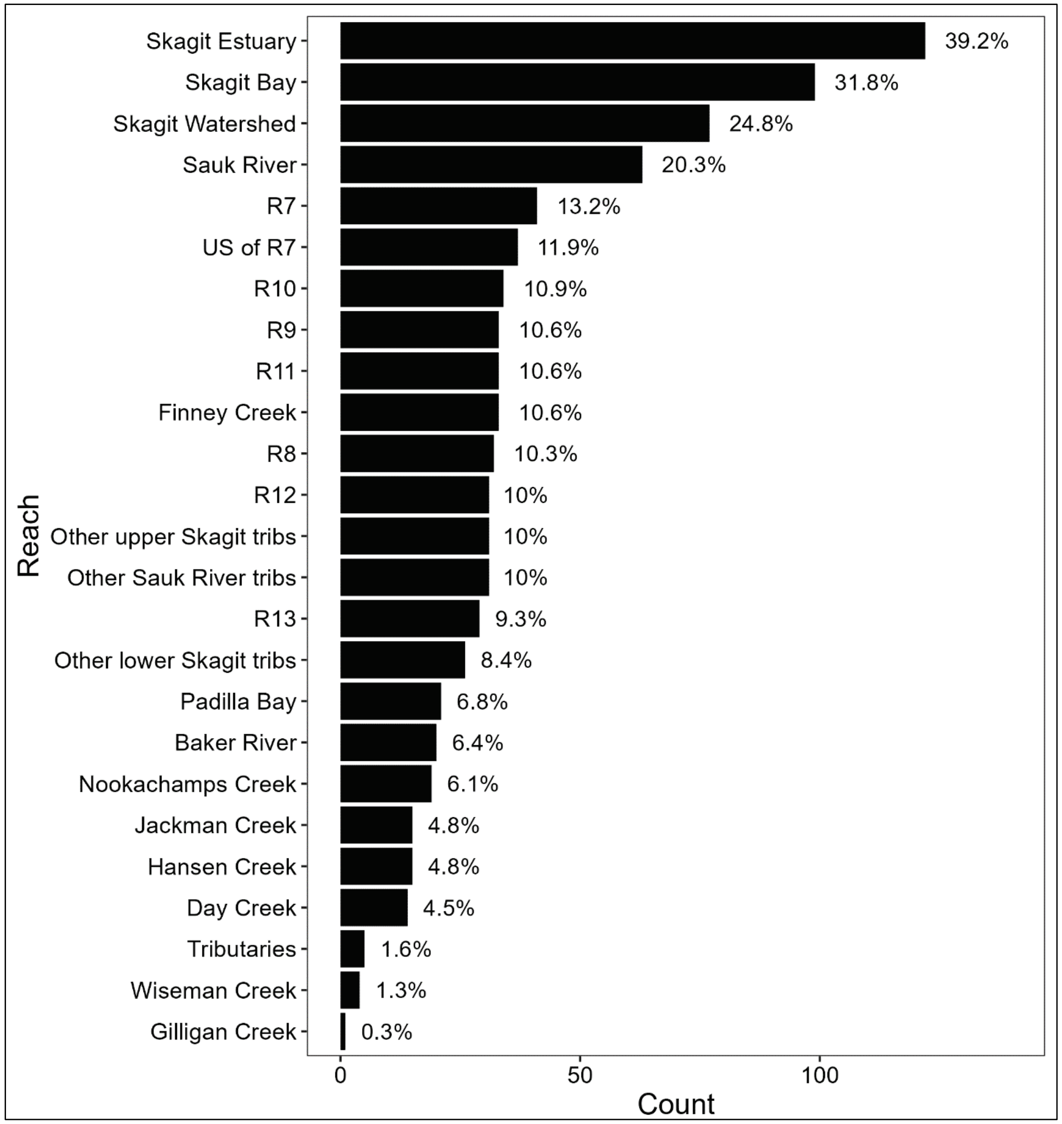


Figure 5.2-6. Count of sources that provide information on spatial strata within the study area. Percentages represent the proportion of sources that provide information on the topic or subtopic. Note that the total of the sources is greater than the total sources reviewed because sources provided information on multiple spatial strata.

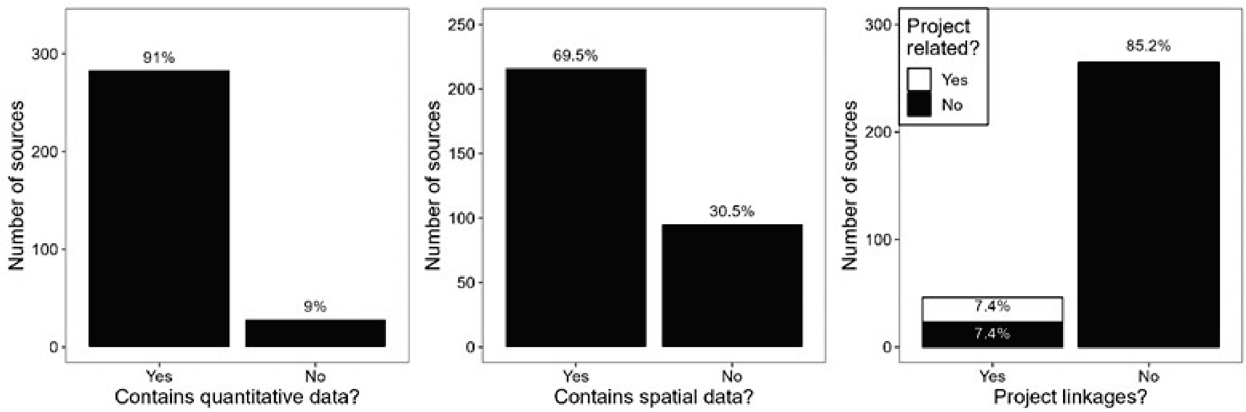


Figure 5.2-7. Count of sources that provide information on data flags. Percentages represent the proportion of sources that provide information on the topic or subtopic.

5.3 Step 3: Life Stage Factors Results

The results of the LSF synthesis are provided in the form of the LSF narratives (Attachment C) and the LSF Tables (Attachment D). The results of the scoring framework were used in the initial assessment of relative importance, and to identify Key Factors based on the aggregate scores. Answers to the Key Factor criteria and results of the scoring are summarized in Figure 5.3-1.

A total of eight factors were classified as being of high relative importance (Figure 5.3-1). These included sediment supply and transport, instream temperature maximums, habitat extent, peak flows, competition during rearing, secondary productivity, habitat connectivity, and riparian conditions. These factors had the highest biological scores (average = 3.5), management scores (average = 2.7), and climate scores (average = 0.5). An additional nine factors were classified as being of Moderate relative importance (Figure 5.3-1). These included several water quality factors (turbidity, dissolved oxygen, general and minimum instream temperatures, and nutrients and organic matter), general and minimum instream flow, hydromodified banks and channel edges, and climate change. These factors scored less than the factors that were identified as having high relative importance for biological scores (average = 2.3), management scores (average = 2.4), and climate scores (average = 0.5). Collectively, the factors that were scored as having High or Moderate relative importance ($S_T \geq 4.5$) were identified as Key Factors for the Synthesis Study.

The remaining 15 factors were identified as having low relative importance (Figure 5.3-1) and included LWD recruitment and retention, primary productivity, competition during spawning, beaver management, downramping, several water quality factors (bacteria and pathogens, contaminants, salinity, and pH), predation (avian, mammal, and fish), fisheries, tidal inundation, hatcheries, and aquaculture. These factors scored the lowest for biological scores (average = 1.5), management scores (average = 1.4), and climate scores (average = 0.2).

Factor	Relevant to one or more target species or life stages?	Limiting factor to one or more species or life stages?	Relevant to one or more spatial strata?	Can be influenced by management actions?	Can be influenced by Project operations?	Sensitive to climate change or WY type?	Biological Score	Management Score	Climate Score	Aggregate Score	Initial Assessment of Relative Importance
Sediment supply and transport	Yes	Yes	Yes	Yes	Yes	Yes	4.0	3.5	0.5	8.0	High
Instream temp max	Yes	Yes	Yes	Yes	~Yes~	Yes	4.0	2.7	0.5	7.2	High
Habitat extent	Yes	Yes	Yes	Yes	~Yes~	Yes	4.0	2.2	0.5	6.7	High
Peak flow	Yes	Yes	Yes	Yes	Yes	Yes	3.0	3.1	0.5	6.6	High
Competition - rearing	Yes	Yes	Yes	Yes	~Yes~	~Yes~	3.2	2.9	0.5	6.6	High
Secondary productivity	Yes	Yes	Yes	Yes	Yes	Yes	2.2	3.8	0.5	6.5	High
Habitat connectivity	Yes	Yes	Yes	Yes	~Yes~	~Yes~	4.0	2.0	0.3	6.3	High
Riparian condition	Yes	Yes	Yes	Yes	No	Yes	4.0	1.5	0.4	5.9	High
Turbidity	Yes	Yes	Yes	Yes	~Yes~	Yes	2.8	2.4	0.5	5.7	Moderate
General flow	Yes	No	Yes	Yes	Yes	Yes	2.0	3.2	0.5	5.7	Moderate
Min flow	Yes	No	Yes	Yes	Yes	Yes	2.0	3.0	0.5	5.5	Moderate
Instream temp min	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.7	0.5	5.2	Moderate
Instream temp general	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.7	0.5	5.2	Moderate
Climate change	Yes	Yes	Yes	No	No	Yes	3.5	1.1	0.5	5.1	Moderate
Hydromodified banks and channel edges	Yes	Yes	Yes	Yes	~Yes~	~Yes~	2.8	1.9	0.3	4.9	Moderate
Nutrients and organic matter	Yes	No	Yes	Yes	~Yes~	Yes	1.5	2.8	0.5	4.8	Moderate
Dissolved oxygen	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.0	0.5	4.5	Moderate
LWD recruitment and retention	Yes	No	Yes	Yes	~Yes~	~Yes~	2.0	2.1	0.3	4.3	Low
Primary productivity	Yes	No	Yes	Yes	~Yes~	Yes	1.5	2.1	0.5	4.1	Low
Beaver management	Yes	Yes	Yes	Yes	No	No	2.2	1.5	0.0	3.7	Low
Bacteria and pathogens	Yes	No	Yes	Yes	No	~Yes~	2.0	1.3	0.3	3.6	Low
Predation - fish	Yes	No	Yes	Yes	No	~Yes~	1.7	1.7	0.3	3.6	Low
Fisheries	Yes	Yes	Yes	No	No	Yes	1.9	1.3	0.3	3.5	Low
Competition - spawning	Yes	No	Yes	Yes	~Yes~	Yes	0.9	2.0	0.5	3.4	Low
Contaminants	Yes	No	Yes	Yes	No	~Yes~	2.0	1.3	0.1	3.4	Low
Predation - avian and mammal	Yes	No	Yes	Yes	No	No	1.7	1.4	0.0	3.1	Low
Downramping	Yes	No	Yes	Yes	~Yes~	~Yes~	1.5	1.3	0.3	3.0	Low
Hatcheries	Yes	No	Yes	No	No	No	1.7	1.3	0.0	2.9	Low
Salinity	Yes	No	Yes	Yes	~Yes~	Yes	0.9	1.4	0.5	2.8	Low
Tidal inundation	Yes	No	Yes	Yes	~Yes~	Yes	0.9	1.3	0.4	2.5	Low
pH	Yes	No	Yes	Yes	No	Yes	0.9	0.8	0.4	2.0	Low
Aquaculture	Yes	No	Yes	No	No	No	0.9	0.5	0.0	1.4	Low

Note: Factors are sorted by aggregate scores to support identification of Key Factors. The color ramp represents the range of scores from lowest (light green) to 50th percentile (medium green) to highest (dark green) for each scoring component and the aggregate score.

Figure 5.3-1. Key factor criteria and summary of initial assessment of relative importance. All biological, management, and climate scores were summarized from the LSF Tables for each factor (see Attachment D).

5.4 Step 4: Key Uncertainties Results

5.4.1 Data Gaps Identified in the Literature

Many studies identified data gaps or monitoring needs in reporting their results and findings. This information was compiled into an attachment and organized by topical areas (Attachment I) to support identification of data gaps and key uncertainties. The reviewed sources represent a range of temporal periods and some data gaps or monitoring needs identified in reports and publications may have been addressed in subsequent studies. Therefore, the summary of data gaps identified in the literature does not represent data gaps identified by this study, but rather provide supporting information for the identification of data gaps during Step 4 of this study.

A total of 20.9 percent of the sources reviewed were flagged as providing information on data gaps for topics of interest. Among the primary topics, descriptions of data gaps were flagged for fish and habitat topics (fish = 9.3 percent, habitat = 6.8 percent, and monitoring = 4.8 percent), geomorphology and landforms (3.9 percent), land use and cover (2.3 percent), modeling tools (2.6 percent), and water quality and productivity (3.2 percent) topics.

Data gaps and monitoring needs identified in the reviewed literature covered instream flows, habitat extent and connectivity, sediment supply and transport, water quality and productivity, riparian condition, and target species and life stages. These are briefly summarized below, with more detail provided in Attachment I.

Information on data gaps and uncertainties identified in the literature included instream flows and the effect of Project operations on instream flows in the study area with contributions from unregulated tributaries and the Baker River. Flows and hydrography for unregulated tributaries were also identified as a data gap with incomplete flow monitoring of tributaries that drain into the lower Skagit River.

Data gaps were also identified for habitat extent and connectivity within the study area. With respect to connectivity, studies identified information on water crossings and fish passage barriers, or habitat connectivity, as a data gap for the study area. Data gaps included the location and status of barriers on tributaries or secondary channels to the mainstem Skagit River, and in tidally influenced habitats of the Skagit River estuary and nearshore habitats. For habitat extent, data gaps were generally identified with respect to tributary and floodplain habitats, and information on target species use of these habitats. Data gaps on estuary and nearshore habitat extent were also identified by sources, as well as juvenile salmon use of estuary and nearshore habitats.

Data gaps on sediment supply and transport identified in the literature influence information on the relative impacts of levees, bank armoring, and channel modifications in relation to the increased transport efficiency of sediment through the estuary to the nearshore. Mapping and monitoring of landslides and driving mechanisms, as well as impacts of hydropower dams on sediment supply and transport processes and habitat formation processes downstream of dams were also identified as data gaps. Sediment supply and transport processes in tributaries were also identified as a data gap by several studies.

Water quality and productivity in tributary systems were identified as data gaps by several studies, including floodplain habitats in the lower Skagit River and estuary. Specifically, temperature was identified as an aspect of water quality monitoring that needed additional research and monitoring in these habitats. However, data gaps for other water quality parameters were also identified (e.g., contaminants and toxins). Some studies identified data gaps and monitoring needs for riparian conditions, but these may have been addressed in recent studies or were related to other factors (e.g., sediment supply and transport or water quality).

Data gaps and monitoring needs were also described for target species and life stages, which included the addition of genetic stock identification with juvenile monitoring programs, and assessment of survival between key life stages and improved understanding of marine survival rates in particular. This included specific data gaps and monitoring needs related to Chinook, Bull Trout, steelhead, and Chum.

5.4.2 Relative Number of Studies Providing Information on Topics, Species, and Spatial Extents

Data inventories were developed from a total of 314 sources, which provided counts of sources that provide information on topics and subtopics, species and life stages, spatial strata, and data flags. Bar plots provided in the data inventory results section (Section 5.2.2 of this study report) show the relative counts of sources that provide information on topics and subtopics, species and life stages, spatial strata, and data flags. The following provides a brief summary of the relative counts among the topics and subtopics, species and life stages, and spatial strata based on the data inventory results.

Among the primary topics, only 10.9 percent of sources provided information on hydroelectric operations topics and was the primary topic with the fewest number of sources providing information on that topic (Figure 5.2-2). Within the hydroelectric operations topic, information on stranding was the least common (1.6 percent) compared to flow regulation in general (9.6 percent) among the sources reviewed (Figure 5.2-3, page 6 of 6). This was consistent with the finding that stranding studies most commonly focused on reaches upstream of the Sauk River confluence (see Attachment C).

In contrast to the hydroelectric operations topic, most studies provided information on fish and habitat topics (94.5 percent) (Figure 5.2-2). Among these sources, most studies provided information on abundance, restoration, estuary habitat, instream flows, and distribution (27.7-61.4 percent). In contrast, fewer than 6 percent of the sources reviewed provided information on invasive species, genetics, scale and otoliths, condition, competition, flow, beaver (habitat), biotelemetry, sex structure, fecundity, sediment (habitat), swimming speed, and aquaculture subtopics (Figure 5.2-3, page 1 of 6).

Information on geomorphology and landforms was provided by 62.7 percent of the sources reviewed (Figure 5.2-2), and most information (>20 percent) was related to sediment supply and transport, substrate and sediment, estuary habitats and landforms, and change. Fewer than 5 percent of the sources reviewed provided information on sinuosity, log jam, scour, channel incision, shallow and deep surface processes, and snowpack subtopics (Figure 5.2-3, page 2 of 6).

A total of 37.6 percent of the sources provided information on water quality and productivity (Figure 5.2-2), with most providing information on temperature. Fewer than 5 percent of the sources reviewed provided information on pH, bacteria, and climate change impacts to water quality and productivity (Figure 5.2-3, page 3 of 6).

Land use and cover information was provided in 42.4 percent of the reviewed literature (Figure 5.2-2), with most information being related to bank and shoreline conditions. Information on specific land cover and uses (e.g., agricultural, forestry, urban, and commercial) was described in about 2-12 percent of the sources, however climate change impacts on land use and cover were described in only 1 percent of the sources reviewed (Figure 5.2-3, page 4 of 6).

Nearly half of the sources reviewed provided information on modeling tools (48.6 percent) (Figure 5.2-2), with most describing hydrology models or modeling studies. Fewer than 5 percent of the sources reviewed provided information on models related to climate change, bioenergetics, adult returns, sediment, life cycle models, or habitat connectivity (Figure 5.2-3, page 5 of 6).

5.4.3 Key Uncertainties

Key Uncertainties were defined as uncertainties related to mechanisms and the influence of Project operations on Key Factors and anadromous resources in the study area. This working definition and list of uncertainties associated with Key Factors were reviewed with LPs during work group meetings (December 19, 2022) to support identification of Key Uncertainties (see Attachment K). Key Uncertainties were identified from the reviewed literature and in coordination with LPs that were related to sediment supply and transport, instream flows, water quality and productivity, habitat extent and connectivity, competition during rearing, riparian condition, hydromodified banks and channel edges, and climate change.

The Key Uncertainties identified in the Synthesis Study are described briefly below. Additionally, Section 6.1.4 of this study report provides more context and detail, including approaches to address Key Uncertainties. Many of the Key Uncertainties can be addressed through modeling (e.g., hydrological, life cycle, sediment, bioenergetics), while others may require additional monitoring (e.g., instream flow monitoring in tributaries or improved juvenile outmigration monitoring) or other coordinated efforts to address.

A common theme to uncertainties identified during the literature review were related to the attenuation of flow regulation influences on instream flows and other Key Factors (e.g., sediment supply and transport, water quality and productivity, habitat extent and connectivity) with increasing contribution of unregulated tributary inputs with increasing distance downstream from the Project and downstream of the Sauk River confluence. Multiple studies detected gradients of factors or biological responses that were related to increasing distance from the Project (e.g., Gislason 1980, ID406; Woodin et al. 1984, ID405; Connor and Pflug 2004, ID385; Austin et al. 2021, ID446). In addition, studies commonly described or implied linkages between Project operations or flow regulation to factors or biological responses, but these were not often quantified. Only 7.4 percent of the studies reviewed included specific analyses or elements designed to determine Project operations influence on resource conditions, but these studies typically only included the upper reaches of the study area near the Sauk River confluence (e.g., Reaches R7 or R8). Unregulated tributary inputs are hypothesized to moderate the influence of Project operations with increasing distance downstream from the Project, but many tributaries lack long-term monitoring data that would support evaluating the spatial extent of Project operation effects on factors or resource conditions.

Tradeoffs between process flows (flows that drive habitat formation, maintenance, and connectivity) and life stage flows represent another area of uncertainty that is related to several Key Factors (e.g., habitat extent and connectivity, sediment supply and transport, competition during rearing, riparian conditions, and channel edge conditions). This uncertainty is also partly related to uncertainty relating to the spatial extent of Project operation influences below the Sauk River and unregulated tributary inputs, but also integrates uncertainties about the influence of reductions in peak flow frequency and magnitude and habitat formation processes in the lower Skagit River and reduced survival during incubation of mainstem spawning species with increasing peak flows.

Uncertainties related to climate change and potential effects of climate change on Key Factors and resource conditions were also identified. A number of studies demonstrated contemporary changes that were related to climate change, including increasing instream temperatures (Austin et al. 2021, ID446), reductions in glacial coverage (Lee and Hamlet 2011, ID196), and reduced progradation rates of tidal marshes (Beamer et al. 2015, ID008). Multiple studies provide estimates of future climate change impacts and point to shifts in hydrological regimes that will likely impact many Key Factors, habitat processes, biological responses, and resources conditions. However, there are large uncertainties associated with these modeling exercises, and it is unclear how climate change will influence recovery planning or Project operations in the study area.

6.0 DISCUSSION AND FINDINGS

6.1 Summary

This study has met the goals and objectives stated in Section 2.0 of this study report. A total of 523 potentially relevant sources were identified during Step 1: Data Compilation, and from these a total of 314 were identified as sources that provide information relevant to the Synthesis Study objectives, study area, target species and life stages, and topics of interest. Annotated bibliographies (Attachments F and G) and data inventories were developed from these sources to address the goals of Step 1 and to support Steps 2-4 of the Synthesis Study. As part of Step 2, data inventories were summarized and conceptual life cycle diagrams and life history models were developed in coordination with LPs (Attachment E) to support Steps 3-4. Information on Life Stage Factors (LSF) were synthesized from these sources into narratives (Attachment C), and a scoring framework was developed for an initial assessment of relative importance and identification of Key Factors for Step 3 (Attachment D). Lastly, the Key Factors were reviewed with LPs to identify Key Uncertainties in Step 4, to support identification of uncertainties that limit our ability to describe how Project operations influence conditions in the lower Skagit River.

6.1.1 Data Compilation and Synthesis of Information

A key outcome of the Synthesis Study was to identify and compile relevant literature on the study area, and the annotated bibliographies and data inventories developed from the available literature represent a valuable resource that could support other studies to address Key Uncertainties or other research objectives. The Skagit River is one of the most intensively studied and monitored systems in the Pacific Northwest, and a total of 523 potentially relevant sources were identified as part of the Synthesis Study. Most sources identified were reports (59 percent, 310/523), although a number of peer reviewed sources were also identified (18 percent, 96/523) (Figure 5.1-1). This large body of literature reflects the extensive research and monitoring that has occurred in the Skagit River to support recovery planning and resource management. The number of potential sources identified by the Synthesis Study was even more impressive considering the fact that this synthesis focused on the lower Skagit River, its tributaries, estuary, and nearshore habitats; even more literature focused on the upper Skagit River upstream of the Sauk River confluence is available that was not considered in this Synthesis Study.

From the 523 potentially relevant sources, a total of 314 were identified as sources that provide information relevant to the Synthesis Study objectives, study area, target species and life stages, and topics of interest. Annotated bibliographies and data inventories were developed from these sources to address the goals of Step 1 and to support Steps 2-4 of the Synthesis Study. The sources that were screened and archived and not used to develop annotated bibliographies or data inventories consisted of previous reports (n=59), studies that do not provide information for the Skagit River (n=47), studies that provide information for the Skagit River but only outside of the study area (n=10), are websites or datasets (n=25), are future or ongoing studies (n=23), or are sources determined to not be relevant to the Synthesis Study objectives (n=6) or for which hard copies or digital copies could not be found to review (n=39) (Figure 5.1-2).

The information synthesized into the annotated bibliographies developed as part of the Synthesis Study provides over 500 pages of focused information describing the studies and information relevant to the Synthesis Study objectives and data inventory results (See Attachments F and G for annotated bibliographies). The annotated bibliographies provide a condensed synthesis of information considering that these annotated bibliographies represent information from over 21,000 pages of reports and journal articles. This information was further synthesized to approximately 100 pages of information on LSFs described by the reviewed literature (See Attachment C). This LSF information was further synthesized into LSF Tables to support identification of Key Factors and Key Uncertainties in Steps 3 and 4, respectively. Collectively, the synthesis represents a condensed version of information intended to support the objectives of the Synthesis Study, while also making the body of literature more accessible for this and other studies. To that end, a literature database application was developed to support accessibility of the compiled literature and annotated bibliographies that includes search capabilities using key words and the topics of interest, target species and life stages, and data flags that were attributed to each source as part of the data inventory.

The following sections provide a summary of the findings of the Synthesis Study based on the key questions that were developed from the study plan and in coordination with LPs during Synthesis Study work group meetings (see Attachment K). These include the following questions:

- What is the condition of resources in the lower Skagit River?
- What are the contributing factors to resource conditions in the lower Skagit River?
- What data gaps and research or monitoring needs might limit our ability to describe how Project operations influence conditions in the lower Skagit River?

6.1.2 What is the Condition of Resources in the Lower Skagit River?

The following sections provide a brief summary of resource conditions in the study area, including anadromous resources and habitat conditions. For more detail and information, refer to the LSF narratives (Attachment C) and annotated bibliographies (Attachment F and Attachment G) compiled as part of the Synthesis Study.

6.1.2.1 Anadromous Resource Conditions

The lower Skagit River (below the Sauk River confluence), tributaries to the lower Skagit River (including the Sauk River), the Skagit estuary, and the nearshore habitats associated with the Skagit River delta (Skagit Bay and Padilla Bay) support all anadromous target species identified in the Synthesis Study. This includes Chinook, Coho, Chum, Pink, and Sockeye salmon; Bull Trout and steelhead; and Lamprey. All these target species rely on the lower Skagit River during both adult and juvenile migration life stages, including populations that spawn upstream of the Sauk River confluence in the upper Skagit River. In addition, the lower Skagit River, its tributaries, and the Skagit estuary provide rearing and spawning habitats for target species and life histories to varying degrees. Native Chinook Salmon, steelhead, and Bull Trout are listed as threatened under the Endangered Species Act, and the Puget Sound/Strait of Georgia Coho Salmon population is listed as a Candidate population under the Endangered Species Act (Ford et al 2022, ID517).

Under existing conditions, the Skagit River basin supports the largest run of Chinook Salmon in the Puget Sound Evolutionarily Significant Unit (ESU) region, one of the largest runs of Pink Salmon in the coterminous United States, and regionally large runs of Coho Salmon (Connor and Pflug 2004, ID385). Trends in Coho abundance are indicative of declining abundance over time in the Skagit River (Rubenstein et al. 2018, ID411). At a regional scale, Puget Sound Chinook escarpment levels were below the range needed for recovery, with the exception of Skagit River populations (Ford et al. 2011, ID135), and the Puget Sound Chinook ESU remains at “moderate” risk of extinction (Ford et al. 2022, ID517). However, most populations have shown increases in abundance since the most recent status review (2015), while 15-year trends showed declines for most major population groups (MPGs) (Ford et al. 2011, ID135). The Skagit River system also supports two of the largest and most diverse Bull Trout Core populations in the Coastal Recovery Unit, which includes western Oregon and Washington (USFWS 2013). A 2007 regional decline in Chum Salmon was found to be partially linked to marine productivity (Malick et al. 2017). Some Chum stocks have now rebounded, although not the Skagit River run (Ruff 2019). Declining trends in steelhead escapement have also been reported for the Skagit River basin (Kinsel et al. 2013, ID147). The current distribution of Pacific Lamprey is limited to the lower Skagit River, although historical distributions extended upriver throughout most of the mainstem Skagit River and Sauk River (Plumb and Blanchard 2021, ID519). Current status of the Skagit River Pacific Lamprey population is cited as unknown, and genetic sampling efforts are underway to support evaluation of population status in the Skagit River basin (Plumb and Blanchard 2021, ID519).

There are substantial recreational fisheries for hatchery spring Chinook, Coho, odd-year Pink Salmon, Bull Trout, and winter steelhead from the mouth of the Skagit River up the mainstem and into the major tributary systems of the Cascade and Sauk rivers (NMFS 2014). The Marblemount and Baker Lake hatcheries, which currently operate within the Skagit River basin, produce summer and spring Chinook, Coho, and Sockeye salmon to augment the natural production of these species[4] (NMFS 2015). A Chum conservation program was also recently established in the upper Skagit at the Marblemount hatchery, with brood stock takes initiating in 2021 (WDFW 2022). The Upper Skagit Indian Tribe and Sauk-Suiattle Indian Tribe also collect Chum Salmon broodstock in the basin. Fisheries for Sockeye and Coho salmon are primarily supported by a combination of hatchery and natural-origin populations. The spring Chinook fishery consists of a targeted harvest on a hatchery stock, and the summer Chinook hatchery program is relatively small and operated as an indicator stock program[5] (NMFS 2014). In 2015, the NWFSC concluded that all Puget Sound Chinook Salmon populations were still well below escapement levels needed to support recovery and found that hatchery-origin spawners were present in high fractions in most populations outside the Skagit River watershed (Ford et al. 2022, ID517).

The long-term abundance of adult steelhead returning to many Puget Sound rivers has decreased significantly since the late 1970s. However, more recently there have been some improvements in abundance and productivity (Ford et al. 2022, ID517). High ocean temperatures in 2014 and 2015 and high stream temperatures and low summer streamflows during 2015 decreased marine and freshwater survival. However, reduced harvest and declining hatchery production were determined to have modestly decreased risks to natural spawners. Harvest of Puget Sound steelhead is limited to terminal Indian Tribe net and recreational fisheries. Harvest rates were curtailed in 2003, with “wild” harvest rates held below 10 percent (Ford et al. 2022, ID517). Recreational fisheries are

4 Chinook Salmon and Coho Salmon are produced at the Marblemount Hatchery, and Sockeye Salmon are produced at the Baker Lake Hatchery. The Marblemount Hatchery winter steelhead program ended in 2016, and the Barnaby Slough winter steelhead program ended in 2009 (NMFS 2015).

5 Indicator stocks are used to model the effects of mixed stock fisheries on wild salmon populations.

mark-selective for hatchery stocks, but some natural-origin fish succumb to hooking mortality and poaching.

Hatchery steelhead production for harvest consists mainly of Chambers Creek winter-run stock and Skamania Hatchery summer-run stock, both selected for run timing that precedes that of natural stocks to reduce interaction between hatchery and naturally spawned fish. To reduce the risk of introgression between native and hatchery-origin fish, Chambers Creek releases were discontinued in the Skagit River (Ford et al. 2022, ID517). Although the risk posed by hatchery programs to naturally spawning populations has recently decreased, it is unclear how long it will take for the genetic legacy of introgression to subside.

Despite the recovery benefits resulting from programs governed by Hatchery and Genetic Management Plans (HGMP) and supplementation of fish harvest, hatchery programs have been shown to have a range of effects on wild fish populations throughout the Pacific Northwest. Pflug et al. (2013, ID154) examined the effects of ecological and genetic interactions between hatchery- and natural-origin steelhead in the Skagit River basin. The authors identify two types of interaction occurring during the juvenile life stage: (1) ecological interactions during the freshwater and early marine outmigration period and (2) ecological and genetic interactions between stray hatchery adults and wild fish on spawning grounds. Competitive interactions among hatchery and wild fish, for both physical habitat and food, during the freshwater, estuarine, and early marine stages of emigration can affect the growth potential and survival of natural origin smolts. The earlier fry emergence timing of hatchery influenced juveniles allows them to occupy habitat before the later emerging natural-origin fry, which confers a competitive advantage on the hatchery influenced fish. Austin et al. (2021, ID446) found that shifts in spawning timing (toward earlier spawning) of wild runs were linked to hatchery practices.

Pflug et al. (2013, ID154) note that hybrid and naturally spawned hatchery juveniles have been found in the Skagit River mainstem, the Sauk, Suiattle, and Cascade rivers, and many smaller tributaries, regardless of distance from the hatchery source. At the time Pflug et al. (2013, ID154) was published, the proportion of hybrids in the basin ranged from 4 percent in the Sauk River collection area to 26 percent in Finney Creek. The authors suggest that introgression was most pronounced where the greatest temporal overlap of stray hatchery and natural steelhead spawning occurred. Introgression likely lowers the productivity of wild steelhead, because hatchery fish have substantially lower marine survival rates than wild fish, and hatchery origin spawners that spawn with natural origin adults may reduce natural origin spawning opportunity with other natural origin adults.

Pflug et al. (2013, ID154) state that hatchery steelhead smolt releases had a highly significant, negative effect on native steelhead returns in the Skagit River that was independent of long-term trends in marine and freshwater conditions. The authors concluded that "the regional analysis on the effects of hatchery smolt releases on native steelhead productivity among Puget Sound watersheds suggests that hatchery releases have had a long-term negative impact on steelhead population growth rates" (Pflug et al. 2013, ID154). McMillan (2012, ID434) and Paulson (1997, ID354) also reported a negative relationship between steelhead smolt releases and population trends in the Skagit.

6.1.2.2 Habitat Conditions

The lower Skagit River, including all streams downstream of the Sauk River confluence, were identified as containing the "…most highly degraded freshwater salmon habitat in the Skagit Basin with considerable impacts in every habitat category" (Smith 2003, ID376). Impairments to habitats are described briefly here but refer to the LSF narratives (Attachment C) for more detail.

Historical Habitat Conversion and Land Uses

Skagit County was established in 1883 and was developed slowly relative to other areas in the region (Smith 2003, ID376). Settlement was slowed by two large logjams near what is now Mount Vernon that prevented upstream navigation. The jams were removed in the 1870s, after which upstream settlement accelerated. Between 1898-1908, thousands of additional snags were removed from the river. Commercial fishing, and operation of its associated canneries, began in the late 1890s (Smith 2003, ID376). Around the same time, the intensity of other types of development, such as dikes, draining of wetlands, land clearing, and timber harvest, increased. Agriculture became important in the lowlands with oats, barley, hay, and other crops grown on floodplain soils. The first dikes along the lower Skagit River are thought to have been constructed in 1863 (Lee and Hamlet 2011, ID196), and the dominant flow in the Skagit River estuary was shifted from the South Fork to the North Fork around 1937.

The first steam locomotive was used in Skagit County in 1889, and by 1901 the larger towns in Skagit County were connected to Seattle by rail lines (Smith 2003, ID376). Around the same time, the upper valley rail line was established to Baker and Rockport. Railroad and road construction proliferated in the early 1900s, which resulted in increased mining, timber harvest, and milling in the basin. Logging in the Sauk River basin started in the 1930s, and in the 1940s cable logging and hauling timber via trucks began. Logging on steeper slopes began in the 1970s.

In addition to the development and conversion of lands, hydroelectric dams and reservoirs were constructed in the Baker River, a tributary to the lower Skagit River, and the upper Skagit River. The Baker River Hydroelectric Project, located on the Baker River, consists of the Lower and Upper Baker developments. There are two powerhouses for the Lower Baker Project, one constructed in 1925 and the second in 2013. The upper Baker development was completed in 1959. The Skagit River Hydroelectric Project was developed over a 42-year period, beginning with construction of Gorge Powerhouse and a timber-crib dam in 1919, and ending with the completion of the Gorge Development in 1961. In the 1950s, the Shell and Texaco oil refineries were constructed near Anacortes, followed by the construction of many marinas and development of boat-related industries (Smith 2003, ID376).

Habitat extent and connectivity

Estuary and nearshore habitats**:** The Skagit River delta, with its numerous distributary channels, consists of a tidal estuarine mixing zone and riverine tidal areas. The tidal estuarine zone includes the channeled emergent and scrub-shrub marshes where freshwater and saltwater mix, forested riverine tidal zone where transitional salinities and forested marshes provide productive habitats, and the riverine tidal zone, where freshwater is tidally pushed but not mixed with marine water. Within these areas, a diversity of habitat is formed and maintained by tidal and riverine processes, creating a mosaic of channels and wetlands. Historically, the delta was an important salmon rearing region, with sloughs, highly productive low-velocity rearing and refuge habitats, and a large degree of connectivity among habitats. The nearshore and marine environments of Puget Sound have been significantly altered relative to their condition prior to settlement by people of European descent. The loss of habitat functions resulting from these impacts is one factor contributing to the decline of the region's salmon and trout populations (e.g., Smith 2003, ID376; Beamer et al. 2005, ID175; Beamer et al. 2005, ID005; Ford et al. 2022, ID517).

Human activities have modified, and continue to alter, nearshore ecosystems by constraining, redirecting, disrupting, or eliminating processes that control the delivery and distribution of sediment, water, energy, organic matter, and nutrients in nearshore environments (Redman et al. 2005, ID100). Major stressors include: (1) loss and simplification of deltas and delta wetlands; (2) flow alteration in major rivers; (3) shoreline modification from bank armoring, overwater structures, and impacts to riparian vegetation; (4) nearshore and marine contamination; (5) alteration of biotic communities; (6) impacts from urbanization; and (7) changes to habitat due to colonization by invasive species (Redman et al. 2005, ID100). Flow patterns in the delta have been altered by tidegates (Redman et al. 2005, ID100). These one-way check valves allow water to flow from a drainage into a marine watercourse during low tide but prevent saltwater from entering the drainage when the tide rises, which can adversely affect fish access to once important rearing areas. Road density in the lower Skagit River floodplain is excessive as the result of development (Smith 2003, ID376). Aquaculture facilities can have ecological effects due to "operational leakage" from damaged holding pens (Redman et al. 2005, ID100), and overwater structures can reduce the extent of eelgrass beds, with significant losses in areas with large numbers of docks (Redman et al. 2005, ID100).

Tidal delta estuary and pocket estuary habitat extent and connectivity were identified as limiting factors for juvenile Chinook Salmon, with rearing capacity limiting the productivity of delta rearing fry migrants (Beamer et al. 2005, ID175; Beamer et al. 2005, ID005). Estimates of estuary habitat losses average about 72 percent total loss of tidally connected estuary extent, with over 90 percent loss of blind tidal channel areas (Beamer et al. 2005, ID005; Redman et al. 2005, ID100; WWAA 2010, ID159; Lee and Hamlet 2011, ID196). Declines in progradation rates and natural losses of tidal marsh habitat at the delta fringes have been identified, but there has been a net increase in estuary area associated with restoration actions (Beamer et al. 2015 ID008; Beamer and Wolf 2017, ID187; Beamer et al. 2019, ID013). Restoration associated with implementation of the Skagit Chinook Recovery Plan has resulted in net increase of 83 hectares (205 acres) of intertidal footprint, increasing the extent of tidal habitat to 30.3 percent of its historic condition and 81.9 percent of the desired future condition (DFC). The increase over the 9-year period resulted from tidal restoration outpacing both natural and human causes of habitat loss; a total of 122 hectares were restored over the 9-year period, an average of 13.6 hectares per year. If net gains continue at the same pace as that observed from 2004-2013, the Skagit River's DFC for tidal delta extent would be achieved in 2096, 91 years after initial implementation of the Chinook Recovery Plan (Beamer and Wolf 2017, ID187).

Pocket estuaries were also identified as providing important rearing habitat for surplus Chinook fry migrants, increasing growth opportunity and survival to adult returns (Beamer et al. 2005, ID005). Studies indicate that 68-86 percent of historical pocket estuary habitat is inaccessible to juvenile salmon (Beamer et al. 2005, ID005; SWC 2022, ID451). Pocket estuary habitat was identified as a limiting factor for Chinook (Beamer et al. 2005, ID005), although the amount of pocket estuary habitat and restoration potential are insufficient to resolve the density-dependent patterns observed in the Skagit River estuary (Beamer and Larsen 2004, ID183). Recent work indicated that pocket estuary counts have increased between 2005 and 2014 (from 24 to 25) due to 94 hectares of restoration actions associated with implementation of the Skagit River Chinook Recovery Plan (SWC 2021, ID430). Ongoing and planned restoration associated with implementation of the Recovery Plan are described in detail in Beamer et al. (2019, ID013).

Overwater structures can reduce the extent of native eelgrass (*Zostera* spp.) beds, with significant losses occurring in areas with large numbers of docks (Fresh et al. 1995, as cited in Redman et al. 2005, ID100). In addition, colonization of Puget Sound habitats by invasive plant species, including *Spartina* spp. and *Sargassum muticum*, have altered native plant communities and sedimentation patterns. *Spartina* and *Sargassum*, both of which proliferate aggressively, out-compete native species and have transformed shorelines more than all other non-native plant species (Redman et al. 2005, ID100). Native eelgrass species and macroalgae have been supplanted by *Spartina*, resulting in negative effects on juvenile Chinook Salmon and Chum Salmon habitats (Thom et al. 1989; Aitken 1998; Grette et al. 2000; Weitkamp 2000; Nightingale and Simenstad 2001, all as cited in Redman et al. 2005, ID100).

Floodplain and River Habitats

When compared to historical conditions, Beamer et al. (2005, ID004) identified a 98 percent loss of area where non-tidal delta habitat can form. The lower Skagit River has the most extensive floodplain habitats in the Skagit River basin, but degradation and disconnection from dikes, levees, roads, riprap, and land uses are extensive (Beechie et al. 2003, ID015; Smith 2003, ID376; Beamer et al. 2005, ID175; Hinton et al. 2018, ID167). Hydromodifications, such as bank armoring, dikes, and floodplain roads reduce the complexity of bank habitat, thereby degrading habitat quality. Hydromodifications also isolate floodplain areas from the river channel, which alters the distribution and type of habitats in the mainstem and floodplains (Beechie et al. 2003, ID015; Smith 2003, ID376). The Skagit River downstream of the Sauk River confluence, except for the Baker River basin, contains the most highly degraded freshwater salmonid habitat in the Skagit River basin, with considerable impacts in nearly all habitat categories, and a large loss of freshwater rearing habitat has occurred in the non-tidal region of the Skagit River delta (Smith 2003, ID376).

Freshwater rearing habitats were identified as a limiting factor for Chinook Salmon, with freshwater rearing capacity limiting parr and yearling rearing capacities and increasing production of smaller and earlier migrating fry migrants (Beamer et al. 2005, ID175; Beamer et al. 2005, ID004). Zimmerman et al. (2015, ID331) described the composition of out-migrants as a density dependent function of spawner abundance, with fry migrant production being density independent, parr production being density dependent, and inconclusive findings for yearling production. Greene et al. (2021, ID056) also described density dependent processes in the estuary that limit delta rearing fry capacity. Surplus Chinook fry migrants can rear in estuaries or pocket estuaries to attain similar size as parr migrants, increasing their survival to adult return, but estuary and pocket estuary rearing capacities are also limiting productivity for Chinook, and restoration of both fresh water and estuary habitats are needed to address rearing capacity limitations in the Skagit River (Beamer et al. 2005, ID175; Beamer et al. 2005, ID004).

In addition to habitat extent and connectivity, hydromodifications were also identified as a factor that limits freshwater rearing capacity in the lower Skagit River (Beamer et al. 2005, ID175;

Beamer et al. 2005, ID004). Juvenile salmon and trout primarily utilize slow-water edge habitats with optimal velocity, depth, and cover (and LWD in particular) for rearing and emigration, and strong associations between edge, cover, and habitat unit types have been demonstrated in the Skagit River basin (e.g., Beamer and Henderson 1998, ID181; Beamer et al. 2005, ID004; Beamer et al. 2005, ID005; Beechie et al. 2005, ID014). Likewise, hydromodifications were identified as having a significant impact on juvenile salmon and trout rearing capacities, with hydromodifications being identified as a limiting factor for juvenile Chinook (Beamer et al. 2005, ID175) and significant factor influencing rearing capacities for Coho (Beechie et al. 1994, ID337).

Fish passage barriers associated with water crossing structures (e.g., culverts and tide gates) and dams were also identified as factors limiting access to habitats in mainstem, tributary, floodplain, and estuary habitats in the study area. Dams can directly impact fish access to spawning and rearing habitats (Beechie et al. 2010, ID017), although most sources indicated that the Baker River dams are the only dams that block fish passage to historical anadromous habitats (e.g., Smith 2003, ID376). Passage barriers such as culverts and water crossing features limit salmonid accessibility to habitat in the Skagit River basin, and numerous studies described barrier assessments with approximately 44 percent of historical anadromous habitat blocked (Beamer et al. 2000, ID190; Beamer et al. 2005, ID175; Souder et al. 2018, ID115; Mickelson et al. 2020, ID289). Mickelson et al. (2020, ID289) identified culverts as barriers to habitat and as a limiting factor to salmon productivity, and uncertainties regarding passage remain for a large number of water crossing features in the watershed.

Riparian Conditions

Riparian form and functions are generally influenced by regional ecosystem processes. Beechie et al. (2003, ID015) indicated that riparian functions are primarily affected by sparse forests, with shade being a dominant function in the western forested mountain ecoregions of the Skagit River basin. In the coastal forest ecoregions of the Skagit River basin, dense forest primarily affects riparian functions, with wood recruitment being a dominant function. Kammer et al. (2020, ID280) indicated that riparian forests under current conditions in the Skagit River basin are composed mostly of hardwood broadleaf species which do not reach the same heights as native conifers, and consequently provide less instream shading and other riparian functions. Most linkages between riparian conditions and instream functions were related to shading and instream temperatures in tributaries, and for LWD recruitment and spawning habitat in mainstem habitats.

Degraded riparian zones were identified as a limiting factor for Chinook Salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) evaluated riparian zones for each Skagit Chinook population and found that multiple Chinook populations experience significantly to heavily degraded riparian conditions, including Lower Skagit Fall Chinook, Upper Skagit Summer Chinook, Lower Sauk Summer Chinook, and Suiattle Spring Chinook. Upper Sauk Spring Chinook experience moderate degradation and Upper Cascade Spring Chinook experience little riparian degradation. Mature or functioning riparian habitats support pool and riffle habitats that are key for spawning adult Chinook and rearing juveniles (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) indicated that improved functional riparian habitats or maturation of riparian habitats will "…increase the pool-riffle habitat and bank cover for rearing juveniles, and can provide additional capacity not just for spawners, but also for producing parr migrants for which existing capacity is limited. In addition, the recovery plan also indicates that …land use activities that eliminate riparian habitats disrupt the natural recruitment process, limiting spawning and rearing habitat."

Land uses are a primary driver and stressor of riparian habitat condition and composition. Forestry, development for agricultural, and rural, urban, and industrial land uses were identified in numerous sources as primary stressors of riparian condition (e.g., Redman et al. 2005, ID100; Seixas and Veldhuisen 2019, ID301). Development of lands can generally result in altered hydrology, while development of riparian habitats can have more direct effects on instream habitat conditions (Redman et al. 2005, ID100). Both the extent and continuity of riparian habitats are primary factors for the form and function of riparian habitats and are used as indicators of riparian habitat condition in the Skagit River basin (Beechie et al. 2017, ID018; Hinton et al. 2018, ID167; Stefankiv et al. 2019, ID112). The impacts of riparian habitat extent and continuity are in part linked to the age or height of tree cover within the riparian zone, as this influences both instream shading potential as well as recruitment of LWD to the stream (Lawrence 2008, ID071; Kammer et al. 2020, ID280). Beechie et al. (2017, ID018) and Stefankiv et al. (2019, ID112) described habitat status and trends monitoring protocols, which include evaluating the percent cover and contiguous width of forested riparian cover as indicators for salmon habitat status and trends.

Hinton et al. (2018, ID167) provided habitat status and trends for riparian conditions for many tributaries to the lower Skagit River from 2006 to 2015. They found that percent functional vegetation increased from 70 to 72.4 percent from 2006 to 2015, increasing in Finney Creek but decreased in Illabot Creek, Diobsud Creek, and lower Sauk tributaries. Infrastructure remained steady at 3.9 percent from 2006 to 2015, increasing in Illabot Creek and lower Sauk tributaries but decreased in Diobsud Creek. Finney Creek remained steady. Dysfunctional vegetation decreased from 26.1 to 23.6 percent from 2006 to 2015, decreasing in Finney Creek, but increasing in Illabot Creek, Diobsud Creek, and lower Sauk tributaries (Hinton et al. 2018, ID167).

Smith (2003, ID376) also reported on riparian conditions for tributaries to the lower Skagit River, with "poor" riparian conditions identified in Nookachamps, Hansen, Jackman, Gilligan, Finney, Day, and Loretta creeks (Smith 2003, ID376). Riparian conditions in the Baker River subbasin were reported as "good" or "fair" for most subbasins (Smith 2003, ID376). Beamer et al. (1998, ID189) also linked degradation of water quality in Finney Creek, Suiattle River, and Sauk River to riparian conditions and private property issues. Lawrence (2008, ID071) also described riparian conditions for many tributaries, including Nookachamps, East Fork Nookachamps, Lake, Hanson, Carpenter, and Fisher creeks. Beechie et al. (2003, ID015) identified impaired riparian conditions for tributaries to the lower Skagit River and Sauk River, and mainstem channels of the lower Skagit River. The lower Skagit River, including all streams downstream of the Sauk River confluence, are identified as containing the "…most highly degraded freshwater salmon habitat in the Skagit Basin with considerable impacts in every habitat category…" including riparian conditions (Smith 2003, ID376). Beechie et al. (2003, ID015) also noted impaired riparian conditions for mainstem Skagit River habitats. In addition to disconnecting floodplains and disrupting other natural processes, hydromodifications of bank edges influences riparian vegetation growth and composition (Smith 2003, ID376).

Environmental Science Associates (ESA 2017, ID039) assessed riparian conditions in Tier 1, Tier 2, and Tier 2S (for Chinook Salmon and steelhead) target areas for habitat restoration and protection in the Skagit River basin identified in the 2015 update to the Strategic Approach (ESA

2017, ID039) and the 2016 Interim Steelhead Strategy (ESA 2017, ID039). The assessment included an analysis of the extent of altered or developed land adjacent to the river channel. Within the study area, riparian cover was classified for 62,683 acres of mainstem and floodplain; of the 62,683 acres, approximately 42 percent of the area was within Water Resources Inventory Area (WRIA) 3, and 58 percent was in WRIA 4. Overall, approximately 26 percent of the study area was composed of altered cover types. In WRIA 3, 41 percent of the riparian cover was considered altered, whereas only 7 percent of the riparian cover was altered in WRIA 4. In the lower Skagit River basin, where agricultural, residential, and commercial land uses are prevalent, forest cover decreases with distance from the active channel. In the upper basin, however, where natural resource land uses dominate, and residential uses are sparse, forest cover typically does not decline with distance from the active channel. The lower watershed also has markedly lower riparian canopy heights than upstream reaches, due to a higher percentage of shrub cover and fewer and smaller trees in the lower watershed.

Effects of Flow Regulation, Water Uses, Flood Risk Management, and Instream Flows

Operations of the Skagit River and Baker River projects alter the natural hydrology and geomorphology of the Skagit and Baker rivers, which in turn affects the quality and quantity of aquatic habitat for resident and anadromous fish. Road building, timber harvest, and farming and grazing are also prevalent in the Skagit River watershed. These land management activities are known to increase the sediment supply to streams through associated mass wasting, surface erosion, or bank erosion, and can adversely affect water quality and water temperatures (Beechie et al. 2003, ID015; Veldhuisen and Couvelier 2006, ID162; Lawrence 2008, ID071). Early hatchery practices in the Pacific Northwest were also initially responsible for loss of natural-origin salmon and steelhead stocks through genetic introgression, competition, and predation, and impacts from construction and operation of hatchery facilities (Hatchery Scientific Review Group 2003). These activities and practices, in combination with overharvest (both recreational and commercial), have led to dramatic declines in the abundance of Chinook Salmon, steelhead, and Bull Trout in the region and their eventual listing under the Endangered Species Act.

In addition to these past and present impacts, continued climate change will cause alterations to hydrology and hydraulics in the Skagit River basin. For example, the Skagit River Basin Climate Science Report (Lee and Hamlet 2011, ID196) forecasts that peak floods could increase by approximately 40 percent on average. Higher winter flows, especially flood discharges, could increase redd scour risk for mainstem spawning fishes and increase sediment transport, which would likely cause increased deposition in the lower Skagit River. Reductions in snowpack and continued glacial recession may also result in less water for power generation, fisheries resources, domestic water supply, and irrigation. However, as noted above, the large volume of cold water stored in Ross Lake will become a valuable fish management tool in the future, particularly in summer, thereby contributing positively to cumulative effects in the Skagit River basin.

Peak flows were identified as a factor affecting survival during the incubation life stage for all target species for the Synthesis Study. All target species spawn in similar habitats and are potentially vulnerable to redd scour during incubation with peak flows (Smith 2003, ID376). It was assumed that this potential vulnerability also applies to lamprey in addition to target salmon and trout species, given similarities in spawning habitats (Smith 2003, ID376; Hayes et al. 2013, ID419; Ostberg et al. 2020, ID422; Wang et al. 2020, ID424), but limited information on Lamprey was available. Flooding was identified as a limiting factor in the Skagit Chinook Recovery Plan, with peak flows having the greatest impact on Chinook egg to migrant survival (Beamer et al. 2005, ID175). Volkhardt et al. (2006, ID404) also identified flows during incubation as limiting Chinook Salmon.

Mainstem lower Skagit River habitats were generally not identified as having impaired hydrology with respect to peak flows (Beechie et al. 2003, ID015), but flow regulation has reduced peak flow magnitudes and frequencies in the lower Skagit River (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305; Redman et al. 2005, ID100; Riedel et al. 2020, ID001). For example, the number of floods between 2-year and 100-year return periods have been reduced by about 50 percent since the construction of upper Skagit River and Baker River dams (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305). In addition to the reduced frequency of peak flow events, pre-dam floods approached or exceeded 200,000 cfs, while floods in the post-dam era have not exceeded 200,000 cfs (Beamer et al. 2000, ID190; Beamer et al. 2005, ID305). Northwest Hydraulic Consultants (NHC 2013, ID428) attributed reductions in peak flows to increases in flood risk management storage, requirements, and levee infrastructure. Flood flows in the Skagit River are regulated by flood control operations at the Upper Baker and Ross dams (NHC 2013, ID428), and flow regulation has resulted in changes to the natural peak flow of the Skagit River system; with flows during the typical spring peak being lower than normal (when snowmelt would normally cause higher flows) and flows during later summer through mid-winter being higher than normal (SWC 2011, ID113).

The U.S. Army Corps of Engineers (USACE) also plays an important role in flood risk management in the lower Skagit River (e.g., USACE 2008, ID355; USACE 2010, ID117; USACE 2013, ID118). Flood risk management operations are initiated by the Seattle District, USACE, Reservoir Control Center whenever it receives a flood forecast from the National Weather Service (NWS), Northwest River Forecast Center (NWRFC), or a flood forecast prepared internally indicating that natural flows at Concrete will reach 90,000 cfs in 8 hours on a rising flood. The Skagit River Project Water Control Manual describes the USACE water control plan for the Skagit River Project, which is the maximum beneficial use of flood risk management storage at Ross to reduce flooding in the lower Skagit Valley during the October-March flood season. During flood events, both Ross and Upper Baker are coordinated concurrently by the Reservoir Control Center to optimize their combined flood risk management storage. The USACE also maintains extensive levee and flood control infrastructure in the lower Skagit River, and flood control in the Skagit River basin is conducted with a system of levees at lower elevations and flood control operations at upper basin reservoirs (USACE 2010, ID117).

Levee and flood control infrastructure have been developed as part of flood control strategies, but these stressors are identified as both a means to reduce flood risk and a potential stressor on instream flows, sediment supply and transport, habitat availability and connectivity, riparian conditions, and other factors considered in this review. Levees and other flood control infrastructure along with general land uses and cover (e.g., urbanization, timber extraction, agriculture, and road building) have also altered the Skagit River's hydrology, including the timing of water infiltration and the system's ability to store water (USACE 2010, ID117). The dam reservoirs are usually refilled during the spring snowmelt and "…as a result, the spring peak discharges are generally reduced" (USACE 2013, ID118). USACE) (2013, ID118) also indicated that "…flood control at Ross and Upper Baker is sufficient to control floods in the lower valley…

with exceedance frequencies of 4 to 5 percent (20–25-year event).” However, flood runoff from the Skagit’s uncontrolled watersheds can produce major flooding, even with flood control regulation at Upper Baker and Ross dams (USACE 2013, ID118). The Upper Baker and Ross reservoirs represent 39 percent of the total Skagit drainage area at Mount Vernon, with the remaining 61 percent being uncontrolled watersheds. The Sauk River contributes 45 to 64 percent (66,900 – 111,000 cfs) to flood events in the Skagit River (145,000 – 214,000 cfs) and represents the largest potential contributor to peak flow events among the uncontrolled subbasins to the lower Skagit River (USACE 2013, ID118). However, many other tributaries can contribute to peak flows in the lower Skagit River.

Many tributaries to the lower Skagit River and Sauk River were identified as having impaired hydrology related to peak flows (e.g., Beechie et al. 2003, ID015; Smith 2003, ID376; SWC 2022, ID451). Minimum flows were also identified as impairments, with some tributaries or tributary reaches drying up during summer or fall low flow periods (Lawrence 2008, ID071; McMillan 2015, ID436; McMillan 2015, ID437; Beamer et al. 2020, ID214; Jackman 2020, ID109).

Water Quality

Water quality impairments and issues of concern were identified for habitats within the study area, although water quality within the general Skagit River basin was reported as high or excellent for most areas (FERC 1980, ID439). Multiple studies identified water quality concerns in the lower Skagit River, tributaries to the lower Skagit River, Skagit estuary, and Skagit and Padilla Bay. For example, Smith (2003, ID376) noted degraded water quality in the lower Skagit River mainstem linked to various types of development or land uses. Water quality in lower Skagit River tributaries was described as “…worse than the mainstem Skagit River and all other Skagit sub-basins” (Smith 2003, ID376). Most tributaries to the lower Skagit River have elevated summer temperatures (including Nookachamps, Hansen, Wiseman, Day, Finney, and Jackman creeks), and elevated nutrients, low dissolved oxygen, increased turbidity, and potential contaminants (five potentially toxic organic compounds, lead, copper, and zinc) of concern in Nookachamps Creek (Smith 2003, ID376).

In Finney Creek, the Suiattle River, and the Sauk River, degradation of water quality is a principal issue of concern for salmonids (Beamer et al. 1998, ID189). Most streams inside agricultural zones of the Skagit River watershed have water quality conditions that are considered subpar for salmonid populations, recreation, and downstream shellfish resources. Most of the substandard water quality occurs in slow-moving agricultural sloughs and in creeks that have low flow in the warmer months (Jackman 2020, ID109). Beamer et al. (2000, ID190) also provided information on water quality impairments within the Skagit River basin based on Ecology’s Candidate 1998 Section 303(d) Impaired and Threatened Water Bodies listings, which were based on listing parameters for dissolved oxygen, fecal coliform, fish habitat, and temperature. USACE 2010 (ID117) also identified reaches that were on the Ecology’s 303d list due to not meeting the state’s water quality standards for fecal coliform, high temperature, pH, and dissolved oxygen. Turbidity, sediment runoff and chemical contamination and nutrients were also listed as areas of concern for mostly lower reaches within the Skagit watershed (USACE 2010, ID117).

Influence of Climate Change

Average temperatures in the Skagit River basin by the 2080s are projected to be between 4.0 and 5.8°F (2.2 and 3.2°C) higher than the 20th century baseline (Lee and Hamlet 2011, ID196). In addition to increases in water temperature brought about by climate change, seasonal changes in precipitation are expected to be substantial. By the end of the 21st century, average precipitation in the Skagit River basin is projected to increase by 9.8 percent in winter, 8.0 percent in spring, and 19.2 percent in fall (Lee and Hamlet 2011, ID196). In contrast, summer precipitation is expected to decrease by 27.6 percent. Despite increasing cool season precipitation, reductions in April 1 snow-water equivalent are projected for the Pacific Northwest. Such reductions in natural storage are expected to be most pronounced at moderate elevations where temperatures are near freezing in midwinter. Hood et al. (2016, ID142) noted that increases in winter river flows and reductions in summer flows due to decreased snowpack will further increase the asynchrony between sediment delivery and marsh vegetation growth, resulting in decreased sediment retention efficiency in delta marshes. Reduced survival of salmon under poor ocean conditions indicates that climate change could impact marine survival (Beamer et al. 2005, ID005).

As discussed above, glaciers significantly influence the flow regime in the Skagit River basin, providing cold water during summer low flows (Lee and Hamlet 2011, ID196). Projected warming for the 21st century is expected to accelerate glacial retreat, which will reduce summer base flows, especially during drought years, resulting in higher water temperatures in the basin (Lee and Hamlet 2011, ID196). Increased temperatures will adversely affect salmon, steelhead, and Bull Trout in the Skagit River basin. Changes in summer flows are also likely to influence water allocation and generation of hydroelectric power. In addition to low-flow impacts, floods are expected to become more intense due to increasing fall and winter precipitation and higher freezing elevations during winter.

Sea level is projected to increase substantially by the end of the 21st century, from 18 centimeters (7.1 inches) to 59 centimeters (23.2 inches), depending on the volume of carbon emissions (Lee and Hamlet 2011, ID196). Studies of sea level rise (SLR) projections are progressing rapidly, and more recent work suggests that SLR could occur at even higher rates than previously projected. Estuarine marshes are especially vulnerable to SLR, with potential effects magnified by declining natural progradation rates and sediment retention (Hood et al. 2016, ID142).

Effects of Ocean Conditions

Large-scale climatic processes (El Niño Southern Oscillation and Pacific Decadal Oscillation) influence marine survival of salmon and steelhead, with average marine survival varying by a factor of three depending on climate regime (Beamer et al. 2005, ID005). Marine survival has a significant impact on the number of returning adult salmon and steelhead. Beamer et al. (2005, ID005) state that modeling indicates a Chinook smolt outmigration of 5,100,000 could yield as few as 4,159 adults under very poor marine conditions or as many as 57,895 adults under more favorable ocean conditions. Because large-scale climatic processes influence ocean survival of salmon, and marine survival is linked to size at outmigration, it is critical to account for the effects of ocean conditions and early growth on adult recruitment when planning restoration (Beamer et al. 2005, ID005).

6.1.3 What are the Contributing Factors to Resources Conditions in the Lower Skagit River?

A number of factors were identified in the Synthesis Study from the reviewed literature and in coordination with LPs (see Attachment K), which represent potential drivers or stressors of resource conditions in the study area. These are shown in the conceptual life history models (Attachment E) and described in more detail in the LSF narratives (Attachment C). The influence of the LSF on target species and life stages is summarized in the LSF Tables, and the initial assessment of relative importance was used to identify Key Factors based on the Key Factor Criteria and scoring framework developed in coordination with LPs (see Attachment D and Attachment K). The results of the initial assessment of relative importance and the identification of Key Factors are described in this section.

A simple and objective scoring framework was developed for the Synthesis Study to support the initial assessment of relative importance for the potential factors identified in this study. The ability to look at multiple effects of factors in a composite assessment is a common element to scoring or evaluating the relative importance of factors, and weighting is often used to identify gradients or levels of potential influences or strengths of association (e.g., Weber et al. 2006; Turpin et al. 2022). The goals and objectives of the scoring framework were to consider multiple criteria and Key Factor criteria, provide a transparent and easily adjustable scoring framework with the ability to discern a gradient of relative importance among multiple factors, and to support identification of Key Factors based on the initial assessment of relative importance.

A total of 17 Key Factors were identified from the initial assessment of relative importance, which were factors that had an aggregate score (S_T) ≥ 4.5 for the initial assessment of relative importance (Figure 5.3-1). These factors were generally relevant to one or more target species and life stages, were identified as a limiting factor for one or more target species or life stages, were relevant to one or more spatial strata in the study area, could potentially be influenced by management actions or Project operations, and were sensitive to climate change (Figure 5.3-1). The Key Factors identified from the initial assessment of relative importance included:

- Sediment supply and transport;
- Instream flows (including peak flow, minimum flow, and general instream flows);
- Habitat extent and connectivity;
- Water quality and productivity (including instream temperature maximums, minimums, and general instream temperatures; dissolved oxygen; turbidity; nutrients and organic matter; and secondary productivity);
- Competition during rearing;
- Riparian condition;
- Hydromodified banks and channel edges; and
- Climate change.

These factors are described briefly in this section. Please see the LSF Tables (Attachment D) and supporting information in the LSF Narratives (Attachment C) for more information on these factors.

6.1.3.1 Sediment Supply and Transport

Sediment supply and transport processes were identified as a Key Factor and scored highest among the factors considered in the initial assessment of relative importance (Figure 5.3-1). The sediment supply and transport factor satisfied all Key Factor criteria and scored high with respect to all scoring components (biological, management, and climate change). Sediment supply and transport influences habitat formation and maintenance processes, as well as primary and secondary productivity, in habitats used by all target species and life stages. Sedimentation and erosion were identified as limiting factors for Chinook and steelhead (Finney Creek). Fine sediment deposition and erosion (redd scour) can reduce incubation survival for all target species, and sediment processes were identified as impaired in tributaries to the lower Skagit River but not the mainstem Skagit River. Excessive fine sediment loading was linked to land uses and cover, riparian conditions, roads, and underlying geology in combination with instream flow and climatological drivers. In the estuary, reduced sediment supply and deposition were identified as stressors to estuary habitat formation and maintenance processes, and estuary habitat extent was identified as a limiting factor for Chinook. Retention of sediments in reservoirs have reduced sediment supply to the lower Skagit River and estuary by 70 percent, and channel modifications and levees have increased transport of sediments through the estuary to the nearshore.

6.1.3.2 Instream Flows

Peak flows were identified as having high relative importance, and both minimum flows and instream flows in general were identified as having moderate relative importance (Figure 5.3-1). Instream flows can potentially be linked to nearly all factors and biological responses identified in the Synthesis Study, with some relationships being more direct than others. Instream flows are relevant to all target species and life stages and influence the timing and duration of habitat uses. Instream flows are relevant in tributary and mainstem reaches, to a lesser extent in the estuary and nearshore habitats. Instream flows are linked to flow and non-flow management actions, with instream flows in mainstem reaches being most directly linked to Project operations along with unregulated tributary inputs. Peak flows are negatively related to incubation survival for salmon and trout (presumed for lamprey), and movement and periodicity for other life stages of salmon and trout. Flow regulation has reduced the magnitude and frequency of mainstem peak flows, but many tributaries to the lower Skagit River were identified as having impaired peak flows. Project operations are only linked to mainstem peak flows but were also identified as having a potential influence in the estuary. Reductions in peak flows can reduce egg to fry mortality, but also have potential negative effects on habitat forming processes. Minimum flows are strongly influenced by climatological processes and flow regulation, unregulated tributary inputs, and groundwater and water withdrawals or diversions. Minimum flows can affect all target species, especially those with extended freshwater rearing life stages, and can influence life history expression, the timing and duration of rearing, and direct mortality through redd dewatering during the alevin stage. For late autumn/winter spawners, like Chum and some Coho, there is also a risk of redd freezing that can occur during low flows.

6.1.3.3 Habitat Extent and Connectivity

Habitat extent and connectivity factors were also identified as having high relative importance among the factors considered in the literature review (Figure 5.3-1). Freshwater, estuary, and nearshore habitat extent were identified as limiting factors for Chinook Salmon, and this resulted in a high biological score for this factor. Project operation linkages were identified as indirect, and uncertainties about the spatial extent of Project operations influence on habitat formation, maintenance, and connectivity in the study area are described in Section 6.1.4.4. Habitat extent and connectivity are influenced by land uses and conversion, diking and levees, hydromodifications, fish passage barriers, and habitat formation and maintenance processes that are linked to instream flows, sediment supply and transport, channel edge conditions, and riparian conditions. Restoration actions, mostly associated with implementation of the Skagit Chinook Recovery Plan are outpacing losses due to natural processes and anthropogenic impacts in the Skagit watershed, and therefore restoration represents one of the largest drivers of changes in habitat extent and connectivity.

Connectivity is a primary stressor on habitat extent and influences the extent of accessible or functional habitat and therefore influences habitat capacities and movement. Levees and dikes, water crossing structures and fish passage barriers, and dams were identified as influencing carrying capacities for salmon by limiting migrations during adult and juvenile life stages. Disconnection and isolation of floodplain and estuary habitats is a primary factor influencing habitat extent for target species and life stages, and therefore connectivity was identified as an indirect limiting factor for freshwater and estuary rearing habitat. Habitat accessibility can also be influenced by instream flow and flow regimes, and flow regulation was linked with changes in habitat formation and maintenance processes that influences off-channel habitat connectivity and formation processes. Restoration priorities identified for riverine, estuarine, and nearshore habitats included restoration of floodplain connectivity and tidal connectivity to tidal marsh and pocket estuary habitats, as well as fish passage barriers. Landscape connectivity was also identified as an important factor that influences the distribution and density of juvenile Chinook in estuary and nearshore habitats, with outmigrants being split between the North and South Fork distributaries. With approximately three times more estuary habitat in the South Fork of the Skagit estuary, density dependent rearing capacity pressure may be greater in the North Fork of the estuary.

6.1.3.4 Water Quality and Productivity

Several water quality and productivity factors were identified as Key Factors, including instream temperature maximums, minimums, and general instream temperatures; dissolved oxygen; turbidity; nutrients and organic matter; and secondary productivity (Figure 5.3-1). These factors were identified as having high to moderate relative importance, and most impairments with respect to water quality factors were identified in the lower Skagit River, its tributaries and floodplains, and estuary and nearshore habitats.

With respect to instream water temperatures in general, flow regulation can influence overall temperature patterns through regulation of instream flows and release of reservoir waters. Studies suggested that flow regulation influences on instream temperatures can extend to the estuary but are mediated by unregulated tributary inputs. Water uses (irrigation and diversions) can influence instream temperatures. Restoration, land uses, and cover can influence instream temperatures through riparian shading and influences on instream flows and hydrological processes. Climate change was also identified as a potential stressor on instream temperatures, particularly through alteration of glacial coverage, hydrological regimes, and global warming. Instream flows can influence instream temperatures, with lower flows generally increasing instream temperatures, and therefore instream temperatures are sensitive to water year type. Instream temperatures were identified as a critical water quality parameter for target species and life stages, with instream temperatures potentially influencing growth and survival, movement and periodicity, and habitat capacities and use.

Among the water quality and productivity factors, instream temperature maximums scored the highest in the initial assessment of relative importance, with maximum temperatures being identified as a limiting factor for Chinook. Many of the same drivers, stressors, and sensitivities for general instream temperatures apply to maximum instream temperatures. Maximum temperatures were generally evaluated with respect to summer low flow periods, although maximum temperatures during other seasons can influence other life stages (e.g., incubation duration). Many tributaries to the lower Skagit River were identified as having impaired water quality due to high instream temperatures, which were linked to riparian conditions, land uses and cover, and reduced instream flows. In the mainstem, maximum instream temperatures are moderated by flow regulation and cold-water reservoir releases. Increasing trends in summer maximum temperatures have been detected, but proximity to the Project moderates temperatures with cold water releases. High water temperatures were identified as a limiting factor for Chinook, but not during incubation life stage. Life histories with extended rearing in freshwater (e.g., yearlings) are more sensitive to maximum instream temperatures, and tributary spawning and rearing populations were also identified as having higher potential exposure to high instream temperatures. High water temperatures can also create thermal barriers to migration, and influence overall periodicity of life stages as well as survival, metabolic rates, and growth.

Minimum instream temperatures are also influenced by the same management actions and climate processes as described for general instream temperatures. Warmer mainstem temperatures in October-December were linked to flow regulation, and increased temperatures typically causes earlier emergence timing that could influence early survival if juveniles emerge before food is available. However, no significant differences in emergence timing were detected associated with Project associated increases in instream temperatures during incubation. Cooler temperatures can also increase rearing duration for larval Lamprey, and slow early growth rates for salmon and trout. Cold water releases from the Project were identified as a moderating factor for shifts in spawn timing compared to other nearby systems.

Temperatures and nutrient inputs are primary drivers of dissolved oxygen concentrations and dissolved oxygen can vary diurnally with primary productivity. Flow regulation and instream flows can influence dissolved oxygen and temperatures, and water uses or stressors that reduce instream flows and temperature in general can influence instream dissolved oxygen. Climate change and water year type can influence dissolved oxygen through increasing temperatures and reduced instream flows. Flow regulation was cited as generally increasing dissolved oxygen with the mainstem being highly oxygenated, but release of sub-thermocline water can reduce dissolved oxygen if sub-thermocline has depressed dissolved oxygen. Tributaries to the Skagit River and floodplain and estuary sloughs were identified as having impaired dissolved oxygen. Hypoxia can cause stress and mortality during adult migrations, incubation, juvenile rearing, and estuary and nearshore rearing and emigration. Gravel permeability and deposition of fine sediments can reduce dissolved oxygen during incubation, which may delay embryo development or reduce survival to emergence or size at emergence.

Nutrients and organic matter loading and cycles are considered important aspects of water quality, with nutrient cycles being a driver of primary productivity that supports target species during rearing life stages. Land uses, underlying geology, groundwater and surface water processes, instream flows, and riparian conditions are primary drivers of nutrient and organic matter inputs and cycles. However, nutrients and carcass productivity were not identified as limiting salmon productivity. Fisheries and hatcheries can indirectly influence carcass abundance instream. Release of low nutrient waters from reservoirs can influence nutrient levels, but this appears to be limited to reaches closer to dams. Excess loading from land and water uses can cause water quality impairments that can lead to eutrophication and hypoxia and reduce survival for salmon and trout, which are described for the dissolved oxygen factor. Water quality impairments with respect to excessive nutrient and organic matter loading were identified in the lower mainstem Skagit River, some tributaries, and estuary and nearshore habitats that were linked to urban and agricultural runoff, wastewater treatment, septic systems, and other land uses and point and non-point sources. Climate change was identified as a potential stressor on nutrient and organic matter cycles that could result in increased frequency of harmful algal blooms and hypoxic events.

6.1.3.5 Competition During Rearing

Competition during juvenile rearing life stages was identified as a factor with high relative importance (Figure 5.3-1). Competition can influence growth, habitat use and capacities, movement, periodicity, and survival through density dependent and size selective processes. Co-occurrence is a primary factor in competition, and juvenile hatchery fish as well as other target species were identified as competitors during rearing life stages. Freshwater, estuary, and nearshore rearing habitats were identified as limiting for Chinook, and therefore competition during these life stages were identified as a limiting factor. Restoration actions have focused on increasing rearing habitat extent during these life stages to increase capacity, and thereby reduce competition. Instream flows, flow regulation, climate change, and water uses were also identified as potential stressors on competition during rearing through influences on habitat extent as well as survival during the incubation life stage.

6.1.3.6 Riparian Conditions

Riparian conditions were identified as a factor with High relative importance (Figure 5.3-1), and were a limiting factor for Chinook Salmon, influencing the extent and quality of spawning and juvenile rearing habitat and thereby limiting capacity. Impaired riparian conditions and functions (shade and cover, and recruitment of insects and LWD) were identified for tributary, lower Skagit River, estuary, and nearshore reaches. Effects on Chinook of impaired riparian conditions were primary associated with reduced LWD recruitment and its influence on habitat formation processes for spawning habitats, as well as instream shading and cover. Management actions, including land uses and restoration and protection were linked to riparian conditions, and riparian habitats are sensitive to climate change and instream flow conditions. Instream water quality, especially temperatures, food availability, and cover were linked to riparian condition that can influence growth, movement, and direct mortality.

6.1.3.7 Hydromodified Banks and Channel Edges

Hydromodifications and bank edge conditions were identified as a factor with Moderate relative importance (Figure 5.3-1) and were linked to habitat quality for target species and habitat formation and maintenance processes as well as connectivity and channel migration (e.g., levees and bank armoring). Hydromodifications were identified as a limiting factor for Chinook, limiting parr production through reduced freshwater rearing capacity. Juvenile salmon densities were higher in habitats with natural bank edges, but natural cover (e.g., LWD and riparian) can increase rearing capacities for hydromodified bank edges. Habitat assessments indicated that hydromodifications of channel edges are prevalent throughout the lower Skagit River, estuary, and nearshore. Hydromodifications can also reduce flood risk. Climate change is an indirect stressor on hydromodifications and bank conditions through influences on instream flows and potential SLR, and flow regulation is indirectly related to bank conditions through instream flows.

6.1.3.8 Climate Change

Climate change was identified as a factor with moderate relative importance (Figure 5.3-1) and was identified as a potential stressor on numerous factors including instream flows, sediment supply and transport, habitat availability and connectivity, LWD and bank conditions, riparian conditions, water quality, competition and predation, and food availability. Likewise, climate change was identified as a potential stressor on all target species and life stages with potential to influence movement and periodicity, growth and survival, and habitat capacities. Climate change processes were also linked to some contemporary patterns as well as predicted future impacts of climate change (e.g., loss of glacial coverage and changes in instream temperatures). Potential influences of climate change habitat availability and connectivity were identified as limiting for Chinook Salmon, including freshwater, estuary, and nearshore rearing habitats.

6.1.4 What Data Gaps and Research or Monitoring Needs Might Limit Our Ability to Describe How Project Operations Influence Conditions in the Lower Skagit River?

Key Uncertainties were defined as uncertainties related to mechanisms and the influence of Project operations on Key Factors and anadromous resources in the study area. It is worth noting that the Synthesis Study intentionally focuses on literature that was related to the lower Skagit River, tributaries to the lower Skagit River, the Skagit estuary, and nearshore habitats. For more information on the upper Skagit River, please see Section 4 of the Draft License Application (City Light 2022b). Therefore, the information compiled in this Synthesis Study does not integrate information from the upper Skagit River that could inform some of the relationships or Key Uncertainties described in the reviewed literature.

A total of 20.9 percent of the sources reviewed were flagged as providing information on data gaps for topics of interest, and these were compiled and summarized in Attachment I. However, the data gaps identified in the sources may not represent current data gaps if subsequent studies have addressed the data gaps, and the data gaps identified in the literature may not be related to Key Factors. The data inventory also provided supporting information for the identification of potential data gaps by highlighting topics and subtopics, species and life stages, or spatial strata that were described in relatively few sources. Where these aligned with Key Factors identified in Step 3, the data inventory results and compiled data gap information from the literature were used to highlight areas where data gaps may limit understanding of how Project operations potentially influence resource conditions in the lower Skagit River. A total of 15 Key Uncertainties were identified, and these are described here, with a description of why the uncertainty is relevant to the Key Factor and potential tools to address the data gaps and uncertainties.

Most of the information synthesized from the literature focused on salmon, with 66 percent of the sources providing information on salmon species as compared to trout (25 percent) or Lamprey (2.3 percent). There was a general lack of information on Lamprey in the study area, with only about 2 percent of the sources reviewed providing information on lamprey in the lower Skagit River, and this is perhaps a specific uncertainty that is not directly addressed by the Key Uncertainties described below. The current distribution of Pacific Lamprey is limited to the lower Skagit River, although historical distributions extended upriver throughout most of the mainstem Skagit River and Sauk River (Plumb and Blanchard 2021, ID519). Current status of the Skagit River Pacific Lamprey population is cited as unknown, and genetic sampling efforts are underway to support evaluation of population status in the Skagit River basin (Plumb and Blanchard 2021, ID519). Among the references that provided information on salmon, information on Chinook Salmon was most prevalent (30.9 percent) compared to Coho Salmon (15.5 percent), Chum Salmon (15.3 percent), Pink Salmon (9.6 percent), and Sockeye Salmon (3.5 percent).

6.1.4.1 Sediment Supply and Transport

Sediment supply and transport was the most common subtopic among the geomorphology and landform topic, with 30 percent of the sources reviewed providing information on sediment supply and transport processes (Figure 5.2-3, page 2 of 6). In general, sediment supply is high in the Skagit River, representing 40 percent of the fluvial sediment delivered to Puget Sound (Curran et al. 2006, ID373). Most fine sediments come from glacial sources, with the Sauk River contributing the highest fine sediment load with 20x higher turbidity than the upper Skagit River (FERC 1980, ID439; Gislason 1980, ID406; USACE 2013, ID118; Curran et al. 2006, ID373). Project reservoirs trap an estimated 70 percent of fine sediment supply to the lower Skagit River (Riedel et al. 2020, ID001), and current sediment loads are estimated to be higher than historical estimates due to reductions in glacial coverage and exposure of bare unconsolidated and fine sediments to overland flow (Bandaragoda et al. 2020, ID379). Sediment loads are expected to increase, as well as shifts in the timing of sediment delivery, with contemporary and predicted future climate change (Lee et al. 2016, ID417; Riedel and Larrabee 2016, ID155; Bandaragoda et al. 2020, ID379).

Excessive sedimentation can have negative impacts on incubation survival for all target species (Smith 2003, ID376), and excessive sediment supply has been identified in tributaries to the lower Skagit River (FERC 1980, ID439; Paulson 1997, ID354; Beamer et al. 1998, ID189; Beechie et al. 2003, ID015; Smith 2003, ID376), as well as reduced primary productivity (Gislason 1980, ID406). In addition, sedimentation and mass wasting were identified as limiting factors for Chinook for incubation life stages, which were primarily linked to land uses and cover in tributary habitats (Beamer et al. 2005, ID175).

However, sediment supply and transport processes are important to habitat formation and maintenance processes that influence the distribution of suitable spawning substrate (Beechie et al. 2001, ID365; Beamer et al. 2005, ID305), connectivity of side channels and the frequency of pool and riffle habitats (Collins et al. 2002, ID418; Beechie et al. 2010, ID017; Nichols and Ketcheson 2013, ID412; Seixas and Veldhuisen 2019, ID301), and formation and maintenance of estuary habitats (Smith 2003, ID376; Beamer and Wolf 2016, ID186; Redman et al. 2005, ID100; Grossman et al. 2020, ID057; Riedel et al. 2020, ID001).

Reduced progradation rates have been observed in the Skagit estuary despite relatively high sediment supply in the Skagit River in general, and specifically to the estuary (Beamer et al. 2015, ID008). Estuary rearing habitat extent was identified as a limiting factor for Chinook (Beamer et al. 2005, ID175), and several potential stressors for reduced progradation rates of estuary habitat were identified in the literature including: sediment trapping in Project reservoirs (Smith 2003, ID376; Beamer and Wolf 2016, ID186; Redman et al. 2005, ID100; Grossman et al. 2020, ID057; Riedel et al. 2020, ID001); sea level rise and reduced glacial coverage linked to climate change (Beechie et al. 2001, ID365; Lee and Hamlet 2011, ID196; Beamer et al. 2015, ID008; Riedel and Larrabee 2016, ID155); timing of delivery with 50 percent of sediments being delivered during winter storms when marsh vegetation is at a seasonal minimum (Hood et al. 2016, ID142), and increased transport efficiency of sediments through the estuary to the nearshore from dikes/levees, channel modifications and straightening, and dredging that increases jet momentum (Grossman et al. 2020, ID057).

Grossman et al. (2020, ID057) found that fluxes of sediment offshore are five to ten times higher under current conditions compared to Holocene rates (from diking, channel straightening, and dredging), and this increased offshore transport bypasses emergent marshes and potentially impacts progradation rates in the Skagit River delta and potential resiliency to climate change. The sediment budget and historical change analyses from Grossman et al. (2020, ID057) provided a framework to assess coast responses to sediment delivery and routing to guide vulnerability assessments and resiliency planning. For example, they estimated that redirecting and retaining just 20 percent of the river sediment load within emergent marsh habitats could offset losses due to subsidence and levee construction, although it would take more than 22 years at this recovery rate to establish emergent marsh elevations that can be naturally maintained in the context of extreme tidal cycles. However, it is unclear to what extent Project operations and sediment trapping in reservoirs influences the supply of fine sediments to the estuary given the impaired retention processes associated with levees and increased transport efficiency of fine sediments through the estuary to the nearshore.

Therefore, there are potential tradeoffs between the negative impacts of excessive sediment on target species and impaired sediment supply and transport processes on habitat formation and maintenance process. In addition, uncertainties regarding potential climate change impacts on sediment supply and transport process, contributions of unregulated tributaries to sediment supply and transport processes, and the spatial extent of Project operations influence on sediment supply and transport processes in the mainstem lower Skagit River and Skagit estuary limit our ability to understand sediment supply and transport mechanisms and the influence of Project operations on anadromous resources in the study area. These uncertainties are described as three Key Uncertainties below, with a general description of approaches that can be used to address the data gaps or uncertainties for these Key Uncertainties.

Key Uncertainties for Sediment Supply and Transport

(1) What are the tradeoffs of sediment supply and transport processes on incubation survival and habitat formation processes in the context of unregulated tributary inputs, flow regulation, and climate change processes?

(2) What is the spatial extent of Project operations (flow regulation and sediment retention in reservoirs) influence on sediment supply and transport processes and associated habitat formation and maintenance processes in the lower Skagit River?

(3) How does sediment trapping in reservoirs influence habitat formation and maintenance processes in estuary habitats in the context of climate change processes and sediment routing?

Tools to Address Key Uncertainties for Sediment Supply and Transport

Modeling tools and Structured Decision Making approaches (SDM; Gregory et al. 2012) can be used to address these Key Uncertainties. The sediment transport modeling tools being developed for the GE-04 Geomorphology Study (City Light 2023f), as well as ongoing work to describe the geomorphology of the lower Skagit River and Skagit estuary (Riedel et al. TBD, ID217) will provide some tools to address these Key Uncertainties. The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. The SDM process can be used to help estimate tradeoffs among management alternatives or Project operations related to sediment supply and transport processes, in coordination with the development and use of hydrological, sediment, and life cycle models to ask dynamic process questions related to the Key Uncertainties.

6.1.4.2 Instream Flows

Compared to all other topics and subtopics, instream flows were the most common topic described among the sources reviewed (31 percent of sources) and hydrology models were the most common modeling tool described (14 percent of sources) (Figure 5.2-3). However, several uncertainties were identified related to instream flows that limit our ability to understand the mechanisms and influence of Project operations in the study areas for the lower Skagit River and Synthesis Study.

Several studies indicate that flow regulation has reduced the frequency and intensity of peak flow events in the lower Skagit River, as well as increased base flows during summer low flow periods (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305; Redman et al. 2005, ID100; Riedel et al. 2020, ID001). However, 62 percent of the drainage area in the Skagit River watershed is unregulated or uncontrolled, with Ross and Baker Dam controlling the flows from 38 percent of the drainage area (USACE 2010, ID117; SWC 2011, ID113). Increasing inputs of unregulated tributary inputs with increasing distance downstream from the Project have been linked to attenuation or moderation of detectible Project operation related effects in instream flow factors and other factors (e.g., Gislason 1980, ID406; Woodin et al. 1984, ID405; Connor and Pflug 2004, ID385; Austin et al. 2021, ID446). However, comparatively few studies attempted to quantify Project operation related effects (7.4 percent) and most of these included only the upper reaches of the lower Skagit River (e.g., Reach R7 and R8). Unregulated tributary inputs are hypothesized to moderate the influence of Project operations with increasing distance downstream from the Project, but many tributaries lack long-term monitoring data (see Figure 6.1-1 for location of stations that are currently active) that would support evaluating the spatial extent of Project operation effects on factors or resource conditions with increasing distance (and increasing unregulated tributary inputs) from the Project. This lack of long-term monitoring in tributaries was also identified in the review literature as a data gap for understanding peak flow and low flow hydrology in tributaries to the lower Skagit River (see Attachment I).

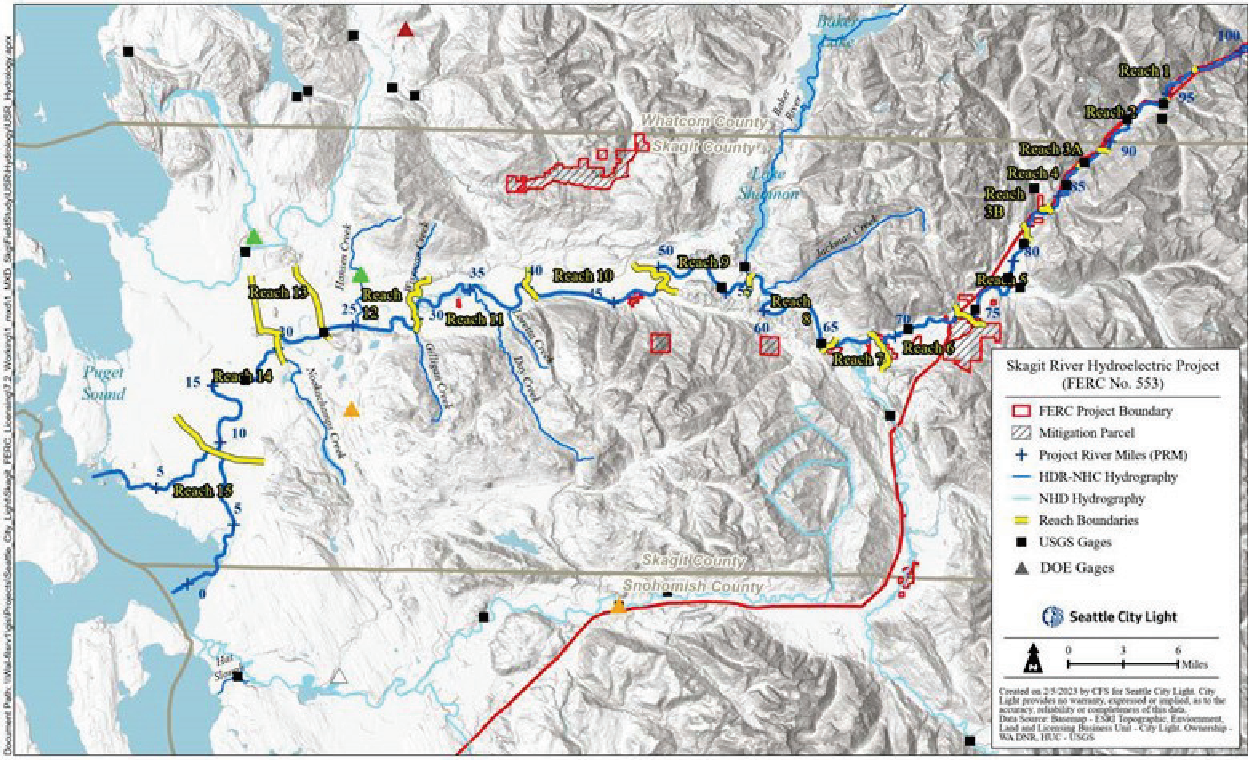


Figure 6.1-1. Location of active USGS and Washington State Department of Ecology (DOE in figure legend) flow gages within the Skagit River watershed.

Climate change was also identified as a potential stressor on future hydrological regimes in the Skagit River basin (Lee and Hamlet 2011, ID196; Lee et al. 2016, ID417). Climate modeling scenarios predict warmer temperatures will result in more precipitation falling as rain in the cool season, resulting in reduced snowpack and a shift in runoff timing. Reduced snowpack will carry over into more extreme low flows in the summer. Compared to the Pacific Northwest as a whole, the Skagit River basin is expected to experience a less severe reduction in April 1st snow water equivalent (SWE). By the end of the 21st century, the Skagit River basin will resemble a rain-dominant watershed (Lee and Hamlet 2011, ID196). Lee et al. (2016, ID417) indicated that climate change will cause substantial seasonal changes in both natural and regulated projected flow conditions in the Skagit. The Skagit River basin will transition from a mixed rain and snow watershed with dual peaks in the winter and spring to a rain-dominated watershed with a single peak in the winter for both natural and regulated flow conditions (Lee et al. 2016, ID417). In addition, contemporary losses of glacial coverage and predicted future declines in glacial coverage associated with climate change predictions will further alter the hydrology and instream flows of the Skagit River (Lee and Hamlet 2011, ID196). However, climate change models have large uncertainties and predicted responses are complicated by dynamic and interacting processes that introduce uncertainties into predicted changes.

Reduced peak flows can benefit certain species during certain life stages (e.g., spawning and incubation), but reduced peak flow intensity and frequency were also cited as reducing habitat formation, maintenance, and connectivity processes (Smith 2003, ID376; Beechie et al. 2003, ID015; Smith 2005, ID177; Riedel et al. 2020, ID001). In addition, reduced peak flow frequency and magnitudes from flow regulation reduces damage to infrastructure and land uses (FERC 1980, ID439). Therefore, there are potential tradeoffs between process flows, or flows to support habitat formation or connectivity, and life stage flows to support target species during key life stages as well as some of the positive benefits of moderating flows (e.g., Graybill et al. 1979, ID 259) and reduced peak flow intensities and frequency (Smith 2003, ID376; Beamer et al. 2005, ID175). However, many unregulated tributaries to the lower Skagit River have been identified as having impaired peak flow hydrology (e.g., Beechie et al. 2003, ID015; Smith 2003, ID376; SWC 2022, ID451) and these unregulated tributary inputs can contribute to flooding and peak flow events in the lower Skagit River (e.g., FERC 1980, ID439), and flow regulation does not affect peak flows in the unregulated tributary basins where target species may spawn or rear. Therefore, unregulated inputs also introduce uncertainty in understanding the tradeoffs of process and life stage flows in the study areas for the lower Skagit River and Synthesis Study.

Therefore, two Key Uncertainties (see below) were identified from the study area related to understanding the spatial extent of Project operations on instream flows in the lower Skagit River, and better understanding tradeoffs between process flows and life stage flows. Approaches to address these are also described below.

Key Uncertainties for Instream Flows

(4) What is the spatial extent of Project operations influence on instream flows, and associated habitat processes or resource conditions, in the lower Skagit River in the context of unregulated tributary inputs and climate change?

(5) What are the tradeoffs between process flows (habitat formation and connectivity flows), life stage flows (maintaining adequate flows during spawning, incubation, and rearing), and flood risk management (reducing peak flow magnitudes to reduce flooding) in the lower Skagit River?

Tools to Address Key Uncertainties for Instream Flows

Modeling tools, including hydrological and climate change modeling tools, can be used to address these uncertainties (FA-02 Instream Flow Model Development Study [City Light 2023a], FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study [City Light 2023c], GE-04 Geomorphology Study [City Light 2023f], and OM-01 Operations Model Study [City Light 2023g]), but likely also require additional long-term monitoring of unregulated tributaries to the lower Skagit River to better understand the attenuation of Project operations effects and spatial extent of influence in the lower Skagit River. The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. SDM and Operation models can also be used to evaluate tradeoffs for process and life stage flows, as well as life cycle modeling to evaluate scenarios and support decision making (e.g., Beechie et al. 2020; Jorgensen et al. 2021).

6.1.4.3 Water Quality and Productivity

Multiple water quality factors were identified as Key Factors, with maximum instream temperatures being identified as a limiting factor for Chinook (Beamer et al. 2005, ID175). Most of the information on water quality and productivity factors were for water temperature (32 percent of sources), dissolved oxygen (16 percent), and turbidity (10 percent) (Figure 5.2-3, page 3 of 6). Dissolved oxygen is strongly linked to temperature, and turbidity is strongly associated with sediment supply and transport processes. Therefore, uncertainties in these water quality factors are described in relation to those factors.

Many tributaries to the lower Skagit River were identified as having impaired temperatures with respect to maximum water temperatures and are 303(d) listed impaired waters (Beamer et al. 2005, ID175; USACE 2010, ID117; Jackman 2020, ID109). Like general instream water temperature patterns, maximum temperatures were linked to land uses, and riparian conditions in particular (e.g., through shading). However, Project operations linkages were also noted with cold-water releases potentially moderating temperatures. Gislason (1980, ID406) indicated that instream temperatures in the Skagit were generally higher than in the Sauk River from October – December, while temperatures were generally lower in the Skagit River from February – September. These patterns were related to reservoir releases and seasonal hydrological regimes (e.g., glacial melt) in the basin, but demonstrated that releases of cold-water from reservoirs moderated seasonal increases in instream temperatures (Beamer et al. 2005, ID175). As with other factors, attenuation of potential Project operations effects were observed with respect to temperatures with detectable effects decreasing with increasing distance from the Project (e.g., see Austin et al. 2021, ID446). These attenuation patterns are likely linked to increasing inputs from unregulated tributaries and other factors or gradients with increasing distance from the Project.

Climate change is a potential stressor as well as current driver of increasing instream temperatures (e.g., Lee and Hamlet 2011, ID196; Austin et al. 2021, ID446). Glacial melt is a primary driver of thermal regimes in the Skagit, and contemporary losses of glacial coverage and predicted losses of glacial coverage with climate change could significantly influence hydrology and thermal regimes in the Skagit River (Lee and Hamlet 2011, ID196). Compared to the rest of the Pacific Northwest, increases in the Skagit River are expected to be somewhat lower than average (Lee and Hamlet 2011, ID196). Austin et al. (2021, ID446) found significant increasing trends in daily maximum instream temperatures for the months of August - October at Mount Vernon (0.05 – 0.02°C/yr from 1963-2018), which they linked to contemporary climate change processes. They found that temperatures have been increasing and the magnitude of increasing temperatures over time were linked to elevation and position relative to hydroelectric dams in the Skagit River. In August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches. However, uncertainties in climate change predictions introduce uncertainty in understanding potential Project operations influence in a climate change context.

Therefore, one Key Uncertainty was identified with respect to water quality and productivity that is related to the spatial extent of Project operations influences on water quality in the lower Skagit River given the influence of unregulated tributary inputs, uncertainties in climate change predictions and effects, and other mitigating factors. Approaches to address this Key Uncertainty are also described below.

Key Uncertainties for Water Quality and Productivity

(6) What is the spatial extent of Project operations influence on water quality and productivity in the lower Skagit River in the context of unregulated tributary inputs, climate change, and other mitigating factors?

Tools to Address Key Uncertainties for Instream Flows

Hydrological modeling and water quality monitoring tools (CE-QUAL-W2 Temp/hydrodynamic model to Concrete), including climate change models can be used to address Key Uncertainties for water quality and productivity factors. Increased monitoring of unregulated tributaries as identified for instream flows would also potentially support Key Uncertainties for water quality and productivity given that water quality and productivity are strongly linked to instream flows and unregulated tributary inputs can attenuate effects of Project operations with increasing distance downstream. The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Bioenergetics and life cycle modeling tools (e.g., see Thompson and Beauchamp 2016, ID114; Beechie et al. 2020; Jorgensen et al. 2021) can also be used to address Key Uncertainties for water quality and productivity given that temperature is strongly linked to metabolic rates, and instream temperatures and other water quality factors can influence multiple target species and life stages.

6.1.4.4 Habitat Extent and Connectivity

Fish and habitat was the most common primary topic described among the literature reviewed (94.5 percent of sources), with habitat being the most common subtopic described (88.1 percent) (Figure 5.2-2). Aspects of habitat connectivity were also described in the reviewed literature that were associated with the geomorphology and landforms topic and subtopics (e.g., floodplain connectivity, aquatic habitats and landforms, estuarine habitats and landforms, and nearshore habitats and landforms, side and off-channels), and these were described in 7-27 percent of the sources reviewed (Figure 5.2-3, page 2 of 6).

As previously described, significant losses of habitat extent and connectivity have occurred within the lower Skagit River, its floodplain, tributaries to the Skagit River, the Skagit estuary, and nearshore habitats (e.g., see Beamer et al. 2005, ID005; Lee and Hamlet 2011, ID196). Losses of habitat extent and connectivity were primarily linked to disconnection of hydrological connectivity or fish passage from levees/dikes and fish passage barriers, land conversion and uses, and alteration of habitat forming and maintenance processes. Losses of habitat extent and connectivity are relevant to the study area given that rearing habitat has been identified as a limiting factor for Chinook Salmon during freshwater, estuarine, and nearshore rearing life stages (Beamer et al. 2005, ID005). Recent and ongoing habitat status and trends monitoring studies (e.g., Beamer et al. 2019, ID013) indicate that gains from restoration actions are currently outpacing natural and anthropogenic losses (e.g., land conversion). Many restoration actions, strategies, and prioritization frameworks have been developed in association with the Skagit River Chinook Recovery Plan to achieve restoration targets aimed at addressing rearing habitat limitations (e.g., SWC 2021, ID430). However, few studies have attempted to evaluate the cumulative effects of restoration on recovery planning and effectiveness evaluation (see Beamer et al. 2019, ID013; Greene et al. 2021, ID056), although some future and ongoing studies are attempting to address some questions about cumulative effects of restoration (e.g., see Beamer et al. 2019, ID013 and WCET 2022, ID518).

Impacts to habitat extent and connectivity are also linked to habitat maintenance and formation processes that may be impaired by impacts to sediment supply and transport, alteration of peak flow hydrology, land uses and cover, riparian and channel edge conditions, and hydromodifications as described previously. Factors that may benefit habitat formation and maintenance processes may also drive negative biological responses during other life stages. For example, survival during incubation declines with increasing peak flows (e.g., Beamer and Pess 1999, ID380) and the magnitude and duration of peak flows have been reduced with flow regulation (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305; Redman et al. 2005, ID100; Riedel et al. 2020, ID001), but reduced peak flows have also been linked to reduced habitat forming processes that support spawning and rearing habitats Smith 2003, ID376; Beamer and Wolf 2016, ID186; Redman et al. 2005, ID100; Grossman et al. 2020, ID057; Riedel et al. 2020, ID001). Therefore, there are uncertainties in the tradeoffs between process and life stage lows in the study area, especially in the context of uncertainties related to unregulated tributary inputs and attenuation of Project operation influences with increasing distance downstream and uncertainty around climate change impacts.

Multiple studies also identified data gaps concerning how juveniles utilize habitats in the study area, especially with regard to stream-type life histories that rear for longer periods in freshwater habitats and attain larger body sizes prior to migration and have reduced capture efficiency with traditional rotary screw trap methods that are used to quantify outmigrant abundances in the Skagit River watershed (e.g., see Kinsel et al. 2013, ID 147; Woodward et al. 2017, ID121; Lisi et al. 2022, ID494). Data gaps associated with juvenile steelhead outmigrations were specifically identified due to poor recapture efficiencies, but a general lack of understanding for yearling Chinook habitat use patterns was also described (see Attachment I). In addition, data gaps were identified for juvenile habitat use of floodplain, refuge, and tidal marsh surface habitats which also limit ability to evaluate rearing capacity limitations and productivity (see Attachment I).

Many potential fish passage barriers have been identified in the basin and study area, which primarily block access to tributary, floodplain, estuary, or nearshore habitats (Beamer et al. 2000, ID190; Redman et al. 2005, ID100; Smith 2010, ID352; Connor et al. 2015, ID413; Souder et al. 2018, ID115; Mickelson et al. 2020, ID289; Hall et al. 2021, ID491). These are primarily water crossing features (e.g., culverts, tide gates, flood gates), but also include natural barriers (e.g., gradient) and dams (but only the Baker River dam is included in the study area). A common theme in these assessments was that the barrier status of features that potentially block access to habitats for rearing, spawning, and refuge during either adult or juvenile life stages are unknown, and this limits understanding of accessible habitat extent and connectivity. For example, Beamer et al. (2000, ID190) reported that barrier status was unknown or had low certainty for 70 percent of the features identified. In addition, a recent study reported that 54 percent of the water crossing features identified in large river deltas in the Puget Sound (which included the Skagit estuary) were previously unmapped in regional datasets (e.g., WDFW Fish Passage and Diversion Screening Inventory database, WDFW 2019, ID487).

Four Key Uncertainties related to habitat extent and connectivity were identified, which included the previously described uncertainty regarding tradeoffs between process and life stage flows (see Key Uncertainty (5) above) and uncertainties related to cumulative impacts of restoration, juvenile life history habitat use patterns, and the status and location of fish passage barriers. Approaches to address these Key Uncertainties are also described below.

Key Uncertainties for Habitat Extent and Connectivity

See Key Uncertainty (5) above, and:

(7) What are the cumulative impacts of restoration, protection, and other recovery actions in the context of climate change and Project operations on resource conditions?

(8) How do juvenile salmon and trout, and especially life histories with extended freshwater rearing, utilize floodplain, refuge, and tidal marsh surface habitats in the context of life history diversity, habitat extent, and habitat connectivity?

(9) What is the location and status of potential fish passage barriers that influence accessibility to rearing, refuge, or spawning habitats for target species in the study area?

Tools to Address Key Uncertainties for Habitat Extent and Connectivity

A combination of life cycle modeling (e.g., see Beechie et al. 2020; Jorgensen et al. 2021) and hydrological modeling as well as SDM can be used to address Key Uncertainties for habitat extent and connectivity and tradeoffs between process and life stage flows. However, these uncertainties may also require additional monitoring to better understand the cumulative effects of restoration and climate change, and influence of unregulated tributary inputs on the attenuation of Project operations influence in the study area. The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Continued habitat status and trends monitoring to quantify and evaluate progress towards recovery and rearing habitat limitations, as well improved monitoring of habitat use patterns for life stages and life histories (e.g., stream type life histories and floodplain habitats) can be used to address Key Uncertainties. Continued inventories and assessment of potential fish passage barriers that impact access and hydrological connectivity to potential rearing habitats can also be used to address Key Uncertainties (see Souder et al. 2018, ID115; Hall et al. 2021, ID491). Restoration actions can also be used to directly address habitat extent and connectivity limitations, but increased monitoring of restoration effectiveness would help evaluate progress towards recovery and restoration planning.

6.1.4.5 Competition During Rearing

As described previously, freshwater, estuary, and nearshore rearing habitats have been identified as limiting factors for Chinook Salmon and therefore competition during rearing was identified as a Key Factor, although information on competition was only described directly in 4.8 percent of the sources reviewed (Figure 5.2-3, page 1 of 6). However, the Skagit Chinook Recovery Plan indicated that hatchery fish predation in rivers affects freshwater rearing life stages but is not a limiting factor for Chinook Salmon (Beamer et al. 2005, ID175). In addition, the Skagit Chinook Recovery Plan identified competition and predation by other fishes as not limiting Chinook during freshwater rearing, tidal delta rearing, and nearshore rearing life stages (Beamer et al. 2005, ID175). Competition during rearing is a complicated issue given that competition may involve interactions between and among target species and populations, interactions between hatchery and natural origin fishes, and interactions that extend across many temporal and spatial scales. A common theme for competition is the co-occurrence of individuals in space and time that results in competition for resources (e.g., rearing or refuge habitat, cover, or food resources) and reduced growth opportunity that translates to reduced survival through size selective mortality and other processes. Multiple studies describe density-dependent processes that drive the expression of fry migrant life histories in Chinook, which were linked to rearing capacity limitations in freshwater, estuary, and nearshore habitats and survival to adult return related to size selective mortality or size at outmigration (e.g., Beamer et al. 2005, ID005; Greene et al. 2021, ID056). However, it is difficult to disentangle survival between habitat strata, especially between estuary, nearshore, and marine life stages (see Greene et al. 2005, ID050; Thompson and Beauchamp 2014, ID054; Woodward et al. 2017, ID121), and this potentially limits our understanding of where bottlenecks occur or how rearing habitat limitations in different spatial extents affect populations.

Multiple studies looked at potential hatchery and natural origin interactions, including competition during rearing life stages (e.g., Redman et al. 2005, ID100; Gamble et al. 2018, ID044; Pflug et al. 2013, ID154). The primary stressors related to hatchery releases are competition, predation, and mixing of hatchery and natural origin fish during migration and spawning, and these stressors are influenced by the size at release and timing of releases (e.g., Beamer et al. 2005, ID175; Redman et al. 2005, ID100; Pflug et al. 2013, ID154; Austin et al. 2021, ID446). Estuary rearing habitat was identified as a limiting factor (Beamer et al. 2005, ID175), and hatchery interactions have been noted in the Skagit estuary (e.g., Beamer et al. 2005, ID005; Greene et al. 2021, ID056). Beamer et al. (2007, ID007) reported an influx of hatchery fish from other river systems to Skagit Bay nearshore beach habitat that peaked in July, but they reported that juvenile hatchery Chinook Salmon from other systems were not extensively using Skagit vegetated delta habitat. Greene et al. (2021, ID056) also concluded that hatchery origin Chinook had a negligible effect on the habitat capacity exceedance frequency in the Skagit estuary compared to other Puget Sound estuaries. Recent studies have shown that hatchery-natural steelhead hybrids have reduced reproductive success, and Pflug et al. (2013, ID154) reported that hybrid steelhead juveniles were detected in all sampled locations in Skagit River tributaries. One key issue with respect to hatchery management was that managers do not have effective tools to prevent hatchery origin adults from spawning outside the hatchery, and the temporal segregation strategy (segregated spawn timing) does not appear to be effective at preventing temporal and spatial overlap with natural spawners in the system or undesired genetic and ecological interactions (Austin et al. 2021, ID446). Furthermore, it is difficult to understand how hybrid or hatchery origin progeny interact with natural origin fishes during rearing life stages given that genetic stock assignments are needed to determine parentage.

Multi-species interactions complicate understanding of competition during rearing given that multiple populations and species overlap in space in time in the lower Skagit River, Skagit estuary, and nearshore habitats. Many studies focused on one species or a subset of species, and multi-species interactions are not often considered due to the complicated nature of modeling or monitoring needed to address such uncertainties, or general lack of data to determine population composition (e.g., genetic stock identification), origin, or life history use patterns (e.g., see previous discussion on uncertainties about stream type habitat use patterns). In addition, there are potential tradeoffs in managing recovery of multiple species that can both directly compete for rearing habitat and resources as well as being potential predators at different life stages. For example, Bull Trout and steelhead predation on juvenile Chinook has been documented and all three species are target species for recovery Redman et al. 2005, ID100; Pflug et al. 2013, ID154; Lowery and Beauchamp 2015, ID074). Therefore, increasing abundances of some target species may negatively impact the abundance of other target species. Lowery and Beauchamp (2015, ID074) suggested that predation impacts on juvenile Chinook (including ocean, subyearling, river type, or yearling life histories) from Bull Trout were likely negligible but impacts on steelhead were potentially very high.

Key Uncertainties for Competition During Rearing

See Key Uncertainty (8) above, and:

(10) What are the influences of hatchery releases and strategies on natural origin juvenile salmon and trout during rearing and emigration life stages?

(11) What are the effects of multi-species interactions and multi-population interactions on competition during rearing and emigration life stages (e.g., between and among target species) in the context of recovery planning?

(12) What are the relative effects of competition on survival during river, estuary, nearshore, and marine life stages?

Tools to Address Key Uncertainties for Competition During Rearing

Modeling tools, especially life cycle models and bioenergetics models, can be used to address Key Uncertainties related to competition during rearing and ask complicated questions that cannot be directly addressed through monitoring (e.g., see Beechie et al. 2020; Jorgensen et al. 2021), as well as approaches previously outlined for Key Uncertainty (8). The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Evaluation of hatchery management strategies, including life cycle modeling, improved monitoring, and potentially SDM can be used to address uncertainties regarding hatchery and natural origin interactions and competition during rearing life stages. Genetic stock assessment associated with juvenile monitoring (e.g., rotary screw traps) can be used to improve our understanding of multi-population demographics and interactions in the lower Skagit River, which would improve understanding of competition during rearing and the relative influence of rearing habitat limitations on populations. As with habitat extent and connectivity, continued monitoring of restoration effectiveness can address uncertainties around the effects of restoration on reducing competition during rearing and progress towards recovery. Continued monitoring can also be used to address uncertainties regarding competition at different spatial scales (e.g., Beamer et al. 2019, ID013), and support evaluation of the relative effects of competition between life stages and spatial strata.

6.1.4.6 Riparian Conditions

Some aspects of riparian conditions were described in 15.1 percent of the sources reviewed (Figure 5.2-3, page1 of 6). Both the extent and continuity of riparian habitats are primary factors for the form and function of riparian habitats and are used as indicators of riparian habitat condition in the Skagit River basin (Beechie et al. 2017, ID018; Hinton et al. 2018, ID167; Stefankiv et al. 2019, ID112). The impacts of riparian habitat extent and continuity are in part linked to the age or height of tree cover within the riparian zone, as this influences both instream shading potential as well as recruitment of LWD to the stream (Lawrence 2008, ID071; Kammer et al. 2020, ID280). Riparian conditions were described in a number of recent assessments (e.g., ESA 2017, ID039; SWC 2021, ID430) and impaired riparian conditions have been identified in the lower Skagit River, tributaries to the lower Skagit River, Skagit estuary, and nearshore habitats (e.g., Beamer et al. 1998, ID189; Smith 2003, ID376; Hinton et al. 2018, ID167). Results from recent assessments suggest that degradation of riparian conditions increases with increasing distance downstream, with lower Skagit River and estuary habitats having the most degraded riparian conditions (SWC 2021, ID430).

Multiple studies have attempted to evaluate the effects of degraded riparian conditions on habitat processes and quality (e.g., instream temperatures and shading, LWD recruitment, organic matter and nutrient fluxes, sediment supply and transport, instream flows, and channel migration or channel edge conditions). However, studies have identified uncertainties in how riparian conditions translate to biological responses (Beamer et al. 2000, ID190; Smith 2003, ID376; Redman et al. 2005, ID100), and how these processes differ in smaller streams compared to larger channels given that functions like shading are related to tree height and channel width. In addition, it can take many years or decades for restoration actions targeting riparian conditions (e.g., planting) to produce measurable results or to achieve desired future conditions (Beamer et al. 2005, ID175)

Two Key Uncertainty were identified for riparian conditions, and these were related to improving understanding of tradeoffs between process and life stage flows as described for Key Uncertainty (5) above, and understanding the relative effects of riparian condition in the larger mainstem channels of the lower Skagit River in contrast to smaller tributary channels. Project operation linkages to riparian conditions are at most indirect, and attenuation of effects are likely to make linkages even harder to detect with increasing distance downstream. However, riparian conditions are linked to habitat forming processes, e.g., channel migration, bank erosion and stability, and LWD recruitment, and therefore flow regulation and peak flow hydrology are potentially related to riparian conditions in the lower Skagit River. While multiple studies identify linkages between riparian condition and LWD recruitment potential, most of the studies evaluating the influence of riparian conditions on water quality parameters like instream temperatures focused on smaller tributary systems (e.g., Hinton et al. 2018, ID167). In fact, some studies demonstrated relatively small effects of riparian condition on instream temperatures in some tributary systems (Lawrence 2008, ID071). Therefore, it is unclear to what extent riparian condition influences instream conditions with respect to water quality parameters like instream temperature in larger mainstem channels like the lower Skagit River.

Key Uncertainties for Riparian Conditions

See Key Uncertainty (5) above.

(13) What is the relative influence of riparian condition on instream water quality (e.g., instream temperatures) in mainstem lower Skagit River or larger channels compared to smaller tributary channels?

Tools to Address Key Uncertainties for Riparian Conditions

Hydrological modeling and SDM can support evaluation of tradeoffs between process and life stage flows as described for Key Uncertainty (5), and life cycle models to support evaluation of restoration strategies or riparian condition scenarios and biological responses (e.g., see Beechie et al. 2020; Jorgensen et al. 2021). The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Continued habitat status and trends monitoring (e.g., ESA 2017, ID039; SWC 2021, ID430) and monitoring to support improved understanding of linkages between riparian conditions and habitat forming and maintenance processes, fluxes, and biological responses will aid in addressing Key Uncertainties for riparian conditions.

6.1.4.7 Hydromodified Banks and Channel Edges

Banks and shoreline conditions were the most common subtopic for the land use and cover topic, with 24.8 percent of the sources reviewed providing information on bank conditions (Figure 5.2-3, page 4 of 6). As noted previously, habitat in the lower Skagit River, its floodplains, and estuary have been extensively impacted by hydromodification (e.g., ESA 2017, ID039), and impaired bank conditions were identified as a limiting factor for Chinook (Beamer et al. 2005, ID175), and significantly impact rearing capacity estimates for Coho (Beechie et al. 2003, ID015), and fish habitat use and association patterns (e.g., Beamer and Henderson 1998, ID181; Beechie et al. 2005, ID014; Smith et al. 2011, ID111). In addition, hydromodifications including armoring, riprap, levees, and dikes impact habitat formation and connectivity processes by disconnecting or isolating floodplains and increasing or focusing the conveyance of peak flows downstream (e.g., USACE 2008, ID355; Lee and Hamlet 2011, ID196). Given that hydromodifications are related to habitat formation and maintenance processes, as well as habitat extent and connectivity, understanding the tradeoffs between process flows and life stage flows was identified as a Key Uncertainty for hydromodified banks and channel edges as described for Key Uncertainty (5).

Key Uncertainties for Hydromodified Banks and Channel Edges

See Key Uncertainty (5) above.

Tools to Address Key Uncertainties for Hydromodified Banks and Channel Edges

Hydrological modeling and SDM can support evaluation of tradeoffs between process and life stage flows as described for Key Uncertainty (5), and life cycle models to support evaluation of restoration strategies and biological responses (e.g., see Beechie et al. 2020; Jorgensen et al. 2021). The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Continued habitat status and trends monitoring (e.g., ESA 2017, ID039; SWC 2021, ID430) can support evaluation of progress towards recovery and spatial extent of habitat impacts related to bank conditions.

6.1.4.8 Climate Change

Climate change was a subtopic for each of the topics considered in this literature review, and climate change effects on topics were described in 1-20 percent of the sources reviewed (Figure 5.2-3). Uncertainties regarding climate change processes and potential impacts were identified by a number of sources (see Attachment I), and many of these were related to uncertainties in climate change predictions or models, and predicting responses with respect to complex system dynamics given that climate change impacts interact at large spatial scales and involved multiple dynamic processes (e.g., thermal regimes, precipitation regimes, sediment supply and transport, hydrological regimes). Some studies provide information on anticipated climate change impacts on flow regimes linked to losses of glacial cover and altered precipitation regimes (e.g., Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155), and studies have detected changes related to climate change processes that are currently occurring, e.g., loss of glacial cover (e.g., Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155), reduced propagation rates in the estuary linked to SLR (Beamer et al. 2015, ID008), and increased instream temperatures (Austin et al. 2021, ID446).

In addition to general changes in hydrological regimes and instream flows, studies also suggested that power generation and flow regulation in general will be impacted by climate change. By the 2080s, hydropower generation in the Skagit River basin is projected to increase by 19 percent in the winter and spring and decrease by 29 percent in the summer (due to climate change and population size), and this may also influence the timing, duration, and magnitude of flow regimes in the Skagit (Lee et al. 2016, ID417). Changes in summer flows are also likely to influence water allocation and generation of hydroelectric power. In addition to low-flow impacts, floods are expected to become more intense due to increasing fall and winter precipitation and higher freezing elevations during winter. These impacts would likely propagate to impacts on strategies to manage process and life stage flows and tradeoffs.

Two Key Uncertainties for climate change were identified, in addition to the uncertainties associated with climate change and other Key Uncertainties identified for other Key Factors described above. These include the potential influence of climate change on Project operations and recovery planning in terms of potential shifting baselines, and specifically improving understanding of climate change and the resiliency of estuary habitats. These are described below as well as approaches to address these uncertainties.

Key Uncertainties for Climate Change

See climate change linkages to uncertainties for other Key Uncertainties described above, and:

(14) What is the potential influence of climate change processes on Project operations, resource conditions, and recovery strategies in the context of uncertainty, shifting baselines, and recovery trajectories and targets?

(15) What is the potential influence of climate change on estuary habitat resiliency and rearing capacity in the context of SLR and infrastructure that constrains tidally connected habitats, and sediment supply and transport processes that form and maintain tidal marsh habitats?

Tools to Address Key Uncertainties for Climate Change

Approaches to address climate change uncertainties are generally described for the other Key Uncertainties, but climate change uncertainties will likely require modeling tools to address, including hydrological, sediment supply and transport, thermal and water quality, as well as life cycle models. The conceptual life history models developed in coordination with LPs can be used to support evaluation of factors within a life history context. Specially, integration of modeling components to account for potential impacts of climate change, or recovery planning to account for the potential influence of climate change on targets and progress towards recovery (e.g., see Beamer et al. 2005, ID005). Monitoring studies that describe ecosystem response to contemporary climate change effects will also provide information to support modeling and planning for potential climate change impacts (e.g., see studies like Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155; Austin et al. 2021, ID446).

6.2 Synthesis Study Modifications Identified in the June 9, 2021 Notice

The June 9, 2021 Notice noted six items of discussion related to implementation of this Synthesis Study. The status of each is summarized in Table 6.2-1.

Table 6.2-1. Status of Synthesis Study modifications identified in the June 9, 2021 Notice.

Study Modifications identified in the June 9, 2021 Notice	Status
City Light acknowledges Project effects in the Lower Skagit River, which includes the area from the confluence of the Skagit River and the Sauk River downstream to the mouth of the Skagit River estuary, can be detected.	City Light acknowledges that such effects can be detected.
City Light will perform the SY-01 synthesis study as proposed in RSP.	The Synthesis Study was implemented as proposed in the RSP with modifications as described within this study report.
City Light will perform additional data field studies in year 2 to fill data gaps in SY-01 that are not addressed in the synthesis study or in other studies below the Sauk River (identified above).	Development of long-term adaptive management, monitoring, additional data collection (including data gaps identified as part of this study), or mitigation for Project effects below the Sauk will be described in the FLA, as appropriate.
City Light will consolidate results of the synthesis study and baseline data collected in other studies that extended below the Sauk in the SY-01 study report to identify Project effects below the Sauk.	As discussed in this Synthesis Study report, several relicensing studies collected empirical data and developed tools to analyze environmental conditions in the lower Skagit River, such that the sediment transport modeling tools and wood tracking as part of the GE-04 Geomorphology Study and the expanded water quality sampling and modeling as part of the FA-01a and FA-01b studies. Results of those studies are provided in their respective study reports and integration of results will be provided for in the FLA, as appropriate.
Results of the study will be shared with the LPs and will inform the long-term ecosystem adaptive management and monitoring program and mitigation for project impacts below the Sauk.	Results of this Synthesis Study were shared during consultation meetings (described above) and as part of a technical briefing held in January 2023. Development of long-term adaptive management, monitoring, additional data collection (including data gaps identified as part of this study), or mitigation for Project effects below the Sauk will be described in the FLA, as appropriate.
City Light will clarify the study plan to indicate that data collection in the Lower River will be addressed through other study plans.	As discussed in this Synthesis Study report, several relicensing studies collected empirical data and developed tools to analyze environmental conditions in the lower Skagit River, such that the sediment transport modeling tools and wood tracking as part of the GE-04 Geomorphology Study and the expanded water quality sampling and modeling as part of the FA-01a and FA-01b studies. Results of those studies are provided in their respective study reports and integration of results will be provided for in the FLA, as appropriate.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

The following variances from and proposed modification to the FERC-approved study plan were described in the Synthesis Study Interim Report (City Light 2022a):

- Based on preliminary data review and comments from LPs during the preliminary Synthesis Study Work Group meeting (see Attachment K), the study area description was revised to include the Sauk River, larger geomorphic delta extent (including Swinomish and portions of the Stillaguamish River delta), and nearshore habitats in Skagit Bay and Padilla Bay. These adjustments to the study area were designed to better capture the extent of habitat that supports target species and life stages produced by the Skagit River (e.g., geomorphic delta extent and nearshore habitats), as well as major sources of potential variation of influences on resource conditions in the lower Skagit River (e.g., the Sauk River).
- In addition, based on preliminary data review and consultation with LPs in the December 2021 Synthesis Study Work Group Meeting, the target species for the Synthesis Study was expanded to include Pacific Lamprey (see Attachment K).
- On June 30, 2021, City Light convened a meeting with LPs to set the agenda for the first Synthesis Study Work Group meeting. During that meeting, LPs expressed an interest in modifying the study's approach (as described in Section 2.7 of the RSP) to provide for a study team to execute the study and convene regular work group meetings to collaborate with LPs. Following this meeting and FERC's issuance of the SPD on July 16, 2021, City Light identified a qualified principal investigator to begin implementation of the study in the fall of 2021. Given the delayed timing of study implementation, City Light proposed to modify the Synthesis Study implementation schedule as described in Section 6.1 of this study report. This adjustment enabled City Light to work with LPs in 2022 to review the data compiled (Step 1), analyze the data (Step 2), identify life stage factors affecting target species (Step 3), and determine data collection needs as part of this study in the fourth quarter (September - December) 2022.

During Step 1: Data Compilation, quantitative data were not extracted into a reference database as planned in the Synthesis Study Interim Report but were summarized in annotated bibliographies and in Step 3: Life Stage Factors. Quantitative data were described or referenced in the annotated bibliographies and life stage factors (see Attachments C, F, and G) to facilitate information extraction, which can be used to develop tools to address Key Uncertainties (e.g., SDM, life cycle models, or other models). The study goals and objectives were not adversely affected by this change because the available quantitative information is described, readily accessible with the development of the literature database application, and can be extracted to address specific data needs.

There are no other variances from the FERC-approved study plan.

8.0 REFERENCES

Note: See Attachment A for full list of references reviewed in this study and for references that are cited with an ID number.

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SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT A

LIST OF REFERENCES

1.0 OVERVIEW

This attachment provides the list of sources compiled and reviewed for the Synthesis Study. Sources listed in the ***Compiled References*** section are sources that were reviewed and annotated (both Tier 1 and Tier 2 sources). Sources identified as ***References Needed*** are sources that have been identified but digital copies were not secured to support screening and review.

2.0 REFERENCES

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SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT B

DATA SOURCE ATTRIBUTES

1.0 OVERVIEW

This Attachment provides a list of source classifications, topics and keywords, and data flag values that were used to attribute and categorize sources and data identified in Step 1 of the Synthesis Study. The following sections provide a working list of attributes for:

- **Source Classifications:** attributes that describe the source itself (e.g., type, year, full citation, category),
- **Topics and Keywords:** attributes that describe the type of information provided by the source organized by topics of interest, and
- **Data Flags:** attributes that identify what kind of data are provided (quantitative, spatial, Project related), target species considered, and the spatial extent of the information.

These attributes are used in the reference database to support data inventories and the identification of sources to support Steps 2-4.

2.0 SOURCE CLASSIFICATIONS

A simple classification framework was developed to help identify sources with relevant information based on a suite of criteria. Information on the year, type, status, and format of the source information are attributed for each identified source in the reference database (Table A-1). The following table provides a list of attributes for the classification of sources and a brief description for each value.

Table B-1. Preliminary list of attributes for the classification of sources.

Field	Values	Description
Citation ID	ID + AFS Citation	A unique sequential ID number based on order of entry concatenated with an intext citation in AFS format (Author and year)
Year	YYYY	Year of publication or production
	TBD	For future studies
Type	Journal	Peer reviewed journal publication
	Report	Project report or memo
	Book	Book or book chapter
	Proceeding	Conference or symposium proceedings, abstract, or presentation
	Thesis	Graduate thesis or dissertation
	Webpage	Online data source/portal, webpage
	Unpublished	Unpublished data or information
	Dataset	Standalone dataset or map
	Future study	Upcoming or ongoing study with relevant results
Status	Draft	Source or publication is in draft form
	Final	Source or publication is in final form
	TBD	Used for future studies
Format	PDF	PDF obtained
	Website	Source is a website (archive PDF copy for synthesis?)

Field	Values	Description
	Dataset	Static dataset or maintained dataset, Excel, Access, CSV, shapefile, etc.
	Citation	Digital copies have not been obtained.
Permissions	Public	Source is readily available in public domain.
	Released	Source is not published but permission has been obtained to release the information, or publication or data have been made available for distribution.
	Restricted	Source is not readily available, and permission has not been obtained. Could be used to indicate the publication is protected by copyright.
	TBD	Future study or ongoing study not yet completed.
Category	Tier 1	Sources that provide extensive information and data that are directly relevant to the Synthesis Study objectives. Annotated bibliographies will be developed for these sources.
	Tier 2	Sources that provide some information relevant to the Synthesis Study objectives but may be specific to one site within the Study Area or only provide watershed scale data from a more regionally focused study. Annotated bibliographies will be developed for these sources.
	GE-04	References that were identified by the GE-04 Geomorphology Study and were included in the list of sources that were used to develop annotated bibliographies and data inventories.
	Previous Reports	Previous reports for projects or studies that are covered by a more recent source. Annotated bibliographies will not be developed for these sources.
	Out of Study Area	Source provides information for the Skagit River, but the focus area is outside of the Synthesis Study Area (e.g., upper Skagit River). Annotated bibliographies will not be developed for these sources.
	Out of Basin	Source does not provide information on the Skagit River or the Synthesis Study Area. Annotated bibliographies will not be developed for these sources.
	Not Relevant	Source does not provide information relevant to the Synthesis Study Area, topics of interest, or target species. Annotated bibliographies will not be developed for these sources.

3.0 TOPICS AND KEY WORDS

A framework of topics and keywords was also developed to identify information in the source based on topics of interest. The following list of topics and keywords were developed from the Synthesis Study RSP and in coordination with LPs at the December 2021 Synthesis Study Work Group meeting (Table B-2). These attributes are associated with Tier 1 and Tier 2 Sources in a relational database to allow the sources to be queried based on topics relevant to the Synthesis Study.

Table B-2. List of attributes for topics and keywords for sources.

Topic	Keyword	Notes
Geomorphology and Landforms	Change	Changes in geomorphology or processes over time.
	History	Geological history and history of formation and processes.
	Channel migration	Channel migration, including lateral channel migration, channel migration zones, or active channel zone.
	Channel incision	Channel incision.
	Sinuosity	Channel sinuosity.
	Slope	Channel slope or gradient.
	Scour	Scour and erosion (e.g., bank erosion).
	Floodplain	Information on floodplain width or flood prone width.
	Glaciers and snowpack	Glacial or snowpack information, distribution, accumulation/loss rates.
	Side and off-channels	Abundance, connectivity, diversity of secondary channel habitats including braids, off-channels, and side channels.
	Floodplain connectivity	Connectivity to floodplains or floodplain habitats.
	Substrate and sediment	Substrate or sediment composition.
	Sediment transport and supply	Sediment transport or supply, including landslides and reservoir retention.
	Shallow and deep surface processes	Hydrostatic rebound, compaction, subsidence.
	Large wood	Large wood abundance, recruitment, transport, retention.
	Log jam	Log jam abundance, growing, decay, stable, variable.
	Nearshore habitats and landforms	Nearshore landforms, beaches, embayments, bluffs.
	Aquatic habitats and landforms	Fluvial geomorphology, or riverine landforms.
	Estuarine habitats and landforms	Tidally influenced or estuarine habitats and landforms.
	Climate change	Impacts of climate change on geomorphology.
	Data gaps	Data gaps are identified.
Water Quality and Productivity	Temperature	Temperature, maximum, mean, 7-day averages.
	Nutrients	Nitrate, phosphorous, ammonia, nitrite.
	Dissolved oxygen	Dissolved oxygen concentration.

Topic	Keyword	Notes
	pH	pH, alkalinity, acidity.
	Bacteria	Fecal coliform or other bacteria.
	Contaminants	Heavy metals, hydrocarbons, pesticides.
	Turbidity	Turbidity, NTU, secchi.
	Salinity	Salinity and conductivity.
	Primary productivity	Periphyton or algal abundance.
	Secondary productivity	Invertebrate abundance or diversity.
	Climate change	Impacts of climate change on water quality.
	Data gaps	Data gaps are identified.
Modeling Tools	Hydrology	Hydrodynamic, hydrologic, or hydraulic models.
	Bathymetry	Bathymetric data or models, digital elevation models.
	Sediment	Sediment models.
	Life cycle	Life cycle models.
	Bioenergetics	Bioenergetic models or food web models.
	Adult returns	Forecasting models for adult returns.
	Juvenile production	Models to predict juvenile production, abundance, density, capacity.
	Climate change	Models the predict effects of climate change or predict climate change.
	Habitat	Models describing habitat, intrinsic potential.
	Connectivity	Habitat connectivity, landscape connectivity.
	Data gaps	Data gaps are identified.
Land Use and Cover	Land cover	General land cover information.
	Forestry	Forestry and logging information, extent, management.
	Agriculture	Agriculture land use information, extent.
	Commercial	Commercial and industrial land use extent and types.
	Urban	Urban land use information, extent.
	Roads	Road densities, distribution, lengths.
	Banks and shoreline	Levees/dikes, shoreline hardening, armoring.
	Floodplain	Irrigation/diking, wetland losses/conversion.
	Climate change	Climate change impacts on land cover.
	Data gaps	Data gaps are identified.
Fish and Habitat	Habitat, instream flow	Peak flows, flood recurrence intervals, mean flows.
	Habitat, riparian	Riparian extent or condition, stand structure, buffers.
	Habitat, wetlands	Wetland quantity, quality, or type.
	Habitat, beaver	Beaver abundance, distribution, habitat effects, conflicts, BDAs, beaver deceiver.
	Habitat, barriers	Fish passage barriers.
	Habitat, invasive species	Aquatic or terrestrial invasive species.
	Habitat, freshwater	Habitat quantity, quality, or type.
	Habitat, estuary	Habitat quantity, quality, or type.

Topic	Keyword	Notes
	Habitat, pocket estuary	Habitat quantity, quality, or type.
	Habitat, nearshore	Habitat quantity, quality, or type.
	Habitat, ocean	Habitat quantity, quality, or type.
	Habitat, connectivity	Patchiness, landscape connectivity, local connectivity, accessibility.
	Habitat, capacity	Capacity of habitat to support fish.
	Habitat, limiting factors	Identifies habitat limiting factors.
	Habitat, status and trends	Habitat status and trends.
	Habitat, restoration	Projects, plans, designs, targets.
	Habitat, climate change	Climate change impacts on habitat.
	Habitat, data gaps	Data gaps are identified.
	Fish, abundance	Abundance estimates for fish.
	Fish, aquaculture	Fish or shellfish aquaculture, net pens, shellfish beds.
	Fish, distribution	Distribution of species among habitats or within a system, including straying.
	Fish, diet	Diet composition, foraging behavior, preference.
	Fish, condition	Measures of condition, condition factor, lipids, weight.
	Fish, density dependence	Measures of density dependent processes or patterns.
	Fish, competition	Interspecific or intraspecific competition, territory.
	Fish, survival	Survival at different life stages (e.g., egg to fry, smolt to adult), size selective mortality, density dependence.
	Fish, genetics	Origin, diversity, genetic mark recapture, eDNA.
	Fish, growth	Growth estimates from mark recapture, otolith or scales.
	Fish, swimming speed	Swimming speeds, travel speeds, movement.
	Fish, physiology	Physiological studies.
	Fish, rearing	Fish rearing patterns or preferences.
	Fish, predation	Predation on fish, avian, marine mammal, fish.
	Fish, life history	Life history characterization, description, diversity, resilience.
	Fish, age structure	Age structure information.
	Fish, size structure	Size structure, length frequency.
	Fish, sex structure	Sex structure, ratios.
	Fish, periodicity	The timing and duration of life stages.
	Fish fecundity	Eggs per female, green eggs per gram, fecundity to length/age relationships.
	Fish, movement	Travel speed, patterns, timing.
	Fish, status and trends	Population status and trends information, extent, management.
	Fish, hatchery	Hatchery abundance, strategies, interactions.
	Fish, harvest	Harvest rates, fisheries, exploitation rates.
	Fish, climate change	Climate change impacts on fish (e.g., temperature or periodicity).
	Fish, data gaps	Data gaps are identified.

Topic	Keyword	Notes
	Monitoring, restoration	Monitoring restoration projects (e.g., response, effectiveness).
	Monitoring, climate change	Monitoring climate change impacts or climate change.
	Monitoring, data gaps	Data gaps are identified.
	Monitoring, habitat	Habitat status and trends, monitoring.
	Monitoring, sediment	Suspended sediment monitoring, ADCP.
	Monitoring, water quality	Various water quality monitoring strategies.
	Monitoring, abundance	Smolt trap, electrofishing, seining, fyking, angling, carcass, redd, or other abundance monitoring methods.
	Monitoring, biotelemetry	PIT, radio, acoustic tagging, mark recapture studies.
	Monitoring, scale or otoliths	Age analysis, time of entry, residency/transition periods, growth.
	Monitoring, genetics	GMR, population assignment, origin.
	Monitoring, flow	Flow monitoring.
Hydroelectric Operations	Flow regulations	General regulation of flow at hydropower facilities (may include Baker River or Upper Skagit River projects).
	Downramping	Diel reductions in flow.
	Flood control	Regulation of flow to reduce flooding or peak flow events.
	Life stage flows	Minimum or maximum flows during specific life stages or periods.
	Stranding	Stranding from flow regulation, downramping, peaking.

4.0 DATA FLAGS

Information and data for target species, life stages, and reaches will also be identified for sources using data flags to allow for easy identification of information relevant to the Synthesis Study. Data Flags will also be used to identify if quantitative data, spatial data, or Project related data are provided by the source. Table A-3 provides a list of data flags to support identification and classification of sources and data compiled. Note Reach flags may include ranges or combinations of reaches depending on the spatial extent of the study and available data. Geomorphic reach descriptions for the mainstem Skagit River were quoted from Riedel et al. (2020).

Table B-3. Data flags to support identification and classification of sources and compiled data.

Field	Values	Description
Species	Chinook	Contains information on Chinook Salmon.
	Coho	Contains information on Coho Salmon.
	Sockeye	Contains information on Sockeye Salmon.
	Chum	Contains information on Chum Salmon.
	Pink	Contains information on Pink Salmon.
	Bull Trout	Contains information on Bull Trout, may include Char or Dolly Varden.
	Steelhead	Contains information on Steelhead, may include rainbow trout.
	Pacific Lamprey	Contains information on Pacific Lamprey.
	Other	Contains information on other non-target species .
	All anadromous species	Contains information on all target anadromous species.
	NA	Data not associated with target species.
Life Stage	Migration	Adult migration, including holding.
	Spawning	Adult spawning.
	Incubation	Egg incubation in substrate.
	Emergence	Emergence from substrate.
	Rearing	Juvenile rearing in freshwater habitats.
	Overwintering	Overwinter rearing in freshwater habitats.
	Fluvial	For Bull Trout with extended juvenile, sub adult, and adult freshwater life stages.
	Outmigration	Juvenile emigration from freshwater habitats.
	Adult outmigration	Adult outmigration for iteroparous species.
	Estuary rearing and emigration	Juvenile rearing, transition, and emigration through estuary habitats.
	Nearshore rearing and emigration	Juvenile rearing in nearshore habitats, including pocket estuaries.
	Ocean	Ocean maturation.
	Migration – spawning	Adult migration through spawning.
	Spawning – rearing	Adult spawning through juvenile rearing.
	Incubation – rearing	Incubation through rearing.
	Incubation – outmigration	Incubation through outmigration.

Field	Values	Description
	Rearing - outmigration	Rearing through outmigration.
	Outmigration – migration	Juvenile outmigration to adult migration.
	Full life cycle	Full life cycle.
	Not specified	Species is listed but does not contain life stage information.
	NA	Does not contain information on species or life stages.
Reach	US of R7	Reaches upstream of R7.
	Sauk River	Includes Sauk River, tributary to the mainstem Skagit River that confluences at R7.
	R7	R7-Sauk River Alluvial Fan – "Wide alluvial fan that forces Skagit to north side of valley. Influenced by Glacier Peak sediment, some from lahars." RM[1] 68-65.
	R8	R8-Sauk Alluvial fan to Baker Mouth – "Steep, narrowed channel because river is incised into 30-50m thick, over-consolidated glacial deposits (till, silt, sand, and gravel)." RM 65-56.5.
	R9	R9-Baker to Finney Cr. – "Channel incised into glacial and lahar terraces, Baker Hydro influence on sediment, large wood, and channel pattern." RM 56.5-49.
	R10	R10-Finney Cr. To Hamilton Moraine – "Sinuosity higher strong right bank ground water influence, extensive lahar terrace." RM 49-36.5.
	R11	R11-HM to Sedro-Wooley – "High sinuosity in wide outwash valley wide meander loops. Extensive lahar terrace on right bank." RM 36.5-NA.
	R12	R12-SW to Burlington Hill – "River leaves valley and enters Puget Lowland. Start of river levees transition to sand bed." RM NA. Downstream extent of tidally influenced habitats.
	R13	R13- Burlington Hill to Nookachamps Creek confluence at about RM 20. Note this reach is still being delineated by the GE-04 Geomorphology Study.
	R14	R14- RM 20 to primary bifurcation of the North Fork and South Fork Skagit River distributaries near RM 10. Note this reach is still being delineated by the GE-04 Geomorphology Study.
	R15	R15- North and South Fork Skagit River distributaries including the Skagit River delta/estuary, tidal channels, and tidal marshes. Note this reach is still being delineated by the GE-04 Geomorphology Study.
	R1 – R6	Reaches R1 – R6 from Skagit Gorge to Barnaby Reach.
	Skagit Estuary	The Skagit River estuary or delta, also the same as R15. Note these reaches are still being delineated by the GE-04 Geomorphology Study.
	Skagit Bay	Skagit Bay – Skagit Bay and nearshore shoreline, including neritic and embayment habitats from the Deception Pass outlet in the North to the mouth between Whidbey Island and Camano Island in the South.
	Padilla Bay	Padilla Bay – northern outlet of Swinomish Channel that is included in the geomorphic delta boundary for the Skagit River.
	Baker River	Major lower Skagit River tributary.

Field	Values	Description
	Jackman Creek	Major lower Skagit River tributary.
	Day Creek	Major lower Skagit River tributary.
	Gilligan Creek	Major lower Skagit River tributary.
	Loretta Creek	Major lower Skagit River tributary.
	Hansen Creek	Major lower Skagit River tributary..
	Wiseman Creek	Major lower Skagit River tributary
	Nookachamps Creek	Major lower Skagit River tributary.
	Finney Creek	Major lower Skagit River tributary.
	Tributaries	Tributaries not named or listed.
	Other lower Skagit tributaries	Other tributaries that drain into the lower Skagit River.
	Other upper Skagit tributaries	Other tributaries that drain into the upper Skagit River.
	Other Sauk tributaries	Other tributaries that drain into the Sauk River.
	Skagit Watershed	Entire Skagit Watershed basin.
	Puget Sound	Study is a regional focus that includes the Skagit but may not present results specific to the Skagit.
	NA	Does not contain information on reaches.
Quantitative Data	Yes/No	Indicates whether the source provides quantitative data on the topic and keyword, and/or species and life stage.
Spatial Data	Yes/No	Indicates whether the source provides spatial data on the topic and keyword, and/or species and life stage.
Project Related	Yes/No/Links	Indicates whether the source provides information that links Project Operations to some aspect of resource conditions. • Yes = a specific element of the study designed to evaluate Project Operation impacts. • Links = source provides information linking Project Operations to a resource condition but is not a specific study element. • No = no information related to Project Operations or links to resource conditions are provided.

1 RM = river mile.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT C

LIFE STAGE FACTORS

1.0 OVERVIEW

This attachment synthesizes the information identified in Step 1 Data Compilation, which was analyzed to develop life-history-based conceptual models of each of the Skagit River target anadromous fish species using the lower river, delta, and estuary (Step 2), in consultation with the LPs, to provide information on life stage factors as part of Step 3. The information presented in this attachment is based only on the information provided by the reviewed literature.

The information is organized by factor categories identified in the conceptual life history models and literature review. Relevant information from the literature is included describing the drivers and stressors that influence the factor, and the species and life stages that are influenced by the factor. The following outline shows the categories (bold) and list of primary factors (italicized) for which information from the literature are described:

(1) **Instream flow:** General flow, peak flow, minimum flow, downramping, tidal inundation.

(2) **Sediment supply and transport:** Supply and transport, deposition and substrate.

(3) **Habitat availability and connectivity:** *Habitat extent, habitat connectivity*.

(4) **Large woody debris and bank condition:** LWD recruitment/retention, hydromodified banks and channel edge.

(5) **Riparian condition:** Condition and composition, extent and continuity, shade and canopy.

(6) **Water quality:** Instream temp general, instream temp maximum, instream temp minimum, dissolved oxygen, organic matter and nutrients, pH, turbidity, salinity, bacteria and pathogens, contaminants.

(7) **Competition and predation:** Predation avian and mammal, predation fish, competition spawning, competition rearing.

(8) **Food availability:** Primary productivity, secondary productivity.

(9) **Other anthropogenic factors:** Climate change, hatcheries, fisheries, aquaculture, beaver management.

These factors are generally presented in order **based on the amount of available information and does not necessarily reflect the order or importance** with respect to a factor’s influence on resource conditions in the study area . In many cases, factors are interrelated, and some factors may be drivers of other factors. These are identified where applicable, and information is presented with references to reduce redundancy where factors and drivers are interrelated. In addition, shorthand was used when referring to the spatial extent of information to reduce text. The following descriptions provide information on shorthand used in the following sections:

- River = Skagit River
- Lower Skagit River = mainstem Skagit River below the Sauk River confluence
- Mainstem = the main channels of the Skagit River
- Upper Skagit River = mainstem Skagit River upstream of the Sauk River confluence

- Middle Skagit River of Middle Reach = portion of the lower Skagit River from approximately Sedro Wooley to upstream of the Sauk River confluence
- Tributary or tributaries = tributaries to the lower Skagit River
- Delta or Estuary = the geomorphic Skagit River delta or Skagit River estuary, including both the North Fork and South Fork distributaries, and Swinomish Channel
- Nearshore = nearshore habitats of Skagit Bay and Padilla Bay

Information specific to each facility are described when provided by the source, otherwise flow regulation is used to describe general influences of flow regulation not specific to a facility. Where information is provided specific to the upper Skagit River facilities, influences of flow regulation may be described as Project operations.

A summary of the information for each factor will also be developed in table form (Attachment D) that summarizes target species and life stages that are related to the factor, the biotic responses that are associated with the factor, the spatial relevance or extent that the factor and biotic responses operate, what management actions are related to the factor, and an initial assessment of relative importance. Collectively this information is intended to support identification of key factors affecting anadromous resources in the study areas as well as key uncertainties for Step 4 of the Synthesis Study.

2.0 INSTREAM FLOW

Instream flow describes the timing, duration, and magnitude of flow conditions in the river. Generally, literature identified climate, underlying geology, land uses and cover, flow regulation, diversions and withdrawals, and channelization as primary drivers that influence instream flows (Redman et al. 2005, ID100; Beechie et al. 2003, ID015; Curran et al. 2016, ID373). In turn, hydrological regime was identified as a driver of physical habitat characteristics and processes, water quality, and primary and secondary productivity of lotic freshwater habitats in general (Beechie et al. 2003, ID015). In estuary and nearshore habitats, tidal inundation adds another layer of complexity to instream flows and is also a primary driver of habitat formation and maintenance processes in estuary and nearshore habitats. The following primary factors related to instream flows represent the factors most often related to biological responses among target species and life stages, or were identified during development of the conceptual life history models:

- ***General flow:*** General instream flow conditions related to the timing, duration, and magnitude of flows instream.
- ***Peak flow:*** Peak or flood flows, and the timing, duration, and magnitude of these flow events.
- ***Minimum flow:*** Base flows or low flow conditions, which typically occur during summer months.
- ***Downramping:*** Changes (diel) in instream flow conditions as a result of power generation that results in falling water levels or instream flows.
- ***Tidal inundation:*** Tidally influenced flows that can result in diel changes in instream flow and the timing and duration of inundation.

2.1 General flows

2.1.1 Drivers and stressors

Flow regulation was cited as a primary driver of instream flows and hydrological regimes by many sources. Curran et al. (2016, ID373) indicated that instream flows in the lower Skagit River were influenced by dams on the upper Skagit and Baker River. Ross Dam and Upper Baker Dam alone *control 38 percent of the Skagit River basin's drainage area; the remaining 62 percent is uncontrolled* (USACE 2010, ID117). USACE (2010, ID117) also indicated that Ross and Upper Baker dams are *operated on a formal basis for flood control and provide a significant reduction to large and small floods*. Other dams along the Skagit and Baker rivers *provide incidental reduction of flood flows during smaller events* (USACE 2010, ID117). Despite a significant portion of the basin's drainage area being controlled by dams, the Skagit's hydrograph was described as typical of a large river in Western Washington. Curran et al. (2016, ID373) described the Skagit hydrograph as having *high flows* [that] *typically occur from mid-October to March as a result of precipitation, and from April to mid-July as a result of snowmelt* and annual low flows that generally occur from mid-July to mid-October.

Flow regulation was identified as potential stressor on habitat creation and maintenance processes. Smith (2005, ID177) developed a regression between effective floodplain width and off-channel habitat densities from unregulated river reaches and hypothesized that departures from that regression in the Skagit River were the result of flow regulation reducing habitat creation and maintenance processes. However, their study focused on the upper Skagit River and only included Reach R7 in the study area, and it is unclear if the pattern holds in the lower Skagit River. Smith (2003, ID376) noted that flows at the Skagit River dams are managed to maintain adequate life stage flows during spawning, incubation, and rearing life stages, but primarily with respect to conditions in the upper Skagit River. However, unregulated flows from tributaries can significantly influence habitat extent and connectivity within the lower Skagit River and tributaries themselves (e.g., Veldhuisen and Haight 2001; NSD 2017, ID086; ID163; Bandaragoda et al. 2020, ID379). Flow regulation was also cited as a concern for the Baker River and the lower mainstem Skagit River habitat downstream of the Baker River confluence as a result of downramping and inadequate life stage flows (Smith 2003, ID376; Beamer et al. 2005, ID175).

Large scale climate patterns were also identified as primary drivers of hydrological regimes in the Skagit River (Lee and Hamlet 2011, ID196). Warm Pacific Decadal Oscillation (PDO) and El Nino Southern Oscillation (ENSO) index years are generally associated with drier and warmer winter and spring weather and vice versa. PDO/ENSO effects tend to be amplified in synchronous phase years. Snowpack and instream flows in the Skagit River are more sensitive to PDO/ENSO driven climate variability than other Pacific Northwest rivers (Lee and Hamlet 2011, ID196).

Glaciers also play a crucial role in the Skagit River basin’s hydrology, and glacial processes have been linked to potential and current climate change processes. Lee and Hamlet (2011, ID196) documented 394 glaciers in the Skagit River basin, which contribute between 12 and 18 percent of the May to September summer flow. Glacial retreat since 1900 has resulted in a 50 percent reduction in total glacial area, the rate of which has been more rapid on the wetter western side of the Skagit River basin than on the drier eastern side (Lee and Hamlet 2011, ID196). These patterns may be exacerbated by climate change processes and result in further changes in basin hydrological regime as a result of changing glacial inputs (Lee and Hamlet 2011, ID196; Bandaragoda et al. 2020, ID379).

Climate change was also identified as a potential stressor on future hydrological regimes in the Skagit River basin (Lee and Hamlet 2011, ID196; Lee et al. 2016, ID417). Climate modeling scenarios predict warmer temperatures will result in more precipitation falling as rain in the cool season, resulting in reduced snowpack and a shift in runoff timing. Reduced snowpack will carry over into more extreme low flows in the summer. Compared to the Pacific Northwest as a whole, the Skagit River is expected to experience a less severe reduction in April 1 snow water equivalent (SWE). By the end of the 21st century, the Skagit River basin will resemble a rain-dominant basin (Lee and Hamlet 2011, ID196). Lee et al. (2016, ID417) indicated that climate change will cause substantial seasonal changes in both natural and regulated projected flow conditions in the Skagit. The Skagit River basin will transition from a mixed rain and snow basin with dual peaks in the winter and spring to a rain dominated basin with a single peak in the winter for both natural and regulated flow conditions (Lee et al. 2016, ID417).

Levees and other flood control infrastructure along with general land uses and cover (e.g., urbanization, timber extraction, agriculture, and road building) have also altered the Skagit’s hydrology, including the timing of water infiltration and the system’s ability to store water (USACE 2010, ID117). These stressors exacerbate high and low flows, making high flows flashier and low flows lower (USACE 2010, ID117). Flow regulation at both the Skagit and Baker operations have also affected Skagit River flows which are both operated for flood control. Flood control operations have changed the natural peak flow of the Skagit River system, with flows during the typical spring peak being lower than normal (when snowmelt would normally cause higher flows) and flows during later summer through mid-winter being higher than normal (SWC 2011, ID113). However, the low divide between Sedro-Woolley and Burlington have occasionally overflown, and towns in the upper portions of the Skagit basin such as Hamilton and Lyman experience flooding more regularly (USACE 2010, ID117). Levee and flood control infrastructure have been developed as part of flood control strategies, but these stressors are identified as both a means to reduce flood risk and a potential stressor on instream flows, sediment supply and transport, habitat availability and connectivity, riparian conditions, and other factors considered in this review.

Beaver are ecosystem engineers and were also cited as potentially influencing instream flows (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Roni et al. 2006, ID104; Beechie et al. 2010, ID017; USACE 2010 ID117; Hood 2012, ID144). Construction of dams by beaver can create pool and wetland habitats, impound water, and influence flood and subsurface hydrology (Beechie et al. 2010, ID017). Most studies indicated that beaver construct dams in small streams, tributaries, and other low gradient floodplain habitats, but beaver are also documented in estuarine and tidally influenced habitats (see Hood 2012, ID144). Beaver may also construct dams in culverts or other water crossing structures, which can be regarded as a nuisance and a potential stressor on instream flows. Beaver are described in more detail in Section 10.5 Beaver management.

2.1.2 Species and life stages

The timing, duration, magnitude, and frequency of instream flows were generally linked to all target species and life stages and the habitats they rely upon. Instream flows can influence the periodicity of species and life stages, as well as the capacity of habitats to support different life stages and life histories, migration behavior and expression of life histories, and direct mortality. For example, instream flows can influence the timing of adult entry into rivers and migration upriver to spawning habitats (Beamer et al. 2005, ID175), as well as the use and maintenance of optimal holding and spawning habitats for adult salmon. In addition, Beamer et al. (2005, ID175) indicated that all stocks are potentially affected by dam operations as fry when they migrate and rear in spawning areas downstream of the dam in the Skagit mainstem and downstream of the Baker River confluence (Beamer et al. 2005, ID175). In general, all salmon species are susceptible to peak flows during incubation periods, and low flows during summer months constrain salmon production for species with extended freshwater rearing periods (Smith 2003, ID376).

Current hydroelectric operations, flooding (peak flows), and water withdrawals in the Skagit River were identified as limiting factors for Chinook Salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Connor and Pflug (2004, ID385) found that flow regulation influenced the abundance and distribution of Chinook, Pink, and Chum Salmon in the upper Skagit River and upper reaches of the lower Skagit River, although these effects attenuated with distance downstream from the upper Skagit River dams (which was primarily attributed to inputs from unregulated tributaries). Zimmerman et al. (2015, ID331) also described density-dependent and density-independent expressions of life history and survival patterns for juvenile Chinook in the Skagit River, which were linked to the magnitude and duration of peak flow events during incubation and flow regulation. However, Graybill et al. (1979, ID259) reported that no correlations could be identified between Chinook escapement/run size and patterns in flow during spawning, incubation, or rearing. In addition, Beamer et al. (2005, ID004) noted a large decline in yearling Chinook contributions in the upper Skagit summer population that coincided with changes in Project flow management (in the mid-1980s and 1991 associated with the last relicensing). However, this shift also coincided with cessation of unmarked hatchery releases (also cited in Beamer et al. 2005, ID005), and it is unclear as to the degree to which these potential factors influenced these patterns, and Beamer et al. (2005, ID004) identified this as an area of future study to better understand mechanisms and processes influencing the decline.

In addition, habitat suitability for spawning is significantly influenced by instream flows. Skagit River adult Chinook and Pink Salmon spawners prefer deeper and faster water than conspecifics in smaller streams. Depth appears to be less important than velocity. Skagit River Chum appear to spawn in deeper waters than conspecifics in other streams, but similar velocities. Skagit River steelhead depth and velocity ranges were similar to other values reported in the literature (Graybill et al. 1979, ID259). Fluctuating low flows have also been shown to drive adult Chinook off their redds, but residual water was always present beneath the redds and adults may reoccupy their redds when water levels return (Graybill et al. 1979, ID259).

Instream flows were also shown to affect estuary life stages. Loss of gradual salinity gradients in estuaries resulting from reduced freshwater input can affect residence times of juvenile salmon rearing within delta habitats. Curtailed residence times in estuaries can impair physiological transitions from freshwater to saltwater (Redman et al. 2005, ID100) and increased residence and rearing times in estuary habitats were associated with increased growth and survival for fry migrant Chinook (Beamer et al. 2005, ID005). Redman et al. (2005, ID100) suggested that changes in the timing, magnitude, and quality of freshwater flow can alter delta rearing habitat available for physiological transition for juvenile Chum and Chinook Salmon (presumably from changes in salinity gradients linked to instream flows as noted above). Diversions and flow regulation can also reduce habitat diversity, alter adult migration pathways, and impair physiological transition for Bull Trout. The mechanisms for these potential impacts were described as working hypotheses, with changes in the timing, magnitude, and quality of freshwater flow from flow regulation and diversions influencing instream flows and observations from other studies. However, it is unclear how unregulated flows and the timing, duration, and magnitude of flow regulation and water use actions interact with periodicities of habitat use or other processes that could influence the effects of these mechanisms.

Climate change and potential effects on instream flows (prolonged summer low flows, increased flooding, and warmer air temperatures) were identified as an additional potential stressor on cold-water fish species, such as salmon and trout (Lee and Hamlet 2011, ID196). Thermal stress is covered under in Section 7.0 Water quality, with low flows as a potential stressor on instream temperatures. Potential effects of increased peak flows and prolonged summer flows are described in more detail in the following sections (Section 2.2 Peak flow and 2.3 Minimum flows).

2.2 Peak flow

2.2.1 Drivers and stressors

Peak flows, also commonly referred to as flood flows or flood hydrology in the literature, are controlled by ecosystem processes and functions, which differ across major ecoregions in the Pacific Northwest (Beechie et al. 2003, ID015). The Skagit River basin spans the Western Forested

Mountains and Coastal Forest Level II Ecoregions. In these Ecoregions, Beechie et al. (2003, ID015) indicated that peak flows are controlled primarily by snowmelt in western forested mountains, and rain and rain-on-snow events in coastal forests. USACE (2013, ID118) provided descriptions of average annual and monthly precipitation, snowfall averages, and storms of 1909, 1990, 1995, and 2003. These storms and the timing of these events caused precipitation to stay over the Skagit River basin, causing high amounts of precipitation and flooding, and the descriptions of these storm events provide good insights into the climatological processes that influence peak flows in the Skagit River.

Flow regulation and unregulated tributary inputs also interact with climatological processes to influence peak flows in the Skagit River. During the fall and winter, the Skagit River system typically receives runoff from both rain and snowmelt and shifts to snowmelt runoff during spring. The dam reservoirs are usually refilled during the spring snowmelt and *…as a result, the spring peak discharges are generally reduced* (USACE 2013, ID118). USACE (2013, ID118) also indicated that *flood control at Ross and Upper Baker is sufficient to control floods in the lower valley… with exceedance frequencies of four to five percent (20–25-year event)*. However, flood runoff from the Skagit's uncontrolled basins can produce major flooding, even with flood control regulation at Upper Baker and Ross dams (USACE 2013, ID118). The Upper Baker and Ross reservoirs represent 39 percent of the total Skagit drainage area at Mount Vernon, with the remaining 61 percent being uncontrolled basins. The Sauk River contributes 45 to 64 percent (66,900 – 111,000 cfs) to flood events in the Skagit River (145,000 – 214,000 cfs) and represents the largest potential contributor to peak flow events among the uncontrolled subbasins to the lower Skagit River (USACE 2013, ID118). However, many other tributaries can contribute to peak flows in the lower Skagit River.

Climate change has also been linked to potential changes in peak flows in the Skagit River. Floods are expected to increase in frequency and magnitude due to more winter precipitation and higher freezing elevations (Lee and Hamlet 2011, ID196; Woodward et al. 2017, ID121). SWC (2011, ID113) stated that *hydrological models indicate that warming trends will reduce snowpacks, decreasing the risk of springtime snowmelt-driven floods in the coldest snowmelt-dominated basins, including the upper Skagit, Sauk, and Suiattle rivers.* Lee et al. (2016, ID417) showed that climate change will cause substantial seasonal changes in both projected natural and regulated flow conditions. The 100-year flood was projected to increase relative to historic baselines for both a natural and regulated scenario in both the 2040s and 2080s. Additionally, annual peak flows are projected to increase in magnitude and occur more frequently in the winter season. Alternative flood control operations that increase flood control storage were shown to be ineffective at mitigating higher flood risks in future climate change scenarios. Lee et al. (2016, ID417) also indicated that increased sediment supply and transport with climate change could increase bed elevations, and this would exacerbate flooding risks with climate change and shifts in the timing and magnitude of flood events in the lower Skagit River.

Numerous sources indicated that peak flows in the lower Skagit River have been reduced since flood storage capacity and flow regulation were added to the upper Skagit River and Baker River (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305; Redman et al. 2005, ID100; Riedel et al. 2020, ID001). For example, the number of floods between 2-year and 100-year return periods have been reduced by about 50 percent since the construction of upper Skagit River and Baker River dams (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015;

Beamer et al. 2005, ID305). In addition to the reduced frequency of peak flow events, pre-dam floods approached or exceeded 200,000 cfs, while floods in the post-dam era have not exceeded 200,000 cfs (Beamer et al. 2000, ID190; Beamer et al. 2005, ID305). NHC (2013, ID428) attributed reductions in peak flows to increases in flood control storage and levee infrastructure. Flood flows in the Skagit River are regulated by flood control operations at the Upper Baker and Ross dams (NHC 2013, ID428). NHC (2013, ID428) indicated that the Lower Baker dam currently has no authorized flood control storage, and that authorization of 20,000 acre-ft of flood control storage at Lower Baker Dam could restrict flow contributions from Baker River into the mainstem Skagit to just 1,200 cfs for up to a 50-year event if full flood control storage is available at Upper Baker and Ross dams. This would result in a predicted 4 percent (8,000 cfs) to 9 percent (13,000 cfs) reduction in peak flows in the Skagit mainstem.

Reduced peak flows can benefit certain species during certain life stages (e.g., spawning and incubation), but reduced peak flow intensity and frequency were also cited as reducing habitat formation, maintenance, and connectivity processes (Smith 2003, ID376; Beechie et al. 2003, ID015; Smith 2005, ID177; Riedel et al. 2020, ID001). However, increased peak flows were also cited as a stressor that can increase the frequency of channel forming and bed mobilization events, which can lead to channel destabilization, less habitat complexity, and increased bed scour depths in some geomorphic settings (Beechie et al. 2003, ID015). Restoring a range of critical flows, including channel-forming flows, habitat maintenance flows, and low flows can potentially address effects from flow regulation on habitat processes (Beechie et al. 2010, ID017).

Humans have also altered the landscape through development, land uses, altered land cover, stream engineering, and hydromodifications (straightening, diking, and bank armoring) which have resulted in loss of floodplain connectivity and increased peak flow severity (PSI and WDFW 2017, ID085). Beaver also alter habitats through dam construction and can influence peak flow or flood hydrology in small streams, floodplain habitats, and tidally influenced habitats (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Roni et al. 2006, ID104; Beechie et al. 2010, ID017; USACE 2010 ID117; Hood 2012, ID144). Beaver are described in more detail in Section 10.5 Beaver management.

Immature forested cover and forest road drainage networks are correlated with increased peak flows in mountain basins (Beechie et al. 2003, ID015). Immature forest cover increases runoff rates during snow melt due to increased snow accumulation, and forest road networks can increase the drainage network and more rapidly transport water to tributaries, thereby increasing peak flow magnitudes (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015). Data describing flood history for unregulated mountain sub-basins in the Skagit basin is limited and models are often used to identify potential impairments with respect to peak flows in tributary basins (Beamer 2005, ID305). In the Sauk River, a paired catchment analysis (to control for climate effects) indicated that forestry practices are responsible for changes in streamflow characteristics, particularly at low flow periods (Bowling et al. 2000, ID020). An analysis of time-series residuals from hydrologic model simulations also revealed increasing trends in peak flows that they linked to forestry practices (Bowling et al. 2000, ID020). Impervious surface cover was frequently used as a proxy for identifying potential impairments to peak flow hydrology in lowland habitats from land uses, and this approach was especially common in tributary drainages given that flow monitoring has not been established for all tributary drainages in the Skagit (e.g., Beamer et al. 2000, ID190; Beamer et al. 2005, ID175). Veldhuisen and Haight (2001, ID163) developed a model that can predict peak flows (as measured by 100-year flow events) for small forested tributary basins of the Skagit (< 10 mi^2) that used drainage area and annual precipitation, which they suggested was an improvement over previous regression approaches and indicated the results could be used to support evaluation or modeling of small unregulated tributary contributions to peak flows in the lower Skagit River.

Habitat assessments and modeling studies have identified impairments related to peak flows for tributaries to the lower Skagit River and Sauk River, but lower Skagit River mainstem habitats have been identified as functioning (Beechie et al. 2003, ID015). Many tributaries and drainages have that were identified as having impaired or moderately impaired flow conditions for peak flows were based on land cover data, including the lower Skagit River, Nookachamps, Hansen, Gilligan, Day, and Finney creeks with likely impairments noted in Loretta and Jackman Creeks (Smith 2003, ID376). The Skagit Basin Council updated strategic approach identified Tier 3 target areas for restoration and protection that included basins with impaired sediment supply or peak flows (SWC 2022, ID451). These Tier 3 target areas have impaired processes that impact Chinook Salmon habitat and were determined to be areas that should be addressed within the next ten years. Some of the priority restoration objectives were to reduce land use (which affects sediment supply) and repair, relocate, or remove structures that contribute to increased erosion or peak flows (SWC 2022, ID451). Peak flows have also been identified as an impairment in estuary distributaries and some tributaries to the Skagit estuary (Beechie et al. 2003, ID015).

2.2.2 Species and life stages

Peak flows were identified as a factor affecting survival during the incubation life stage for all target species for the Skagit River Relicensing SY-01 Synthesis Study. All target species spawn in similar habitats and are potentially vulnerable to redd scour during incubation with peak flows (Smith 2003, ID376). It was assumed that this also applies to Lamprey in addition to target salmon and trout species, given similarities in spawning habitats (Smith 2003, ID376; Hayes et al. 2013, ID419; Ostberg et al. 2020, ID422; Wang et al. 2020, ID424), but limited information on Lamprey was available. Flooding was identified as a limiting factor in the Skagit Chinook Recovery Plan, with peak flows having the greatest impact on Chinook egg to migrant survival (Beamer et al. 2005, ID175). Volkhardt et al. (2006, ID404) also identified flows during incubation as limiting Chinook Salmon. Beamer (2005, ID175) predicted that the actions listed in the Skagit Chinook Recovery Plan for egg to fry survival can change all impaired basins to functioning levels, but there could be a future reduction in egg to fry survival due to climate change if basin conditions remain the same. Therefore, restoration of impaired basins was a high priority in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175).

The primary mechanisms identified for peak flow effects on target species during incubation life stages were through redd scour or burial that causes direct mortality of eggs. Survival from incubation to outmigration was described as an exponential function with increasing peak flow during incubation life stages increasing mortality during incubation (Beamer and Pess 1999, ID380; Beamer et al. 2005, ID005; Beamer 2005, ID305; Greene et al. 2005, ID050). However, most studies focusing reporting on peak flow effects on survival during incubation were focused on Chinook Salmon. Beamer 2000 (ID191) reported that the factor with the greatest effect on freshwater survival for Chinook was peak flows occurring during egg deposition to emerged fry life stages, and studies have found evidence that freshwater habitat conditions are potentially constraining or limiting production rates for Skagit River Chinook stocks, including the lower Skagit River, Sauk River, and upper Skagit River populations (Beechie 1992, ID127; Beamer and Pess 1999, ID380). Beamer and Pess (1999, ID380) reported that Chinook populations were sensitive to peak flow events even when flooding was not severe (e.g., 2-year flood events), and egg incubation survival limited production 30 percent of the time. At flood levels less than a 2-year event, egg to migrant survival tended to have higher variance with overall higher survival. For events over a 2-year recurrence interval, egg to migrant fry survival decreased with less variance in the pattern (Beamer 2005, ID305). A 20-year flood recurrence interval corresponded to a 5 percent Chinook egg to migrant fry survival rate (Beamer and Pess 1999, ID380). Egg to outmigrant survival was negatively correlated to four out of six flow metrics tested by Zimmerman et al. (2015, ID331), including basin peak flows, proportion recurrence interval (RI) > 2, stock peak flows, and proportion RI >1.

Peak flow effects on egg survival were also described with respect to flow regulation and landscape position, and land uses where conditions were identified as impaired with respect to peak flows. Egg to migrant fry survival rate in impaired habitat was reported as 3.5 percent compared to 21.4 percent in functioning habitats (Beamer 2000 ID191). It was generally assumed from the available literature that risk of redd scour from peak flow events was higher for tributary spawning species and populations with unregulated flows, and multiple studies identified peak flow impairments in tributaries to the lower Skagit River (Beechie et al. 2003, ID015; Smith 2003, ID376). Likewise, studies reported that flow regulation has mitigated some of the effects of peak flows on spawning and rearing in the upper mainstem of the Skagit through reduced peak flows and life stage flow regulations (PSI and WDFW 2017, ID085).

Several other factors can influence production loss due to scouring flow, aside from the magnitude of peak flow events. The timing and duration of peak flows relative to spawning and incubation periods, scouring depths, variations in annual flow regime within the river basin, and geographic extent of spawning populations can also influence peak flow effects during incubation (Woodward et al. 2017, ID121; Wang et al. 2020, ID424). Relationships between predicted Chinook egg to fry survival and stream bed scour depth suggested that a relatively small increase in scour depth will result in a relatively large increase in egg mortality (Beamer 2005, ID305). Beechie (1992, ID127) indicated that early run Coho may tend to utilize higher elevation portions of drainages that have reduced risk of rain-on-snow floods during the spawning period, and therefore run timing of target species and populations as well as their geographic spawning extent has the potential to influence risk of mortality during incubation. Differences in in-river survival to migration were also reported among hatchery and natural origin Chinook, which could be related to differences in exposure to instream conditions and density-dependent processes (Volkhardt et al. 2006, ID404). Freshwater survival of Chinook Salmon in the Skagit River was described as largely density-independent due to peak flow mediated survival during incubation (Zimmerman et al. 2015, ID331). In-river survival may be impacted by sustained moderate flow events just as much as short-duration high flow events and populations have different exposure to flows due to flow regulation and unregulated tributaries (Zimmerman et al. 2015, ID331).

Changes in the timing of peak flows, through both climate change and flow regulation processes, have also been identified as a factor that can influence the timing of adult migrations and spawning, as well as juvenile rearing and emigration patterns for target species (Beamer et al. 2005, ID175; Rubenstein et al. 2018, ID411; Wang et al. 2020, ID424). Shifts in peak flow events have been identified as a major factor affecting abundance of steelhead returns (Pflug et al. 2013, ID154), and flood magnitudes were a strong predictor of adult Chinook return rates in the Skagit (Green et al. 2005, ID050). Changes in the periodicity can have cascading ecosystem effects that can affect later life stages as well other species. For example, shifts in the timing of adult spawning were shown to have potential impacts on emergence timing of juvenile salmon that can influence exposure to peak flows during incubation and rearing life stages (Austin et al. 2021, ID446). In addition, Rubenstein et al. (2018, ID411) reported that later timing of adult migrations of Chum and Coho increase carcass exposure to flood events that can influence eagle foraging opportunities. Wang et al. (2020, ID424) also reported numerous potential effects of climate change on Lamprey, including changes in peak flows, that could influence the periodicity of migrations and effects on incubating eggs or rearing larvae.

Peak flows were also identified as an important habitat formation and maintenance process driver, and multiple studies indicated that reductions in peak flow and habitat forming events have reduced habitat extent or connectivity for key habitats for multiple target species and life stages (e.g., side channel and floodplain habitats) (Beechie et al. 2003, ID015; Smith 2003, ID376; Smith 2005, ID177; Riedel et al. 2020, ID001). The Upper Skagit Summer Chinook population has lost riverine side channels due to the loss of floods that can create new side channels, but it is unclear as to whether or not similar processes are occurring in the lower Skagit River (Beamer et al. (2005, ID175). However, Beechie et al. (2003, ID015) also indicated that increased peak flow frequency and duration could also lead to channel destabilization, less habitat complexity, and increased bed scour depths that can negatively affect salmonids. Therefore, Beechie et al. (2010, ID017) described a processes-based restoration strategy of restoring a range of critical flows, including channel-forming flows, habitat maintenance flows, and low flows as a means to potentially address effects from flow regulation and altered peak flow hydrology (Beechie et al. 2010, ID017).

2.3 Minimum flows

2.3.1 Drivers and stressors

Primary drivers and stressors for minimum or base flows were identified by numerous studies, and included climatological drivers and stressors, flow regulation, water uses (e.g., diversions and withdrawals), runoff delivered to streams through surface (including unregulated tributaries), and subsurface flow paths and groundwater processes (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Beamer 2005, ID305; Beechie et al. 2010, ID017; Beechie et al. 2003, ID015). The Skagit River basin spans the Western Forested Mountains and Coastal Forest Level II Ecoregions, and Beechie et al. (2003, ID015) indicated that low flow hydrology was primarily influenced by diversions and dams in both ecoregions of the Skagit River basin (Beechie et al. 2010, ID017). Beaver also alter habitats through dam construction and can influence minimum flows in small streams, floodplain habitats, and tidally influenced habitats (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Roni et al. 2006, ID104; Beechie et al. 2010, ID017; USACE 2010 ID117; Hood 2012, ID144). Impounded water associated with beaver dams can improve minimum flows and subsurface or groundwater exchange in small streams. Beaver are described in more detail in Section 10.5 Beaver management.

Studies indicated potential low flow concerns in mainstem and tributary habitats. Flow regulation in the mainstem has generally increased the magnitude of low flows compared to historical conditions, or in other words, flow regulation has moderated low flows (Lee et al. 2016, ID417).

However, unregulated tributary inputs, climate change, and water uses were identified as potential stressors on low flow hydrology in the Skagit (Smith 2003, ID376; Veldhuisen and Haight 2003, ID164). In the Sauk River, risk from human water consumption (i.e., withdrawals) was identified as a low threat to water quantity or base flows in the Sauk River basin due to low water consumption in the basin (Smith 2003, ID376). Risk associated with water uses in other tributaries or mainstem habitats were also described in the Skagit Chinook Recovery Plan, with over-appropriation of water rights, withdrawals from exempt wells, and illegal withdrawals cited as exacerbating dewatering of off channel habitats and water quality problems (e.g., Beamer et al. 2005, ID175).

Veldhuisen and Haight (2003, ID164) developed regression models to predict mean and low flows for small to moderately sized tributaries to the Skagit (<100 mi^2). In these models, mean annual precipitation was a significant predictor of mean annual runoff whereas basin area and mean elevation were not significant predictors. For their low flow model (2-year 7-day min flow), basin area and mean annual precipitation were significant predictors of mean annual runoff, and they indicate that the models worked well for glaciated and unglaciated basins. Such models could be used to inform development or evaluation of instream flow requirements for tributaries to the lower Skagit River.

Smith (2003, ID376) reported that *no information regarding low flow impacts or conditions was found* for the lower Skagit River and its tributaries. In addition, Beamer et al. (2000, ID190) indicated that GIS layers and data were not available to evaluate low flows in their analysis of impaired habitat conditions. However, several reports indicated that some tributaries or reaches of tributaries may dry up during summer or fall low flow conditions (e.g., Hansen Creek, Dry Creek, and Red Creek) (Lawrence 2008, ID071; McMillan 2015, ID436; McMillan 2015, ID437; Beamer et al. 2020, ID214; Jackman 2020, ID109). Summer low flows and reduced water velocities were also identified as a stressor on instream temperatures in tributaries (e.g., Lawrence 2008, ID071, Lee and Hamlet 2011; ID071; Kammer et al. 2020, ID280). Lawrence (2008, ID071) confirmed exceedances of high temperature criteria during summer low flow conditions for eight tributaries to the lower Skagit River. However, Veldhuisen and Haight (2003, ID164) also noted that groundwater and inter-bed exchanges have an increasing effect on stream temperatures during very low flows, and this can result in a departure from the accepted pattern of increasing instream temperatures during low flow conditions. Low flow conditions and instream temperatures are discussed in more detail in Section 7.0 Water quality.

Potential changes in minimum flows or base flows in the Skagit River were also linked to climate change by several studies. Climate change is expected to further reduce flows and lengthen the duration of summer low flows (Woodward et al. 2017, ID121). SWC (2011, ID113) states *that the duration of the summer low flow period is projected to increase substantially for both transient and snowmelt dominant basins, including the Skagit, which will increase temperatures and reduce habitat availability for stream type salmon* as a result of climate change predictions. Predicted changes in summer low flows are expected to be more pronounced in basins with significant [current] glacial influence (Lee and Hamlet 2011, ID196). Loss of glacial coverage has already impacted summer base flow on the Skagit River (Riedel and Larrabee 2016, ID155). Current losses of ice in the basin were estimated to be roughly equivalent to 100 years of freshwater consumption at current rates in the basin.

Potential climate change impacts on lower Skagit River flows were also described from the perspective of lower summer low flows of unregulated tributaries that contribute to the lower mainstem Skagit River, especially related to the Sauk River (Bandaragoda et al. 2015, ID416; Bandaragoda et al. 2020, ID379). The Sauk River currently has a bimodal annual hydrograph and is projected, with climate change, to progressively lose the summer peak (from snowmelt) and increase winter peak (from rainfall) (Bandaragoda et al. 2015, ID416; Bandaragoda et al. 2020, ID379). By 2099, the Sauk River annual hydrograph is projected to have a single peak consistent with hydrograph timing of rain-dominated systems (Bandaragoda et al. 2015, ID416; Bandaragoda et al. 2020, ID379). The effects of this shift will be most apparent in August with a projected 60 percent reduction in flows. Bandaragoda et al. (2015, ID416; 2020, ID379) reported that the lowest flows are currently about 2,000 cfs at the Gorge Dam, and this is predicted to decrease approximately 500 cfs in each 30-year period, to lower than 500 cfs in August by the end of the century. Little change was detected for the current rain dominated Skagit lowland tributaries, which will remain rain dominated systems.

Extreme low flows under regulated conditions were also projected to decrease due to an increase in evapotranspiration and a decrease in summer precipitation (Lee et al. 2016, ID417), and the occurrence of intermittent or ephemeral streams may become more prevalent with climate change (McMillan 2015, ID436). However, projected low flows under regulated conditions in mainstem habitats may still be higher than historic low flows under natural conditions (Lee et al. 2016, ID417). This suggests that ecosystem effects from a changing low flow regime may be modest in flow regulated reaches. By the 2080s, hydropower generation in the Skagit River basin is projected to increase by 19 percent in the winter and spring and decrease by 29 percent in the summer (due to climate change and population size), and this may also influence the timing, duration, and magnitude of flow regimes in the Skagit (Lee et al. 2016, ID417).

2.3.2 Species and life stages

The Skagit Chinook Recovery Plan identified low flows as a result of water uses and flow regulation as a limiting factor for Chinook, with lower Skagit fall Chinook being primarily impacted (Beamer et al. 2005, ID175). The plan identified instream flow rules, life stage flows, and water use/rights as means to address this limiting factor. In addition, climate change predictions are predicted to exacerbate summer low flow conditions and the potential impacts of water uses and flow regulation on salmonids (Beamer et al. 2005, ID175).

Predicted changes in hydrology associated with climate change suggests that summer (August) flows will be significantly reduced in the mainstem Skagit River and Sauk River, and generally drainages with glacial inputs, and this represents a significant change in salmon habitat during a critical period (Bandaragoda et al. 2015, ID416; Bandaragoda et al. 2020, ID379). Little change was predicted for Skagit lowland tributaries that are currently and will remain rain dominated systems under climate change predictions. However, some studies cited increased concern for ephemeral streams with potential climate change impacts (e.g., McMillan 2015, ID436).

Low flow conditions can create barriers to migration for returning adults, or delay upriver migrations (McMillan 2015, ID436; Wang et al. 2020, ID424). McMillan 2015, ID436 indicated that Dry Creek, a tributary to lower Finney Creek, commonly becomes dewatered and may be among the last to recharge among lower Skagit River tributaries and this may influence access for late spawning species (e.g., Pink Salmon). Wang et al. (2020, ID424) also indicated that Lamprey are sensitive to potential climate change effects on low flow conditions, with inadequate flow during summer and fall months having the potential to …*reduce spawning habitat, prevent access to backwater or side-channel habitats, creating low water barriers, and contributing to mortality if incubating eggs or burrowing larvae are dewatered or exposed to a high temperature or low oxygen environment.* Redd dewatering can also occur as a result of flow reductions following adult spawning and can contribute to direct mortality and reduced egg to fry survival. Higher summer flows are associated with increased numbers of returning adults and increased habitat availability (Woodward et al. 2017, ID121), and summer or low flow conditions can influence rearing habitat extent and quality for target species with extended riverine rearing periods (e.g., Chinook, Coho, steelhead, Bull Trout, and Lamprey) (SWC 2011, ID113). Increased thermal stress was described with low flow conditions, which is discussed in more detail in Section 7.0 Water quality, and redd dewatering associated with downramping is described in more detail in Section 2.4 Downramping below.

2.4 Downramping

2.4.1 Drivers and stressors

Downramping describes an aspect of power generation and flow regulation whereby water levels drop on diel cycles, which can result in rapid changes in water levels in habitats downstream of hydroelectric facilities. Downramping effects in the Skagit River were described in relation to both upper Skagit River and Baker River operations, and the primary influences described were related to changes in wetted habitat extent or habitat connectivity.

Downramping effects on instream flows from the upper Skagit River dams are also documented in many studies in the upper Skagit River (Thompson 1970, ID410; Phinney 1974, ID511; Monk 1989, ID407; Pflug and Mobrand 1989, ID409), but no studies described downramping effects from the Skagit River dams on instream flows below the Sauk River confluence. Unregulated tributary inflows were observed as moderating hydroelectric downramping effects (Woodin et al. 1984, ID405), and increased contributions of unregulated tributaries to the lower Skagit River with increasing distance from the upper Skagit River facilities may reduce the influence of downramping on habitat in the lower Skagit River. Woodin et al. (1984, ID405) also reported that downramping during low tributary inflow periods can contribute to dewatering of pothole habitats. Smith (2003, ID376) indicated that changes in Project operations at the upper Skagit River facilities have improved with respect to managing flows for and life stage flows. For more information on downramping studies and evaluation of changes in flow regulation to address stranding and life stage flows, see Connor and Pflug (2004, ID385), which was included in this Skagit River Relicensing SY-01 Synthesis Study, and Pflug and Mobrand (1989, ID409) and Hunter (1992), which focused on the upper Skagit River upstream of the Skagit River Relicensing SY-01 Synthesis Study area.

Downramping effects from the Baker River facilities were also described, with potential impacts to the lower Skagit River. The Baker River dams may cause water levels to drop in the mainstem Skagit River faster than seven inches per hour, which leads to an increased rate of Chinook redd stranding (Beamer et al. 2005, ID175). Smith (2003, ID376) indicated downramp agreements have not been met, and inadequate life stage flows have been noted downstream of the Baker River facilities, including in the mainstem Skagit River below the confluence of Baker River. Smith (2003, ID376) indicated that monitoring of the Skagit River at Concrete found that negative effects of downramping and flow regulation from the Baker Project were persistent in the Skagit River near the Baker River confluence.

2.4.2 Species and life stages

The primary effects of downramping considered in studies related to stranding or dewatering during adult spawning, egg incubation, and fry emergence and rearing life stages. However, most studies of downramping were focused on the upper Skagit River due to their proximity to Skagit River Hydroelectric Project Operations (e.g., Connor and Pflug 2004, ID385; Pflug and Mobrand 1989, ID409; Hunter 1992). However, studies did provide documented impacts of downramping on target species and life stages that were associated with the Baker River project. Downramping at the Baker River project was cited as causing water levels to drop in the mainstem Skagit River faster than seven inches per hour at the time the Skagit Chinook Recovery Plan was drafted (Beamer et al. 2005, ID175). This could lead to an increased rate of Chinook redd dewatering or stranding, and the Recovery Plan indicated that this was a particular concern for the lower Skagit fall Chinook population (Beamer et al. 2005, ID175). However, a new 50-year license agreement for the Baker River facilities have improved downramping operations since 2008 (FERC 2008).

Studies of downramping and stranding found that the timing of downramping events significantly influences salmon fry stranding on gravel bars. Fewer stranding instances were observed when downramping occurred before dawn (apparently due to a reduced dependence on substrate for refuge during darkness) than after (post-dawn downramping increased stranding rates by a factor of 10.5) (Woodin et al. 1984, ID405). The rate of the downramp event (change in flow over time) was not correlated with stranding for pre-dawn events, but a positive correlation between fry stranding and downramping rates were observed in post-dawn trials. Stober et al. (1982, ID402) reported that with a *greater amount of daylight dewatering at sites farther downstream from Newhalem [there] was a progressively higher incidence of stranded fry,* and that higher ramp rates for longer periods of time were associated with higher fry stranding (Stober et al. 1982, ID402).

Tributary inflows were observed as moderating hydroelectric downramping effects on salmon fry stranding rates, and dewatering of potholes associated with low tributary inflow was also a contributing factor to stranding related mortality, which would potentially be unrelated to downramping (Woodin et al. 1984, ID405). However, these studies focused on the upper Skagit River, and it is unclear to what extent the findings are applicable to the lower Skagit River given that unregulated tributary inputs may attenuate the effects of downramping (Stober et al. 1982, ID402; Woodin et al. 1984, ID405).

The timing of downramping events with respect to periodicity may also influence the potential effects of downramping on target species and life stages. Engman et al. (1983, ID438) suggested that steelhead fry may be most susceptible to stranding early in the emergence period, and more generally, that smaller fry were more susceptible to stranding. Greater protection of fry from stranding was achieved by through downramping rates, and specifically by substantially reducing the annual number of downramping events and by reducing downramping during the daytime, when fry are most vulnerable to stranding (Connor and Pflug 2004, ID385). Redd protection is achieved through maintaining minimum flows and limiting amplitudes, and Connor and Pflug (2004, ID385) found that *increasing the minimum incubation flows created improvements in redd protection levels* associated with the implementation of flow management measures in 1981. They noted that these measures were collectively *intended to minimize redd dewatering during the* *spawning and incubation periods and fry stranding during the emergence and outmigration periods.*

In response to these flow measures, Connor and Pflug (2004, ID385) also reported that Pink, Chum, and Chinook spawner abundance progressively increased in an upstream direction following implementation of flow measures. Stober et al. (1982, ID402) found that Gorge discharges resulting in flows below 2,000 cfs jeopardized redds that were spawned during 4,500 cfs at Marblemount. At Rockport, these changes in discharge flow were predicted to not be severe due to tributary inputs (like the Cascade River and Illabot Creek), providing some cushion in flow levels. They reported that Chum instream flow tests did not find any correlations between dewatering events and egg/alevin survival (Stober et al. 1982, ID402). Stober et al. (1982, ID402) also reported that Chinook females were found to *stay at their redds through moderate flow and left when flow reductions nearly completely dewatered some active redds…but returned later after flows increased.* This indicated that female Chinook would complete and/or stay at their redds so long as the flow levels *provided adequate flows over the redd site for at least several hours each day* (Stober et al. 1982, ID402). These findings and studies provide some additional insights into how downramping and flow regulation potentially relate to redd dewatering and adult spawning behavior, but it is unclear how these findings relate to the lower Skagit River given the documented muting effects of unregulated tributary inputs described above.

2.5 Tidal inundation

2.5.1 Drivers and stressors

The frequency and duration of tidal flooding was identified as a primary driver of habitat formation and maintenance processes in estuary habitats. Tidal patterns are primarily driven by factors outside of the Skagit River basin, but the geomorphology of the tidal delta including the arrangement and connectivity of distributaries, tidal channels, and tidal wetlands can significantly influence the duration, magnitude, frequency, and extent of tidal inundation and tidally influenced fluctuations in instream flows and conditions. Instream flows interact with tidal forces to influence the timing, duration, and frequency of flooding as well as important instream habitat characteristics (e.g., salinity, depth, velocity). The interaction between instream flows and salinity are described in more detail in Section 7.0 Water quality.

Tidal forcing and circulation patterns are complex, and hydrodynamic models have been developed that describe and characterize tidal patterns, factors influencing tidal inundation patterns, and responses to a number of scenarios (e.g., restoration) (Yang and Khangaonkar 2009, ID336; Khangaonkar et al. 2016, ID334). In addition, allometric models have been developed that describe how tidal channels are formed based on marsh island size and landscape connectivity that are related to tidal dynamics (e.g., Hood 2015, ID063; Beamer et al. 2016, ID212).

Land use was also identified as a primary driver of tidal inundation in estuary and nearshore habitats, with levees and dikes, tide gates, filling, land conversion, and dredging influencing the duration, magnitude, frequency, and extent of tidal inundation and fluctuations. Historical alterations to the Skagit River delta, including the Swinomish Channel, flood control levees, tide gates, and a jetty have significantly altered tidal dynamics and instream flows in the Skagit estuary and routing to nearshore habitats (Smith 2003, ID376; Redman et al. 2005, ID100; Hinton et al. 2008, ID174; Yang and Khangaonkar 2009, ID336). However, natural avulsions can also influence the arrangement of distributaries and routing of river flows and tidal forcing within the Skagit estuary (Beamer and Wolf 2016, ID186). Beamer and Wolf (2016, ID186) described the effects of an avulsion that occurred in 2006 in the North Fork distributary, which resulted in significant changes in habitat formation and maintenance processes. Beaver also alter habitats through dam construction and can influence flows in tidally influenced habitats (Hood 2012, ID144). In estuaries and tidally influenced habitats, beaver dams can create impoundments of water where tidal channels would have otherwise dewatered during an ebbing tidal cycle. Beaver are described in more detail in Section 10.5 Beaver management.

Restoration was also identified as a primary driver of tidal inundation and circulation patterns in the estuary and nearshore habitats (Beamer et al. 2005, ID005; Hinton et al. 2008, ID174; Souder et al. 2008, ID115; Yang and Khangaonkar 2009, ID336; WWAA 2010, ID159). In fact, most current changes in tidally flooded habitat extent have been attributed to restoration actions (e.g., dike breaches and setbacks, tide gate replacements or restoration), which are currently outpacing losses due to natural erosion and anthropogenic impacts. Restoration effects on the extent of tidal inundation are described in more detail in Section 4.0 Habitat availability and connectivity.

Climate change and sea level rise (SLR) were identified as potential stressors on tidal inundation in Skagit estuary and nearshore habitats (Lee and Hamlet 2011, ID196; Hood 2015, ID063; Hood et al. 2016; 142; Khangaonkar et al. 2016, ID334). Increasing sea levels can increase tidal flooding extent and the duration, magnitude, and frequency of tidal inundation, which can result in loss of tidal marsh habitats along marsh fringes and landward migration of tidal marsh habitats (Hood et al. 2016; 142). However, this can also increase landward extent of tidal inundation and influence, but this potential benefit can be offset by flood control or other infrastructure that restrict tidal flooding (Lee and Hamlet 2011, ID196; Hood 2015, ID063; Hood et al. 2016; 142; Khangaonkar et al. 2016, ID334).

2.5.2 Species and life stages

Tidal inundation patterns were identified as a primary driver of habitat use and fish distributions in the Skagit estuary (Beamer et al. 2005, ID005; Beamer and Wolf 2016, ID186). Tidal inundation primarily influences the duration and timing of access to optimal rearing or refuge habitats during estuary rearing and emigration life stages (Beamer et al. 2005, ID005), and intermediate salinity habitats that support physiological transition to marine waters as described in more detail in Section 7.0 Water quality. Some species and life histories may rear for weeks to months in estuaries (e.g., Chum and Chinook), and therefore are more likely to be influenced by tidal inundation patterns. Changes in salinity gradients related to instream flows, restoration, land use, and tidal forcing have been related to changes in residence time for juvenile salmon rearing within delta habitats. Curtailed residence times in estuaries can impair physiological transitions from freshwater to saltwater and reduce survival to adult return (e.g., Redman et al. 2005, ID100; Beamer et al. 2005, ID005). Similarly, Beamer and Wolf (2016, ID186) reported that peak instream flows were related to nearshore densities of Chinook fry migrants along the shoreline of Whidbey Island, but not densities in the Skagit River estuary. They concluded that increased instream flow can increase export of fry migrants through the estuary and reduced rearing opportunity, which may result in reduced survival of adult returns due to size selective mortality and reduced marine survival of smaller outmigrants (Beamer and Wolf 2016, ID186).

Tidal inundation patterns were also identified as a driver of food availability and feeding for target species during estuary rearing and emigration life stages, during which highly productive transitional habitats can provide high growth potential for estuary rearing species and life histories. For example, Congleton (1978, ID255) found that Chum fry fed mostly during periods of marsh submergence when they moved out of the marsh channels (where they reside during low tides) and onto the marsh flats. Feeding intensity greatly decreased when Chum were concentrated in low tide channel holding areas. Food availability and estuary habitats are described in more detail in Section 9.0 Food availability.

In addition, losses of tidal marsh habitats and changes in connectivity and their impacts to target species and life stages are described in detail in Section 4.0Habitat available and connectivity. Loss of estuary rearing habitat was identified as a limiting factor for Skagit Chinook, and current rearing capacities for delta rearing fry migrants are limiting Chinook production (Beamer et al. 2005, ID175). Restoration actions focused on increasing the extent and connectivity of tidally inundated habitats are hypothesized to support increased rearing capacity and survival to adult return for Chinook (Beamer et al. 2005, ID175).

3.0 SEDIMENT SUPPLY AND TRANSPORT

Sediment supply and transport describes the sources of sediment inputs to the river and transport of sediments, including deposition of sediments in riverbeds, floodplains, and the estuary. Sediment supply and transport are dynamic processes that are controlled by a number of drivers and stressors, and sediment supply and transport processes are major drivers of habitat formation and maintenance processes. Sediment supply and transport is related to the extent, distribution, and connectivity of key salmon habitats (also see Section 4.0 Habitat availability and connectivity) and can influence survival during incubation life stages, as described below. Beechie et al. (2010, ID017) describes the dynamic processes that control and interact with sediment supply and transport processes well, indicating that:

> *Channel migration, bank erosion, bar formation, and floodplain sediment deposition create a dynamic mosaic of main-channel, secondary-channel, and floodplain environments. Wood recruitment results in part from bank erosion and channel migration, and wood accumulations reduce bank erosion rates or enhance island formation. Sediment and wood transport and storage processes drive channel cross-section shape, formation of pools, and locations of sediment accumulation. Bank reinforcement by roots reduces bank erosion rates and may force narrowing and deepening of channels. Animals such as beaver physically modify the environment and create new habitats* (Beechie et al. 2010, ID017).

Information on sediment supply and transport are described for two primary factors or aspects of sediment supply and transport in the following sections. These include:

- ***Supply and transport:*** Sources of sediment inputs to the river and transport of sediments.
- ***Deposition and substrate:*** The deposition of sediments in river and composition and distribution of substrates.

3.1 Supply and transport

3.1.1 Drivers and stressors

The Skagit River delivers about 40 percent of the fluvial sediments that enter Puget Sound (Curran et al. 2006, ID373). Sediment supply and transport processes in the Skagit are driven by high level influences such as climatological and hydrological regimes, and glacial, gross geomorphology, and geology processes (Beechie et al. 2003, ID015; Beechie et al. 2001, ID365). Beechie et al. (2003, ID015) indicated mass wasting and gullying are primary drivers in western forested mountain ecoregions of the Skagit River basin, while mass wasting and surface erosion are primary drivers in the agricultural lowlands (Beechie et al. 2003, ID015). Particle size was identified as an important factor controlling sediment delivery, transport, and deposition processes, and particle size interacts with instream flows to influence sediment supply and transport processes (Curran et al. 2006, ID373).

3.1.1.1 Supply and composition

Total annual sediment transported was estimated at 10 million tons for the Skagit River basin, with most sediment being sourced from glacial inputs (FERC 1980, ID439; USACE 2013, ID118; Curran et al. 2006, ID373). USACE (2008, ID355) indicated that suspended sediment loads at

Mount Vernon ranged from 0.4 million tons in the driest years to 10.4 million tons in the wettest years between 1940-2004. Curran et al. (2006, ID373) also reported that individual large flood events accounted for as much as 40 percent of annual sediment delivery. Storms with daily discharges greater than 50,000 cfs are a major factor in sediment production (USACE 2008, ID355), and the percentage of fines generally increases with increasing discharge during the winter storm season (Curran et al. 2006, ID373). Jaeger et al. (2017, ID374) also indicates that annual variations in sediment loads in the fall, winter, and spring are related to the frequency and intensity of discharge events. However, in the summer, sediment loads scaled with discharge but were more strongly related to average summer temperatures (Jaeger et al. 2017, ID374). Jaeger et al. (2017, ID374) also indicated this was related to *higher rates of sediment-rich meltwater from the glaciers caused by higher temperatures*.

Turbidity monitoring indicated that about one-half of the mean annual suspended-sediment load in the Skagit was composed of fines (Curran et al. 2006, ID373). At Mount Vernon, USACE (2008, ID355) also reported that annual suspended sediment yields were composed of approximately 50 percent sand and 50 percent silt and clay that are transported through the lower river and into Skagit Bay. Curran et al. (2006, ID373) indicated that turbidity was a useful surrogate for the concentration of suspended clay and silt that is held in the water column but less useful for suspended sands. Turbidity is described in more detail in Section 7.7 Turbidity, but supply and transport of fine sediments were identified by a number of studies as important drivers of habitat processes and water quality (e.g., Curran et al. 2006, ID373; USACE 2008, ID355; Grossman et al. 2020, ID057; Riedel et al. 2020, ID001).

Volcanic activity and processes, and glacial history and processes, have defined the underlying geomorphology and geology as well as contributing large volumes of sediment within the Skagit River basin (Beechie et al. 2001, ID365; Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155). Studies described lahars associated with volcanic eruptions that generated significant inputs of sediment that likely impacted habitat processes and quality for ~30 years after the events in mainstem Skagit River and Sauk River reaches (Beechie et al. 2001, ID365). This indicated that large episodic events, like volcanic or large landslide events, can have persistent and long-term impacts on habitat processes. Glacial coverage has reduced in the last century, with Lee and Hamlet (2011, ID196) estimating that glacial retreat has resulted in a 50 percent reduction in total glacial area. Glaciers are a primary driver of instream flow and sediment supply and transport processes, and therefore changes in glacial coverage in the Skagit can influence sediment supply and transport processes within the basin (Beechie et al. 2001, ID365; Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155).

Differences in sediment supply and transport were noted among the major subbasins of the Skagit River, with linkages to differences in land uses and cover, underlying geology and mass wasting and erosion, flow regulation, and glacial coverage identified as primary drivers of subbasin patterns. The Cascade and Sauk rivers were identified as major sources of sediment to the lower Skagit River (USACE 2008, ID355). Most sediment delivered to streams in the Skagit River basin (75 percent) originated from inner gorge landforms, even though these features accounted for 20 percent of mountainous basins in the Skagit (Beechie et al. 2003, ID015). However, approximately half the basin does not contribute sediment because the sediment is stored in reservoirs (USACE 2008, ID355). Multiple studies cite reductions in sediment supply to the lower Skagit River and estuary as a result of sediment retention in reservoirs, which includes both the Skagit River and

Baker River facilities (Smith 2003, ID376; Beamer and Wolf 2016, ID186; Redman et al. 2005, ID100; Grossman et al. 2020, ID057; Riedel et al. 2020, ID001). Riedel et al. (2020, ID001) indicated that the Skagit reservoirs have resulted in a 70 percent reduction in sediment supply, and reduced sediment supply and transport to the estuary was cited as an issue of concern for estuary habitat formation and maintenance processes (e.g., Grossman et al. 2020, ID057). Riedel et al. (2020, ID001) also noted that dams in general influence sediment supply and transport processes in the Skagit River stating that *river processes of erosion and deposition are now strongly influenced by the presence of five large dams, three on the upper Skagit River and two on the Baker River, the Skagit's second largest tributary.* Furthermore, dams and their reservoirs were cited as cutting off sediments to the rivers below them and reducing peak flow events, which in combination with fill of reservoirs with snowmelt *has a particularly strong effect on the geologically important (habitat-forming), long-duration spring flood* (Riedel et al. 2020, ID001). However, excessive sediment supply and transport concerns from unregulated tributaries were also cited as a source of concern for farming operations in the lower Skagit (FERC 1980, ID439).

3.1.1.2 Land uses and sediment supply and transport

Land use and cover were identified as significant drivers of sediment supply and transport processes. Beechie et al. (2003, ID015) indicated that land use influences vegetation, and vegetation coverage influences sediment supply, hydrological regime, and other processes (Beechie et al. 2003, ID015). Dredging and agriculture were also identified as land uses that influence sediment supply and transport, with differences in pool areas among river habitats being linked to channel dredging or increased supply of sediments from pastures and croplands (Beechie et al. 2001, ID365). Beamer (2005, ID305) used vegetation cover class to estimate the relative increase in sediment supply due to land uses like timber harvest and roads, which can be used to estimate risk of high sediment supply and transport that can negatively impact salmonid habitats.

Clearcutting and forest roads associated with forestry land uses increased landslide frequency and magnitude, and increased supply of coarse sediments (>2 mm in diameter). Increased coarse sediment supply can fill pools and aggrade channels, resulting in reduced habitat complexity and extent of key salmonid habitats (Beechie et al. 2003, ID015). Increased fine sediment (<2 mm diameter) supply was also associated with forest roads and mass wasting, which can negatively impact incubation habitats and food webs in riverine habitats (Beechie et al. 2003, ID015). Increased surface erosion and sediment delivery from forest roads can be addressed by resurfacing or removing them (Beechie et al. 2010, ID017).

Mass wasting was identified as a large source of sediment to the Skagit River, and studies indicated that landforms (geology) and land use (and roads in particular) were both related to mass wasting rates, surface erosion rates, and soil creep processes. Paulson (1997, ID354) found that …*geologic association strongly influenced rates of sediment delivery to streams by mass wasting*. Hillslopes greater than 30° tended to produce shallow, rapid landslides and are generally unstable, and mass wasting rates are 6 and 44 times higher in clearcut forest and forest road areas, respectively, compared to mature forested cover (Beechie et al. 2003, ID015). Average road-related failure rates in several subbasins were more than 30 times the rate of failure observed with mature forest cover, which demonstrated the linkage between land use and land cover in relation to sediment supply processes. However, sediment delivery from roads tended to be much lower than sediment delivery to streams from mass wasting events (Paulson 1997, ID354).

Landslides, a more specific type of mass wasting, was also described as a significant driver of sediment supply and transport that were also generally related to land uses, riparian conditions, climatology, and underlying geology. Veldhuisen (2018, ID166) evaluated landslide inventories, mostly from tributaries of interest in the study area, to better understand potential impacts of landslides on fisheries. Stream flow data from U. S. Geological Survey (USGS) gages located on the Samish and Sauk rivers were used to analyze frequency of major storm events as a proxy to high soil moisture (which could trigger landslides). In addition, forest harvest and road construction rates were inferred from forest ages. Temporal landslide rates peaked between 1982 to 2001 before dropping from 2002 to 2011. High landslide rates from 1982 to 2001 coincided with high logging rates. Forest practice regulations became stronger in 1987 and revamped in 2001, which coincided with the drop in 2002-2011. Forest buffers on unstable slopes were slightly common in the 1990s but then were mandatory after 2001. This study indicated that forest roads were a significant trigger for landslides in the Skagit River basin. Increases in discharge events after 1975 were also apparent, which could explain the increase landslide rates during the 1980s and 1990s. However, there were major flows in 2004, 2007, and 2009, which did not coincide with the low frequency of landslide rates during 2002-2011. Out of the 42 landslides identified in 2002-2011, 78 percent originated from areas last logged prior to 1987 or on roads. Only 10 percent of the landslides originated in sites that were logged since 2001. Overall, 34 percent of landslides were classified as debris flows, which were the most damaging of shallow landslide types. Deep-seated and small shallow landslides were estimated to contribute 36 percent and 17 percent of landslide sediment volume delivered to Skagit tributaries, although the authors did not evaluate sediment volume from the landslides identify in this study.

Erosion was another primary stressor of sediment supply and transport processes that was also linked to land uses as well as underlying geology, channel migration, instream flows, LWD, and riparian conditions. Erosion is influenced by channel migration, and pool formation and bar deposition processes influence sediment transport processes (Beechie et al. 2010, ID017). Rothleutner (2017, ID375) found that recruitment of floodplain sediment from the middle reach of the Skagit River to the active channel produced approximately 27 percent of the annual sediment mean load measured in Mount Vernon. The source of these sediments was dominated by lateral incision at rates of 3-8 m/year in several areas of high relief (3-15 m) banks that were characterized by unconsolidated deposits. Rothleutner (2017, ID375) also identified increasing erosion rates in comparison to aggradation in more recent periods (2006-2015 compared to 2003-2006), and predictions with climate change suggested that erosion will likely be much higher during the winter months with periods of higher flow and more precipitation falling as rain.

3.1.1.3 Assessment and impairments to sediment supply and transport

Multiple habitat assessments have used indicators of sediment supply and transport to identify potentially impaired salmonid habitats to support recovery strategies, with excessive sediment supply being an indicator of impaired habitats. For example, Beamer et al. 2000 (ID190) evaluated sediment supply and transport processes based on field measurements and spatial modeling and considered habitat as functioning with rates of <100 m^3/km^2/year or <1.5x natural rate, while impaired basins had rates of >100 m^3/km^2/year or >1.5x natural rate. Beechie et al. (2003, ID015) also identified drainages that were impaired with respect to modeled sediment supply risk with rates >200 percent of natural sediment budgets based on land use and landslide hazard mapping.

Many tributaries to the lower Skagit River and Sauk River were identified as impaired with respect to sediment supply and transport, while mainstem channels were generally identified as functioning (FERC 1980, ID439; Paulson 1997, ID354; Beamer et al. 1998, ID189; Beechie et al. 2003, ID015; Smith 2003, ID376). In Finney Creek, Suiattle River, and Sauk River, degradation of water quality and riparian areas due to erosion and mass wasting, loss of historical spawning and rearing habitat, increased temperatures and turbidity, and impacts of private property are principal issues of concern for salmonids (Beamer et al. 1998, ID189). Hansen Creek was classified as having a moderate overall sediment supply rating (100-200 m^3 /km^2 /year) and has been heavily logged, while Finney Creek and Jackman Creek were classified as having a high supply (>200 m^3 /km^2 /year) (Paulson 1997, ID354). Paulson (1997, ID354) indicated that 50 percent of the supply from Jackman Creek was from a large failure event that occurred in deep glacial sediments that had been recently harvested, and Finney Creek had been intensively logged with high road building intensity.

Smith (2003, ID376) reported that excess sedimentation was identified in Nookachamps, Hansen, Finney, Loretta, and Gilligan creeks. However, they suggested that very few drainages have been assessed to identify the sources of sedimentation. Smith (2003, ID376) indicated that landslides associated with roads and clearcuts are major sources of sediment where assessments have occurred. Smith (2003, ID376) also indicated that most of the known impacts to salmonid habitat in the Sauk River basin occur in areas that are primarily private or state owned, with high road densities, poor riparian conditions, excess sedimentation, peak flows, and reduced pool habitat and LWD. Baker River tributary habitat was identified as generally good, but a few drainages were identified as having sediment supply and transport impairments due to landslides and high road densities (Smith 2003, ID376).

Many of the assessments were used to identify potential restoration and protection opportunities to support salmon recovery (e.g., Beamer et al. 2005, ID175; SWC 2022, ID451). The Skagit Basin Council's updated strategic approach identified target areas for restoration and protection, which included basins identified as having impaired sediment supply or peak flows (SWC 2022, ID451). These target areas had impaired processes that impact Chinook Salmon habitat and were determined to be areas that should be addressed within the next ten years. Some of the priority restoration objectives were to reduce land use (which impacts sediment supply) and repair/relocate/or remove structures that contribute to increased erosion or peak flows (SWC 2022, ID451).

Smith (2003, ID376) identified shoreline modifications (e.g., dikes, riprap) as one of the greatest nearshore habitats impacts in WRIA 3, with shorelines rated as poor in east Skagit Bay, Swinomish Channel, Padilla Bay, and north Fidalgo Island. Shoreline modifications, including overwater structures, armoring, and riparian conditions disrupt sediment supply and transport processes, which can impact habitat formation and maintenance processes (Smith 2003, ID376; Redman et al. 2005, ID100). Smith (2003, ID376) also indicated that contaminated sediments in Padilla Bay, Fidalgo Bay, and Guemes Channel, and overwater structures are a concern in Swinomish Channel and north Fidalgo Island. Therefore, the presence of contaminated sediments is an additional factor that should be considered with respect to sediment supply and transport processes in nearshore habitats.

3.1.1.4 Sediment supply and transport and habitat formation

Sediment supply and transport processes were linked to habitat formation and maintenance processes in riverine habitats by numerous studies. In addition, while increased sediment supply rates are identified as a potentially negative factor in some riverine habitats, reduced sediment retention prevents recovery of incised channels (Beechie et al. 2010, ID017) and can negatively influence tidal marsh habitat formation and maintenance processes (e.g., Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196; Beamer and Wolf 2016, ID186; Grossman et al. 2020, ID057). Large wood was also identified as a primary driver of sediment supply and transport (e.g., Redman et al. 2005, ID100), and restoration strategies have been evaluated with respect to their effectiveness at improving sediment processes (e.g., Seixas et al. 2020, ID303). Sediment supply and transport should be evaluated in the context of underlying habitat formation and maintenance processes to determine where sediment supply and transport is functional or impaired with respect to too much or not enough supply or retention (Beechie et al. 2010, ID017). Given that habitat formation and maintenance processes and sediment supply and transport are related to both erosion and deposition processes, habitat formation and maintenance processes are also described in Section 3.2 Deposition and substrate.

Within the Skagit estuary, sediment supply and transport processes were directly linked to habitat formation and maintenance processes by a number of studies. Diking, levee building, channelization, and large wood removal has fundamentally altered the spatial arrangement, function, and connectivity of distributaries while also increasing the sediment load transported to the Skagit delta (Lee and Hamlet 2011, ID196). Reservoirs were generally cited as reducing sediment supply and transport in the Skagit River system, which has potentially effected habitat formation and maintenance processes in the estuary (Redman et al. 2005, ID100; Beamer and Wolf 2016, ID186; Grossman et al. 2020, ID057). Redman et al. (2005, ID100) specifically linked reduced flows related to flow regulation to a reduction in sediment transport to the estuary, and Gislason (1980, ID406) also identified impoundment of water at reservoirs as a factor reducing the supply and transport of sediment downstream. However, they indicated that inputs from unregulated tributaries would increase the amount of sediment supply and transport as distance downstream from the dams increases (Gislason 1980, ID406).

Anthropogenic obstruction of historical distributaries and levee construction along the remaining distributaries likely increases the jet momentum of river discharge, forcing much suspended sediment to bypass the tidal marshes and be exported from Skagit Bay (Hood et al. 2016, ID142). Marsh habitat in the South Fork Skagit has been actively eroding since the dominant flow path was forced to the North Fork (Lee and Hamlet 2011, ID196). Today, most of the sediment reaching the delta bypasses the shoreline and tidal flats and is deposited onto the delta face in deeper areas (Lee and Hamlet 2011, ID196). Beamer and Wolf (2016, ID186) also identified areas where rapid habitat changes are occurring as a result of changed water flow and sediment deposition patterns associated with a new distributary avulsion. Hood et al. (2016, ID142) also indicated that estuary and marsh habitats of Skagit Bay are eroding despite the high sediment delivery because sediment delivery is temporally bimodal and not synchronous with periods of marsh vegetation growth. Additionally, at least half of the annual sediment load is delivered during winter storms, which is when marsh vegetation is minimal and unable to store sediment. With climate change, winter precipitation is predicted to take on the form of rain versus snow, which will increase winter river discharge and decrease summer river discharge (Hood et al. 2016, ID142).

With increased transport of sediments to the nearshore, sediment supply and transport also influences nearshore habitats (Grossman et al. 2020, ID057). In addition, shoreline modifications in nearshore habitats, including overwater structures, armoring, and removal of riparian vegetation have been identified as stressors on habitat formation and maintenance processes in nearshore habitats (Smith 2003, ID376; Redman et al. 2005, ID100). Grossman et al. (2020, ID057) found that fluxes of sediment offshore are 5-10x higher under current conditions compared to Holocene rates (from diking, channel straightening, and dredging), and this increased offshore transport bypasses emergent marshes and potentially impacts progradation rates in the Skagit River delta and potential resiliency to climate change. The sediment budget and historical change analyses from Grossman et al. (2020, ID057) provided a framework to assess coast responses to sediment delivery and routing to guide vulnerability assessments and resiliency planning. For example, they estimated that redirecting and retaining just 20 percent of the river sediment load within emergent marsh habitats could offset losses due to subsidence and levee construction, although it would take more than 22 years at this recovery rate to establish emergent marsh elevations that can be naturally maintained in the context of extreme tidal cycles.

3.1.1.5 Climate change and sediment supply and transport

Multiple studies identified climate change as a potential stressor on sediment supply and transport processes in the Skagit River, some of which were described in the previous sections. These were primarily related to predicted changes in hydrography and glacial processes, which are described in more detail in Section 2.0 Instream flow. Given that glaciers impact overall hydrography patterns and sediment supply and transport, significant changes in glacial area and volume predicted with climate change could significantly impact sediment supply and transport in the Skagit River (Riedel and Larrabee 2016, ID155). Lee et al. (2016, ID417) predicted a dramatic increase in sediment load with climate change, with the total sediment discharge from December to February at the Skagit River near Mount Vernon increasing by 376 percent. In addition, Lee et al. (2016, ID417) indicated that there will be large changes in the magnitude and timing of sediment load at the Skagit River near Mount Vernon.

The Sauk River is a major unregulated tributary to the lower Skagit River that is influenced by glacial inputs, and loss of snow and ice cover with climate change in the Sauk River could result in exposure of unconsolidated and fine sediments to overland flow that would also increase predicted suspended sediment loads in the Sauk River (Bandaragoda et al. 2020, ID379). Historical suspended sediment loads were approximately 40 percent lower than the 5-year mean annual historic yield reported by the USGS study in the Sauk River, indicating that increases in sediment supply and transport may already be occurring with the observed reductions in glacial coverage (Lee and Hamlet 2011, ID196; Bandaragoda et al. 2020, ID379).

3.1.2 Species and life stages

Sediment supply influences physical habitat characteristics, water quality, and primary productivity, and these can be related to biological responses among target species and life stages (e.g., Beechie et al. 2003, ID015). Most of the relationships between target species and life stages and sediment supply and transport identified in the literature were related to either erosion (e.g., redd scour), habitat formation processes, or fine sediment deposition (redd burial) during incubation life stages (e.g., Beamer 2000, ID191; Beamer et al. 2005, ID175; Jaeger et al. 2017, ID374). This section focuses on erosion and scour related processes and their effects on target species and life stages, as well as general habitat formation and maintenance patterns related to target species habitats. However, turbidity (related to the suspended transport of sediments) has also been linked to target species impacts, specifically Chinook salmon at various life stages (e.g., Jaeger et al. 2017, ID374), and these linkages are described in Section 7.7 Turbidity and Section 9.0 Food availability.

The Skagit Chinook Recovery Plan identified sedimentation and mass wasting as a limiting factor for Chinook for incubation life stages. Habitat degradation was identified as a limiting factor for steelhead in Finney Creek with respect to sediment supply and transport (McMillan 2018, ID400). Logging operations and road construction activities along Finney Creek were identified as stressors for serious silting and erosion problems, with large numbers of landslides documented that impacted substrate composition in Finney Creek (McMillan 2018, ID400). The Skagit Chinook Recovery Plan indicated that sub-yearling Chinook production was partly constrained by lower than expected egg to fry survival, but that restoration of peak flow and sediment supply processes to improve egg to fry survival would have limited benefits without increasing estuary rearing capacity (Beamer et al. 2005, ID175). In contrast to riverine habitats, estuary rearing capacity is potentially limited by reduced sediment supply and transport as noted in the previous sections (e.g., Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) suggests that the actions listed in the Skagit Chinook Recovery Plan for egg to fry survival can change all impaired basins to functioning levels, but that egg to fry survival could decline due to climate change in the future if basin conditions stay the same. Therefore, restoration of impaired basins is a high priority for the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175).

3.2 Deposition and substrate

3.2.1 Drivers and stressors

Particle size, instream flows, and LWD are important factors controlling sediment delivery and deposition processes (Curran et al. 2006, ID373; Seixas et al. 2020, ID303). Like sediment supply and transport, sediment deposition and substrate composition were linked to peak flow events as well as underlying geomorphology and land uses (e.g., Curran et al. 2006, ID373). Sediment deposition and substrate processes were described for both riverine and delta habitats.

3.2.1.1 Sediment deposition in riverine habitats

Since 1931, there has been a long-term trend of sediment deposition in the channels downstream of Sedro-Wooley (USACE 2008, ID355). There has been an overall averaged bed elevation increase of approximately 2.25 ft since 1931. The bed upstream of RM 15.8 appears to be rising slightly faster than the overall average (USACE 2008, ID355). Geomorphic studies have shown that sediment formations in floodplains of the Skagit can be explained by historical channel migration and floodplain deposition patterns. Part 1 of a geomorphic assessment and inventory provides information on sediments and geomorphology from George Dam to Sauk River (Riedel et al. 2020, ID001). Similar information, including detailed spatial data on formations and sediment accumulations and composition will be developed in ongoing phases of that study. Curran et al. (2016, ID373) also provides descriptions of sediment load and distribution patterns in the lower Skagit River, and Rothleutner (2017, ID375) describes sediment storage processes and patterns for the middle Skagit River.

LWD was identified as a primary driver of sediment deposition and sorting (Collins et al. 2002, ID418; Nickols and Ketcheson 2013, ID412). Seixas et al. (2020, ID303) found that wood-keyed steps were significantly more likely to trap sediment than clast- and root-keyed steps. The authors suspected this effect was due to the geometry of most wood pieces having a much larger length compared to their diameter. This increases the likelihood of jamming in between channel banks which creates stable structures that accumulated sediment. Restoration strategies have used LWD to restore sediment supply and transport processes to improve salmonid habitats (e.g., Nickols and Ketcheson 2013, ID412; NSD 2017, ID086; Seixas et al. 2020, ID303), and large wood can be part of process-based restoration strategies for riverine habitats (e.g., Beechie et al. 2010, ID017; SWC 2011, ID113). More information on LWD is provided in Section 5.0 Large woody debris and bank condition.

In riverine habitats, substrate composition, size, distribution, and embeddedness are important aspects of habitat quality and complexity that can influence target species and life stages (Smith and Anderson 1921, ID347; Stober et al. 1982, ID402; Beechie et al. 2003, ID015; Beamer et al. 2005, ID305; Beechie et al. 2005, ID014). Many potential drivers interact with sediment supply and transport to influence deposition processes and the composition of substrates, including stream gradient, instream flows or stream power, underlying geology, LWD, and sediment supply and transport processes in general (Beechie et al. 2001, ID365; Beechie et al. 2005, ID014; McMillan 2018; ID400; Riedel et al. 2020; ID001). These drivers create depositional and erosional zones that influence the composition and distribution of substrates that can influence the distribution of suitable spawning substrate and habitats, and formation of pools, glides, riffles, and other habitats and cover for target species (Beechie et al. 2001, ID365; Beamer et al. 2005, ID305). Higher gradient streams tend to have larger substrates while lower gradient reaches and streams will tend to have finer substrates (Beechie et al. 2001, ID365).

3.2.1.2 Sediment deposition in delta habitats

Sand deposition has also been occurring in the estuary and on the delta (USACE 2008, ID355), although tidal marsh progradation rates have declined in the Skagit estuary despite large suspended sediment loads from the Skagit River (Hood et al. 2016, ID142). Skagit delta marshes have prograded into Skagit Bay for most of the record (1937 to present), but progradation rates have been declining in recent decades (Hood et al. 2016, ID142). Grossman et al. (2020, ID057) used bathymetric change, sediment cores, and modeling to show how an estimated 142 ± 28 M m^3 of sediment, of which 68 percent was sand deposits, accumulated across the Skagit River delta between 1890 and 2014 related to land uses. Reduced sediment supply and transport related to retention of sediments in reservoirs were identified as a stressor on progradation rates and tidal marsh habitat formation and maintenance processes (Redman et al. 2005, ID100; Beamer and Wolf 2016, ID186; Grossman et al. 2020, ID057). Grossman et al. (2020, ID057) indicated that amount of sediment stored in reservoirs represents approximately 39 percent of the fluvial sand fraction over this time period. However, accumulation of 83 percent of the fluvial sand fraction found near the river mouth make retention in the delta forest and tide flats effective metrics to evaluate land use impacts on sediment dynamics and ecosystems. A higher ratio of sand retention during the period 1890-1939, coinciding with extensive deforestation, channel dredging, and channelization activities, was found relative to the period 1940-2014, which was characterized by improved forest practices, and sediment management to protect endangered species. Comparable offshore sand retention over time and higher nearshore retention before 1940, after normalizing for the assumed reduction in sediment runoff associated with improved forest practices, suggested that channelization has continued to influence sediment export at a magnitude equal to the effects of early logging.

Other studies also pointed to anthropogenic obstruction of historical distributaries and levee construction along the remaining distributaries as increasing the jet momentum of river discharge, forcing much suspended sediment to bypass the tidal marshes and be exported from Skagit Bay (Lee and Hamlet 2011, ID196; Hood et al. 2016, ID142). Beamer et al. 2015 (ID008) also showed that levees, floodgates, and tidegates are potential barriers to sediment and debris transport in both the delta and freshwater environments, and tide gates may also impact sediment transport and deposition patterns in the Skagit estuary (Souder et al. 2018, ID115).

Beamer and Wolf (2016, ID186) also identified areas where rapid habitat changes are occurring as a result of changed water flow and sediment deposition patterns associated with a new distributary avulsion. This includes areas of distributary channel infilling and conversion to marsh/blind tidal channel habitat, and areas with less certain habitat change trajectories. This links the concept of landscape connectivity to habitat formation and maintenance process in the estuary related to sediment transport. Along these lines, sediment supply and routing (transport) were identified as an issue of concern for erosion and progradation of marsh habitats (Beamer and Wolf 2017, ID187).

Vegetation assemblages in tidal marsh habitats are a primary driver of sediment deposition (Redman et al. 2005, ID100; Hood 2007, ID061). Invasive plants, such as *Spartina spp.*, *Sargassum muticum*, and *Zostera japonica*, have altered the vegetation assemblages and sedimentation patterns in Puget Sound, and could be potential stressors on sediment deposition processes in estuary and nearshore habitats of the Skagit (Redman et al. 2005, ID100). Elevation is a primary driver of marsh vegetation establishment and assemblages, and increased vegetation coverage can increase sediment retention in feedback processes (Hood et al. 2006, ID142; Hood 2013, ID273). Tidal marsh restoration sites that were previously disconnected from riverine and estuarine tidal and sediment processes are often subsided, and this can influence vegetation recovery and sediment deposition processes (Hood et al. 2006, ID142; Hood 2013, ID273; Grossman et al. 2020, ID057). Similar to riverine systems, LWD can play an important role in sediment retention processes in tidal marsh habitats (e.g., Hood No Date, ID065).

3.2.1.3 Climate change and sediment deposition

Most of the linkages between climate change and sediment supply and transport processes described in the previous section apply to sediment deposition processes. However, Hood et al. (2016, ID142) also implicated SLR and wave-generate erosion as potential factors that can overwhelm sediment supply. Beamer et al. (2015, ID008) also reported that a relative SLR and sediment routing within the tidal delta are partly responsible for the decline in the formation of tidal delta habitat, providing support for present day climate change impacts as well as potential future effects on sediment deposition processes in the Skagit estuary. In the long term, climate change and SLR are identified as drivers that could affect marsh progradation rates as well as inundation frequency and duration of existing tidal marsh habitats (Beamer and Wolf 2016, ID186).

Climate change is also expected to further increase sediment loads as glaciers and snowpack retreat, exposing more bare earth. SLR may increase coastal erosion as well, but Lee and Hamlet (2011, ID196) suggested that little is known about whether SLR will lead to marsh accretion or net loss in tidal marsh habitat. Initial modeling exercises predicted net losses of tidal marsh with SLR. Removal of existing dikes may increase marsh habitat and mitigate potential impacts of SLR (Lee and Hamlet 2011, ID196). Beamer and Wolf (2017, ID187) indicated that sea level, storm surge, and sediment routing should be incorporated into an updated recovery strategy for the Skagit River estuary to address sources of (natural) habitat losses and improve habitat forming processes in the estuary. Given the vulnerability of Skagit River estuary marshes to SLR, restoration strategies need to increase sediment retention to offset declining progradation rates and increase marsh resilience to SLR (Hood et al. 2016, ID142).

3.2.2 Species and life stages

Many studies indicated that fine sediment deposition was important to incubation life stages of all target species given that they spawn in similar habitats (e.g., Beechie et al. 2003, ID015; Beamer 2005, ID305). Fine sediment deposition in spawning gravels during the incubation life stage can cause direct mortality of all target species through redd burial (Beechie et al. 2003, ID015). Increases in fine sediment (<2 mm diameter) can reduce survival during egg incubation as well as affect food availability by impacting the benthic invertebrate community (Beechie et al. 2003, ID015). Sediment deposition and food availability is described in more detail in Section 9.0 Food availability.

Beamer (2005, ID305) predicted the effects of sediment supply on incubation survival for Skagit Chinook may be smaller in larger streams (mainstem) compared to tributary habitats. This was consistent with the finding that many tributary habitats were identified as having impaired sediment supply with respect to excessive sediment delivery to streams. In Finney Creek, construction of numerous LWD features, and channel stabilization actions, were linked to reformation of pools and increasing exposure of gravel, cobble, and boulder substrate that are more suitable for steelhead spawning (McMillan 2018, ID400). As a result, spawning escapement of winter-run steelhead appears to be improving, but still far below historic levels (McMillan 2018, ID400). Studies have identified that sediment supply and transport are limiting factors for steelhead and Chinook Salmon in the study area, primarily in tributary habitats (Beamer et al. 2005, ID175; McMillan 2018, ID400), with both scour/erosion and deposition processes impacting incubation and fry emergence survival.

Substrate size can also influence gravel permeability and dissolved oxygen concentrations that can reduce egg to emergent fry survival or reduce ability of alevins to move to more oxygenated waters during intergravel life stages (Stober et al. 1982, ID402; Beamer 2005, ID305). Increases in coarse sediments (>2 mm diameter) can also fill pools and aggrade channels resulting in reduced habitat complexity and rearing capacity for some salmonids (Beechie et al. 2003, ID015). Although fine sediment supply and deposition can negatively impact incubation survival of target species, slow-water habitats with fine or silty substrate are required for rearing during the larval life stage of Lamprey, which may rear for up to 7+ years before migrating downstream (Hayes et al. 2013, ID419; Ostberg et al. 2018, ID422; Wang et al. 2020, ID424).

Estuary rearing habitat availability was also influenced by progradation rates, which are influenced by sediment supply, transport, and deposition in the estuary (e.g., Beamer and Wolf 2016, ID186;

Grossman et al. 2020, ID057). Therefore, sediment supply and transport processes are directly related to estuary rearing capacity for target species and life histories that are more reliant on estuary habitats (e.g., Chinook, Chum, and Coho). Estuary habitat capacity was identified as a limiting factor for Chinook production by multiple studies (e.g., Beamer et al. 2005, ID005; Greene et al. 2021, ID056); therefore, factors limiting the formation and maintenance of estuary habitats, including recovery from restoration of tidal connectivity, are potentially limiting estuary habitat capacity. The effects of estuary rearing habitat availability and connectivity on target species are described in more detail in Section 4.0 Habitat availability and connectivity.

4.0 HABITAT AVAILABILITY AND CONNECTIVITY

Habitat availability and connectivity represents an aggregation of factors relating to the extent of habitats (e.g., area of different habitat types) or the connectivity of habitats (e.g., tidal connectivity, floodplain connectivity, fish access). This includes the extent of aquatic, estuarine, and nearshore habitats and landforms and the characteristics of those habitats that are related to fish uses. Some studies described historical habitat extents or conditions prior to construction of hydroelectric facilities or prior to development (e.g., Smith and Anderson 1921, ID347; Collins 1998, ID226; Collins 2000, ID227; Collins and Sheikh 2005, ID031). Numerous other sources provide information on the current extent or connectivity of large river and floodplain, tributary, estuary, and nearshore habitats (e.g., Beechie et al. 2005, ID005; Beamer et al. 2015, ID008; Beechie et al. 2017, ID018; Hinton et al. 2018, ID167).

A number of the primary drivers and stressors related to the extent or connectivity of habitat are covered in other sections. For example, instream flows were identified as a primary driver of habitat extent and connectivity as well as habitat formation and maintenance processes. In general, the magnitude, timing, and duration of inundation and flows defines the wetted extent or accessible extent of habitats, as well as key habitat characteristics (e.g., depth and velocity) and processes (e.g., channel migration, erosion/deposition, floodplain and channel connectivity). As noted in Section 2.2 Peak flow, peak flows are a primary driver of habitat formation processes (e.g., side channel formation, channel migration) and habitat extent and connectivity (Beechie et al. 2003, ID015; Smith 2003, ID376; Smith 2005, ID177; Riedel et al. 2020, ID001). Furthermore, the timing, duration, and magnitude of minimum flows also influence the extent and connectivity of habitats that can influence habitat use and periodicity for target species and life stages. See Section 2.0 Instream flow for more information on instream flows.

Sediment supply and transport processes were also identified as a primary driver of habitat availability and connectivity in large river, floodplain, and estuary habitats (e.g., Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196; Hood et al. 2016, ID142; Beamer and Wolf 2016, ID186; Lee et al. 2016, ID417; Beamer and Wolf 2017, ID187; Grossman et al. 2020, ID057). In the estuary, several studies provided information on the formation of marsh and channel habitats and current or historical distributions estuary habitats. These were mostly linked to sediment supply and transport processes, land use and levees/dikes, restoration, and climate change (e.g., Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196; Beamer and Wolf 2016, ID186; Hood et al. 2016, ID142; Lee et al. 2016, ID417; Beamer and Wolf 2017, ID187; Grossman et al. 2020, ID057). See Section 3.0 Sediment supply and transport for more information on sediment supply and transport.

Large wood recruitment and retention was also identified as a primary driver of habitat formation and maintenance processes, and LWD can significantly influence the distribution and connectivity of habitats in large river, floodplain, tributary, and estuary habitats (e.g., Beechie et al. 2003, ID015; Redman et al. 2005, ID100; NSD 2017, ID086; Seixas et al. 2020, ID303). In large river and floodplain habitats, large wood is a primary driver of habitat formation and maintenance processes (e.g., Beechie et al. 2003, ID015; Redman et al. 2005, ID100; NSD 2017, ID086; Seixas et al. 2020, ID303). Throughout the Skagit River basin, LWD forms key riverine habitat features that have a significant impact on hydraulic processes, geomorphology, and salmonid habitat quality. Changes in LWD abundance are related to changes in pool spacing, pool area, and pool depths, and can directly influence the carrying capacity of instream habitat for salmonids (Beechie et al. 2003, ID015). The depletion of LWD has led to extensive degradation of fish habitats throughout the Skagit River basin and region (NSD 2017, ID086). Large wood is also linked to habitat formation and maintenance processes in estuary habitats (e.g., Hood 2007, ID061). See Section 5.0 Large woody debris and bank condition for more on LWD.

This section focuses on some aspects of geomorphology and processes, land use and cover, restoration, and climate change that were related to the following factors:

- ***Habitat extent:*** The extent or distribution of aquatic, estuarine, or nearshore habitats and landforms.
- ***Habitat connectivity:*** The hydrological connectivity or accessibility of habitats for target species.

4.1 Habitat extent

4.1.1 Drivers and stressors

4.1.1.1 Geomorphology and processes

Underlying geomorphology and geological history are primary drivers of habitat formation and maintenance processes that influence the distribution and connectivity of habitats within the Skagit River basin (Beechie et al. 2001, ID365; Beechie et al. 2003, ID015). Historically, volcanic and glacial processes have defined the underlying geomorphology and geology of the basin (e.g., Beechie et al. 2001, ID365; Lee and Hamlet 2011, ID196; Riedel and Larrabee 2016, ID155; Riedel et al. 2020, ID001). Geomorphology is a primary driver of habitat formation processes and influences important habitat characteristics like depth, velocity, gradient, cover, structure, bank, and substrate (Beechie et al. 2003, ID015). Smith et al. (2011, ID111) described reaches where habitat formation processes are more or less likely to occur, and they generally found that reaches that have wide floodplains and larger inundation areas were likely to have the greatest potential for habitat formation. While all inundated areas may not be used by fish as habitat during flood flows, this metric (the amount of floodplain area inundated during the 25-year flow) provided a good indicator of where channel changes or habitat formation may occur in the future and persist during lower flow conditions. Channel migration, erosion and deposition, and large wood recruitment and accumulation processes also contribute to the mosaic of channel and floodplain habitats, which are in part driven by underlying geomorphology (Beechie et al. 2010, ID017).

Geomorphology is also a primary driver of habitat formation and maintenance processes in marshes and delta distributaries. Hood (2010, ID272) indicated that the location of marsh islands within delta distributaries is not random and there are strong geomorphic relationships between channel and marsh geometry. Islands are disproportionately associated with blind tidal channel/distributary confluences. Additionally, blind tidal channel outlet width is positively correlated with the size of the marsh island that forms at the outlet and the time until island fusion occurs within mainland marsh. These observations suggest confluence hydrodynamics favor sandbar/marsh island development (Hood 2010, ID272). Hood (2007, ID271) also reported a strong relationship between tidal channel and marsh island geometric metrics including total channel length, total channel surface area, tributary count, and more. These strong scaling or allometric relationships can be used to inform evaluations of the current status of tide channels in the Skagit delta (e.g., to identify departures from reference or functional condition), as well as inform evaluation and development of restoration designs based on the expected number, area, or complexity of tidal channels for a given marsh area (Hood 2010, ID272; Beamer et al. 2016, ID212). Hood (2007, ID271) reported that minimum marsh areas that sustain tidal channels are 0.21-0.45 ha. In addition, they found that given the disproportionate scaling pattern, restoration of a 100-ha marsh would be preferable to restoration of 10 separate 10-ha sites, based on predicted channel metrics. They also found pronounced differences in scaling function intercepts between the marsh island group cut off from sediment inputs and the other marsh island groups. Such differences can be used to identify marsh restoration opportunities or locations were sediment and marsh processes are impaired.

Channel size and complexity in estuary habitats were also positively related to tidal range and negatively related to wave height in tidal channels throughout Puget Sound (Hood 2015, ID063). Hood (2015, ID063) also found that larger tidal channels in the South Fork Skagit delta compared to North Fork delta is consistent with an apparent accretion deficit and greater declines in historical salt marsh progradation rates in the SF compared to the NF delta. This study suggested that restoration of system-scale natural processes through relaxation of anthropogenic constraints on sediment supply could likely change patterns within the affected deltas. The author's conclusions claim that *...river systems with known anthropogenic reductions in river sediment delivery, through dam construction and flow diversion, also tended to have larger channel networks* in describing the role of sediment supply and transport on tidal marsh channel geometry. Wave environments also appear to affect channel geometry, with wave-sheltered areas experiencing relative sediment deficits, with some salt marshes in Puget Sound, such as the SF Skagit delta, suffering from the impacts of SLR (Hood 2015, ID063).

4.1.1.2 Land uses and cover

Land use and cover are primary drivers of the current extent of aquatic habitats and landforms in the Skagit River basin. For the purposes of this review, land use and cover generally include anthropogenic development or conversion of land, bank modifications or armoring, diking and levees, and other land uses that impact habitat extents or connectivity. However, connectivity is related to habitat extent and many aspects of land use and cover (e.g., dikes/levees) but these are described in more detail in Section 4.2 Habitat connectivity. Historically, the first dikes along the lower Skagit River are thought to have been constructed in 1863 (Lee and Hamlet 2011, ID196) and this initiated large changes in habitat extent and connectivity.

In river and floodplain habitats, major habitat impacts were linked to land cover in general, with impacts occurring where land use was predominately agricultural, urban, or private/state forestry (Smith 2003, ID376). Road densities increase with increasing percentage of state or private land contained within a basin, and road density is identified as a major indicator of sedimentation and fish passage impacts as well as hydrological changes (Smith 2003, ID376). The four land uses that alter rates of geomorphic processes the most, and subsequently affect the quantity or quality of fish habitat in the Skagit River basin, are agriculture, forestry, rural residential development, and hydropower dams (Beechie et al. 2001, ID365). Agricultural and rural residential areas are almost exclusively within the floodplains and deltas and overlap with more than 59 percent of the historical range of salmon (Beechie et al. 2001, ID365). The lower Skagit River, including all streams downstream of the Sauk River confluence, are identified as containing the …*most highly* *degraded freshwater salmon habitat in the Skagit Basin with considerable impacts in every habitat category* (Smith 2003, ID376). The lower Skagit River has the most extensive floodplain habitats in the basin (108 square miles), but degradation from dikes and riprap are extensive (Smith 2003, ID376). An estimated 62 percent of the mainstem river length from Sedro-Woolley to the mouth has been hydromodified, and only 10 percent of its length has split channels or forested island habitats (Smith 2003, ID376). Hydromodifications disconnect floodplain habitats, increase water and sediment transport, and disrupt other natural processes like LWD recruitment, riparian vegetation growth, hydrological connectivity, and side- and off-channel development (Smith 2003, ID376).

Pool habitat is a key habitat for target species life stages, including adult and juvenile life stages, and land use in the Skagit River basin has been shown to influence pool area. In the Skagit River basin, almost all tributaries in agricultural lands are low-slope channels, and pool areas are much less than in reference sites or in streams with other adjacent land uses (Beechie et al. 2001, ID365). Much of this difference in pool areas is likely due to channel dredging or increased supply of sediments from pastures and croplands associated with land uses. In forest lands in terrace tributaries, reduced wood recruitment has caused the greatest reductions in pool areas in moderate-slope streams (0.02-0.04). Reductions in pool areas in rural areas are similar to those in forestry areas (Beechie et al. 2001, ID365).

Off-channel habitat such as side channels, sloughs, and beaver ponds in the lower Skagit River have been disconnected and reduced due to agricultural practices, diking, and bank revetments. (USACE 2010 ID117). USACE 2010 (ID117) indicated that *continued maintenance and construction of levees as it exists now… would further constrain the river,* and continuing to constrain the river would consequently create less complex habitat, decrease benthic invertebrate habitat, further decrease off-channel habitat, and river speeds would increase during high flow events. This would also further decrease LWD retention and create thinner riparian corridors. This ripple effect would *directly affect ESA listed species that depend on cold, clean water, organic detritus and benthic invertebrates for food, and LWD and bank complexity for cover.* USACE 2010 (ID117) also described current habitat conditions as *fragmented, poorly connected, and provided inadequate protection of habitats and refugia for sensitive aquatic species such as salmon* due to landscape alteration from *road building, bank hardening, hydropower operations, timber harvest… and rural development.*

Much of the floodplain and channel area in the middle Skagit has also been modified by human activities. Smith et al. (2011, ID111) indicated that the straight channel types in the middle Skagit study area had the highest percent of floodplain greater than 75 years and the highest average floodplain age, indicating less disturbance from lateral channel erosion than other channel types, and likely less habitat diversity. The meandering and island-braided channel types together had a lower percent of floodplain greater than 75 years and lower mean floodplain ages, indicating higher rates of disturbance, but likely still less than would be expected for braided channel types. This suggests a more intermediate rate of channel disturbance and higher habitat diversity for these channel types. The meandering and island-braided reach types were poorly distinguished from one another within the middle Skagit study area. It is likely that the cause of this discrepancy is that so much of the floodplain and channel area in the middle Skagit has been modified by human activities that the resulting vegetation ages provide a less accurate measure of natural floodplain disturbances (Smith et al. 2011, ID111).

In the estuary and nearshore habitats of the study area, diking, levee building, channelization, jetties, dredging, and large wood removal have fundamentally altered the spatial arrangement, function, and connectivity of distributaries, tidal marshes, and pocket estuary habitats (e.g., Beamer et al. 2005, ID005; Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196). Beamer et al. (2005, ID005) reported a net loss of 72.8 percent tidal delta estuarine habitat area from the 1860s (11,483 ha [ha]) to 1991 (3,118 ha), which includes the areas most relevant to Skagit River Chinook from Padilla Bay to Camano Island. Open distributary channel densities were 11.6 m channel length/ha of wetland for historic conditions and 39-41.2 m/ha for current conditions. Area of open tidal channels declined by 30.4 percent from historic (1860s) to current (2000), with a 20.7 percent loss of edge area and a 94.6 percent loss of blind tidal channel area, which translates to an 87.9 percent loss of preferred Chinook delta rearing habitat (Beamer et al. 2005, ID005). WWAA (2010, ID159) indicated current conditions represent a 72 percent loss of total estuarine habitat from historical conditions, with an 84 percent loss of riverine tidal habitat, 66 percent loss of estuarine forested transition habitat, and a 68 percent loss of estuarine emergent marsh habitat. The report indicated that nearly all the historic salt marsh associated with Padilla Bay has been disconnected from tidal processes due to diking and drainage, but the amount of current or lost habitat is not quantified aside from 454 wetlands identified in the Padilla Bay basin (WWAA 2010, ID159).

Agricultural and urban land uses are primary stressors in estuary and nearshore habitats, with losses of subaerial wetlands, marsh and intertidal areas, channels, organic matter (detritus), riparian vegetation, LWD, and tidal channel surface area in the Skagit estuary and pocket estuary habitats (Redman et al. 2005, ID100). Agricultural and urban land uses also alter the tidal prism and sediment supply dynamics, simplify habitat, and reduce accessibility to pocket estuaries and tidal marsh habitats. Channelization results in habitat simplification and loss of channel sinuosity, and construction of jetties and training walls in the Skagit River delta cause a loss of intertidal rearing habitat and potential barriers to migration (Redman et al. 2005, ID100). Anthropogenic obstruction of historical distributaries and levee construction along the remaining distributaries is also identified as a driver of increased jet momentum of river discharge, forcing much suspended sediment to bypass the tidal marshes and be exported from Skagit Bay, as described in the Sediment supply and transport Section 3.0 (Hood et al. 2016, ID142). Between 1892 and 1937, a series of USACE projects developed the Swinomish Channel into its current form. The resulting modifications have contributed to two critical changes in the environment for Pacific Salmon species which include changes in the distribution and migration pathways as well as hydrology and tidal/freshwater mixing patterns (Hinton et al. 2008, ID174). Smith (2003, ID376) identified shoreline modifications (e.g., dikes, riprap) as one of the greatest impacts to nearshore habitats in WRIA 3, with shorelines rated as poor in east Skagit Bay, Swinomish Channel, Padilla Bay, and north Fidalgo Island. Shoreline modifications disrupt sediment and nutrient supply and transport, which are important habitat processes in nearshore habitats as well as connectivity, as described in Section 4.2 Habitat connectivity.

4.1.1.3 Restoration

Restoration is a primary driver of habitat extent and connectivity, with restoration being primarily intended to increase the availability, connectivity, or quality of key habitat types, or restore important ecosystem processes that support habitat formation or maintenance processes. Beamer et al. 2015 (ID008) provided results chains models to support implementation and evaluation of the Skagit Chinook Recovery Plan. These models showed that levees, floodgates, and tidegates impact fish passage and therefore estuary rearing success and outmigration success, as well as floodplain connectivity or dissipation of flows to floodplain areas. In riverine and floodplain habitats, levees prevent flooding and formation of secondary channels, and levee setbacks or removal can increase connectivity to floodplain habitats (Beechie et al. 2010, ID017). However, it should be noted that while levees are seen as a negative driver of habitat availability and connectivity from the perspective of fish habitat, levees are intended to reduce flooding risk and can protect infrastructure and land uses (e.g., agricultural). For example, levee projects are identified as a means to reduce flood damage in the floodplains and Skagit estuary where extensive agricultural land uses occur, and where the Samish and Skagit River deltas become connected during high flow events (FERC 1980, ID439). Therefore, restoration planning requires balancing competing needs for habitat availability and connectivity for target species with flood protection for anthropogenic land uses.

Significant restoration efforts have been undertaken as part of the Skagit River Chinook Recovery Plan (Beamer et al. 2005; ID175), and restoration was identified as a primary driver of positive changes in the extent and connectivity of marsh and channel habitats in the Skagit estuary (Beamer and Wolf 2017, ID187; Beamer et al. 2019, ID013). Removal of existing dikes or levee setbacks are primary restoration actions being used to increase marsh habitat and mitigate potential future impacts of SLR (Lee and Hamlet 2011, ID196). In contrast to dike breaching, dike removals and levee setbacks are actions that can restore full tidal inundation and access to off-channel refugia (low velocity) habitats (Souder et al. 2018, ID115). Tide gate removal or enhancement actions have also been used in the Skagit estuary to improve habitat connectivity. However, studies note that that tide gate removal or restoration projects may still result in high velocities and muted inundation, sediment scour, and deposition processes (Souder et al. 2018, ID115). Upgrading tide gates can improve connectivity and hydrological function that is balanced with protection of property or land uses (Souder et al. 2018, ID115). However, restoration sites with muted hydrology or limited connectivity performed poorer than projects that restored connectivity to a greater extent in estuary habitats (Beamer et al. 2019, ID013), and this finding supports restoring full tidal connectivity over partially or muted connectivity with dike and levee removal and setback actions. Studies in the Skagit estuary have found that combining levee setbacks with tide gate restoration can significantly improve hydrological connectivity and fish use (e.g., Fisher Slough Restoration Project, see Beamer et al. 2017, ID010).

Recent evaluations of progress towards restoration targets indicated that increases in habitat in the Skagit estuary from restoration are outpacing losses from natural and human causes (Beamer and Wolf 2017, ID187; Beamer et al. 2019, ID013). Quantitative data on habitat status and trends showed a net increase of 83 ha of marsh between 2004 and 2013, with a 122-ha increase from restoration and an 18-ha increase from passive breaches and progradation (Beamer and Wolf 2017, ID187). Losses during the same timeframe included a loss of 0.4 ha from channel filling and levee repairs, 36 ha lost from invasive spartina removal, and a 30-ha loss from natural erosion (Beamer and Wolf 2017, ID187). A more recent report indicated that increases in estuary habitat are a result of some natural progradation and 653 ac of restoration projects, and restoration was the primary source of changing estuary habitat extents during the monitoring period (Beamer et al. 2019, ID013). An additional 398 acres of planned restoration projects are described in Beamer et al. (2019, ID013).

Overall, the Skagit River is gaining tidal delta habitat faster than it is being eroded, mostly due to active restoration projects, as noted above. However, current rates of restoration are slow and are not projected to meet the desired future conditions outlined in the 2005 Recovery Plan until 2100 (SWC 2021, ID430). 122 ha were restored in the Skagit River estuary between 2004 and 2013, at a pace of 13.6 ha/year (Beamer and Wolf 2017, ID187). Annual restoration efforts varied, and if it occurred at the slowest observed pace of 10.2 ha/year, habitat would reach the desired condition target (for the Skagit Chinook Recovery Plan) by year 2106, while the fastest observed pace of 25.8 ha/year would result in reaching the target by 2045 (Beamer and Wolf 2017, ID187).

4.1.1.4 Climate change

Natural losses of tidal marsh habitat predominately occurred along the Skagit Bay front or tidal marsh fringes, which Beamer and Wolf (2017, ID187) indicated are sensitive to climate change and potential SLR, which could increase the rate of tidal marsh losses in the delta over time. USACE 2010 (ID117) also reported that climate change could result in losses of wetland function and habitat. Relative SLR and sediment re-routing has also been identified as a driver of overall declines of natural progradation (SWC 2021, ID430), emphasizing the role of active habitat management in creating net gains in tidal habitat. Landscape/habitat connectivity within the delta is highest in the South and North forks and lowest in Swinomish Channel and Padilla Bay. The rate of progradation at Central Fir Island and in the South Fork is negative, meaning that habitat is disappearing faster than it is being formed. Beamer et al. (2005, ID005) reported that a 45 cm increase in sea level due to climate change would cause an estimated 12 percent (235 ha) loss of tidal marshes in the vicinity of Fir Island, and an 80 cm increase would result in an estimated loss of 22 percent (437 ha) of tidal wetland habitat near Fir Island. The North Fork progradation rate was approximately zero, thus tidal delta progradation rates are an area of concern for the Skagit estuary (SWC 2021, ID430). Hood 2015 (ID063) suggested that sediment-challenged salt marshes in Puget Sound are already showing impacts from 20th century SLR. The results of this study suggest restoration of system-scale natural processes through relaxation of anthropogenic constraints on sediment supply could likely change patterns within the affected deltas.

4.1.2 Species and life stages

The extent of freshwater rearing and delta rearing habitats were identified as limiting factors for Chinook (Beamer et al. 2005, ID175). Loss of habitat extent and connectivity were identified by many sources as primary factors influencing the demographics of target species (e.g., abundance, distribution, growth, survival, and migration). The Skagit Chinook Recovery Plan and associated appendices and reports evaluating progress towards recovery provided the most information on the extent and connectivity of key salmon habitats for the study area, although the focus was primarily on Chinook Salmon. Beamer et al. (2005, ID004) recommended restoration strategies to address freshwater rearing habitat limitations for yearling life histories in the Skagit River basin which included restoring habitat access, reconnecting side channels, and restoring the natural process of habitat formation though channel migration. For parr life histories, they recommended addressing hydromodifications and restoration or removal of other floodplain disturbances (e.g., dikes and levees, riprap) that hinder river movements, reduce formation of backwaters and other complex edge habitats that freshwater rearing parr prefer, and increasing connectivity to off-channel floodplain habitats that are important for refuge and rearing. The Skagit Chinook Recovery Plan also identified illegal habitat destruction and degradation as a limiting factor for Chinook salmon in the Skagit basin (Beamer et al. 2005, ID175).

The Skagit Basin Council's (SWC) updated strategic approach for 2022 identified updated priority target areas for restoration and protection to support the Skagit Chinook Recovery Plan (SWC 2022, ID451). The Skagit Chinook Recovery Plan and the updated strategic approach identified the following four habitat areas that limit Chinook production:

(1) Tidal freshwater and estuary habitats in the delta,

(2) shallow nearshore habitats that include pocket estuaries,

(3) freshwater rearing areas in mainstem and tributary floodplains, and

(4) loss from altered basin processes that control tributary habitat conditions (e.g., flow regime, riparian functions, and sediment supply changes).

Estuaries, riverine tidal deltas, and river floodplains provide important rearing habitat for multiple populations of Skagit River Chinook. The updated strategic approach identified restoration target areas (Tier 1 habitats) that include these habitat types because of their importance in providing rearing habitat for juvenile Chinook for multiple Skagit River populations (SWC 2022, ID451). Priority restoration objectives in the strategic approach include restoring distributary channels connecting the North Fork Skagit River to the bayfront. Floodplain habitats were also identified as Tier 1 target areas because *floodplain habitats and contributing upland areas have been significantly altered over the past 100+ years due to road building, bank hardening, hydropower operations, and timber harvest in riparian and upland zones*. Priority restoration objectives for floodplain habitats included reconnecting isolated floodplain areas and restoring mainstem edge habitats (SWC 2022, ID451). Hartson and Shannahan (2015, ID415) developed an updated field inventory of hydromodified banks that encompasses all recorded Chinook Salmon bearing channels within the Skagit River basin, which could be used to inform restoration planning to address Tier 1 target areas identified by SWC (2022, ID451).

Tier 2 and Tier 3 target areas included pocket estuaries, river floodplains, and sediment impaired basins. Pocket estuaries in nearshore marine areas and river floodplains also provide rearing habitat for Skagit Chinook Salmon populations and the SWC updated strategic approach identified these as Tier 2 target areas because they are mostly inaccessible (SWC 2022, ID451). Pocket estuary habitats provide extended rearing and growth opportunities for juvenile Chinook Salmon, yet 86 percent of the total historic pocket estuary area near the Skagit delta was blocked to non-natal salmon use (SWC 2022, ID451). While this is a listed target area, the full extent of how Chinook Salmon utilize all nearshore marine habitats such as vegetated tidal flats, subtidal flats, and rocky reefs is unknown. Tier 3 target areas are basins that have impaired sediment supply or peak flows that impact Chinook Salmon habitat and should be addressed within the next ten years. Some of the priority restoration objectives were to reduce land use (which impacts sediment supply), and repair/relocate/or remove structures that contribute to increased erosion or peak flows (SWC 2022, ID451).

The following sections provide more detailed information on how the extent or connectivity of habitats were linked to anadromous resource conditions in the study area in the considered literature. This information is generally organized by river and floodplain habitats (including tributaries) and estuarine and nearshore habitats (including pocket estuaries). As noted previously, most of this information was developed from the Skagit Chinook Recovery Plan and associated monitoring and research.

4.1.2.1 River and floodplain habitats

Because of the variation in life history strategies within and among salmon and trout species, there are differences in their required river and floodplain habitats. In general, floodplain habitats were identified as being most important for juvenile Coho Salmon, while Chum and Pink Salmon are the least sensitive to stream conditions because they spend little time rearing in freshwater habitats (Smith 2003, ID376). Bull Trout, steelhead, and Sockeye are the most dependent on freshwater habitats due to their extended rearing life histories (Smith 2003, ID376). Beechie et al. (2003, ID015) identified key habitat features for target salmon and trout species based on the habitat types that are required for the persistence of a dominant life history type for at least one life stage or preference by most life stages considered. Tributary reaches, ponds and wetlands (including those associated with beavers) are key habitats for Chinook and steelhead and are critical for Coho. Pool riffle habitats are key habitats for Chum, Coho, Chinook, Pink, and steelhead. Forced pool riffle habitats are key habitats for Coho, Chinook, steelhead, and Pink, and step-pool and cascade habitats are key habitats for steelhead (Beechie et al. 2003, ID015). In main channel rivers, floodplain <2 channel widths are key habitats for steelhead, while main channel floodplain >2 channel widths are key habitats for Chum, Chinook, steelhead, and Pink Salmon. Off-channel habitats like ponds, sloughs, side channels, and oxbows are key habitats for Chum and Chinook, and critical habitats for Coho Salmon. In estuary habitats, estuarine and tidally influenced wetlands are key habitats for Chum and critical habitats for Chinook. Blind tidal channels are key habitats for Chum and Coho and critical habitats for Chinook Salmon. Subsidiary and main channels are key habitats for Chum, Coho, Chinook, and steelhead. Beamer et al. (2010, ID202) indicated that juvenile Chinook abundances are higher in bank edge, pool, and glide habitats, while longer rearing life histories of juvenile Coho prefer pools in the summer and juvenile steelhead prefer bar and glide habitats in the summer. There are also variations in the spatial-temporal distribution of the stream-type life history expressed by anadromous salmonids within the Skagit River (Lowery et al. 2020, ID075). In general, interactions between hydro-region (physiographic variables), channel type (aquatic habitat variables), and season best described the spatiotemporal distribution patterns of stream-type salmon, steelhead, and trout (Lowery et al. 2020, ID075).

Freshwater rearing capacity is a limiting factor for sub-yearling Chinook production in the Skagit River, despite earlier reports to that were inconclusive on the issue (Beamer 2000, ID191; Beamer et al. 2005, ID004; Beamer et al. 2005, ID005). Annually, the Skagit River system produces 1.2-1.3 million migrant parr Chinook (Beamer 2014, ID218; PSI and WDFW 2017, ID085) *regardless of escapement levels, providing evidence of limited habitat capacity and reductions to population productivity* (PSI and WDFW 2017, ID085). Yearling life history abundance has ranged from 6,000 – 97,000 (Beamer 2014, ID218), and yearling life histories are even more strongly linked to rearing habitat extent given their longer freshwater rearing duration. Using a Ricker function, Beamer et al. (2005, ID004) estimated freshwater rearing capacity was reached when total juvenile production reached approximately 4.5 million, with parr production leveling off and fry migrant (early migrant) production increasing as total production increases.

Freshwater rearing capacity for Skagit Chinook is also influenced by density dependence processes. Beamer and Wolf (2016, ID186) identified freshwater rearing habitats in general as limiting, and that restoration in the estuary is one way to alleviate some of the limitations by increasing growth potential for "excess" fry migrants produced as a result of density dependence and freshwater rearing capacity limitations. Expression of life history patterns were also linked to density dependent processes occurring during freshwater and estuary rearing and emigration life stages (Beamer 2014, ID218). In addition, Zimmerman et al. (2015, ID331) reported that overall survival of Chinook was density-independent, but the composition of juveniles post-emergence implies density-dependence during juvenile rearing. Therefore, continued efforts to improve quantity, quality, and connectivity of habitats (e.g., restoration) important to juvenile stages (i.e., backwaters, side-channels, off-channel habitats, and log-jams) is important to improving out-migrant survival (Zimmerman et al. 2015, ID331).

The abundance of wild steelhead in the Skagit has declined significantly since the 1980s and fell below escapement goals of 6,000 in the 2000s. Historical estimates of escapement (1895) range between 70,000-149,000 steelhead with a mean of 105,600 adults. The nearly 10x decline in abundance was not explained by 33 percent losses in available stream length or ocean indices of productivity (Pflug et al. 2013, ID154). Roni et al. (2006, ID104) found that constructed floodplain habitats produced smolts of similar size and density compared to natural floodplain habitats, and that shoreline irregularity positively influenced abundance metrics. They also found that smolt length was negatively correlated with distance to saltwater, which they interpreted as an indication of habitat productivity (i.e., lower primary production further upstream).

In Finney Creek, Suiattle River, and Sauk River, loss of historical spawning and rearing habitat are primary issues of concern for salmonids (Beamer et al. 1998, ID189). Beechie et al. (2006, ID016) provided information on areas that do not provide spawning habitat for Chinook as well as the factors that prevent these habitats from providing spawning opportunities. They assumed that no spawning occurred in the lower mainstem Skagit River downstream of river kilometer 33 (reach R13) due to fine-grained beds, in the mainstem Suiattle due to high turbidity during the spawning period, in channels less than 5 m bankfull width, or upstream of migration barriers based on channel slope (>0.04 m/m). They also assumed dams on Baker River and the upper Skagit River limit adult spawning distributions. Similarly, Smith (2010, ID352) reported that the current location of Diablo Dam probably blocked upstream migration of all migratory fish, including Bull Trout. Today, Bull Trout can only migrate as far as Gorge Dam. These migration barriers have resulted in highly differentiated genetics among Bull Trout populations above and below the barriers, indicating total reproductive isolation. No Bull Trout collected below the dams originated from populations above the dams, further supporting the conclusion that the populations are isolated (Smith 2010, ID352). Connor et al. (2015, ID413) provided estimates of the amount of potential Chinook rearing habitat in the tributaries of the Skagit River. They considered stream segments to have suitable rearing habitat if they had a gradient of 4 percent or less and were classified as moderately confined or unconfined. They excluded tributaries that were less than 7.3 m (24 ft) in width from the analysis because they were less likely to support increased Chinook densities.

Anthropogenic land uses are the main cause of impacts to salmonid habitat in the Skagit River basin. Beechie et al. (2003, ID015) indicated that basins with effective impervious area greater than 10 percent have degraded channel habitat compared to basins with less impervious surface area, and this reduces species and habitat diversity and abundance. Hydromodification of channel edges can also increase sediment transport rates and reduced edge habitat complexity and rearing capacity, and juvenile Coho and Chinook abundances in the Skagit were strongly correlated with wood and other natural cover types compared to riprap or rubble cover commonly associated with hydromodified bank edges (Beechie et al. 2003, ID015). Smith (2003, ID376) identified a lack of large wood and pool habitat as a potential concern, and Beechie et al. (2003, ID015) indicated that changes in LWD abundance are related to changes in pool spacing, pool area, and pool depths. Pool spacing, area, and depths directly influence the carrying capacity of instream habitat for salmonids (Beechie et al. 2003, ID015). Likewise, Smith (2003, ID376) indicated that most of the known impacts to salmonid habitat in the Sauk River basin are in areas that are primarily private or state owned. High road densities, poor riparian conditions, excess sedimentation, peak flows, and reduced pool habitat and LWD are noted for tributaries to the Sauk River. However, risk from human water consumption is identified as a low threat to fish habitat (via water quantity) in the Sauk River basin due to low water consumption in the basin (Smith 2003, ID376).

Removal of beaver ponds, diking, ditching, and dredging of floodplains and deltas has isolated or eliminated approximately 50 percent of Coho Salmon winter rearing habitat in both the Skagit and Stillaguamish basins. In the Skagit River basin, tributaries have lost more than 30 percent of their potential Coho smolt production (Beechie et al. 2001, ID365). Beechie et al. (1994, ID337) estimated that the Coho Salmon smolt production capacity of summer habitats in the Skagit River basin have been reduced from 1.28 million smolts to 0.98 million (-24 percent) and that the winter habitats have been reduced from 1.77 million to 1.17 million smolts (-34 percent). Hydromodification, agriculture, and urbanization accounts for 73 percent of summer habitat losses and 91 percent of winter habitat losses. Blocked fish access on small tributaries accounted for 13 percent of summer habitat losses and 6 percent of winter habitat loss, whereas forestry activities were attributed with 9 percent and 3 percent of summer and winter habitat losses, respectively.

4.1.2.2 Estuary and nearshore habitats

Losses of delta habitats are a limiting factor for Chinook salmon in the Skagit, according to the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Loss and degradation of Skagit estuary habitat was identified as one of the most important habitat issues for salmonids at a regional scale given that the Skagit River basin *produces most of the salmonids and salmonid stocks in Puget Sound*, and restoration and conservation of Skagit estuary habitats and nearby non-natal pocket estuaries should be a regional priority for Puget Sound salmon recovery (Souder et al. 2018, ID115). Estuary habitats are most important to juvenile Chinook and Chum Salmon, and to a lesser extent Pink Salmon (Smith 2010, ID352). Loss and simplification of estuarine, delta, and wetland habitats is a major stressor on anadromous fishes in Puget Sound and the Skagit River (Redman et al. 2005, ID100).

Intertidal habitat has been reduced by approximately 72 percent in the Skagit delta (Smith 2003, ID376; Beamer et al. 2005, ID005; Greene et al. 2021, ID056), which is a particular concern for juvenile Chinook Salmon. Numerous studies point to a lack of estuary habitat as limiting capacity for delta rearing and delta fry rearing life histories of Chinook (Beamer and Larsen 2004, ID183; Beamer et al. 2005, ID005; Beamer et al. 2005, ID004; Beamer and Wolf 2016, ID186; Beamer and Wolf 2017, ID187, Beamer 2000, ID191; Greene et al. 2021, ID056). Beamer and Larsen (2004, ID183) reported that density dependence results in export of surplus fry migrants to nearshore habitats and reduced estuary rearing duration. Estuary rearing abundance increases with increasing outmigrant abundance until ≈2.5 million outmigrants, after which density dependent processes result in an increased proportion of fry migrants (Beamer and Larsen 2004, ID183; Beamer 2014, ID218). Delta rearing fry obtain greater size and condition and have increased survival to adult return. Skagit Bay tidal delta rearing capacity is estimated at 2.25 million tidal delta rearing juvenile Chinook per year (Beamer 2014, ID218).

Estuary habitat extent and connectivity also influence life history expression and size of juvenile Chinook produced by the Skagit River through density dependent processes (Beamer and Larsen 2004, ID183; Beamer et al. 2005, ID005). Density dependence influences the timing of emigration, duration of rearing, size at entry, and expression of life histories and thereby use of delta, estuary, nearshore, and pocket estuary habitats (Beamer et al. 2005, ID005; Greene et al. 2021, ID056). Likewise, Beamer et al. (2005, ID005) indicated that delta habitats (circa 2005) are limiting the abundance and size of juvenile Chinook that the delta can support through density dependent processes, and this potentially limits marine survival rates or survival at later stages based on size selective mortality. Natural origin Chinook fry outmigrants in the Skagit rear extensively in blind channels and transition more slowly through wetland habitat (Greene et al. 2021, ID056). Beamer 2000 (ID191) indicated that sub-yearling Chinook production is constrained by (1) lower than expected egg to fry survival and (2) density dependence during the estuarine rearing life stage, but that restoration of peak flow and sediment supply processes to improve egg to fry survival would have limited benefits without increasing estuary rearing capacity.

Greene et al. (2021, ID056) found that local juvenile Chinook densities regularly exceeded estimated capacity in the Skagit estuary, with > 60 percent of observations exceeding 95 percent of the estimated capacity annually. Hatchery origin Chinook had a negligible effect on the exceedance frequency in the Skagit but had larger influence in other estuaries. Forested riverine tidal and estuarine forest transition habitat were more likely to exceed capacity than estuarine emergent marsh habitats, as were blind channels with respect to distributaries (Greene et al. 2021, ID056). A bioenergetics model used to evaluate growth among wetland habitat types showed that freshwater wetland habitats were more important for Chinook growth early in the rearing period while marine-influenced habitats offered more benefits to growth later (Greene et al. 2021, ID056).

Beamer and Henderson (2004, ID160) found that Bull Trout use blind tidal channels in deltas, but they may not use smaller/shallower tidal channel habitats or tidal channel habitats farther from distributary channels. They detected no trends in abundance in delta habitats and significant variation in the timing of presence in delta habitats among years. A significant increasing trend in abundance and length were detected for Bull Trout in Skagit Bay. Bull Trout were not observed in habitats with depths < 0.3 m, they were infrequent in depths 0.3 – 1.0 m, and most frequent when depths > 2.5 m. Bull Trout densities were highest in spit habitats (Beamer and Henderson 2004, ID160).

Dikes, levees, and fish-blocking tide gates were identified as the primary causes of disconnected estuary habitats. Dikes and levees completely block tidal connectivity, and tide gates generally cause complete or significant impacts to tidal connectivity while also preventing fish passage during closed periods or may impede passage when open due to high velocities, raised sills, or debris barriers (Greene et al. 2012; ID051; Souder et al. 2018, ID115). Removal or upgrading of tide gates can improve fish passage, improve sediment transport, and increase mixing of salt and freshwater (Souder et al. 2018, ID115). Ditching, channelization, filling, riparian loss, and loss of habitat complexity are also creating isolated habitats in the delta (Souder et al. 2018, ID115). Landscape connectivity, or the arrangement and position of habitat features, is an important driver influencing the relative abundance and distribution of juvenile salmon among estuary and pocket estuary habitats (Beamer et al. 2005, ID005; Beamer et al. 2007, ID215; Beamer et al. 2015, ID008; Beamer et al. 2016, ID212). Depending on the year, landscape connectivity explained 36 percent to 74 percent of the variation in seasonal juvenile Chinook Salmon density at Skagit River delta long-term monitoring sites (Beamer et al. 2017, ID010).

Pocket estuaries are important rearing and refuge habitats for Skagit River Chinook, and studies found that use of pocket estuaries was linked to conditions in the estuary as well as the arrangement and accessibility of pocket estuary habitats. The Skagit Chinook Recovery Plan identifies loss of pocket estuary habitats as a limiting factor for Chinook (Beamer et al. 2005, ID175). Juvenile Chinook and Chum were slightly larger in lagoon habitats (pocket estuaries) than adjacent nearshore habitats (Beamer 2007, ID215) and this supports the hypothesis that pocket estuaries provide important rearing habitat with higher growth opportunity than other nearshore habitat landforms (e.g., exposed beaches). In addition, the timing of habitat use and growth rates observed by Beamer (2007, ID215) suggested that pocket estuaries provide important refuge habitat from predators, thereby increasing survival during nearshore rearing life stages.

4.1.2.3 Restoration in estuary and nearshore habitats

Restoration strategies have been identified and implemented to address limiting freshwater, estuary, and nearshore habitats described above (Beamer et al. 2005, ID005). Riverine and floodplain restoration strategies and priorities linked to the Skagit Chinook Recovery Plan are described in the previous sections (Beamer et al. 2005, ID175; SWC 2022, ID451), as well as in the following Section 4.2 Habitat connectivity.

Restoration strategies in estuary and nearshore habitats are primarily focused on restoring tidal connectivity (e.g., through breaching or setting back dikes and replacement or enhancement of tide gates). Restoration of estuary habitats can increase delta rearing fry capacity or nearshore fry rearing capacity in embayments, with landscape connectivity influencing the potential benefits of restoration with respect to rearing capacity (Beamer and Larsen 2004, ID183; Beamer et al. 2005, ID005; Beamer and Wolf 2016, ID186; Beamer and Wolf 2017, ID187). Delta and pocket estuary habitat extents have also decreased and become more fragmented, and restoration opportunities exist for both delta and pocket estuary habitats (Beamer et al. 2005, ID005). Several studies provide evidence for changes in fish densities, growth, and habitat use patterns in the Skagit River estuary related to restoration actions. For example, juvenile Chinook abundance and mean fork length in Fisher Slough upstream of the floodgate increased significantly in years 2012-2013 following the dike setback relative to years 2009-2011 prior to the dike setback. They conclude that floodgate operation and dike setback actions were important factors resulting in the increased habitat use for rearing observed at Fisher Slough (Beamer et al. 2017, ID010), as evidenced by increased relative abundances and size. Mean fork length of juvenile Chinook rearing in Fisher Slough was significantly higher following the dike setback (a 5.2 mm increase based on least squares means of pre- versus post-dike setback), indicating increased growth associated with rearing in the restored habitat. Analyses presented in Beamer et al. (2019, ID013) revealed that juvenile Chinook densities have decreased with increasing restoration as a result of increased habitat opportunities, and the length of residence in the estuary has increased with increasing restoration. Some support was also found for reduced frequency of fry migrants in marine habitats and increased smolt to adult return rate with increasing restoration. Collectively, these findings support the hypotheses and questions addressed by the Skagit River Intensively Monitored Basin and Skagit River Chinook Recovery Plan that estuary restoration can address limiting factors and increase habitat capacity and productivity to support salmon recovery.

A sensitivity analysis of the Chinook life cycle model developed for the Skagit River revealed that small changes in juvenile mortality in nearshore habitats contributed the greatest to changes in escapement. Therefore, the model implies that practitioners should focus on strategies to improve nearshore habitat quantity and quality for juvenile Chinook and/or ways to increase survival within these habitats (NWFSC 2003, ID087). Beamer et al. (2007, ID215) reported that *pocket estuaries in northern Skagit Bay have consistently higher juvenile Chinook salmon densities compared to all pocket estuary sites studied within the Whidbey Basin and this was … presumably due to northern Skagit Bay's proximity to the North Fork Skagit River, where large numbers of wild Chinook salmon exit the Skagit River due to loss and simplification of delta habitat*. However, Smith (2003, ID376) indicates that less is known about how alterations to nearshore habitats impact salmonids; therefore, there is more uncertainty regarding the benefits of restoration actions (Smith 2003, ID376).

Actions focused on restoring or protecting estuary and nearshore habitats can benefit all populations in the Skagit, not just those that spawn in the study area. Beamer et al. (2005, ID005) reported that all six Chinook populations in the Skagit River express delta rearing and fry migrant life history strategies and can be found rearing in Skagit delta and pocket estuary habitats; therefore, all six stocks utilize Skagit delta and estuary habitats for emigration as well as rearing for certain life histories. Beamer et al. (2000, ID192) provided evidence from otolith analyses that juvenile Chinook can move between estuary, freshwater, and bay habitats during their early rearing life stages and that rearing patterns are not one-directional from freshwater to estuary to bay habitats. Individuals expressing these atypical patterns rear for a longer duration before migrating to offshore habitats. This also has implications for non-natal habitat use for rearing in estuary and nearshore habitats as well as restoration strategies related to habitat connectivity (Beamer et al. 2000, ID192).

4.1.2.4 Climate change and estuary habitats

Climate change has the potential to exacerbate the issues faced by salmonids in estuary and nearshore habitats. The predicted estuary habitat losses associated with climate change and SLR reported in Beamer et al. (2005, ID005) translate to an estimated losses of rearing capacity of 211,000 and 530,000 smolts, respectively. Invasive plants, such as *Spartina spp.*, *Sargassum muticum*, and *Zostera japonica*, have also altered the vegetation assemblages and sedimentation patterns in Puget Sound, and *Z. japonica* is established in northern Puget Sound and is known to negatively affect native eel grass beds, which are considered essential habitats for juvenile salmon rearing in estuaries (Redman et al. 2005, ID100). Access to historical eelgrass beds and rearing habitat in Padilla Bay through Swinomish Channel is cited as a significant factor influencing estuary rearing for juvenile salmon (Pink, Chum, Coho, and Chinook), and the Swinomish Channel was an important adult migration pathway as they returned to their natal rivers. Hinton et al. (2008, ID174) indicates that *reconnecting the North Fork Skagit River with the Swinomish Channel will allow access to significant current habitat within the channel and in Padilla Bay, and to significant future restoration sites in the Swinomish Channel which are in progress or proposed*.

4.2 Habitat connectivity

4.2.1 Drivers and stressors

Many of the primary drivers identified for habitat extent, which were described in the previous section, also influence habitat connectivity. In river and floodplain habitats, Beechie et al. (2003, ID015) indicated that culverts, dams, and dikes are primary stressors affecting habitat connectivity in the Skagit. Levees prevent flooding and formation of secondary channels, and levee setbacks or removals can increase connectivity to floodplain habitats (Beechie et al. 2010, ID017). Beamer et al. (2005, ID004) found that 31 percent of the floodplain area in the Skagit Basin River basin has been isolated. They also documented over 98 km of hardened stream banks in the mainstem Skagit River reaches, and an average reduction of 28.6 percent in the effective floodplain compared to historical conditions. They found approximately 2 times higher density of off-channel habitats in connected floodplains compared to isolated or shadowed floodplains, and that floodplain gradient and effective floodplain width were significant predictors of off-channel habitat extent among reaches.

Disconnection of rivers from floodplains influences other processes that are drivers of habitat availability and connectivity, including the supply, transport, and storage of water, sediment, and wood (Beechie et al. 2003, ID015). This in turn can constrain the formation and maintenance of floodplain habitats, and streambank modification or hardening can reduce channel migration, large wood recruitment, and connectivity to floodplain habitats through channel narrowing and steepening processes and reduced channel migration. Hydromodification of channel edges can also increase sediment transport rates, reduce edge habitat complexity, and reduce rearing capacity (Beechie et al. 2003, ID015). Beamer et al. (2005, ID175) indicated that the total area of large river floodplain in the Skagit Basin is approximately 14,293 ha. Currently, 31 percent of the total floodplain area is either isolated or shadowed from natural riverine processes (Beamer et al. 2005, ID175). Historically, lower floodplain forest area was 12,297 ha, which has been reduced to 314 ha. Reaches R7 through R11 contain 6,451 ha of floodplain with 37 percent isolated or impaired by roads, hydromodification, or other floodplain structures (Beamer et al. 2005, ID175). More recently, Hinton et al. (2018, ID167) reported that 10,510 ha of total floodplain area was exposed to hydrologic processes in 1998, with 31 percent of the floodplain impaired or isolated by roads or hydromodifications. Total floodplain area was 352 ha greater in 2015, with 28 percent of the floodplain impaired or isolated. Hydromodified length in 1998 was 49,418 m, whereas in 2006 and 2015, it was 41,375 km and 39,886 km, respectively (Hinton et al. 2018, ID167). Beechie et al. (2001, ID365) indicated that side channels accounted for at least 44 percent of channel length in the Skagit and Sauk River floodplains prior to European settlement, and 45 percent of the floodplain side-channel habitat has been isolated or disconnected in the Skagit River basin.

Dams can directly impact fish access to spawning and rearing habitats (Beechie et al. 2010, ID017), although most sources indicated that the Baker River dams are the only dams that block fish passage to historical anadromous habitats (e.g., Smith 2003, ID376). The hydroelectric dams and operations are identified as having the greatest impact on salmonid habitat in the Baker River basin (Smith 2003, ID376). Inadequate life stage flows have been noted downstream of the Baker River facilities, which can extend into the mainstem Skagit River, and an estimated 117 acres of wetlands and ponds, 5 miles of side channel habitat, and 52 miles of tributary habitat have been lost due to reservoir creation (Smith 2003, ID376).

Passage barriers such as culverts and water crossing features limit salmonid accessibility to habitat in the Skagit. Mickelson et al. (2020, ID289) identified culverts as barriers to habitat and as a limiting factor to salmon productivity, with 443 culverts identified in the Skagit Basin. Beamer et al. (2000, ID190) provided information on fish passage barriers that could affect access to spawning habitats, but approximately 70 percent of the barriers identified in their analysis were unconfirmed or had low certainty for barrier classifications. A subsample of water crossing features indicated that 14 percent of features did not meet passage criteria; therefore, they estimate they will find approximately 150 more features blocking fish passage with additional surveys. They found that 44 percent of the historical channels remain accessible to anadromous salmon in their study area. The Skagit Chinook Recovery Plan identified 600 fish passage barriers (circa 2000) that impact access to Chinook habitats (Beamer et al. 2005, ID175). Natural or land use related landslides can also impact habitat connectivity, as noted in Smith (2010, ID352) regarding a landslide that occurred in Goodell Creek in 2003.

In estuary and nearshore habitats, diking, levee building, channelization, jetties, dredging, and large wood removal have also been directly linked to the connectivity of distributaries, tidal marshes, and pocket estuary habitats (e.g., Beamer et al. 2005, ID005; Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196). The reported losses of estuary and nearshore habitats were directly linked to losses of tidal connectivity, as noted in the previous section above, although some changes were related to natural progradation and erosion processes. Pocket estuaries are important for target species during nearshore rearing and emigration life stages, and pocket estuaries are especially sensitive to connectivity impacts. Beamer et al. (2005, ID005) estimated that 68 percent of historical pocket estuaries are inaccessible to juvenile salmon as a result of land disturbances, with all current (n=27) pocket estuaries having some modifications that have reduced usable fish habitat, for a net reduction of 80 percent in pocket estuary habitat area. Distance to the nearest pocket estuary from a natal river mouth was unchanged from historic to current conditions, at 0.96 km. However, the number of pocket estuaries within 9.5 km (the distance a juvenile Chinook can travel in one ebb tide) has declined by 50 percent from historic (n=18) to current (n=9) conditions. Within 25 km of the natal river mouth, the number of accessible pocket estuaries under current conditions (n=14) was 42 percent of historic (n=33).

As with habitat extent, restoration actions in large river, floodplain, estuary, and nearshore habitats have focused on increasing hydrological connectivity or access to key habitats. In both floodplain and estuary habitats, dike and levee breaches can restore partial connectivity to habitats, while setbacks or removals can restore greater connectivity and accessibility to habitats (e.g., Souder et al. 2018, ID115). Tide gate and floodgate removals and enhancements can also increase habitat connectivity and fish access (Souder et al. 2018, ID115). However, restoration sites with muted hydrology or limited connectivity performed poorer than projects that restored connectivity to a greater extent in estuary habitats (Beamer et al. 2019, ID013), and this finding supports restoring full tidal connectivity over partially or muted connectivity with dike and levee removal and setback actions. Studies in the Skagit estuary have found that combining levee setbacks with tide gate restoration can significantly improve hydrological connectivity and fish use (e.g., Fisher Slough Restoration Project, see Beamer et al. 2017, ID010). Restoration of hydraulic connectivity between the North Fork Skagit River and Swinomish Channel is also a priority project in the Skagit Chinook Recovery Plan, and this would increase connectivity and fish passage between the Skagit estuary and Padilla Bay habitats (WWAA 2010, ID159).

4.2.2 Species and life stages

Disconnection or isolation of habitats by levees and culverts has reduced salmon carrying capacities in the Skagit, which includes blocking upstream migrations of adults and movement of juvenile salmon during rearing and outmigration life stages in both freshwater and estuary habitats (Beechie et al. 2003, ID015). Fish passage barriers are a primary factor affecting connectivity or access to habitats during both adult (e.g., migration) and juvenile life stages (e.g., juvenile outmigration and rearing, overwintering). Mickelson et al. (2020, ID289) indicated that culvert crossings constitute the overwhelming majority of known fish passage barriers in Washington State. Multiple sources identify and describe fish passage barriers including culverts and other water crossing structures as well as dams. Smith (2003, ID376) identified high priority and medium priority blockages in the Nookachamps and Hansen Creek basins. They documented 205 barriers and 38 unknown status barriers on streams known or modeled to be used by steelhead in the Skagit River Basinbasin. Using the three-tiered categorization system for Chinook habitat, they found that 66 barriers and 41 unknown status barriers that are within the portion of the Skagit Basin for SWC's Strategic Approach are classified as Tier 1. For Tier 2, there were only six barriers and three unknown status culverts (Mickelson et al. 2020, ID289).

Water velocities can potentially influence fish passage through floodgates, but the duration that floodgates are open has more influence on passage opportunity (Greene et al. 2012; ID051; Souder et al. 2018, ID115). Beamer et al. (2017, ID010) indicated that water velocities support evaluation of passage at the floodgates and habitat use. They reported 0.89 ft/sec as the critical fatigue swimming speed for small Chinook fry, and 1.1 ft/sec is a recommended maximum water velocity for structures like floodgates to enable salmon fry less than 60 mm in fork length to migrate upstream. These thresholds were considered to evaluate measured velocities, but the authors found in previous analyses that passage opportunity was best explained by the duration that floodgates were open during tidal cycles and dropped water velocity metrics from the analyses.

Dams can directly impact fish access to spawning and rearing habitats as well as cause reproductive isolation (Beechie et al. 2010, ID017; Smith 2010, ID352), although most sources indicated that only the Baker River dams block fish passage to historical anadromous habitats (e.g., Smith 2003, ID376). Beechie et al. (2001, ID365) estimated that culverts and other stream crossing structures have reduced rearing capacity by 6 percent in the Skagit River basin, and the construction of two dams on Baker River have reduced Coho winter rearing habitats by about 5 percent, although they estimated this was offset by increased rearing capacity within the reservoir habitats. They also indicated that the upper Skagit River dams do not block passage to historical anadromous habitat and therefore do not influence changes in fish capacity. An estimated 117 acres of wetlands and ponds, 5 miles of side channel habitat, and 52 miles of tributary habitat have been lost due to reservoir creation on the Baker River (Smith 2003, ID376). Beamer et al. (2005, ID175) specifically identified the Lower Skagit Fall Chinook population as being affected by the Baker Lake Hydroelectric Dam, which inundated a total of 68.8 miles of anadromous habitat. Inadequate life stage flows have also been noted downstream of the Baker River facilities, which can extend into the mainstem Skagit River and would presumably reduce the extent or connectivity of habitats and increase direct mortality (e.g., stranding or redd dewatering). Smith (2010, ID352) reported that the location of Diablo Dam caused a migration barrier to Bull Trout resulting in highly differentiated genetics among Bull Trout populations above and below the barrier, indicating total reproductive isolation. They indicated that this is both a result of the dams blocking migration and historical natural gradient barriers at present day Diablo Dam, which probably existed prior to the construction of the dams. None of the Bull Trout collected below the dams originated from populations above the dams, further supporting the conclusion that the populations are isolated (Smith 2010, ID352).

Re-plumbing of streams and river networks, along with migration barriers described above, can also alter or reduce historic migration pathways and associated chemical signals (Redman et al. 2005, ID100). Landslides may create barriers to fish movements and migrations and can influence local straying rates. For example, first generation migrants were detected in Bacon Creek and the Cascade River following a landslide that occurred in Goodell Creek in 2003 that inhibited migration (Smith 2010, ID352). This highlighted the importance of nearby subbasins, and habitat connectivity overall, as supporting refuge habitats following major disturbances and the potential importance of straying among population (Smith 2010, ID352).

Hydromodification, loss of delta habitat and connectivity, loss of pocket estuary and connectivity, and illegal habitat destruction and degradation are all identified as limiting factors for Chinook Salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Channelization can also create physical barriers to migration while also reducing rearing habitat and impair physiological transitions for salmon and Bull Trout in estuary habitats (Redman et al. 2005, ID100). Expression of life history patterns were also linked to density dependent processes occurring during freshwater and estuary rearing and emigration life stages (Beamer 2014, ID218). Fry emigrating to estuary habitats in excess of tidal delta rearing capacity respond by moving downstream to Skagit Bay and bypass rearing in the delta, which have reduced survival compared to delta rearing fry that attain a larger size before emigrating to nearshore habitats (Beamer 2014, ID218). Increased growth and size at bay entry, associated with increased growth opportunity for delta rearing fish, are linked to increased survival to adult return, which supports the importance of increasing delta rearing capacity in the Skagit River estuary (Beamer and Larsen 2004, ID183).

Access to pocket estuary habitat has also been shown to improve nearshore rearing success for juvenile Chinook. The distance to a pocket estuary from distributary mouths and fragmentation of pocket estuaries can influence habitat use for rearing (Beamer et al. 2015, ID008). Pocket estuaries are identified as a potential benefit for exported fry migrants (Beamer and Larsen 2004, ID183; Beamer et al. 2015, ID008), but the amount of pocket estuary habitat and restoration potential are insufficient to resolve the observed density-dependent patterns observed in the Skagit estuary (Beamer and Larsen 2004, ID183). In addition, it is estimated that 68 percent of historical pocket estuaries are no longer accessible to juvenile salmon as a result of land disturbances, with all current (n=27) pocket estuaries in the Skagit Bay having some modifications that have reduced usable fish habitat for a net reduction of 80 percent in pocket estuary habitat area (Beamer et al. 2005, ID005). Beamer et al. (2015, ID008) reported that 24 pocket estuaries were accessible to juvenile salmon in the Whidbey Basin in 2005 and 14 of the 24 pocket estuaries had documented juvenile salmon presence. Based on their mapping, they reported *total pocket estuary habitat accessible to juvenile salmon for the Whidbey Basin in 2004-2006 was 63.30 ha of channel and impoundment combined and a total of 238.30 ha of habitat exposed to tidal hydrology*.

In estuary and nearshore habitats, including pocket estuaries, landscape connectivity is an important structural driver that influences the relative abundance and distribution of juvenile salmon among habitats (Beamer et al. 2005, ID005; Beamer et al. 2007, ID215; Beamer et al.

2015, ID008; Beamer et al. 2016, ID212). Connectivity also influences the potential benefits of restoration actions in estuary and nearshore habitats and can be used to predict carrying capacities or restoration benefits from potential projects (e.g., Beamer et al. 2016, ID212). For example, in the nearshore environment pocket estuaries located within a shorter distance of distributary mouths (e.g., source of juvenile salmon entering the nearshore) have greater potential value than habitats located farther away (Beamer et al. 2005, ID005; Beamer et al. 2007, ID215). Depending on the year, landscape connectivity explained 36 percent to 74 percent of the variation in seasonal juvenile Chinook Salmon density at Skagit River delta long-term monitoring sites (Beamer et al. 2017, ID010). It was also determined that landscape connectivity was an important predictor of density of natural origin Chinook in Greene et al. (2021, ID056), but not necessarily presence, and they also found that blind channels disproportionately supported rearing for natural origin fish (Greene et al. 2021, ID056). Beamer and Wolf (2016, ID186) found that a new distributary that was created by a natural avulsion increased landscape connectivity and resulted in increased export of fry migrants to nearshore habitats.

Swinomish Slough historically connected Skagit and Padilla Bays and was a significant migratory corridor for juvenile Skagit River Chinook Salmon seeking rearing habitat in Padilla Bay. However, *decades of engineering have changed this waterway from a highly complex, braided deltaic distributary wetland to a simplified, yet efficient, navigation channel* (Hinton et al. 2008, ID174). Padilla and Samish Bays are used by independent populations spawning in the Skagit, Stillaguamish, and Snohomish Rivers. Padilla, Samish, and Fidalgo bays were historically part of the Skagit River natal estuary, but alterations to the delta have fragmented the historic connection and they are no longer directly accessible to outmigrating Skagit Chinook. Despite having no natal estuary, the Padilla/Samish Bay subbasin contains large eelgrass beds (most prominently in Padilla Bay), which are important for juvenile salmon in Puget Sound, including Skagit River populations (Redman et al. 2005, ID100). Previous surveys indicated juvenile Chinook Salmon use or enter Swinomish Channel, but abundances are low compared to other areas in the North Fork Skagit marsh habitats. Catches of juvenile Chinook show steady declines with increasing distance northward within and from the Swinomish Channel. The authors cite evidence of density dependence in the Skagit estuary from previous studies, and that juvenile salmon are split between the North and South Fork, which has three times more marsh habitat than the North Fork. Therefore, they postulate that density dependent effects are likely three times greater in the North Fork compared to the South Fork and suggest that restoration is needed in the North Fork despite overall Skagit estuary habitat extent being high (Hinton et al. 2008, ID174).

5.0 LARGE WOODY DEBRIS AND BANK CONDITION

Large woody debris recruitment and retention processes and bank conditions are primary factors that influence habitat use by target species, habitat formation and maintenance processes, habitat availability and connectivity, food availability, water quality, sediment supply and transport, and edge habitat conditions. Bank conditions influence habitat characteristics that are related to habitat preferences and use by target species, and LWD itself plays an important role in edge habitat conditions and fish use patterns (e.g., Beamer and Henderson 1998, ID181). In this section, information from the literature is described for the following factors:

- ***LWD recruitment/retention:*** LWD recruitment and retention, including LWD supplementation and natural recruitment and retention.
- ***Hydromodified banks and channel edges:*** Hydromodified banks (e.g., armoring, pilings, levees) and general channel edge conditions.

5.1 LWD recruitment/retention

5.1.1 Drivers and stressors

LWD recruitment and retention is influenced by several potential drivers and stressors, and LWD itself is a driver for a number of factors identified in this review. Factors that limit the presence of LWD in streams include: (1) low seeding levels, (2) degraded riparian zones, (3) dam operations, (4) sediment and mass wasting, (5) flooding, (6) high water temperatures, and (7) hydromodification (NSD 2017, ID086). Throughout the Skagit River basin, LWD forms key riverine habitat features that have a significant impact on hydraulic processes, geomorphology, and salmonid habitat quality. The depletion of LWD has led to extensive degradation of fish habitats throughout the Skagit River basin and region (Collins et al. 2002, ID418; NSD 2017, ID086).

Historically, LWD removal from channels and navigable waters reduced LWD abundance and distribution (Collins et al. 2002, ID418; Redman et al. 2005, ID100; Lee and Hamlet 2011, ID196; Seixas and Veldhuisen 2019, ID301). Early management practices included large scale “snag removal” or “stream cleaning” operations, with removal of 30,000 snags upstream of the Skagit estuary between 1898-1908 (Redman et al. 2005, ID100). Collins et al. (2002, ID418) reported on archival information that described a log raft on the Skagit River near Mt. Vernon that was *nine meters deep, consisting of from five to eight tiers of logs, which generally ranged from three to eight feet in diameter and existed for at least a century. This accumulation was further described as being large enough to support live trees 0.6 to 1.2 meters in diameter* and greater than 1-kilometer in length. Collins et al. (2002, ID418) also reported that distributaries and tidal channels were described in historical documents as *hundreds of miles of old channels that were choked with wood, filled with sediment, and abandoned.* Historical removal of log jams also reduced connectivity to floodplains and relict side channels in the Skagit River (Seixas and Veldhuisen 2019, ID301).

Recent assessments and studies have reported on current abundances of LWD as an indicator of habitat conditions and processes. Collins et al. (2002, ID418) noted that current LWD abundances and loading in Puget Sound rivers are not reflective of historical conditions and should therefore not be used as reference points for recovery. They suggested that LWD abundance was one to two orders of magnitude more abundant pre-European settlement. Tributaries to the Sauk River were identified as having reduced LWD abundance (Smith 2003, ID376), and assessments suggest there is a lack of large wood in the Skagit River system downstream of the hydroelectric dams (USACE 2010, ID117). ESA (2017, ID039) reported that lack of sufficiently tall trees within active channel riparian zones may also contribute to reduced recruitment of LWD to the mainstem.

Land cover and uses such as logging, agriculture, and development are primary drivers of the reduction of LWD recruitment in the Skagit River (Beechie et al. 2001, ID365; Redman et al. 2005, ID100; ESA 2017, ID039; Seixas and Veldhuisen 2019, ID301). Bank conditions, specifically hardening or hydromodifications and floodplain disconnection, were identified as a primary driver of decreased LWD recruitment and retention by multiple studies (e.g., Collins et al. 2002, ID418; Beechie et al. 2003, ID015). Logging and forestry were also commonly identified as primary drivers of decreased LWD recruitment, causing reduced recruitment of key pieces of LWD large enough to influence habitat formation and maintenance processes in large channels (e.g., mainstem Skagit and Sauk River) (Beechie et al. 2001, ID365). Agricultural, industrial, and residential development also reduce LWD recruitment and retention in both river and estuary habitats (Redman et al. 2005, ID100; USACE 2010 ID117).

In addition to land cover and uses, LWD recruitment is partially driven by tree height (commonly used as a proxy for diameter) and proximity to the active channel (ESA 2017, ID039). ESA (2017, ID039) also reported that no reaches in the mainstem Skagit had over 70 percent >60 ft tree height canopy within 0-40 m of the active channel, which limits LWD recruitment. In contrast, they found that the Sauk-Suiattle had higher percentages of tall trees >60 ft within 0-40 m of the active channel (ESA 2017, ID039).

Fire and vegetation establishment and succession processes are also primary drivers of LWD recruitment (Beechie et al. 2010, ID017). Replanting of riparian forests can increase wood delivery and stream shading (Beechie et al. 2010, ID017; NHC 2013, ID428). Conversely, clearing riparian forest can reduce instream LWD abundance, and the effect can be detected for decades after the disturbance (Beechie et al. 2003, ID015). Bank erosion processes are also partially influenced by riparian vegetation condition, with rooting depths and coverage of old-growth trees in riparian and floodplain habitats being related to channel migration and wood recruitment processes in the Skagit River (Seixas and Veldhuisen 2019, ID301). Seixas and Veldhuisen (2019, ID301) also noted that historical removal of old growth timber in currently active channel migration zones was a contributing factor to continued avulsion risk.

Tree diameter is also a factor that influences the function of recruited wood in river channels. Seixas et al. (2020, ID303) indicated that the size of wood recruited to the channel influenced the potential for formation of key-steps, but the potential was strongly influenced by river size. In Finney Creek, Sauk River, other lower Skagit tributaries, and other Sauk River tributaries, wood within the 40-100 cm (16-39 inches) diameter class had the greatest potential to form key pieces relative to the total piece count associated with step formation in that diameter class. Additionally, wood smaller than 10 cm (4 inches) diameter played a significant role in key-step formation within channels that were less than 2 m (6.6 feet) wide, but this dropped off sharply in wider channels. These findings demonstrated that wood in larger size classes were particularly effective at anchoring steps and were critical for step formation in small headwater channels. The observation that smaller wood in channels less than 2 m wide played a more significant role in key-step formation than in wider channels indicated that potential wood function depends on channel size, even within a small range of 1- to 4-meter (3.3- to 13.1-feet) width channels (Seixas et al. 2020, ID303). However, it should be noted that Collins et al. (2002, ID418) hypothesized that the influence of LWD on habitat processes decreases with increasing channel size. They concluded that this generalization is reflective of the cumulative effects of human actions and not necessarily a process-based mechanism.

Water crossing structures like bridges, culverts, and floodgates are also significant hydraulic control features that can impact the transport, retention, or accumulation of LWD. The Burlington Northern Santa Fe Railway bridge is the most significant hydraulic structure in the lower Skagit River, with a low deck elevation that entraps debris at high flows resulting in debris jams that cause flooding (NHC 2013, ID428). Hydraulic modeling of flooding impacts from the Burlington Northern Santa Fe Railway railroad bridge suggested that debris accumulation is highly variable between and within flood events. Debris accumulation can happen relatively rapidly following or during a flood event. NHC (2013, ID428) suggested that long-term trends will likely result in greater total volume and size of logs becoming entrained during floods, especially as riparian restoration projects along the upstream banks mature and recruit more wood into the river (NHC 2013, ID428).

Instream flows, flow regulation, and Project operations were also identified as a primary driver of LWD recruitment and retention (Redman et al. 2005, ID100; USACE 2010, ID117). Peak flows in the lower Skagit River have been reduced with flow regulation in the upper Skagit River (see Section 2.2 Peak flow), and peak flows are a primary factor influencing bank erosion and channel migration processes, and therefore LWD recruitment. In addition, peak flows can directly influence the transport and mobilization of instream LWD (Redman et al. 2005, ID100; USACE 2010, ID117).

Hydroelectric dams themselves are another factor that directly reduces LWD recruitment to reaches downstream of dams (Redman et al. 2005, ID100; USACE 2010, ID117; NSD 2017, ID086). There is no transport of LWD from above the upper Skagit River dams by either natural or human processes, and assessments indicate that there is a lack of large wood in the system USACE (2010, ID117). Hydroelectric dams with reservoirs for significant portions of the Skagit River drainage area, including the upper Skagit and Baker rivers, have significantly altered the hydrosystem and LWD recruitment and transport. Some wood trapped by the Gorge Dam and Diablo Dam is moved downstream (NSD 2017, ID086), but all large wood trapped by Ross Dam is isolated from the lower river (NSD 2017, ID086). However, the City Light Pre-Application Document (Section 4.5.5) indicates that since 2010, a portion of the large wood that is trapped by Ross Lake is collected in the summer and stored until it can be placed in the river. NSD (2017, ID086) also noted that significant unregulated inputs remain from mainstem reaches downstream of dams and from unregulated tributaries like the Sauk River, which can contribute to LWD recruitment in the lower Skagit River.

Riparian planting and restoration strategies that supplement LWD recruitment or install instream LWD structures (e.g., engineered log jams) have been used to increase LWD abundance and support the associated beneficial processes (Nichols and Ketcheson 2013, ID412; NSD 2017, ID086). For example, Nichols and Ketcheson (2013, ID412) found that LWD restoration strategies in Finney Creek have increased pool areas, residual depths, and channel cross-section areas as well as reduced instream temperatures. LWD placement projects as a restoration strategy can have immediate benefits to preferred fish habitats and can also be used as a supplement for impaired riparian conditions where restoration of riparian habitats would take decades to influence LWD recruitment to the stream (Beamer et al. 2005, ID175).

LWD retention and distribution patterns are also described for the estuary and nearshore habitats in several studies by the Skagit River System Cooperative (SRSC). Factors that influence LWD retention and distribution in estuaries include topography, fetch, elevation, proximity to distributaries and dikes (Hood 2007, ID061; Hood *No Date,* ID065). Preliminary analyses indicated that marsh island size strongly correlates ($R^2 = 0.90$) with total LWD length and count in the South Fork Skagit, and tidal channel size affects wood density and size. There was more total wood on the marsh surface than in channels, but channel density is higher as wood appeared to get trapped in tidal channels, especially smaller channels (Hood *No Date,* ID065). LWD in tidal marsh habitats can significantly influence vegetation assemblages by providing higher elevation colonization surfaces as well as supporting sediment deposition (Hood 2007, ID061), which is described in more detail in the following section.

Climate change is also a potential driver of LWD recruitment and retention, through impacts of changes in basin and riparian vegetation composition and growth, increased fire disturbances, and changes in peak flow and instream flow regimes (USACE 2010 ID117). These processes are described in more detail in Section 6.0 Riparian condition. Changes in LWD recruitment and retention may also occur with climate change impacts on instream flows given that flows influence habitat formation, channel migration, erosion, and other processes that could influence recruitment of wood to the active channel (Redman et al. 2005, ID100; USACE 2010 ID117). Climate change influences on instream flows are described in more detail in Section 2.0 Instream flow.

5.1.1.1 Effects of LWD recruitment and retention on other factors

LWD recruitment and retention influences habitat formation and maintenance processes and a number of the factors, some of which were generally described in the previous section. LWD recruitment itself is also tied to habitat formation processes like channel migration and bank erosion. Wood recruitment and retention can reduce bank erosion rates and enhance island formation (Beechie et al. 2010, ID017; Seixas and Veldhuisen 2019, ID301). Wood retention drives sediment accumulation or sediment supply and transport processes, which in turn can influence channel morphology, formation of pools, and substrate composition (Collins et al. 2002, ID418; Beechie et al. 2010, ID017; Nichols and Ketcheson 2013, ID412; Seixas and Veldhuisen 2019, ID301). LWD removal and reduced recruitment also affects organic matter and nutrient processes, hydrological exchange processes, and bank stabilization processes in nearshore habitats (Redman et al. 2005, ID100).

Interactions between LWD recruitment and retention, geomorphology, and land uses influence the formation and maintenance of pool habitats in the Skagit River. Beechie et al. (2001, ID365) found that reduced wood recruitment has caused the greatest reductions in pool areas in moderate-slope streams (0.02-0.04) in forested terrace tributaries. Beechie et al. (2001, ID365) also reported that reductions in pool areas in rural areas are similar to those in forestry land use areas. They also reported that total pool area has decreased by more than 35 percent in large channels greater than 24 meters wide (e.g., mainstem Skagit and Sauk River), and that retention of key LWD pieces of more than 1-meter in diameter are needed to create stable jams and more deeper pools. Seixas et al. (2020, ID303) also reported that there was a significant correlation between large wood frequency and distance between pools, similar to what has been observed in larger streams. As the frequency of large wood increased, the average distance between pools decreased and they indicated that this emphasized the importance of large wood in headwater streams to form pools (Seixas et al. 2020, ID303). Nichols and Ketcheson (2013, ID412) reported increases in large pool areas, residual and maximum pool depths, and deeper channel cross-sections associated with increases in log jams in Finney Creek. They also linked these changes with reduced in-stream temperatures, improved gravel deposits, and vegetation colonization on gravel bars.

NSD (2017, ID086) also describes how river channel size and LWD interactions influence habitat formation processes in the Skagit River. In narrow, high-gradient, headwater Skagit River reaches individual LWD can span the channel and dominate stream bedform and hydraulics. In wider, intermediate-gradient reaches in the middle of the Skagit River system, LWD no longer spans the channel and is often lodged on the bank, on bars, or in the channel bed. In low-gradient tributaries, single pieces of wood usually do not span channel, but can form snags in the channel that can cause large LWD jams and obstruct large portions of the channel. In the wider, low-gradient Skagit River reaches surrounded by historic floodplain, single pieces of wood can lead to the formation of massive LWD jams that can change the course of the river, block river channels, and induce massive floods.

In the estuary, research suggests that LWD abundance and distribution patterns also influence tidal marsh habitat structure and vegetation. Hood (2007, ID061) found that LWD plays a role in the establishment of shrubs, particularly nitrogen-fixing *Myearica gale* L. (*M. gale*; sweetgale) in the Skagit delta tidal marshes. There was a strong association between LWD and *M. gale*. Sweetgale was very rare on LWD < 30 cm (12 in), more common on LWD between 30-75 cm (12-30 in), and always present on LWD ≥ 75 cm (30 in). The marsh surface was generally 45 cm below mean higher high water (MHHW), suggesting LWD provides a growth platform at an elevation near MHHW and reduces flood stress. The largest and most abundant tree in the marsh averaged only 35.8 cm (14 in), which suggests LWD recruitment from upstream sources is necessary to sustain sweetgale populations in the geomorphologically dynamic Skagit marsh. *M. gale* dependence on estuarine LWD suggests upstream riparian management can affect LWD subsidies to estuaries, with potentially cascading effects on estuarine ecology, particularly community structure, nitrogen dynamics, and secondary marsh production. Based on these findings, Hood (2007, ID061) recommended that long-term estuarine habitat management should include upstream riparian zone management to allow LWD recruitment to the estuary to sustain LWD-dependent estuarine ecosystem structures and processes. The authors suggested that dike breaching actions alone may not be enough to restore marsh vegetation communities given the reduced recruitment of LWD to marshes.

5.1.2 Species and life stages

In general, LWD is a factor that influences habitat use by target species, including salmon and trout, by increasing beneficial habitat characteristics like cover, slow water habitat, refuge habitat, optimal depths, and food availability. As noted above, LWD abundance and features also support habitat formation and maintenance processes that are important for life stages of target species, such as juvenile rearing, adult migration, and adult spawning. These processes include maintenance and formation of pool habitats, off-channel or side channel habitats, and spawning substrates.

Many studies indicated that the abundance of juvenile salmonids was positively associated with LWD and associated habitat features. For example, juvenile Chinook and Coho abundances were significantly correlated (positive) with wood cover, explaining 82 percent and 62 percent of the variance in species abundance, respectively. Among wood cover types, abundances were greatest with rootwads compared to single logs for all species and life stages except subyearling Chum, which preferred aquatic plant and cobble cover (Beamer and Henderson 1998, ID181; Beamer et al. 2000, ID190). Preference of riprap edges and some wood cover types among Rainbow Trout were also reported (Beamer and Henderson 1998, ID181). Beamer (2000, ID191) reported that sub-yearling Chinook use of stream edge habitat with natural wood cover is over five times greater than their use of riprap cover. Similarly, LWD jams and jam-related river features had the highest densities of juvenile Chinook across multiple seasons in the lower reaches of the Skagit River (NSD 2017, ID086).

Given the positive associations between juvenile life stages of the target species and LWD abundance or features, changes in LWD abundance were also linked to changes in abundance or capacity in the Skagit. For example, changes in LWD abundance that translate to changes in pool spacing, pool area, and pool depths as well as habitat complexity influence the abundance of juvenile salmonids, or carrying capacity of instream habitats, as well as suitable holding habitat for migrating adult salmonids (Beechie et al. 2003, ID015; USACE 2010 ID117). Redman et al. (2005, ID100) also indicated that removal of riparian vegetation and LWD can increase physiological stress, reduce viability of summer spawning forage fish, reduce terrestrial insect recruitment, and reduce refuge opportunities for salmon and Bull Trout. Likewise, Beamer and Henderson (1998, ID181) suggested that integration of natural cover types in bank protection, like LWD, can mitigate some habitat capacity limitations caused by hydromodified channel edges.

Estuary habitat formation and maintenance processes are strongly linked to elevation and topography in general, and LWD abundance and distribution in estuary marsh and channel habitat features influence the topography and vegetation assemblages in estuary habitats (e.g., Hood 2007, ID061; Hood *No Date,* ID065). LWD provides important colonization opportunities for marsh vegetation that can influence food availability and cover for target species, as well as influence sediment sorting and retention. As noted, juvenile salmonids prefer slow water edge habitats with optimal velocities, depth, and cover (e.g., Beamer et al. 2005, ID005), and LWD in estuary channels may provide the same habitat benefits as observed in riverine habitats (Hood 2007, ID061; Hood *No Date,* ID065).

5.2 Hydromodified banks and channel edge

5.2.1 Drivers and stressors

Hydromodifications of channel edges and general channel edge characteristics were linked to habitat conditions and habitat formation and maintenance processes in many studies considered in this review. LWD accumulations along channel edges are an important feature of edge habitat condition and processes, and these were discussed in the LWD recruitment/retention factor section above. This section focuses on hydromodifications and other aspects of edge condition not directly related to LWD.

Hydromodified banks and poor channel edge conditions impair important habitat processes or create impaired habitat conditions. For example, Beamer et al. (2000, ID190) used bank hardening data to classify floodplain process impairments. Hydromodifications are generally cited as a factor that influences disconnected floodplain habitats, increases water and sediment transport rates, and disrupts other natural processes like LWD recruitment, riparian vegetation growth, edge habitat complexity, hydrological connectivity, channel migration, and side- and off-channel development (Beamer et al. 2000, ID190; Beechie et al. 2003, ID015; Smith 2003, ID376). Beamer and Henderson (1998, ID181) also found that natural banks had a higher percentage of area with wood, cobble, boulder, aquatic plants, and undercut banks compared to hydromodified banks. Wood cover increased along hydromodified banks with increasing time after hydromodifications were constructed, and bank gradient and streamflow discharge were correlated with water surface velocities of bank units (Beamer and Henderson 1998, ID181).

Multiple studies report on the status or distribution of hydromodifications and edge conditions within the Skagit. Hydromodifications of bank edges are generally higher in the lower Skagit River compared to upper Skagit River and Sauk-Suiattle River reaches (ESA 2017, ID039). The lower Skagit River has the most extensive floodplain habitats in the basin (108 square miles), but degradation from dikes and riprap are extensive, with an estimated 62 percent of the mainstem river length from Sedro-Woolley to the mouth hydromodified, and only 10 percent of its length with split channels or forested island habitats (Smith 2003, ID376). In addition, Beamer et al. (2000, ID190) reported 45.6 km of hydromodified edge length upstream of the Skagit delta and 50.9 km of hardened banks in the mainstem upstream of the Skagit delta. In the estuary, dike and levee building, as well as channelization, are the primary drivers of fundamental changes in the spatial arrangement, function, and connectivity of distributaries (USACE 2008, ID355; Lee and Hamlet 2011, ID196). While levees and bank protection are primary drivers of channel alignment and stability in the Skagit estuary, intermittent bank protections in the middle reach of the Skagit River are reported as allowing for active channel migration zones of up to two miles wide (USACE 2008, ID355).

5.2.2 Species and life stages

The Skagit Chinook Recovery Plan identified hydromodifications as a limiting factor for Chinook, with hydromodifications specifically limiting parr migrant production through reduced freshwater rearing habitat capacity (Beamer et al. 2005, ID175). However, the plan also cites hydromodifications as limiting habitat formation processes that further impact rearing capacity for freshwater habitats. Most literature links hydromodifications or channel edge habitat conditions to juvenile life stages of salmon and trout. However, the influence of edge conditions such as armoring and levees significantly influences habitat formation and maintenance processes as well as aspects of connectivity that can impact multiple life stages.

In general, juvenile salmon and trout prefer channel margin habitats with optimal depth, velocity, and cover over mid-channel habitats (Beamer and Henderson 1998, ID181; Beamer et al. 2005, ID004; Beamer et al. 2005, ID005; Beechie et al. 2005, ID014). Many studies reported significant differences in habitat use by target species among channel edge types (e.g., Beamer and Henderson 1998, ID181; Beechie et al. 2005, ID014; Smith et al. 2011, ID111). Many studies reported LWD as an important component of edge habitat use, with respect to the benefits of cover, depth, velocity, and food availability. This section focuses on the general associations between target species and channel edges.

Hydromodification of channel edges can reduce edge habitat complexity and rearing capacity. Juvenile Coho and Chinook abundances in the Skagit were strongly correlated with wood and other natural cover compared to riprap or rubble commonly associated with hydromodified bank edges (Beechie et al. 2003, ID015). Likewise, sub-yearling Chinook use of stream edge habitat with natural wood cover was over five times greater than their use of riprap cover (Beamer 2000, ID191). Several studies provided quantitative estimates of changes in capacity or abundance related to various aspects of bank or edge conditions. For example, Beechie et al. (1994, ID337) reported that hydromodification, agriculture, and urbanization accounted for 73 percent of summer habitat losses and 91 percent of winter habitat losses with respect to Coho smolt production potential.

Furthermore, fish use of channel margin edge unit types (bank, bar, and backwaters) differed among seasons and species (Beechie et al. 2005, ID014). Bank units had higher densities of all species compared to bar units during the winter, and higher densities of Coho were observed with bank edges in the summer. Chinook, Coho, and Chum had higher densities in backwaters compared to other edge types. Smith et al. (2011, ID111) also reported that the highest densities of juvenile Chinook were found in natural backwater, natural bank, hydromodified backwater, and natural bars. Beechie et al. (2005, ID014) found that Rainbow Trout densities were similar in bar and backwater habitats. Chinook, Chum, and winter Coho Salmon densities were the highest in low-velocity points compared to winter Rainbow Trout, and summer Coho Salmon had comparable densities in low and medium-velocity points. Juvenile Coho Salmon selected low to moderate velocities in the summer but avoided bar units because bar habitats had no cover or was predominantly cobble and boulder coverage. Age-0 and age-1 or older steelhead were evenly distributed along edge habitat types in the summer and evenly distributed across all velocity classes. Chinook and Chum occupied low-velocity areas and used all cover types (Beechie et al. 2005, ID014).

Hydromodified banks generally lack natural features that provide important habitat for fish. Beamer and Henderson (1998, ID181) found that natural banks had a higher percentage of area with wood, cobble, boulder, aquatic plants, and undercut banks compared to hydromodified banks. Wood cover increased along hydromodified banks with increasing time after construction of hydromodifications, and bank gradient and streamflow discharge were correlated with water surface velocities of bank units that influence potential fish use. Beamer and Henderson (1998, ID181) reported the greatest association of fish with wood cover and edge types, but they also reported evidence for some preferences of riprapped edges by Rainbow Trout. Ultimately, the authors of this study recommended that natural cover types be integrated into bank protection strategies to mitigate some hydromodification impacts. Beamer et al. (2005, ID004) recommended restoration strategies to address freshwater rearing habitat limitations for parr life histories that included addressing hydromodifications and restoration or removal of other floodplain disturbances (e.g., dikes and levees, riprap) that hinder river movements, reduce formation of backwaters and other complex edge habitats that freshwater rearing parr prefer, and increasing connectivity to off-channel floodplain habitats important for refuge and rearing.

Shoreline modifications are also cited as having multiple effects on salmon and Bull Trout (Redman et al. 2005, ID100). Shoreline armoring can alter nearshore habitat characteristics, reduce production of prey items, and diminish refuge for juveniles. Overwater structures can reduce primary and secondary productivity, cause potential behavioral changes, and provide potential exposure to contaminants (Redman et al. 2005, ID100).

6.0 RIPARIAN CONDITION

The functional condition of riparian habitats in the Skagit River was described in the reviewed literature sources. A healthy riparian zone was described in Beamer et al. (2005, ID175) as *having vegetation that harbors insects, contributes nutrients, and provides shade and cover for fish.* "Impaired riparian" is a term that was most often related to regulatory or management concerns and was generally described as riparian habitats that do *not function as necessary for fish habitat*. Percent coverage of riparian vegetation was often used as an indicator of riparian habitat conditions. Riparian species composition, seral stage, or stand age structure were also identified as important aspects of riparian habitat condition. The width or extent of functional riparian habitats, the continuity of riparian buffers, instream shading, and the composition or condition of riparian canopies are all primary factors that influence the form and function of riparian habitats. Collectively, these aspects of riparian condition can influence instream habitat processes and condition (e.g., nutrient fluxes, primary and secondary productivity, food availability, thermal inputs, channel migration, sediment supply and transport, and LWD recruitment), and therefore riparian condition is both a factor and a primary driver of other factors considered in this literature review. Many of the drivers and stressors that influence the condition and composition of riparian habitats also influence the extent, continuity, and shading and canopy characteristics of riparian habitats. Therefore, the drivers, stressors, and species and life stage effects are described collectively for riparian condition.

6.1 Riparian condition

6.1.1 Drivers and stressors

Riparian form and functions are generally influenced by regional ecosystem processes. Beechie et al. (2003, ID015) indicated that riparian functions are primarily affected by sparse forests, with shade being a dominant function in the western forested mountain ecoregions of the Skagit River basin. In the coastal forest ecoregions of the Skagit River basin, dense forest primarily affects riparian functions, with wood recruitment being a dominant function. Kammer et al. (2020, ID280) indicated that riparian forests under current conditions in the Skagit River basin are composed mostly of hardwood broadleaf species which do not reach the same heights as native conifers, and consequently provide less instream shading and other riparian functions.

Land uses are a primary driver and stressor of riparian habitat condition and composition. Forestry, development for agricultural, and rural, urban, and industrial land uses were identified in numerous sources as primary stressors of riparian condition (e.g., Redman et al. 2005, ID100; Seixas and Veldhuisen 2019, ID301). Development of lands can generally result in altered hydrology, while development of riparian habitats can have more direct effects on instream habitat conditions (Redman et al. 2005, ID100). Riparian vegetation and composition were frequently described based on percent cover of functional vegetation (e.g., woody or tree species) within a riparian zone or buffer. For example, Hinton et al. (2018, ID167) binned the condition of riparian habitats into three functional tiers: (1) functional vegetation (i.e., woody species present), (2) dysfunctional vegetation (i.e., lawns, invasive species present, and or agriculture lands), and (3) infrastructure (i.e., roads, parking lots, or structures present). Lawrence (2008, ID071) described functional riparian conditions based on cover classes that included barren pasture, grasses, sparse trees, dense trees, no vegetation, sparse shrubs, dense shrubs, or tall trees.

Both the extent and continuity of riparian habitats are primary factors for the form and function of riparian habitats, and they are used as indicators of riparian habitat condition in the Skagit River basin (Beechie et al. 2017, ID018; Hinton et al. 2018, ID167; Stefankiv et al. 2019, ID112). The impacts of riparian habitat extent and continuity are in part linked to the age or height of tree cover within the riparian zone, as this influences both instream shading potential as well as recruitment of LWD to the stream (Lawrence 2008, ID071; Kammer et al. 2020, ID280). Beechie et al. (2017, ID018) and Stefankiv et al. (2019, ID112) described habitat status and trends monitoring protocols, which include evaluating the percent cover and contiguous width of forested riparian cover as indicators for salmon habitat status and trends.

Hinton et al. (2018, ID167) provided habitat status and trends for riparian conditions for many tributaries to the lower Skagit River from 2006-2015. They found that percent functional vegetation increased from 70 to 72.4 percent from 2006 to 2015, increasing in Finney Creek but decreased in Illabot Creek, Diobsud Creek and Lower Sauk tributaries. Infrastructure remained steady at 3.9 percent from 2006 to 2015, increasing in Illabot Creek and Lower Sauk tributaries but decreased in Diobsud Creek. Finney Creek remained steady. Dysfunctional vegetation decreased from 26.1 to 23.6 percent from 2006 to 2015, decreasing in Finney Creek, but increasing in Illabot Creek, Diobsud Creek, and Lower Sauk tributaries (Hinton et al. 2018, ID167).

Smith (2003, ID376) also reported on riparian conditions for tributaries to the lower Skagit River, with “poor” riparian conditions identified in Nookachamps, Hansen, Jackman, Gilligan, Finney, Day, and Loretta creeks (Smith 2003, ID376). Riparian conditions in the Baker River subbasin were reported as “good” or “fair” for most subbasins (Smith 2003, ID376). Beamer et al. (1998, ID189) also linked degradation of water quality in Finney Creek, Suiattle River, and Sauk River to riparian conditions and private property issues. Lawrence (2008, ID071) also described riparian conditions for many tributaries, including Nookachamps, East Fork Nookachamps, Lake, Hanson, Carpenter, and Fisher creeks. Beechie et al. (2003, ID015) identified impaired riparian conditions for tributaries to the lower Skagit River and Sauk River, and mainstem channels of the lower Skagit River. The lower Skagit River, including all streams downstream of the Sauk River confluence, are identified as containing the *…most highly degraded freshwater salmon habitat in the Skagit Basin with considerable impacts in every habitat category*, including riparian conditions (Smith 2003, ID376). Beechie et al. (2003, ID015) also noted impaired riparian conditions for mainstem Skagit River habitats. In addition to disconnecting floodplains and disrupting other natural processes, hydromodifications of bank edges influences riparian vegetation growth and composition (Smith 2003, ID376).

Riparian conditions have also been the focus of assessments in estuary and nearshore habitats, with conditions rated as poor along sloughs and streams in the Skagit estuary (WWAA 2010, ID159). Similar to riverine riparian zones, marine riparian zones support important ecological functions including the movement of material from terrestrial to marine systems (Hood 2004, ID243). Much of the Skagit Bay’s eastern shoreline and the much of the Swinomish Channel have less than 10 percent overhanging riparian vegetation (WWAA 2010, ID159). Beechie et al. (2003, ID015) also identified riparian habitats associated with channels in the estuary as impaired with respect to riparian functions.

Restoration is a primary driver of riparian condition and composition, with restoration strategies actively focused on protecting or planting in riparian habitats. Degraded riparian zones were identified as a limiting factor for Chinook Salmon in the Skagit Chinook Recovery Plan with respect to pool-riffle spawning and rearing habitats (Beamer et al. 2005, ID175). Riparian restoration and protection have therefore been a focus of recovery efforts in the Skagit River basin (e.g., Beamer et al. 2005, ID175). Restoration actions that can benefit riparian habitats include fencing riparian areas to reduce grazing pressure, protecting riparian buffers associated with logging or other land uses, or planting trees. However, it is noted that riparian restoration strategies often take decades before benefits are realized with respect to improved habitat form and function (Beamer et al. 2005, ID175). For example, LWD placements is a strategy for addressing impairments in the short term, given that riparian planting will take decades to improve LWD recruitment.

Lawrence (2008, ID071) described effectives of shade from current and site potential riparian vegetation in Carpenter, Fisher, Hansen, Lake, East Fork Nookachamps, and Nookachamps creeks to simulate potential climate change impacts. Assuming a 2 percent reduction in minimum flows associated with climate change, predicted increases in instream temperatures with current riparian vegetation were negligible in Nookachamps Creek (0.06°C increase). With riparian vegetation at one site potential tree height, which would optimize shading potential, 2 percent reductions in minimum flows resulted in simulated increases of 0.04°C, which represented a small (0.02°C) difference between riparian condition scenarios. However, this study did provide evidence that tree height and shading potential in riparian zones can influence instream temperatures as well as vulnerability to climate change.

Climate change is expected to impact vegetation communities, specifically the composition of tree and vegetation communities, as a result of drier and warmer summers. Drought-susceptible species such as western red cedar may be more sensitive to climate change and forecasted future conditions will likely favor forest pest species, diseases, and wildfire (Lee and Hamlet 2011, ID196). USACE (2010 ID117) also reported that climate change could result in changes in basin and riparian vegetation composition which could impact LWD recruitment. Fire frequency and intensity can also influence the condition and composition of riparian habitats (Beechie et al. 2010, ID017), and fire frequency and intensity are also potentially influenced by climate change. In general, fire influences successional processes and can reset the seral stage of riparian communities, influence litterfall and shading processes, and influence LWD recruitment and sediment supply and transport (Beechie et al. 2010, ID017). Beechie et al. (2010, ID017) stated that *seedling establishment, tree growth, and succession drive reach-scale riparian plant assemblages,* and these can be strongly influenced by fire frequency and intensity.

6.1.1.1 Effects of riparian condition on other factors

Many studies reported on the linkage between riparian conditions and instream temperatures and sediment supply and transport conditions (e.g., Smith 2003, ID376; WWAA 2010, 159; Kammer et al. 2020, ID280). For example, many of the same basins with summer temperature problems in Smith (2003, ID376) also had impaired riparian and sediment conditions, which were contributing factors to water quality issues in lower Skagit River tributaries. Removal of riparian vegetation/LWD can alter organic matter input, increase light and temperature, alter hydrologic and sediment transport processes, alter groundwater delivery to nearshore, and reduce bank stabilization (Redman et al. 2005, ID100). Likewise, riparian condition can influence food availability through both primary and secondary production (Smith 2003, ID376; Redman et al. 2005, ID100).

The condition and composition of riparian habitats can influence bank erosion and channel migration processes (e.g., Seixas and Veldhuisen 2019, ID301), while bank erosion and channel migration processes also directly influence the condition and composition of riparian habitats. For example, Seixas and Veldhuisen (2019, ID301) indicated that riparian logging practices that historically removed old growth trees along channel banks, decreased the overall rooting depth of floodplain vegetation and increased the likelihood for undercutting of banks. Clearing riparian forest can influence large wood recruitment to streams, which influences the characteristics and complexity of instream habitats, and the effects of clearing can result in reduced LWD abundance and recruitment for decades after the disturbance (Beechie et al. 2003, ID015).

Studies also linked forest cover in general and within riparian zones as a factor that influences hydrology and instream flows (e.g., Redman et al. 2005, ID100). Immature forest cover was correlated with increased peak flows in mountain and tributary basins (Beechie et al. 2003, ID015). Immature forest cover was cited as a factor that can increase runoff rates during snow melt due to increased snow accumulation, as well as reduce interception of rainfall, allowing it to be rapidly transported to tributaries (Beechie et al. 2003, ID015).

6.1.2 Species and life stages

Degraded riparian zones were identified as a limiting factor for Chinook Salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) evaluated riparian zones for each Skagit Chinook population and found that multiple Chinook populations experience significantly to heavily degraded riparian conditions, including Lower Skagit Fall Chinook, Upper Skagit Summer Chinook, Lower Sauk Summer Chinook, and Suiattle Spring Chinook. Upper Sauk Spring Chinook experience moderate degradation and Upper Cascade Spring Chinook experience little riparian degradation. Mature or functioning riparian habitats support pool and riffle habitats that are key for spawning adult Chinook and rearing juveniles (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) indicated that improved functional riparian habitats or maturation of riparian habitats will *…increase the pool-riffle habitat and bank cover for rearing juveniles, and can provide additional capacity not just for spawners, but also for producing parr migrants for which existing capacity is limited. In addition, the recovery plan also indicates that …land use activities that eliminate riparian habitats disrupt the natural recruitment process, limiting spawning and rearing habitat.*

Like the Chinook Recovery Plan, many studies linked degraded riparian conditions to potential impacts on target species through altered habitat processes (e.g., Beechie et al. 2003, ID015; Redman et al. 2005, ID100; USACE 2010, ID117). For example, impaired riparian conditions were linked to levees and hydromodifications that impair river processes as well as riparian condition. USACE (2010, ID117) indicated that *continued maintenance and construction of levees as it exists now… would further constrain the river* which would consequently create less complex habitat, decrease benthic invertebrate habitat, decrease further off-channel habitat, and increase river speeds during high flow events. This would also further decrease LWD retention and create thinner riparian corridors. This ripple effect would *directly affect ESA listed species that depend on cold, clean water, organic detritus and benthic invertebrates for food, and LWD and bank complexity for cover.* Similarly, impaired riparian vegetation linked with shoreline modifications are also an issue, and shoreline shading is identified as an important factor for forage fish spawning habitat in the nearshore environment (Smith 2003, ID376). Forage fish species are not target species for the Skagit River Relicensing SY-01 Synthesis Study, but forage fish are an important food source during estuarine and marine life stages for target species.

More directly, riparian conditions influence instream shading and temperatures (e.g., Lawrence 2008, ID071; Kammer et al. 2020, ID280). As noted previously, Beechie et al. (2003, ID015) indicated that riparian functions are primarily affected by sparse forests with shade being a dominant function in western forested mountains of the Skagit River basin. Kammer et al. (2020, ID280) reported that inter-annual temperature variability was strongly correlated with Air Temperature Index but not with Drought Index or SWE, emphasizing the impact of direct solar radiation on summer instream temperatures, which is directly related to riparian habitat condition. It was noted in Kammer et al. (2020, ID280) that riparian forest canopies under present day conditions are composed mostly of hardwood broadleaf species, which do not reach the same heights as native conifers, and consequently provide less instream shading (Kammer et al. 2020, ID280). Instream temperature effects on target species are described in Section 7.0 Water quality.

7.0 WATER QUALITY

Water quality represents multiple factors that describe instream habitat conditions, which are influenced by a suite of potential drivers and stressors. Furthermore, water quality factors themselves can influence other factors. For example, turbidity is related to sediment supply and transport, and factors such as dissolved oxygen and temperature influence food availability through primary and secondary production. In addition, factors such as temperature influence chemical, physical, and biological processes which can affect other water quality factors such as dissolved oxygen, contaminants, and solubility related factors.

In general, climatological regimes, hydrological regimes and instream flows, land uses and cover, sediment supply and transport, and riparian conditions are primary drivers of water quality factors. Major habitat impacts associated with water quality were linked to land cover in general, mostly occurring where land use was predominately agricultural, urban, or private/state forestry (Smith 2003, ID376).

Water quality impairments and issues of concern were identified for habitats within the study area, although water quality within the general Skagit River basin was reported as *high* or *excellent* for most areas (FERC 1980, ID439). Multiple studies identified water quality concerns in the lower Skagit River, tributaries to the lower Skagit River, Skagit estuary, and Skagit and Padilla bays. For example, Smith (2003, ID376) noted degraded water quality in the lower Skagit River mainstem linked to various types of development or land uses. Water quality in lower Skagit River tributaries was described as …*worse than the mainstem Skagit River and all other Skagit sub-basins* (Smith 2003, ID376). Most tributaries to the lower Skagit River have elevated summer temperatures (including Nookachamps, Hansen, Wiseman, Day, Finney, and Jackman creeks), and elevated nutrients, low dissolved oxygen, increased turbidity, and potential contaminants (five potentially toxic organic compounds, lead, copper, and zinc) of concern in Nookachamps Creek (Smith 2003, ID376).

In Finney Creek, Suiattle River, and Sauk River, degradation of water quality is a principal issue of concern for salmonids (Beamer et al. 1998, ID189). Most streams inside agricultural zones of the Skagit River basin have water quality conditions that are considered subpar for salmonid populations, recreation, and downstream shellfish resources. Most of the substandard water quality occurs in slow-moving agricultural sloughs and in creeks that have low flow in the warner months (Jackman 2020, ID109). Beamer et al. (2000, ID190) also provided information on water quality impairments within the Skagit River basin based on Ecology's Candidate 1998 Section 303(d) Impaired and Threatened Water Bodies listings, which were based on listing parameters for dissolved oxygen, fecal coliform, fish habitat, and temperature. USACE 2010 (ID117) also identified reaches that were on the Ecology's 303d list due to not meeting the state's water quality standards for fecal coliform, high temperature, pH, and dissolved oxygen. Turbidity, sediment runoff and chemical contamination and nutrients were also listed as areas of concern for mostly lower reaches within the Skagit River basin (USACE 2010, ID117).

In general, water quality parameters such as dissolved oxygen, temperature, turbidity, nutrient loading, and levels of toxic substances are critical to salmon health and survival (Beechie et al. 2003, ID015). The following sections describe information on water quality factors based on the reviewed literature which include the following factors:

- ***Instream temperature general:*** General instream temperatures.
- ***Instream temperature maximum:*** Maximum instream temperatures.
- ***Instream temperature minimum:*** Minimum instream temperatures.
- ***Dissolved oxygen:*** Dissolved oxygen concentrations.
- ***Organic matter and nutrients:*** Organic matter inputs (e.g., leaf litter, and carcasses) and nutrient inputs and concentrations (e.g., phosphorous, nitrates).
- ***pH:*** Instream alkalinity or acidity, power of hydrogen.
- ***Turbidity:*** Instream turbidity, suspended particles in water.
- ***Salinity:*** Instream salinity associated with marine water influence.
- ***Bacteria and pathogens:*** Fecal coliform or other bacteria and pathogens in water.
- ***Contaminants:*** Heavy metal, pesticide, or other toxic pollutants.

7.1 Instream temperature general

7.1.1 Drivers and stressors

Lawrence (2008, ID071) provides a conceptual model for pathways of human influence on instream temperatures. The model identified riparian management, upland management, water withdrawals, channel engineering, and dam operations as stressors to instream temperatures. These interact with other processes like LWD recruitment and retention, sediment supply and transport, groundwater exchange, and instream flows.

At a large scale, climatological processes and instream flows are a primary drivers of instream temperatures (Lawrence 2008, ID071; Beechie et al. 2010, ID017; Austin et al. 2021, ID446). This includes the timing, magnitude, and duration of rainfall and snowfall, and the accumulation and melting of snowpacks and glaciers in the Skagit River basin (e.g., Lee and Hamlet 2011, ID196). Instream temperatures generally follow seasonal instream flow patterns, and seasonal variations in solar insolation and advective heat transfer to the water column influence water temperatures (Beechie et al. 2010, ID017). Exchange of water between surface and hyporheic flows can also regulate stream temperatures at the scale of habitat units and reaches (Beechie et al. 2010, ID017).

Many studies linked instream temperatures to riparian conditions via instream shading and interactions with light/heat inputs (e.g., Beechie et al. 2003, ID015; Redman et al. 2005, ID100; Kammer et al. 2020, ID280). Land use and cover, particularly riparian conditions, are the primary factors affecting local stream shading at habitat unit and reach scale (Beechie et al. 2003, ID015; Redman et al. 2005, ID100; Beechie et al. 2010, ID017). Landslides and logging were also implicated in stream widening and loss of riparian shading that can exacerbate stream warming patterns (Kammer et al. 2020, ID280).

Instream temperature patterns were also linked to flow regulation, which is potentially related to both regulation of instream flows and reservoir storage and releases. Austin et al. (2021, ID446) reported that the magnitude of increasing temperatures over time was linked to elevation and position relative to hydroelectric dams in the Skagit River. In August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Skagit River

Hydroelectric Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches. Graybill et al. (1979, ID259) indicated that the Skagit River temperature regime is warmer than it was before the dams were present. Gislason (1980, ID406) reported that instream temperatures in the Skagit were generally higher than in the Sauk River from October – December, while temperatures were generally lower in the Skagit River from February – September. These patterns were related to reservoir release patterns and seasonal hydrological regimes (e.g., glacial melt) in the basin. However, Beamer et al. (2005, ID175) noted that given the withdrawals from Ross Lake are taken from below the thermocline, there is little room to influence instream temperature patterns with respect to cold-water inputs to the upper Skagit River. The effect of flow regulation on instream temperature patterns may extend to the Skagit River estuary, but effects occur in combination with water uses and other factors affecting instream flows that interact with the balance of river and tidal forcing in the estuary (Redman et al. 2005, ID100).

Geomorphic processes, with aspects of gradient and elevation in particular, were linked to instream temperature patterns (e.g., Lowery et al. 2020, ID075). Lowery et al. (2020, ID075) found that geomorphological processes increased instream temperatures to extremes beyond the effects of total annual solar radiation alone. Levees, floodgates, tide gates, and other shoreline infrastructure are also stressors for instream temperatures (Beamer et al. 2015 ID008).

Restoration was also linked to changes in temperature patterns in the Skagit estuary. Beamer et al. (2017, ID010) reported that changes in temperature patterns at Fisher Slough were linked to the dike setback, with new sources of warm water from blind channels that are shallow and unshaded. However, the setback also increased the volume of tidal water exchange that increased cooling effects linked to the dike setback. At Fisher Slough, instream flows, tributary inflows, and tidal exchange interacted to influence temperature patterns. River water tended to be colder than tributary water, and the period when water temperatures were high coincided with the period when tributary inflow was the lowest in Fisher Slough. This suggests that Skagit River water has a stronger influence on water temperature than tributary inflow during high temperature months (Beamer et al. 2017, ID010).

Climate change is also a potential stressor and current driver of temperature patterns in the Skagit River. Austin et al. (2021, ID446) found significant increasing trends in daily maximum instream temperatures for the months of August - October at Mount Vernon (0.05 – 0.02°C/year from 1963-2018), which they linked to climate change. Predicted changes in glacial coverage, snowpack, and the timing, duration, and magnitude of precipitation events with climate change scenarios could result in altered temperature patterns, especially with respect to increased duration of low flow conditions (e.g., Lee and Hamlet 2011, ID196).

7.1.2 Species and life stages

Instream temperature is among the many water quality parameters that were identified as critical to salmon health and survival (Beechie et al. 2003, ID015). Thermal conditions are described for Chinook fry and parr life stages as optimal with surface temperatures of 11-14°C, less than optimal with surface temperatures of 14.1-16°C, stressful with surface temperatures of 16.1-20°C, and negative growth with surface temperatures of ≥20.1°C (Beamer et al. 2020, ID214). In general, instream temperatures influence growth and survival of target species, and temperatures were linked to the periodicity of adult migration and spawning, incubation and emergence, and juvenile rearing and emigration life stages in multiple studies (e.g., Graybill et al. 1979, ID259; Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Kinsel et al. 2013, ID147; Austin et al. 2021, ID446). Cooler temperatures can also increase the duration of the larval lamprey life stage, which can range from 2-10 years (personal communication, Ben Clemens, Oregon Department of Fish and Wildlife).

The periodicity of summer-fall Chinook was reported as being similar to other river systems, with peak spawning occurring in early September (Graybill et al. 1979 ID259). Pink Salmon spawned from the end of September to the end of October, with peak spawning occurring in early October (Graybill et al. 1979 ID259). Chum Salmon spawning period ranged from early November to late December and peaked in early to mid-December. steelhead spawned from March to June, but peak spawning was not well defined (Graybill et al. 1979 (ID259). Finally, Coho spawned from mid-October until mid-January (Graybill et al. 1979 ID259). Studies have documented shifts in the timing of adult migrations that were linked to general changes in instream temperatures, mainly increasing temperatures. Most adult salmonids migrate at temperatures less than 14°C. Salmonids have been observed to spawn at temperatures ranging from 1-20°C, but most spawning occurs at temperatures between 4 and 14°C (Lawrence 2008, ID 071).

For Skagit Fall Chinook populations, median spawn timing has increased at a rate of 0.14-0.84 days/year, while the timing for Sauk River Chinook populations has increased 0.09-1.18 days/year for mainstem and tributary spawners aside from South Fork Sauk River and Dan Creek tributary spawners, which had an earlier shift in timing of -0.05–0.30 days/year (Austin et al. 2021, ID446). Increasing trends in lower Skagit River were linked to increasing mean August temps. Shifts in spawn timing cited for Chum and Coho from other studies in the Skagit supports effects of increasing temperature on shifts to later spawn timing (Austin et al. 2021, ID446). The shift in Chinook spawn timing appears to be an adaptive response at the population level that maintains fry emergence timing rather than shifting to earlier in the year when freshwater and estuarine fry rearing conditions would be less favorable (Beamer et al. 2020, ID214). However, Austin et al. (2021, ID446) reported the lowest shifts in timing for mainstem Skagit River spawning species relative to other nearby river systems, and they attributed this pattern with the cooler and less variable hypolimnetic water released by the dams.

The Skagit Chinook Recovery Plan provided analyses and information that described potential effects of instream temperatures on juvenile salmonids in the Skagit River. Flow regulation, including cold-water reservoir releases, is a potential stressor that could affect emergence timing of food for juvenile salmonids (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) hypothesized that *mainstem dams, due to thermal inertia in the reservoirs and temperature gradients at the depths from which spill is withdrawn, have changed the temperatures downstream from what they were pre-dam*. This would result in instream temperatures being warmer during incubation, and colder in the summer and could *speed up larval development, with the possibility that salmon would emerge earlier than their food is available.* To evaluate this hypothesis, the authors compared Sauk River temperatures to upper Skagit River temperatures on the basis that sufficient pre-dam temperature data were not available, and the Sauk River was representative of free-flowing river conditions similar to what the upper Skagit River would have looked like. Based on those assumptions, they concluded that there was *strong evidence that the mainstem Skagit is now warmer in the fall and early winter, colder from mid-February to May, intermediate in the late spring, and colder in the summer.* However, Beamer et al. (2005, ID175) reported that flow regulation and its influence on instream temperatures does not have a significant effect on Skagit Chinook. Lab studies suggested that the changes in temperatures should translate to a shift in emergence timing of up to two months, but otolith analyses suggested that emergence timing was similar among upper Skagit and Sauk River juvenile Chinook. However, Austin et al. (2021, ID446) indicated that shifts in temperatures of 1°C can result in a shift in emergence timing by a month.

Shifts or differences in the periodicity of juvenile steelhead outmigrations were also documented among tributaries to the Lower Skagit River, which were related to differences in temperature patterns. The results of the 2012 juvenile salmonid monitoring efforts conducted by the Washington Department of Fish and Wildlife (WDFW) showed the median migration (catch) dates of steelhead smolts were much earlier for Bacon and Illabot creeks (April 21st and 25th, respectively) compared to Finney Creek and the mainstem trap (May 13th and 15th, respectively). Trapping locations further upstream or at higher elevations (Bacon and Illabot creeks) had earlier median catch dates than the lower tributary (Finney Creek). steelhead smolt population age structure was different in each sampled tributary. The higher elevation and colder water tributaries of Illabot and Bacon creeks had more age-4 and age-3 smolts than Finney Creek and the mainstem trap. Finney Creek steelhead smolts were the smallest among the trapping locations. They sampled 164 fish for fork lengths and the average size was 155.7 mm. Age structure of Finney steelhead was dominated by age-2 smolts (74.1 percent) followed by age-3 (18.5 percent) and age-1 (7.4 percent). steelhead smolts captured in the mainstem traps averaged 174 mm fork length, the largest among the trapping locations. Scale age composition of smolts captured in the mainstem was 77.1 percent age-2 and 22.9 percent age-3 migrants. No age-1 or age-4 smolts were seen in the mainstem traps. Size of the age-2 smolts captured in the mainstem was significantly larger than those captured at tributary locations. This suggests that age-2 smolts reared in the mainstem Skagit River or other unsampled tributaries are growing faster than those captured in the higher elevation tributary traps (Kinsel et al. 2013, ID147).

Early growth was also identified as an important factor for juvenile salmonid survival, with studies providing evidence of size selective mortality (SSM) for target species. Instream temperatures influence metabolic pathways and, therefore, early growth for juvenile salmonids (e.g., Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114). Thompson and Beauchamp (2014, ID054; 2016, ID114) evaluated patterns of SSM for steelhead from different precipitation zones. They found that SSM was apparent during freshwater and marine life stages. Growth during the first, second, and third years of freshwater rearing strongly influenced SSM leading to the smolt migration, and growth trajectories set during these years appear to have influenced survival in marine environments. Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood. Survival in the marine environment may be driven by an overall higher growth rate set earlier in life, which results in a larger size at smolt migration. They indicated that recent studies have highlighted the importance of survival in marine environments for steelhead, but the locations and modes of mortality for steelhead populations in the Salish Sea have not been conclusively determined. By linking SSM, growth, and life history expression to different precipitation zones within the Skagit River basin, this study provided information to support hypotheses of how climate change could impact Skagit steelhead populations.

Thompson and Beauchamp (2016, ID114) developed a bioenergetics model to examine the factors affecting growth during juvenile rearing that could affect survival. Sensitivity analyses were performed to identify target feeding rates and prey energy densities during the growing season which would improve survival to smolt and adult stages. In growth simulations, temperature was the ultimate constraint on growth potential but incremental increases in feeding rate and prey energy density broadened the temperature ranges at which faster growth was possible. These results suggest that chances of survival to later life stages can be improved by increasing feeding rates or prey energy density during summer months when warm water temperatures facilitate faster growth. Growth in freshwater rearing habitats is crucial to survival into later life-stages. Thompson and Beauchamp (2016, ID114) indicated that climate change has potential to alter the temperature regimes of tributaries in the Pacific Northwest, and understanding the mechanisms affecting growth limitations in rearing habitats can help fisheries managers take actions to improve growth conditions and survival. Given that the authors found temperature to be a significant factor limiting growth, they recommended continued water temperature monitoring to better understand and resolve factors limiting growth.

Temperature patterns in nearshore habitats, and pocket estuary habitats in particular, is an important factor in early growth of juvenile salmon that translated to increased marine survival through size selective mortality. Based on known thresholds for juvenile Chinook Salmon growth, current conditions in most nearshore habitats within the study area provided optimal growth conditions in pocket estuary and rocky beach shore types located farther from rivers (Beamer et al. 2020, ID214). By July and August, temperatures within all the river and pocket estuarine habitats exceed metabolically favorable conditions for juvenile Chinook Salmon, potentially explaining why juvenile Chinook left estuaries for marine waters at this time of year. Beamer et al. (2020, ID214) suggested that growth opportunity for juvenile Chinook Salmon is dependent on their rearing and migration timing such that they utilize each habitat type when temperature and food availability are optimal. Chinook Salmon appear to be adapted to transition from large river estuaries to nearshore habitats as temperatures begin to exceed optimal metabolic thresholds. Under a climate change scenario, where sea surface temperatures increase by 2.2°C, Beamer et al. (2020, ID214) predicted a reduction in the average percent of optimal Chinook habitat across shore types from 16.5 percent to 0.3 percent. This could potentially cause a premature move to more favorable temperatures in nearshore habitats at the expense of increased predation risk.

7.2 Instream temperature maximum

7.2.1 Drivers and stressors

Many of the same drivers and stressors that influence general instream temperature patterns described above also influence maximum instream temperatures. In this section, we describe drivers and stressors as they relate to high water temperatures specifically, which typically occur during summer low flow conditions. With respect to high instream water temperatures, it should be noted that instream temperatures can exacerbate the effects of other water quality factors on habitat quality (Jackman 2020, ID109).

Like general instream water temperature patterns, maximum temperatures were linked to land uses and riparian conditions in particular. Many studies reported on monitoring efforts that identified tributaries with impaired habitat conditions due to high instream temperatures. In tributaries to the Skagit River, high water temperatures were generally linked to riparian conditions, reduced instream flow, and land uses (e.g., Beamer et al. 2005, ID175; McMillan 2018, ID400). Lawrence (2008, ID071) indicated that increasing riparian shade is a crucial factor in the reduction of stream temperatures. Most tributaries to the lower Skagit River have elevated summer temperatures (including Nookachamps, Hansen, Wiseman, Day, Finney, and Jackman creeks; Smith 2003, ID376). Jackman (2020, ID109) reported increasing temperature trends for approximately 25 percent of tributary sites since 2003, with the most notable increases observed in Nookachamps Creek. Kammer et al. (2020, ID280) reported on tributaries that exceeded 20°C between 2008 and 2018 and found that the highest recorded temperatures were observed in lower Day Creek and Finney Creek, and below the outlet of Grandy Lake. Quartz Creek and Dan Creek occasionally showed temperatures above the sub-lethal threshold. These sites all had wide channels with little forest canopy and slow water velocities (Kammer et al. 2020, ID280). McMillan (2018, ID400) reported that logging within the riparian zone of Finney Creek reduced the amount of wood in the stream channel and increased stream temperatures. Baker River tributaries were reported as having "*good*" water quality with respect to instream temperatures except for one subbasin (Smith 2003, ID376). USACE 2010 (ID117) also identified reaches that were on the Ecology's 303d list for not meeting state water quality standards for high temperatures.

Veldhuisen and Couvelier (2006, ID162) evaluated peak summer temperatures and the influence of forest management (i.e., streams in forests, buffers, and or clear cuts) on instream temperature. The four objectives of the study were to: (1) characterize temperature regimes during summer peak temperature period; (2) compare observed peak temperatures to other headwater streams in Washington; (3) compare observed peak temperatures to current and proposed regulatory standards; and (4) evaluate the role riparian logging, shade, aspect, and channel dimensions in influencing temperature change.

Each year had a slightly different monitoring protocol to address their objectives, and their primary findings were:

(1) Lower gradient streams require more shade and wider buffers to ameliorate temperature impacts compared to steeper gradient streams, and buffered streams have a greater daily range than fully forested streams, a pattern which resembles clearcut streams.

(2) Skagit headwater tributaries appear to be more sensitive to temperature increases in warm, dry years than other western Washington systems.

(3) Skagit headwater tributaries show a range of sensitivities to thermal inputs from surface processes (e.g., sunlight, air temperature) and riparian forest conditions (clearcut and debris-flow-scoured streams had significantly higher maxima and wider daily ranges during warm periods than did forested or buffered sites).

(4) 78 percent of their study sites that exceeded the 16℃ threshold (Class AA standards, classified as 7-day average of daily maxima temperatures not exceeding 16℃) had upstream areas impacted by logging.

(5) Study sites that did not exceed 16℃ were 87 percent of forested sites and 52 percent of managed streams.

(6) Buffers that are 10-30 meters of un-thinned forest along each side of headwater streams are effective at mitigating increases in temperature maxima, with sparse or blown-down buffers appearing to provide little temperature mitigation.

(7) Groundwater influences can alter the general pattern of increasing downstream temperatures.

In the mainstem Skagit River, maximum temperatures were reported as being moderated by flow regulation and cold-water reservoir releases in particular. FERC (1980, ID439) reported maximum recorded stream temperatures at Mount Vernon of 18°C with a mean high of 9.4°C, and instream temperatures were higher than pre-dam conditions for the mainstem Skagit River (Graybill et al. 1979, ID259; Beamer et al. 2005, ID175). Gislason (1980, ID406) indicated that instream temperatures in the Skagit River were generally higher than in the Sauk River from October – December, while temperatures were generally lower in the Skagit River from February – September. These patterns were related to reservoir releases and seasonal hydrological regimes (e.g., glacial melt) in the basin, but demonstrated that releases of cold-water from reservoirs moderated seasonal increases in instream temperatures (Beamer et al. 2005, ID175).

Climate change is a potential stressor as well as current driver of increasing instream temperatures (e.g., Lee and Hamlet 2011, ID196; Austin et al. 2021, ID446). Compared to the rest of the Pacific Northwest, instream temperature increases in the Skagit River are expected to be somewhat lower than average (Lee and Hamlet 2011, ID196). Austin et al. (2021, ID446) found significant increasing trends in daily maximum instream temperatures for the months of August - October at Mount Vernon (0.05 – 0.02°C/year from 1963-2018), which they linked to contemporary climate change processes. They found that temperatures have been increasing and the magnitude of increasing temperatures over time were linked to elevation and position relative to hydroelectric dams in the Skagit River. In August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches.

Bandaragoda et al. (2020, ID379) also reported on projected instream temperature increases associated with climate change. Historic daily maximum temperatures during summers were 17.8°C (64.0°F), 19.2°C (66.6°F), and 17.4°C (63.3°F) at the Sauk River above Suiattle, the Sauk River near Darrington, and the White Chuck River, respectively (Bandaragoda et al. 2020, ID379). Daily maximum temperatures were projected to increase by 2-3°C for all scenarios and sites. The Sauk River near Darrington showed the largest potential increase in maximum temperature and the White Chuck River the least (Bandaragoda et al. 2020, ID379).

7.2.2 Species and life stages

High water temperatures were identified as a limiting factor in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175), but river temperatures during incubation were not a limiting factor. High water temperatures can stress Chinook Salmon and result in reduced survival through direct and indirect mortality. High temperatures can also create barriers to migration for both spawning and rearing life stages for Chinook (Beamer et al. 2005, ID175). Wang et al. (2020, ID424) also indicated that Lamprey are sensitive to potential climate change effects on low flow conditions, with inadequate flow during summer and fall months having the potential to *...reduce spawning habitat, prevent access to backwater or side-channel habitats, creating low water barriers, and contributing to mortality if incubating eggs or burrowing larvae are dewatered or exposed to a high temperature or low oxygen environment*. Increased instream temperatures during adult holding can increase metabolic rates and increase pre-spawn mortality for anadromous salmon, trout, and Lamprey (Wang et al. 2020, ID424).

High temperatures generally occur in July and August, which is typically after juvenile outmigration and before adult migration (except for yearling life history Chinook) (Beamer et al. 2005, ID175). However, instream temperatures can exacerbate the effects of other water quality impairments (Jackman 2020, ID109). For example, high water temperatures combined with low levels of dissolved oxygen can affect adult Chinook Salmon within estuaries, sometimes leading to increased spawner mortality and delays in upstream migration (Redman et al. 2005, ID100).

Given that Coho and Chinook Salmon, as well as trout species and lamprey, can express extended freshwater rearing life histories, instream temperatures during the summer after emergence have the potential to influence survival through direct and indirect mortality as well as growth and movement (Beamer et al. 2005, ID175; Wang et al. 2020, ID424). Austin et al. (2021, ID446) documented increasing trends in summer temperatures, but that proximity to the Skagit River Hydroelectric Project moderated temperature increases through cold-water releases.

As noted in the previous section, many studies identified tributary habitats with high water temperatures that were a concern for fish habitat. The Skagit Chinook Recovery Plan identified Carpenter, Cumberland, Day, Fisher, Finney, Hansen, Jones, Nookachamps, East Fork, Nookachamps, Grandy, and Jackman creeks as having impaired water quality due to high temperatures based on Ecology’s 303(d) list of impaired waters (Beamer et al. 2005, ID175). Of these tributaries, Nookachamps, East Fork Nookachamps, Grandy, Day, Finney, and Jackman creeks have significant Chinook production potential, but Beamer et al. (2005, ID175) indicated that *…Chinook are now scarce to non-existent in all of these, except Day and Finney Creeks*. Beamer et al. (2005, ID175) also indicated that high temperatures exceeding 19°C can occur in upper Sauk River downstream of Falls Creek, which can affect the survival of yearling Chinook. In Finney Creek, Suiattle River, and Sauk River, degradation of water quality associated with increased temperatures is a principal issue of concern for salmonids (Beamer et al. 1998, ID189).

Many authors noted shifts in spawn timing by target species that were related to changes in instream temperature. McMillan (2015, ID436) found a potential negative trend between monthly air temperatures and monthly steelhead redds. McMillan (2015, ID437) highlights observations of early emergence in lower Finney Creek due to severely dry and warm conditions in April-May 2015 and draws correlations between high instream temperatures and accelerated egg-to-fry emergence rates. McMillan also suggested wild steelhead may be able to resist late-season temperatures in intermittent tributaries due to the prolific spawning observed after March 15th. Ultimately, increasing instream temperatures and intermittency due to warming conditions, coupled with reduction of hatchery steelhead, may promote natural selection toward earlier entry and spawning for wild steelhead in the mid-Skagit River basin over time. Shifts in spawn timing for Coho and Chum were also linked to changes in instream temperatures, which were generally influenced by climate change and hydroelectric operations (Austin et al. 2021, ID446). Graybill et al. (1979, ID259) also reported earlier timing for Skagit River Chinook fry emergence, about one month earlier than Sauk River and Cascade River fry, that was associated with increased temperatures after dam construction. They indicated that the early emergence of Chinook from the Skagit River appears to coincide with less favorable environmental conditions for rearing (Graybill et al. 1979, ID259).

Generally, water temperatures explained habitat use for juvenile Chinook in estuary habitats, but the relationship varied among years (Beamer et al. 2017, ID010). As noted in the general instream temperature section, temperatures can influence estuary and nearshore habitat use and biological responses of target species (e.g., Beamer et al. 2020, ID214). Increasing temperatures increase metabolic rates and growth rates for estuary rearing Chinook Salmon (Sobocinski 2004, ID176). Redman et al. (2005, ID100) indicated that water temperatures affect growth rates, with warmer temperatures increasing early growth and shifting arrival of fry migrants to estuary and nearshore habitats, which can influence estuary and nearshore rearing and emigration patterns.

At Fisher Slough, restoration actions, including dike setbacks and tide gate operations, were linked to changes in temperature patterns. Beamer et al. (2017, ID010) suggested leaving floodgate doors open during times when juvenile Chinook Salmon are present and water temperatures approach their lethal limit. They also recommend floodgates only be closed after times when water temperature has peaked, when flows are still low, and when juvenile Chinook Salmon are not present, most likely in September of each year.

As with general instream temperatures, maximum temperatures are sensitive to climate change. Some climate change scenarios (NorWeST project) predict that August temperatures may reach 18-20 ºC in 24 km of the South Fork Skagit River and in parts of Hansen, Day, and Finney creeks by the 2080s (Woodward et al. 2017, ID121). Areas of the Nookachamps may reach temperatures as high as 20 – 30 ºC (Woodward et al. 2017, ID121). These results suggested that instream temperatures may exceed thermal tolerances for target species and therefore influence survival, periodicity, and movement.

7.3 Instream temperature minimum

7.3.1 Drivers and stressors

As noted for general instream temperatures, instream temperature patterns were linked to flow regulation and large-scale climatological regimes and processes. Austin et al. (2021, ID446) reported that reservoir releases moderated summer temperature increases, with August and September temperatures being the lowest in the upper Skagit River mainstem closest to the Project, while the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches. However, Graybill et al. (1979, ID259) indicated that the Skagit River temperature regime is warmer that it was before the dams were present. Beamer et al. (2005, ID175) also indicated that the Skagit River is generally warmer than pre-dam conditions as evidenced by comparisons to the Sauk River. However, cold water releases from reservoirs influences instream temperatures during incubation life stages, with cold water being released from reservoirs below the thermocline (Beamer et al. 2005, ID175).

Climate change and trends in glacial retreat (also described in Section 2.0 Instream flow) are identified as drivers of instream temperatures and specifically seasonal minimums. Glacial retreat since 1900 has resulted in a 50 percent reduction in total glacial area and has been more rapid on the wetter, western side of the Skagit River basin than on the drier, eastern side (Lee and Hamlet 2011, ID196). These patterns may be exacerbated by climate change processes and result in further changes in the hydrological regime in the basin. Changing glacial inputs could influence the timing and magnitude of seasonal minimum instream temperatures. However, climate change will cause increasing temperatures and shifts in the timing, duration, and magnitude of low flow periods which could also contribute to increasing minimum instream temperatures (Lee and Hamlet 2011, ID196).

7.3.2 Species and life stages

As noted for general instream temperatures, increased instream temperature during incubation could speed up emergence timing, and potentially impact survival of juvenile Chinook if juveniles emerge before their food is available (Beamer et al. 2005, ID175). Conversely, cooler temperatures during incubation would increase incubation duration and slow down emergence timing. However, Beamer et al. (2005, ID175) found no significant difference in emergence timing among temperatures based on otolith analyses. Cooler temperatures can also increase the duration of the larval lamprey life stage, which can range from 2-10 years (personal communication, Ben Clemens, Oregon Department of Fish and Wildlife [ODFW]). Cooler water temperatures also influenced early growth rates of steelhead (e.g., Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114). In addition, cold water releases from the upper Skagit River dams were identified as a mitigating factor for shifts in spawn timing observed for target species. Austin et al. (2021, ID446) reported the lowest shifts in timing for mainstem Skagit River spawning species relative to other nearby river systems, and they attributed this pattern to the cooler and less variable hypolimnetic water released by the dams.

7.4 Dissolved oxygen

7.4.1 Drivers and stressors

Dissolved oxygen concentrations correlate with many other water quality parameters described in this review, and this correlation is indicative of physical, chemical, and biological processes that can influence the actual or potential concentration of dissolved oxygen (e.g., Greene et al. 2012, ID052). Temperature is a primary driver of dissolved oxygen concentrations, and studies reported strong correlations between dissolved oxygen and instream temperatures in the Skagit estuary (Beamer and Wolf 2016, ID186) and Skagit Bay (Greene et al. 2012, ID052). Greene et al. (2012, ID052) also found that pH was strongly correlated with dissolved oxygen and temperature patterns, and there were strong regional patterns in nearshore dissolved oxygen concentrations, with seasonal lows occurring in October in Skagit Bay.

Dissolved oxygen concentrations are also influenced by the time of day, with concentrations being lower at night due to algal oxygen consumption in freshwater habitats (Jackman 2020, ID109). Studies also reported strong linkages between dissolved oxygen and organic matter inputs as a result of primary productivity pathways (Redman et al. 2005, ID100; WWAA 2010, ID159). Dissolved oxygen concentrations are partially driven by interactions between organic matter inputs and primary productivity, with excessive nutrient and organic matter loading potentially leading to eutrophication and hypoxia (Redman et al. 2005, ID100; WWAA 2010, ID159). Certain parts of Whidbey basin nearshore habitats are susceptible to low levels of dissolved oxygen due to high nutrient inputs and low circulation (Redman et al. 2005, ID100). Altered hydrology associated with land uses and cover generally influence nutrient loading which can lead to eutrophication and hypoxia in stream and estuary habitats (Redman et al. 2005, ID100). Greene et al. (2012, ID052) also reported that dissolved oxygen concentrations were correlated with land use patterns at a regional scale for nearshore habitats in Puget Sound.

Linkages between restoration and the interchange between tributary inflows, instream flows in the Skagit River, and estuary mixing were found at the Fisher Slough restoration project in the Skagit estuary. Beamer et al. (2018, ID010) reported that dissolved oxygen levels at Fisher Slough were higher in the spring and decrease during the summer and early fall. Dissolved oxygen was not strongly correlated with tributary flow, but models including tributary flow and Skagit River flow metrics better explained dissolved oxygen in Fisher Slough, and higher tributary flow generally resulted in lower dissolved oxygen. Increased duration of floodgate opening also equated to higher dissolved oxygen in Fisher Slough in late spring and summer. Beamer et al. (2018, ID010) found that the dike setback at Fisher Slough resulted in no changes in the average dissolved oxygen concentrations, but minimum dissolved oxygen concentrations were reduced after the dike setback. Changes in temperature after the dike setback potentially caused the observed patterns of dissolved oxygen at Fisher Slough.

In the mainstem Skagit River, dissolved oxygen concentrations were at near saturation, but it was unclear at what location or specific extent this is in reference to (FERC 1980, ID439). Gislason (1980, ID406) indicated that dissolved oxygen concentrations were nearly identical for the Sauk and Skagit rivers, and that the Skagit River is generally highly oxygenated. Flow regulation was also identified as a potential driver of dissolved oxygen concentrations, with reservoir releases potentially increasing dissolved oxygen with cold waters and aeration or reducing dissolved oxygen if sub-thermocline released waters have depressed dissolved oxygen.

Multiple water quality monitoring reports provided information on dissolved oxygen concentrations for tributary or off-channel habitats (e.g., sloughs). USACE 2010 (ID117) identified reaches that were on Ecology's 303d list for not meeting state water quality standards for dissolved oxygen. Jackman (2020, ID109) reported that 8 sites out of 40 near agriculture met the dissolved oxygen standard in 2019 (no change from 2018). Trend analysis indicated that 11 sites have improved dissolved oxygen conditions compared to 2003, and 18 have improved in the most recent 5-year period (Jackman 2020, ID109). Nookachamps Creek was also identified as having low dissolved oxygen (Smith 2003, ID376).

7.4.2 Species and life stages

Dissolved oxygen concentration is among the many water quality parameters critical to salmon health and survival (Beechie et al. 2003, ID015). Low dissolved oxygen concentrations are a concern in terms of water quality and fish habitat in general because it can impact adult migrations (delayed migrations and mortality), incubation (egg to emergent fry survival), and juvenile rearing (survival and emigration).

Hypoxia is generally defined as less than 3 mg/L dissolved oxygen, and the upper limit of biological stress from reduced dissolved oxygen concentrations for higher trophic organisms is 5 mg L^{-1} (Greene et al. 2012, ID052). State water quality standards for dissolved oxygen ranges from 6.0 mg/L to 9.5 mg/L for a single-day minimum measurement, depending on the watercourse type (lowland, marine, other) (Jackman 2020, ID109). Redman et al. (2005, ID100) indicated that dissolved oxygen impairments associated with land uses can cause physiological stress and other sub-lethal effects, or even direct mortality in the case of hypoxia. In the Fisher Slough restoration monitoring project, low dissolved oxygen and high temperatures were found to influence juvenile Chinook absence/presence in the Skagit tidal delta (Beamer and Wolf 2016, ID186; Beamer et al.

2017, ID010). However, these patterns were variable among years and were not consistent factors influencing distribution and habitat use.

Reductions in gravel permeability can reduce water movement around and through egg pockets, resulting in reduced dissolved oxygen levels which may delay embryo development, lead to early emergence, and decrease emergent fry size of Chinook in the Skagit River Basinbasin (Beamer 2005, ID305). Stober et al. (1982, ID402) also reported that substrate size can impact alevin survival by influencing their movements to more oxygenated waters.

High water temperature combined with low dissolved oxygen is a concern for adult Chinook Salmon migrating within estuaries, sometimes leading to increased spawner mortality and delays in upstream migration (Redman et al. 2005, ID100). Low dissolved oxygen from sewage discharges and poor circulation was also cited as a concern for Bull Trout and salmon using Whidbey basin nearshore and estuary habitats (Redman et al. 2005, ID100).

7.5 Organic matter and nutrients

7.5.1 Drivers and stressors

Organic matter inputs, as well as nutrient and chemical inputs, influence physical habitat characteristics, water quality, and primary productivity (Beechie et al. 2003, ID015). Land uses and cover in general, with respect to both riparian condition and overall drainage basin land uses and cover, are drivers or stressors that influence organic matter and nutrient processes or fluxes in stream and estuary habitats (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175). Altered hydrology associated with land uses and cover also influences nutrient loading (Redman et al. 2005, ID100). Redman et al. (2005, ID100) identified municipal, stormwater, cruise ship, and industrial wastewater discharges as stressors that can alter the cycling of carbon and nutrients and shift tropic structures and communities of producers and consumers. Smith (2003, ID376) also indicated that shoreline modifications disrupt nutrient supply and transport processes.

Gislason (1980, ID406) reported that the Skagit and Sauk rivers are generally low pH, highly oxygenated, and low nutrient rivers, with the amount of total nitrate, ammonia nitrogen, and total phosphorous being slightly higher in the Sauk River compared to the Skagit River. Gislason (1980, ID406) reported that water quality samples collected in the upper Skagit River near the Gorge Powerhouse were reflective of low nutrient waters released from the reservoir. However, the effects of low nutrient reservoir releases on the study area or reaches farther downstream from the Gorge Powerhouse were not reported.

Where nutrient and organic matter loading are high or excessive, eutrophication and hypoxia are potential concerns (Redman et al. 2005, ID100; WWAA 2010, ID159). For example, land use in the Padilla Bay drainage area is mostly agricultural (65 percent), and eutrophication was cited as a concern for Padilla Bay (WWAA 2010, ID159). Smith (2003, ID3876) reported degraded water quality in the lower mainstem Skagit River with elevated nutrient levels being linked to urban and highway runoff, wastewater treatment, failing septic systems, and agricultural/livestock impacts. Nookachamps Creek has elevated nutrient levels and the lower reaches of the Skagit River are also areas of concern for elevated nutrients (Smith 2003, ID376; USACE 2010, ID117).

Underlying geology and reach morphology were also identified as drivers of nutrient and chemical inputs (Beechie et al. 2003, ID015). Beechie et al. (2010, ID017) indicated that dissolved nutrients can be delivered to a stream via groundwater and hyporheic exchange. Tree fall and leaf-litter are also drivers of organic matter and inputs, as well as delivery of dissolved nutrients via groundwater flow (Beechie et al. 2010, ID017). Therefore, these processes link organic matter and nutrient inputs to riparian condition as well as drainage area hydrology and land uses.

Nutrient cycles are also mediated by uptake from aquatic and riparian plants, including algal growth (Beechie et al. 2010, ID017; Jackman 2020, ID109). Jackman (2020, ID109) reported that most plant nutrients had moderate levels in natural streams and elevated levels in drainage infrastructure, providing additional evidence for the influence of land use on nutrient loading. In that study, phosphorus was the only nutrient that showed an increasing trend across the Skagit valley, which was notable because phosphorus is an important limiting nutrient for algal growth (Jackman 2020, ID109).

Climate change is another potential stressor for nutrient delivery to streams, with increased nutrient runoff to Skagit Bay and increased frequency of harmful algal blooms and hypoxia events (Lee and Hamlet 2011, ID196). In addition, linkages between instream flows and climate change described in Section 2.0 Instream flow are assumed to potentially influence the timing, duration, and magnitude of organic matter, as well as nutrient inputs and cycles. Similarly, changes in land use patterns, wastewater, and surface water runoff with increasing urban development are expected to negatively influence organic matter and nutrient inputs and cycles (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Redman et al. 2005, ID100).

7.5.2 Species and life stages

Nutrient loading was among the many water quality parameters identified as critical to salmon health and survival (Beechie et al. 2003, ID015). However, nutrient loading and carcass productivity levels were not found to be limiting factors for Chinook productivity in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). From this perspective, sufficient nutrients and carcass inputs are desired to support primary and secondary productivity needed by emergent juveniles during rearing life stages. Leaf-litter inputs are a primary driver of detritus-based food webs which influence primary and secondary productivity (Beechie et al. 2010, ID017).

However, excessive nutrient and organic matter inputs are a potential concern for water quality and target species given the risk of eutrophication and hypoxia (e.g., Redman et al. 2005, ID100; WWAA 2010, ID159). This is described in more detail in the dissolved oxygen section but is linked to nutrients and food web pathways due to the relationships between nutrients, organic matter, and primary and secondary production with eutrophication and hypoxia.

7.6 pH

7.6.1 Drivers and stressors

Gislason (1980, ID406) reported that the Skagit and Sauk rivers are generally low pH, highly oxygenated, and low nutrient streams. Mean annual pH was reported as nearly identical in both rivers (Gislason 1980, ID406). Declining trends in pH have been linked to ocean acidification and climatic processes (e.g., Greene et al. 2012, ID052; Jackman 2020, ID109), but these were not linked to freshwater conditions in the Skagit River. Greene et al. (2012, ID052) reported on a nearshore monitoring program that included water column profiles in Skagit Bay. They found that pH was strongly correlated with dissolved oxygen and temperature patterns, and there were strong regional patterns in nearshore pH conditions. In general, dissolved oxygen and pH in Skagit Bay reached seasonal lows in October.

USACE 2010 (ID117) identified reaches that were on Ecology's 303d list for not meeting state water quality standards for pH. ESA (2017, ID039) also indicated that several reaches in the lower Skagit River basin are listed as impaired for dissolved oxygen, pH, and temperature including Burlington-Sedro, Cockreham, Day Creek, EF Nookachamps, Fir Island, Fisher, Carpenter, Hansen Creek, Mt Vernon, Ross Island, Upper Sauk, Siskiyou, and WF Nookachamps. Lawrence (2008, ID071) reported on water quality monitoring that included pH, and indicated that pH monitoring was recommended for Fisher, Carpenter-Hill Ditch, Nookachamps, East Fork Nookachamps, Lake, and Hansen creeks. WWAA (2010, ID159) reported high pH in Browns Slough (9.2-9.4) with pH increasing as samples were taken closer to the bay.

7.6.2 Species and life stages

Implications of changes in pH for fish species were cited as unclear in water quality monitoring studies (Jackman 2020, ID109). However, Jackman (2020, ID109) suggested that decreasing trends in pH are an indicator of declining water quality and recommended continued monitoring of pH as a water quality indicator for fish habitat. Ocean acidification is also a concern (e.g., Greene et al. 2012, ID052) and may affect marine and estuary food webs by impacting carbonate dependent prey items for target species.

7.7 Turbidity

7.7.1 Drivers and stressors

Turbidity is primarily driven by sediment supply and transport processes, but it can be linked to other factors and processes. For example, sediment supply and transport were identified as a driver of water quality, presumably related to turbidity, but potentially through effects of sediment supply and transport on primary or secondary production (Gislason 1980, ID406; Beechie et al. 2003, ID015). Glacial melting is a primary source of turbidity in the Skagit River system, with seasonal melting contributing glacial flour or suspended fine sediments to reaches downstream of glaciated basins (Gislason 1980, ID406). Therefore, climatological drivers and stressors, including climate change and instream flows, are linked to turbidity.

Turbidity varies geographically within the study area due to differences in glaciated coverage, underlying geomorphology, and sediment supply and transport processes. In general, the Skagit River mainstem is considerably less turbid than the Sauk River (Gislason 1980, ID406). Turbidity was also noted as being 20 times higher in the Sauk River compared to the Skagit River, and these high turbidities were linked to lower overall chlorophyll a concentrations (Gislason 1980, ID406). Within the Sauk River, differences in turbidity between upper and lower reaches are driven by glacial-origin waters from the Suiattle River.

Several glaciated subbasins in the upper Skagit River contribute suspended sediment to the reservoirs where it settles (Gislason 1980, ID406). Therefore, flow regulation and Project operations were identified as drivers of turbidity in the Skagit River. However, unregulated flows from the Sauk River, with higher reported turbidities, are a primary source of turbidity to the lower

Skagit River and the study area. Some studies noted that turbidity is a concern in the lower reaches of the Skagit River (e.g., USACE 2010 ID117) as well as some tributaries (Smith 2003, ID376). Specifically, Nookachamps Creek has elevated turbidity (Smith 2003, ID376). USACE 2010 (ID117) also indicated that with continued logging and other land use practices, turbidity is expected to increase in the lower reaches of the Skagit River and Skagit Bay. However, sediment supply and transport processes are important for tidal marsh habitat formation and maintenance processes, and sufficient sediment supply (including fine sediments as measured by turbidity) and retention are needed to sustain marsh progradation and maintenance rates (e.g., Redman et al. 2005, ID100; Beamer and Wolf 2016, ID186; Grossman et al. 2020, ID057).

7.7.2 Species and life stages

Turbidity is among the many water quality parameters that are critical to salmon health and survival (Beechie et al. 2003, ID015). Woodward et al. (2017, ID121) reported that the effects of turbidity are complex and, at times, contradictory. Turbidity values as low as 18 nephelometric turbidity units can have deleterious effects on fish survival and/or behavior (Woodward et al. 2017, ID121). In addition, effects depend on exposure durations and whether or not pollutants co-occur (Woodward et al. 2017, ID121). PSI and WDFW (2017, ID085) reported that glacial turbidity from the Suiattle River and Whitechuck River may limit egg survival in the lower Sauk River. However, increased turbidities were also identified as a factor that can reduce predation with turbidity acting as a substitute for cover (Woodward et al. 2017, ID121).

High turbidities in the Sauk River were also linked to lower chlorophyll a concentrations (Gislason 1980, ID406) which are an indicator of primary productivity. Therefore, high turbidity may affect food availability for target species. In Finney Creek, the Suiattle River, and the Sauk River, degradation of water quality associated with increased turbidity was identified as a principal issue of concern for salmonids (Beamer et al. 1998, ID189).

7.8 Salinity

7.8.1 Drivers and stressors

Salinity is primarily a relevant factor for estuary and nearshore habitats, although land uses and other factors can influence instream conductivity values and some studies reported specific conductance patterns for freshwater habitats (e.g., Gislason 1980, ID406). This section focuses primarily on salinity in estuary and nearshore habitats.

In estuary and nearshore habitats, salinities generally scale with instream flows (Yang and Khangaonkar 2009, ID336). Yang and Khangaonkar (2009, ID336) found that salinity intrusion in the Skagit estuary scaled proportionally to river flow at the -1/4 power, and that salt intrusion in the North Fork can reach RM 2 under low flow conditions. In contrast, high river flow conditions result in a strong river plume that pushes salt intrusion out approximately 1 km seaward from the river mouth. Yang and Khangaonkar (2009, ID336) also provided potentially useful information on the history of modifications in the Skagit estuary and its delta that have influenced habitat formation and maintenance processes, including the construction of the jetty in 1938 along the northern river bank of the North Fork to prevent sediment transport into the Swinomish Channel (Yang and Khangaonkar 2009, ID336).

Hinton et al. (2008, ID174) also reported that the jetty constructed in Skagit Bay influences mixing of freshwater and saltwater, and historical salinity gradients within the Swinomish Channel (that supported transition of juvenile salmonids) are not currently present (Hinton et al. 2008, ID174). The Swinomish Channel is predominately polyhaline (>18 ppt), while the channels on the west side of the jetty are predominately freshwater (Hinton et al. 2008, ID174).

Flow regulation influences salinity patterns in the Skagit estuary, along with diversions or other water uses that affect flows and the interaction between river and tidal forcing in the estuary (Redman et al. 2005, ID100). Similarly, channelization and re-plumbing of river and distributary flow paths can increase flow rates to the estuary and further influence salinity patterns by increasing the conveyance of freshwater through estuary to nearshore habitats (Redman et al. 2005, ID100).

Climate change may change instream flow conditions and SLR processes and thus is a potential stressor for salinity patterns in the Skagit estuary (Khangaonkar et al. 2016, ID334). The results of a 3-D hydrodynamic analysis of circulation and transport in the Skagit estuary, including the interaction between the interconnected basins of Skagit Bay, Padilla Bay, and Saratoga Passage, showed that expected SLR and lower summer flows in the future will increase salinity in the nearshore environment of the Skagit estuary and result in possible upstream salinity intrusion, but the magnitude of change is predicted to be relatively small. An increase in salinity of ~1 psu in the nearshore environment and a salinity intrusion of approximately 3 km further upstream is predicted in the Skagit River (2008 compared to 2070) (Khangaonkar et al. 2016, ID334).

In contrast to transitional rearing habitats that support juvenile salmonids, saltwater is more of a concern for water uses and agricultural land uses. Saltwater intrusion in groundwater was cited in FERC (1980, ID439) as a concern for floodplains in the Skagit River delta, but current concentrations were low at the time of the report, suggesting minimal effects to groundwater.

7.8.2 Species and life stages

Salinity is an important attribute of estuarine habitats that influences target fish species distribution and habitat use patterns as well as physiological processes (e.g., Beamer et al. 2005, ID005; Beamer et al. 2007, ID007). There were no reported salinity thresholds for Chinook Salmon fry, but Chinook Salmon parr have a salinity threshold of greater than 15 practical salinity units and less than 27 practical salinity units (Beamer et al. 2020, ID214). Juvenile salmonids require transitional habitats to adapt to marine waters, and some species and life histories may rear in estuaries and transitional salinity habitats for weeks to months. Beamer et al. (2007, ID007) reported that habitat type within the Skagit Bay, estuary, and Padilla Bay had the greatest effect on fish assemblages (Chinook, Chum, Coho, and Bull Trout), but salinity also greatly impacts juvenile assemblages and distributions during some months.

Hinton et al. (2008, ID174) indicated that the jetty has altered salinity gradients that supported transitional habitats for juvenile salmonids, with the Swinomish Channel being predominately polyhaline (>18 ppt) and the channels on the west side of the jetty being predominately freshwater. Yang and Khangaonkar (2009, ID336) also documented changes in salinity patterns associated with the jetty that would influence fish distribution and habitat use patterns in the Skagit estuary and nearshore. Similarly, Redman et al. (2005, ID100) indicated that alteration of flows from dams and diversions impact transitional estuarine habitats and can influence Bull Trout and other estuarine dependent species that require transitional habitats to physiologically adapt to marine waters.

7.9 Bacteria and pathogens

7.9.1 Drivers and stressors

Bacterial and pathogen concentrations and prevalence are influenced by a wide range of potential factors, including instream flows, instream temperatures, and runoff from point and non-point sources related to land uses (e.g., agricultural, residential, wastewater treatment). Aquaculture (net pens) were reported as a potential source of diseases, non-native species, and possibly increased nutrient loading which contributes to eutrophication (Redman et al. 2005, ID100). However, no studies reported on the effects of the aquacultural net pen in Skagit Bay.

Most information reported on bacteria and pathogens was related to fecal coliforms. Jackman (2020, ID109) indicated that standards for waterborne fecal coliforms are interpreted using the "most probable number" method (MPN) of bacterial colony counts. State standards set fecal coliform limits based on the geometric mean of the samples taken and the percent of samples that exceed a given threshold (Jackman 2020, ID109). In general, the geometric mean of fecal coliforms cannot exceed 100 MPN, and no more than 10 percent of samples can exceed 200 MPN (Jackman 2020, ID109). Upriver sites may not exceed a geometric mean of 50 MPN, and no more than 10 percent of samples may exceed 100 MPN (Jackman 2020, ID109). Marine sites cannot exceed a geometric mean of 14 MPN, with no more than 10 percent exceeding 41 MPN to protect shellfish beds (Jackman 2020, ID109). Sixteen sites met the state standard for fecal coliforms during the 2019 water year (Jackman 2020, ID109). Eleven sites showed declining trends in fecal coliform compared to 2003. Bacteriological concentrations were cited in FERC (1980, ID439) as variable, with counts of coliform increasing downstream of Marblemount due to residential inputs. USACE 2010 (ID117) identified reaches that were on Ecology's 303d list for not meeting state water quality standards for fecal coliform, which were related to land use patterns.

Bacterial concentrations were found to be associated with land use patterns in Skagit Bay and covaried with temperature, salinity, turbidity, and chlorophyll a concentrations (Green et al. 2012, ID052). This finding was consistent with demonstrated relationships between land use and fecal coliform indicators at freshwater monitoring sites.

7.9.2 Species and life stages

There was speculation that flow regulation and altered thermal regimes downstream of dams could increase the occurrence of some diseases for Chinook (Beamer et al. 2005, ID175). However, there was no evidence to support this speculation; disease was not determined to be a limiting factor for Chinook productivity in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175).

Much of fecal coliform monitoring efforts reported in the reviewed literature related to water quality for anthropogenic uses, and it is unclear how or if fecal coliforms relate to biological responses among target species.

7.10 Contaminants

7.10.1 Drivers and stressors

Altered hydrology associated with land uses and cover influences toxic loading to streams and estuaries (Redman et al. 2005, ID100). Beechie et al. (2010, ID017) indicated that delivery of contaminants, including pesticides from agricultural and industrial land uses, occurs through surface runoff or shallow subsurface flows. Point sources were also identified as a potential source of pesticides and pollutants (Beechie et al. 2010, ID017).

Several monitoring studies provided information on contaminants in the study area. Smith (2003, ID3876) documented degraded water quality in the lower Skagit River mainstem with chronic levels of lead and copper being linked to urban and highway runoff, wastewater treatment, failing septic systems, and agricultural/livestock operations. USACE 2010 (ID117) identified the lower reaches of the Skagit River as an area of concern for chemical contamination. Nookachamps Creek has elevated contaminants, including five potentially toxic organic compounds, as well as lead, copper, and zinc (Smith 2003, ID376). However, chemical water quality in all sections of the Skagit River met US Public Health Service drinking water standards, and toxic and deleterious material concentrations were low (FERC (1980, ID439).

Contaminants also occur in estuary and nearshore habitats of the study area. Land use in the Padilla Bay drainage area is mostly agricultural (65 percent), where sediment toxicity is a concern (WWAA 201, ID159). Loss of estuarine and marsh habitats due to SLR was also cited as a potential stressor for increased delivery of pollutants into Skagit Bay (Lee and Hamlet 2011, ID196). Mining operations can potentially introduce contaminants to basins through surface water runoff and groundwater exchange, but these impacts appear to be primarily upstream of the study area (FERC 1980, ID439; Lee and Hamlet 2011, ID196).

7.10.2 Species and life stages

Contaminants, or toxic substances in general, can affect salmon health and survival (Beechie et al. 2003, ID015). Contamination and contaminant sources can have a multitude of effects on salmon and Bull Trout such as toxicity, mortality, and indirect effects through disruptions to the food chain (Redman et al. 2005, ID100). Delivery of pesticides and other pollutants from point sources was identified as a source of damage to the health and survival of biota in general (Beechie et al. 2010, ID017). Municipal and industrial wastewater discharges and cruise ship discharges can reduce production of high-quality prey items and diminish refuge opportunities. Stormwater discharges can increase sub-lethal and lethal toxicity and increase potential for hypoxia. On-site sewage effluent discharges can increase potential for hypoxia (Redman et al. 2005, ID100). Oil spills and other hazardous chemical spills can reduce immune competence, increase mortality, and cause possible DNA damage (Redman et al. 2005, ID100). Oil spills and other hazardous chemical spills can also result in multiple potential toxic effects to organisms and food chains through bioaccumulation (Redman et al. 2005, ID100). Beamer et al. (2005, ID175) indicates that nearshore juvenile life stages are also susceptible to spills associated with boat harbor or other marina land uses.

8.0 COMPETITION AND PREDATION

Competition and predation are influenced by a suite of potential drivers and stressors, including abundances of potential competitors or predators and factors that can influence those abundances (e.g., instream flows, instream temperatures, habitat extent and connectivity, water quality, and other anthropogenic factors). The Skagit River Chinook Recovery plan evaluated a number of aspects related to competition and predation and concluded that predation by hatchery fish on natural origin fish, birds, marine mammals, and other species, as well as hatchery and general competition were not limiting factors for Chinook production (Beamer et al. 2005, ID175). However, multiple studies provided information on competition and predation that are potentially relevant to the target species and life stages in the study area. This information was generally organized into the following factors:

- ***Predation – avian and mammal:*** Predation on target species from birds or mammals in freshwater, estuarine, and marine habitats.
- ***Predation – fish:*** Predation on target species from other fishes including target species.
- ***Competition – spawning:*** Competition during adult migration and spawning life stages, which may include inter- and intraspecific competition.
- ***Competition – rearing:*** Competition during juvenile rearing and emigration life stages, which may include inter- and intraspecific competition.

Given that the drivers and stressors of competition and predation are closely tied to the biological responses of the target species, the information on drivers and biological responses is combined in the following sections.

8.1 Predation – avian and mammal

Predation by birds and marine mammals is not a limiting factor for Chinook Salmon during freshwater, tidal delta, and nearshore rearing life stages, according to the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). However, predation by birds and mammals can influence survival of juvenile rearing and adult migrating life stages, but additional research is recommended to quantify the potential impacts of these factors (Beamer et al. 2005, ID175). The presence of predators can cause avoidance behaviors, which may lead to indirect or delayed mortality and changes in movement patterns (Beamer et al. 2005, ID175). Predator avoidance behaviors increase energy expenditures and can influence growth rates (Beamer et al. 2005, ID175).

Many potential factors and stressors influence avian and mammal predator abundance, distribution, and predation opportunities. Natural resource management and other anthropogenic factors play a potential role in predator abundance. For example, Beamer et al. (2005, ID175) identified the Marine Mammal Protection Act of 1973 (MMPA) as a contributing factor to increased abundance of potential marine mammal predators. Land uses, hydromodifications, and other infrastructure were also identified as factors that can influence local abundances of avian and marine mammal predators (e.g., docks and piers, haul outs, marinas, overwater structures) (Beamer et al. 2005, ID175).

With respect to avian predation, the evidence points to potential impacts on juvenile life stages of target species. Beamer et al. (2005, ID175) reported that only two bird species, common mergansers and double-crested cormorants, might be significant predators on Chinook in the Skagit, but other species, including great blue herons and western grebes, may also eat salmon species. Cormorant predation has also been observed near schools of juvenile Pink and Chum salmon, but they appeared to target larger fish. Cormorants preferred larger yearling size classes of Chinook, but additional research is needed to determine ecological effects of avian predation on juvenile salmon (Beamer et al. 2005, ID175). Eagle consumption of adult salmon was documented in some studies. Rubenstein et al. (2018, ID411) described phenological relationships between bald eagles and Coho and Chum salmon in the Skagit River. The authors reported a strong correlation between eagle and Chum counts, and the evidence supported consumption of carcasses as opposed to pre-spawn adults.

Approximately 15 marine mammal species are potential predators of salmon, but only two, California sea lions and Pacific harbor seals, have increased in abundance relative to historical conditions (Beamer et al. 2005, ID175). These increases were primarily associated with the MMPA, and pup counts have increased at a rate of 5.4 percent per year since 1975 (Beamer et al. 2005, ID175). California sea lions have been observed consuming both adult and juvenile life stages and tend to congregate where prey abundances are high (Beamer et al. 2005, ID175). This is particularly relevant to hatchery release practices or development of infrastructure (e.g., at potential barriers) that can result in pulses of abundance or congregations of fish that attract predators (Beamer et al. 2005, ID175). However, Beamer et al. (2005, ID175) indicated that California sea lions are generally present for only part of the year, and this may reduce their potential impact on some runs, populations, and life stages.

Pacific harbor seals have increased at rate of 7.7 percent per year and, unlike California sea lions, they remain in Puget Sound all year (Beamer et al. 2005, ID175). Even though Pacific harbor seals prey on both juvenile and adult salmon, salmon comprise a small portion of their diet. However, Beamer et al. (2005, ID175) reported that even at a 5 percent predation rate, seals could consume 350,000 adult salmon per year, given current abundance levels, and therefore there is potential for significant impacts. However, as with avian predation, Beamer et al. (2005, ID175) reported that insufficient pre-development data were available to determine if marine mammal predation represents a limiting factor or constraint on production.

Bears and river otters are also potential mammal predators of target species. However, no information predation rates by these species in the Skagit River was found in the literature reviewed for the Skagit River Relicensing SY-01 Synthesis Study.

8.2 Predation – fish

The Skagit Chinook Recovery Plan indicated that hatchery fish predation in rivers affects freshwater rearing life stages but is not a limiting factor for Chinook Salmon (Beamer et al. 2005, ID175). In addition, the Skagit Chinook Recovery Plan identified competition and predation by other fishes as not limiting Chinook during freshwater rearing, tidal delta rearing, or nearshore rearing life stages (Beamer et al. 2005, ID175). Similar to the impacts of avian and mammal predation, predator avoidance expends energy, and predator encounters can result in delayed mortality and can influence growth and movement. Pocket estuaries and estuary habitats are important predator refuge habitats (e.g., Beamer et al. 2005, ID175).

Potential predatory fishes include non-target species and target species considered in this literature review. Therefore, many of the drivers and stressors that potentially influence the abundance, distribution, and size of target fish species could also influence predatory fishes. Given the potential for interspecific and intraspecific predation among and between target fish species, food availability and predation factors are potentially interconnected, and benefits to one target species from increased food availability may be at of another target species in terms of survival. For example, lower densities of delta rearing Chinook fry represents less foraging opportunity for Bull Trout (Redman et al. 2005, ID100).

Bull Trout and steelhead (or *O. mykiss* in general) of sufficient size were identified as predators of juvenile salmon and trout species, including Chinook salmon (Lowery and Beauchamp 2015, ID074). Bull Trout, steelhead, and Chinook Salmon are managed under the ESA (Lowery and Beauchamp 2015, ID074), and this complicates predator and competitor relationships among these species given that actions benefiting one species may negatively influence others. Juvenile salmon that grow enough to become piscivorous (e.g., Chinook and Coho), including hatchery produced fishes, are also predators of target species. Co-occurrence of species and relative size structure are the primary drivers of predation between target species. For example, predation by Bull Trout (>300 mm FL) on target salmonids (Chinook and trout species) in the Skagit River varied throughout the seasons, but most predation occurred during winter (i.e., the fry emergence period) and spring (i.e., the smolt out-migration period) (Lowery and Beauchamp 2015, ID074). Lowery and Beauchamp (2015, ID074) also detected differences in Bull Trout diets between two years of monitoring, which they attributed to the presence of juvenile Pink Salmon that primarily spawn in odd years. Overall, Lowery and Beauchamp (2015, ID074) suggested that predation impacts on juvenile Chinook (including ocean, subyearling, river type, or yearling life histories) from Bull Trout were likely negligible, but impacts on steelhead were potentially very high. Bull Trout were also noted as feeding on other non-target fish species (dace, sculpins), as well as fish eggs and terrestrial and aquatic insects (Lowery and Beauchamp 2015, ID074). Therefore, Bull Trout have the potential to impact other target species through both direct predation and competition for food resources, while also potentially alleviating interspecific competition from other potential competitors.

Beamer 2007 (ID215) provided further evidence that co-occurrence and size are primary drivers of predation. They reported that while staghorn sculpins were very abundant in lagoon habitats (pocket estuaries), they were not typically large enough to prey on average sized Chinook salmon when juvenile Chinook salmon were present. This finding supports the hypothesis that pocket estuaries provide important refuge habitat from predation during nearshore rearing life stages.

Hatchery release strategies, including fish size at release and the timing of releases, influence predation rates on wild steelhead. Direct mortality is possible if hatchery releases are large enough to prey on wild origin juveniles, and/or large pulses of releases attract other predators (e.g., Bull Trout) that prey on wild origin smolts (Pflug et al. 2013, ID154). Pflug et al. (2013, ID154) addressed concerns about hatchery released steelhead preying upon natural origin steelhead and juvenile salmonids in general. They found that the stomachs of hatchery steelhead smolts contained juvenile salmonids (including Chinook, Coho, Pink, and Chum Salmon), Lamprey, and various invertebrates. However, they noted the absence of juvenile steelhead in the hatchery smolt diet analysis. Pink Salmon dominated hatchery steelhead diets in years with Pink Salmon outmigrations, whereas diets were dominated by other juvenile salmonids in non-Pink Salmon outmigration years. This finding was consistent with Bull Trout diet analyses. Overall, results suggested that hatchery origin steelhead smolts are opportunistic feeders and potentially impact survival of other juvenile salmonids, but do not appear to significantly impact natural origin steelhead juveniles during freshwater rearing and outmigration life stages.

The size of fish released from hatcheries also influences the level of predation pressure on Chinook Salmon as well as intra- and interspecific competition (Redman et al. 2005, ID100). Redman et al. (2005, ID100) reported that competition between hatchery and wild origin fish (including Coho and Chinook) has a negative impact on juvenile Chinook, with hatchery Chinook juveniles tending to be larger than their natural origin counterparts. Redman et al. (2005, ID100) suggested that predation pressure from hatchery origin fishes may be high in nearshore habitats given that larger hatchery origin Chinook dominated nearshore beach seine catches (54-75 percent of all Chinook caught).

Climate change and temperature can also influence predation pressure on target species by influencing assemblages of warm water adapted, non-native predators. Warmer water fish species, and non-native species in particular, can increase in abundance with increasing temperatures and potentially increase both predation and competition pressure (Beamer et al. 2005, ID175). Recreational fisheries for target and non-target species, as well as food planting for game fishes (e.g., bass, bullhead) can also influence predation risk to target species by increasing predator abundance or reducing abundances through fisheries (Lawrence 2008, ID071; Beamer et al. 2005, ID175).

Land uses and cover were linked to predation on target species by other fish and can also influence the abundance of predatory game and non-native fishes (Lawrence 2008, ID071; Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) reported that riprap may provide ambush cover for predatory fish species. However, natural cover from bank edges, LWD, and substrate provide refuge from predators for target species (e.g., Beamer and Henderson 1998, ID181; Woodward et al. 2017, ID121). Factors influencing cover are described in more detail in Section 5.0 Large woody debris and bank condition. Similar to the impacts of avian and mammal predation, congregations of prey fish species can attract predators like Bull Trout, and potentially increase predation risk (Paulson 1997, ID354). Congregations could be the result of infrastructure or natural constrictions or barriers, as well as hatchery release practices that increase local abundances of potential prey (Beamer et al. 2005, ID175).

Lamprey transition from filter feeder to parasitic feeding on fish flesh during their estuary/nearshore rearing and emigration life stages and potentially feed on salmon and trout (Beamer et al. 2015, ID008). This lamprey behavior may not cause direct mortality to salmon and trout, but it potentially has indirect effects.

8.3 Competition – spawning

In general, seeding levels were not identified as a limiting factor to Chinook populations, given that at least three juvenile life stages show rearing limitations (fry, parr, and delta rearing fry) (Beamer et al. 2005, ID175). Similar to predation, co-occurrence is a primary driver of competition during adult migration and spawning life stages. For example, Pflug et al. (2013, ID154) indicated there was opportunity for spatial and temporal overlap in natural and hatchery origin adult spawners, especially in the months of March and April and early spawning populations (e.g., Finney Creek). Stray hatchery spawners have been detected in the mainstem Skagit, Sauk, and Cascade rivers as well as mid Skagit tributaries including Savage, Finney, and Mill creeks. The authors acknowledged that the extent to which hatchery fish residualize and become residents in the Skagit is unclear, based on the data, but this is another possible source of hatchery and natural origin steelhead interaction. If seeding levels approach capacities as populations increase, potential hatchery interactions and competition for spawning habitat could also increase (Beamer et al. 2005, ID175). Restoration actions have also increased spawning habitat areas as part of recovery plans and non-flow actions for the Project (e.g., off-channel spawning habitats created for Chum), but most of these are located upstream of the Sauk River confluence (Smith 2005, ID177).

Studies also examined the potential effects of competition between hatchery-wild hybrids and natural origin fish during spawning (Pflug et al. 2013, ID154). These topics are described in more detail in the Hatcheries section. It is generally hypothesized that hybridization can influence reproductive success, genetic diversity, run timing, or other important demographic factors that could reduce the productivity of natural origin fish. Pflug et al. (2013, ID154) indicated that hatchery managers do not have effective tools to prevent hatchery origin adults from spawning outside of hatcheries, and the temporal segregation strategy (segregated spawn timing) does not appear to be effective at preventing temporal and spatial overlap of hatchery fish with natural spawners in the system or undesired genetic and ecological interactions.

Fish gender and size do not affect the amount of time it takes for fish to reach their spawning location, but earlier tagged adults had longer migration times and tended to spawn in the furthest upstream reaches of the basin (Pflug et al. 2013, ID154). This suggests some level of competition with respect to spawning and potentially holding behaviors. Green et al. (2005, ID050) found no evidence of competition between Pink Salmon and Chinook Salmon in terms of Chinook productivity. Beamer et al. (2005, ID175) also indicated that there was no evidence for redd superimposition or competition for redd space by summer Chinook in the upper Skagit. However, Beamer et al. (2005, ID175) suggested that superimposition, especially in the mainstem Skagit River, should be monitored as populations increase with recovery actions. Superimposition is an indicator of competition for spawning habitat and can impair egg to fry survival because eggs are dislodged or buried when competing redds are constructed on top of existing redds. Similarly, instream flows (and therefore climate change and water uses) and downramping could be potential concerns for spawning habitat competition, as discussed in Section 2.0 Instream flow, whereby reduced flows reduce available spawning habitat.

8.4 Competition – rearing

Competition during rearing primarily influences growth, habitat use and capacities, movement, periodicity, and survival through density dependent or size selective mortality processes. Competition occurs when fish co-occur and compete for the same resources. Hatchery as well as natural origin fishes are potential competitors, as described above. However, the Skagit Chinook Recovery Plan identified competition and predation by hatchery origin and other fishes as a non-limiting factor for Chinook during freshwater rearing, tidal delta rearing, and nearshore rearing life stages (Beamer et al. 2005, ID175). Beamer et al. (2005, ID175) identified freshwater and delta rearing habitat extent and connectivity, rather than direct competition, as limiting, which is described in Section 4.0 Habitat availability and connectivity.

Competition generally drives composition, distribution, and abundance patterns of invertebrate, amphibian, and fish assemblages (Beechie et al. 2010, ID017). For example, Bull Trout feed on non-target fish species (dace, sculpins), as well as fish eggs, and terrestrial and aquatic insects (Lowery and Beauchamp 2015, ID074). Therefore, Bull Trout have the potential to impact other target species through both direct predation as well as competition for food resources. Similarly, competition during rearing and emigration life stages may include inter- and intraspecific competition among target species. Density dependent processes, rearing habitat limitations during freshwater and estuary life stages, hatchery releases, instream flows, instream temperatures, habitat availability, and climate change can all influence the frequency and intensity of competitive interactions.

Density dependent processes, an important aspect of competition, were specifically identified in numerous sources as limiting the productivity of freshwater, estuary, and nearshore habitats in the Skagit (e.g., Beamer et al. 2005, ID175; Volkhardt et al. 2006, ID404; Greene et al. 2021, ID056). These issues are discussed in more detail in Section 4.0 Habitat availability and connectivity section. In general, the lack of rearing habitat availability during freshwater, estuary, and nearshore rearing life stages limits the production and growth of juvenile Chinook in the Skagit. Density dependent effects are most likely occurring in the lower Skagit River and estuary reaches where populations from tributaries and upper basins mix and share rearing and emigration habitats (see Greene et al. 2021, ID056 for the most recent report on these processes). Restoration can be used to increase habitat capacity and reduce negative density dependence effects during freshwater, estuary, and nearshore life stages (e.g., Beamer et al. 2005, ID175; Greene et al. 2021, ID056).

Increased competition for food or habitat during early life stages reduces growth opportunity or rearing duration and increases size selective mortality. For example, growth of steelhead during the first, second, and third years of freshwater rearing strongly influenced size selective mortality leading to the smolt migration, and growth trajectories set during these years appeared to influence survival in marine environments (Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114). Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood, suggesting that early growth rates and competition influence size selective mortality (Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114).

Hatchery releases, and specifically the abundance, timing, and size at release, were all factors that influenced competition during rearing life stages in multiple studies. Hatchery releases/introductions can result in altered food web processes and increased competition for a limited prey base during juvenile life stages (Redman et al. 2005, ID100). Pflug et al. (2013, ID154) found that population growth rates significantly declined as the number of hatchery smolts per spawner increased. Strong negative relationships were detected between cumulative hatchery smolt releases and wild spawner escapement (Pflug et al. 2013, ID154). Pflug et al. (2013, ID154) also reported that outmigration observed at smolt traps in Mount Vernon showed similar timing patterns for wild and hatchery origin steelhead outmigrants, with peaks for both origins occurring in May, although the duration of outmigration was shorter for hatchery origin smolts. The authors indicated that this synchrony in timing was consistent with WDFW management objectives but allowed for direct competition between outmigrating smolts as well as from residualized hatchery fish (juveniles that do not migrate and remain in freshwater) for habitat and food. However, Pflug et al. (2013, ID154) noted the effects of competition between wild and hatchery origin smolts are not well known and additional research is needed to improve hatchery management strategies. Pflug et al. (2013, ID154) recommended reducing the size of hatchery releases and altering the timing of releases to reduce potential competition between hatchery and wild steelhead juveniles.

Potential competition between hatchery and natural origin fish during estuary and nearshore life stages was noted by Pflug et al. (2013, ID154). They reported that hatchery and natural origin smolts occupy the same habitats in space and time, which could lead to competition, resulting in influences on natural origin steelhead growth and survival. Greene et al. (2021, ID056) reported on temporal overlap of hatchery and natural origin juvenile Chinook in Puget Sound estuaries, and they found that peak co-occurrence of natural origin and hatchery origin Chinook for all estuaries occurred between weeks 17 and 36, overlapping with natural origin residence (weeks 10-27). However, the duration of co-occurrence in the Skagit estuary was shorter than in other Puget Sound estuaries (Greene et al. 2021, ID056), suggesting that competition between hatchery and natural origin Chinook during estuary rearing life stages may be less prevalent in the Skagit compared to other systems.

Hatchery interactions and competition may also come from fish produced in other systems, given that juveniles may migrate to non-natal nearshore and estuary habitats for rearing. However, Beamer et al. (2007, ID007) reported that juvenile hatchery Chinook Salmon from other systems were not extensively using Skagit vegetated delta habitat. They reported an influx of hatchery fish from other river systems to Skagit Bay nearshore beach habitat that peaked in July. In Padilla Bay, they noted that nearshore beaches and delta flats had no fish originating from rivers south of the Skagit (Redman et al. 2005, ID100).

Peak flows during incubation life stages, as described in Section 2.2 Peak flow, also has the potential to significantly impact the abundance of juvenile Chinook during rearing and emigration, which could also impact density dependence and competition in the Skagit. Therefore, stressors and drivers of instream flows and peak flows during incubation life stages are linked to competition during rearing and emigration life stages.

Aquaculture has the potential to increase competition and Greene et al. (2021, ID056) noted that aquaculture releases can potentially increase negative density dependence in delta habitats. Aquaculture (net pens and shellfish) was identified as a potential source of non-native species by Redman et al. (2005, ID100) which may increase competition for food and habitat resources (Redman et al. 2005, ID100; Beechie et al. 2010, ID017).

Climate change can also influence competition, with changes in flow and thermal regimes potentially influencing early growth opportunity, rearing duration, and outmigration timing. For example, shifts in climate regimes could alter precipitation patterns that have been linked to early growth in steelhead that in turn influenced size selective mortality (Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114). Instream temperatures, as well as estuary and nearshore temperatures, can influence competition. As noted in Section 7.0 Water quality, temperatures are influenced by many factors, including climate change. Beamer et al. (2005, ID175) reported that when temperatures exceed 22°C, peamouth chubs begin to out-compete juvenile Chinook Salmon. However, temperatures under current conditions rarely exceeded 22°C or did so outside of the normal rearing period for juvenile Chinook. Warmer water fish species, and non-native species in particular, can increase in abundance with increasing temperatures and potentially increase both predation and competition pressure (Beamer et al. 2005, ID175).

9.0 FOOD AVAILABILITY

Food availability is described in the following sections with respect to primary and secondary productivity. Like the competition and predation section above, drivers and stressors of food availability and its impacts on species and life stages are discussed together in this section. Both primary and secondary productivity and food availability in general are influenced by a range of potential drivers and stressors, which include instream flows and flow regulation, habitat availability and connectivity, sediment supply and transport, riparian conditions, LWD and bank conditions, and water quality. Target species themselves can influence food availability, with some target species and life stages preying on other target species and life stages, as described in this section and Section 8.0 Competition and predation.

9.1 Primary productivity

Photosynthesis drives primary production of algae and aquatic plants, and primary production and detritus-based food webs were linked to organic matter and nutrient inputs (Beechie et al. 2010, ID017). Nutrient cycles are mediated by uptake from aquatic and riparian plants, and leaf-litter inputs are a primary driver of detritus-based food webs which influences primary and secondary productivity (Beechie et al. 2010, ID017). Therefore, riparian conditions influence both primary and secondary productivity via instream shading and photosynthesis as well as organic matter and nutrient inputs. Nutrient and salmon carcasses influence both primary and secondary productivity, although they were not determined to be a limiting factor for Chinook productivity in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Larval Lamprey (ammocoetes) may rear in freshwater habitats for 4-10 years (Hayes et al. 2013, ID419; personal communication, Ben Clemens, ODFW). During the larval life stage, Lamprey are filter feeders and are more directly reliant on planktonic food webs compared to juvenile salmon and trout during rearing life stages.

Land use and cover in general and in combination with altered hydrological regimes associated with development were linked to primary productivity. Jackman (2020, ID109) reported that most plants in natural streams had moderate levels of nutrients, and plants in drainage infrastructure had and elevated levels, providing additional evidence for land use linkages to nutrient loading. Phosphorus was the only nutrient that showed an increasing trend across the Skagit valley, which was notable because phosphorus is an important limiting nutrient for algal growth (Jackman 2020, ID109). Altered hydrology associated with land uses and cover influence nutrient loading that can lead to eutrophication and hypoxia in stream and estuary habitats (Redman et al. 2005, ID100). Hydrological regimes generally influence physical habitat characteristics, and water quality influences primary productivity (Beechie et al. 2003, ID015). In general, reducing water level fluctuations by implementing a stable flow regime resulted in higher standing crop of periphyton and benthic insects (Graybill et al. 1979, ID 259). Therefore, primary productivity was linked to instream flows and flow regulation, or other water uses that influence the frequency, duration, fluctuations, and magnitude of instream flows. The potential effects of flow regulation and instream flows on food availability are described in more detail in Section 9.2 Secondary productivity below.

Sediment supply and transport, which is also linked to land use and cover, is a driver of primary and secondary production (Gislason 1980, ID406; Beechie et al. 2003, ID015). In the Sauk River, high turbidity was linked to lower overall chlorophyll a concentrations, which is an indicator for primary productivity, and therefore high turbidity may affect food availability for target species (Gislason 1980, ID406). Peak flow events in the Sauk River caused scour and thus reductions in periphyton in the months following the peak flow event (Gislason 1980, ID406).

Eelgrass communities are important habitats for prey of target species nearshore habitats (Beamer et al. 2015, ID008). However, invasive plants, such as *Spartina spp.*, *Sargassum muticum*, and *Zostera japonica*, have altered the vegetation assemblages and sedimentation patterns in Puget Sound's nearshore habitats. *Zostera japonica* is established in northern Puget Sound, including nearshore habitats of Skagit Bay and Padilla Bay, and is known to negatively affect native eel grass beds, which are considered essential rearing habitats for juvenile salmon (Redman et al. 2005, ID100). Declining diatom abundances within estuaries shaded out by invasive *Spartina spp*. is another concern, especially for planktivorous salmon such as Sockeye (Redman et al. 2005, ID100).

9.2 Secondary productivity

Secondary productivity with respect to target species and food availability, describes the abundance or quality of prey items, including macroinvertebrates and fishes. Primary productivity drives secondary productivity, but a wide range of potential drivers and stressors interact with food webs and habitat processes that can influence secondary productivity and the availability of food for target species. The following section provides information the factors that affect food availability, results of bioenergetics and diet studies, and feeding behaviors of target species.

9.2.1 Factors influencing food availability

Prey availability is a limiting factor for Chinook Salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). This determination was specifically related to the abundance and availability of forage fish species (hearing, smelt, and other forage fishes) in nearshore rearing habitats. However, they indicated that more research is needed to understand the habitat requirements of forage fish in order to sustain adequate populations needed to support Chinook. Forage fish are important food sources for Chinook and Bull Trout during nearshore rearing life stages, and therefore management actions that improve or protect forage fish spawning habitat (e.g., restoration and protection) will also benefit Chinook and Bull Trout (Beamer 2007, ID215). According to Beamer (2007, ID125), *surf smelt, herring, and sandlance are commonly consumed by Chinook salmon when the salmon exceed about 120 mm in length. Surf smelt, herring, sandlance, and shiner perch are an important part of the diet of anadromous bull trout*.

However, nutrient and carcass productivity levels were not determined to be limiting factors for Chinook productivity in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175). Although carcass and nutrient inputs support primary and secondary productivity and therefore prey availability for target species, the Recovery Plan reported that carcass abundance was often negatively correlated with productivity rates (e.g., smolts per spawner). Although these correlations were not statistically significant, they suggest that carcass biomass, and potentially secondary productivity, was not a limiting factor for Chinook productivity.

Benthic Index of Biotic Integrity metrics have been used as indicators of habitat disturbance and can also be directly related to food availability for target species (Beechie et al. 2003, ID015). Species richness indicators, including mayfly, stonefly, and caddisfly species, decrease with increasing human disturbance, which may correlate with land uses or water quality impacts (Beechie et al. 2003, ID015; Redman et al. 2005, ID100). Relative dominance by the top three taxa increases with increasing human disturbance, which indicates a simplification of the invertebrate population structure or species richness (Beechie et al. 2003, ID015). The richness of long-lived and disturbance intolerant taxa decreases with increasing human disturbance, while tolerant taxa abundance increases with increasing disturbance. Clinger taxa richness and predator abundance decrease with increasing human disturbance (Beechie et al. 2003, ID015). Redman et al. (2005, ID100) indicated that contamination and discharges from municipal, industrial, stormwater, and other land uses or disturbances can reduce production of high-quality prey items and diminish refuge opportunities.

The distribution of macroinvertebrates was linked to seasonal changes in stream flows and potentially to flow regulation. In riverine habitats, peak flow events affect prey availability for juvenile Chum and Chinook. A rapid decline in both lipid levels and condition factors of Chinook and Chum Salmon were hypothesized to be the result of reduced food availability following the first peak river discharge (Davis 1981, ID257). Flow fluctuations in an experimental channel that were designed to mimic weekend flow variations in the upper Skagit River resulted in a 22 percent reduction in insects, which would significantly reduce potential food resources available to salmonids (Gislason 1980, ID406). Flow reductions likely strand many aquatic insects, and mayflies (Ephemeroptera) are especially susceptible to stranding (Graybill et al. 1979, ID 259). However, it is unclear if these results apply in the lower mainstem Skagit River given the attenuation of effects of flow regulation with increasing distance from the dams (Gislason 1980, ID406). In general, reducing water level fluctuations by implementing a stable flow regime resulted in a higher standing crop of periphyton and benthic insects (Graybill et al. 1979, ID 259). Davis (1981, ID257) also reported a rapid decline in lipids and condition factors for target species that were associated with reduced food availability following peak river discharge events.

However, studies also found evidence that flow regulation, impoundments, and other water uses that create more stable flow conditions can increase standing crops of macroinvertebrates (Gislason 1980, ID406). Gislason (1980, ID406) indicated that this could ameliorate negative impacts from downramping that result in stranding and reductions in macroinvertebrate standing crops. Ultimately, the author concluded that ...*comparisons of benthic insect standing crop under the fluctuating and stable flow regimes clearly indicate the beneficial effects of stabilized flow in the Skagit River, and that reduction in the degree of daily peaking fluctuations would greatly enhance insect production in the river. However, they also recommend that …a relative natural seasonal flow regime should be maintained, including the release of large volumes of water at some time during the year, to flush accumulated sediment out of the interstices between substrate particles* (Gislason 1980, ID406). Reservoirs created by dams may also influence food availability. Graybill et al. (1979, ID 259) reported that zooplankton production in the reservoirs above the dams survive passage to the upper Skagit and were observed as far down river as Reach R9, where they are presumably available to salmonid fry. However, feeding on zooplankton appears sporadic and opportunistic (Graybill et al. 1979, ID 259).

Climate change is also a potential stressor on prey availability and growth of target species, via impacts on instream flows and temperatures. Thompson and Beauchamp (2016, ID114) indicated that climate change has the potential to alter the temperature regimes of tributaries in the Pacific Northwest. Understanding mechanisms affecting growth limitations in rearing habitats can help fisheries managers take actions to improve growth conditions and survival. Given that temperature was a significant factor limiting growth, there is a need for continued water temperature monitoring and restoration, especially in the face of climate change (Thompson and Beauchamp 2016, ID114).

Land use can cause shifts in species assemblages and thus food availably (Redman et al. 2005, ID100), and land uses and cover as well as sediment supply and transport processes are drivers and stressors of secondary productivity. Sediment supply and transport processes, including deposition of fine sediments, can impact macroinvertebrate communities and assemblages (Gislason 1980, ID406). Beechie et al. (2003, ID015) indicated that increases in fine sediment (<2 mm diameter) associated with forest roads and mass wasting can affect food availability by impacting the benthic invertebrate community. Redman et al. (2005, ID100) also indicated that changes in sediment processes can impact eelgrass beds and foraging opportunity for target species. Leaf-litter inputs are also cited as a primary driver of detritus-based food webs which influences primary and secondary productivity (Beechie et al. 2010, ID017). Therefore, land cover and riparian conditions in particular are key drivers of both primary and secondary productivity.

Habitat availability and connectivity, and the extent and accessibility of key habitat types can influence food availability, and this was particularly evident in studies of growth in estuary habitats. Skagit System Cooperative and USGS (1999, ID171) found differences in juvenile Chinook growth rates among tidal marsh habitat types, which were linked to differences in prey abundance and prey quality for target species among different habitat types. Growth in estuarine emergent marsh was three times greater than the average growth rate in forested riverine tidal or emergent forested transition habitats (SSC and USGS 1999, ID171). Among pocket estuary, small stream, tidal delta estuarine emergent marsh (EEM), tidal delta forested riverine tidal (FRT), and tidal delta scrub shrub (SS) habitats, Chinook growth rates were the highest in tidal delta EEM, followed by tidal delta FRT and tidal delta SS, and then pocket estuary and small stream mouths (Beamer 2014, ID218). These differences were potentially linked to differences in food availability among tidal marsh habitats (Beamer 2014, ID218).

Studies also indicated that a large percentage of outmigrating Chum and Chinook utilize salt marsh habitats for rearing rather than migrating through the estuary directly to nearshore habitats (Congleton 1978, ID255; Congleton et al. 1981, ID256; Beamer et al. 2005, ID175). This suggested that delta rearing Chum and Chinook are more dependent on food availability and access to rearing and foraging habitats in the estuary than other species and life histories that may move through estuaries more rapidly. Fry sampled in tidal marsh sites were larger than fry sampled concurrently at Skagit River sites, and growth was hypothesized to be slower in river sites because stomachs of fry from the river site contained less food than stomachs from fry at the marsh site (Congleton 1978, ID255; Congleton et al. 1981, ID256).

Greene et al. (2021, ID056) developed a bioenergetics model that also provided support for differences in growth rates among tidal marsh habitat types. Greene et al. (2021, ID056) indicated growth patterns of juvenile Chinook Salmon were dependent on arrival date and size in estuary habitats, with growth rates varying among tidal marsh habitat types. While energy densities were variable throughout the rearing period, each habitat type displayed high growth conditions at some point in time. This supports the hypothesis that the timing of habitat use interacts with prey availability, and habitats provide different functions throughout complex salmonid life cycles to create a gradient of potential foraging benefits. The authors recommended that a "portfolio approach" to habitat management be used to improve juvenile Chinook growth conditions in Puget Sound estuaries rather than focusing on one habitat or life history type (Greene et al. 2021, ID056).

Habitat complexity also appears to be a driver of macroinvertebrate densities. For example, USACE 2010 (ID117) indicated that *continued maintenance and construction of levees as it exists now… would further constrain the river*, which would consequently create less complex habitat, decrease benthic invertebrate habitat, decrease further off-channel habitat, and increase river speeds during high flow events. This would also further decrease LWD retention and create thinner riparian corridors. This ripple effect would *directly affect ESA listed species that depend on cold, clean water, organic detritus and benthic invertebrates for food, and LWD and bank complexity for cover.*

Restoration is also a potential driver of food availability for target species. In nearshore habitats, restoration or protection of beach faces that provide spawning area for surf smelt, sand lance, and other potential forage fishes can increase prey availability (Beamer 2007, ID215). Souder et al. (2018, ID115) indicated that restoration of tidal connectivity to tidal marshes can improve access to low-velocity refuge habitats and improve food webs that support prey availability for target species that rely on estuary habitats for rearing. However, simulation models suggested that fish surveyed at a restoration site had to consume 27 percent more food than fish at reference sites to attain the same weight, suggesting that the quality of prey found at the reference sites was more energy rich than the restoration sites (Sobocinski 2004, ID176).

Shoreline modifications and hydromodifications are also stressors on food availability. Redman et al. (2005, ID100) indicated that shoreline armoring can alter nearshore habitat characteristics, reduce production of prey items, and diminish refuge for juvenile salmon and trout. Overwater structures can reduce primary and secondary productivity, cause potential behavioral changes, and provide potential exposure to contaminants. Removal of riparian vegetation/LWD can increase physiological stress, reduce viability of summer spawning forage fish, reduce terrestrial insect recruitment, and reduce refuge opportunities (Redman et al. 2005, ID100).

9.2.2 Bioenergetics modeling and diet studies

Several studies provided bioenergetic modeling results or diet analyses that describe relative energy densities or availability of prey items in a variety of habitats, including tributaries, mainstems, and estuary habitats. These studies and models provide more detailed insights into the food availability, growth, and diets for target species. Bioenergetics modeling and diet studies for steelhead, Bull Trout, and Chinook are described in this section.

Thompson and Beauchamp (2016, ID114) described prey consumption and prey availability for steelhead. They found that prey energy densities ranged from a low of 2911 joules/gram (J/g) (diptera larvae-nymph) to a high of 6387 J/g (Coleoptera adult) in tributaries to the Skagit River. Average observed prey energy density was 3276 J/g at Bacon Creek, 3422 J/g at Illabot Creek, and 4308 J/g at Finney Creek. Simulated growth between annuli ranged from 9.4 g (Finney Creek juveniles) to 53.1 g (Finney Creek adults) with a mean of 20.16 g (SD = 10.75) across all sites and life-stages for steelhead The daily growth for age 1 and 2 steelhead roughly doubled at all sites when prey energy density was increased to 5000 J/g. This highlights the importance of prey densities and energy densities for early growth, but they noted that temperature was the limiting factor for early growth. In growth simulations, temperature was the ultimate constraint on growth potential, but incremental increases in feeding rate and prey energy density broadened the temperature ranges at which faster growth was possible. These results suggested that chances of survival to later life stages can be improved by increasing feeding rates or prey energy density during summer months when warm water temperatures facilitate faster growth. Growth in freshwater rearing habitats is crucial to survival into later life-stages (Thompson and Beauchamp 2016, ID114).

McMillan (2012, ID434) also indicated that juvenile Pink Salmon abundance patterns were important to steelhead growth and age structure patterns. They reported that annual 2-salt and 3-salt (adults who spent 2 or 3 years in the ocean before returning, respectively) wild steelhead run-sizes dominated alternating years, corresponding with nutrient benefits of odd-year Pink Salmon spawning prior to juvenile steelhead outmigrations in the Skagit.

SSM among steelhead from different precipitation zones was evaluated in several studies in the Skagit River basin (Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114). In these studies, SSM was apparent during freshwater and marine life stages. Growth during the first, second, and third years of freshwater rearing strongly influenced SSM leading to the smolt migration, and growth trajectories set during these years appear to have influenced survival in marine environments. Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood. Survival in the marine environment may be driven by an overall higher growth rate set earlier in life, which results in a larger size at smolt migration. Recent studies have highlighted the importance of survival in marine environments for steelhead, but the locations and modes of mortality for steelhead populations in the Salish Sea have not been conclusively determined. By linking SSM, growth, and life history expression to different precipitation zones within the Skagit River basin, this study provided information to support hypotheses of how climate change could impact Skagit steelhead populations.

Hatchery steelhead releases are also a concern for juvenile salmon and trout species, as described in the Section 8.2 Predation – fish. Pflug et al. (2013, ID154) found that hatchery steelhead diets were comprised of juvenile salmonids (including Chinook, Coho, Pink, and Chum Salmon), Lamprey, and various invertebrates. They noted an absence of juvenile steelhead in the hatchery smolt diet analysis. Pink Salmon dominated the diet in years with Pink Salmon outmigrations, whereas other juvenile salmonids dominated the diet in non-Pink Salmon outmigration years. Overall, their findings suggest that hatchery origin steelhead smolts are opportunistic feeders and potentially impact survival of other juvenile salmonids, but do not appear to significantly impact natural origin steelhead juveniles during freshwater rearing and outmigration life stages.

According to a bioenergetics model, energy budgets for Bull Trout in the Skagit River basin were different at each life stage and between tributary and mainstem habitats (Lowery and Beauchamp 2015, ID074). Aquatic invertebrates made up 92-96 percent of the estimated energy budget for the 30-95 mm size class in tributaries, whereas the 96-300 mm size class got most of their energy from Coho Salmon (73 percent). Bull Trout greater than 300 mm got most of their energy from salmon eggs (41-44 percent). Lowery and Beauchamp (2015, ID074) reported that salmon carcasses and eggs contributed approximately 50 percent of the annual energy budget for large Bull Trout in Skagit River mainstem habitats, whereas those prey types were largely inaccessible to smaller Bull Trout in tributary habitats. The remaining 50 percent of the energy budget was acquired by eating juvenile salmon, resident fishes, and immature aquatic insects (Lowery and Beauchamp 2015, ID074). The model simulations also indicated that the majority of energy intake was during the fall and summer (Lowery and Beauchamp 2015, ID074). Redman et al. (2005, ID100) also indicated that lower densities of delta rearing Chinook fry present a loss in potential foraging opportunity for Bull Trout, which links Chinook salmon recovery to Bull Trout as both a potential response and stressor.

Greene et al. (2021, ID056) developed a bioenergetics model that suggested the growth pattern for juvenile Chinook Salmon was dependent on arrival date and size in estuary habitats. Mean growth potential was highest in forested riverine tidal (FRT) habitats early in the outmigration period and shifted to estuarine forest transition (EFT) habitats later. A primary result of their research and modeling was that energy in diets was variable throughout the rearing period, as each habitat type displayed high growth conditions at some point in time. Freshwater wetland habitats (FRT) tended to be more important early in the rearing period while marine-influenced habitats (EEM) offered more benefit later. Their model also provided trends in total energy consumption by estuary, week, and in relation to prey availability, which are useful for understanding the dynamics of life history diversity, timing and size structure, and variations in prey availability among seasons and habitat types during estuary life stages. In addition, they found that prey consumption was dominated by natural origin Chinook fry between February and May, while natural origin Chinook parr and hatchery Chinook dominate prey consumption throughout the remainder of the season.

Sobocinski (2004, ID176) reported on diets of juvenile Chinook in the Skagit estuary obtained through monitoring and simulation modeling. The simulation model results suggested that juvenile Chinook may have to consume more food at restoration sites compared to reference marshes due to reduced prey quality at restoration sites. At four sites within the Deepwater Slough monitoring area of the Skagit estuary, *N. mercedis* was the dominant prey item in Chinook diets (40 percent of total biomass, across all sites). Dipterans, specifically chironomids in several life stages, were also important prey items for Chinook Salmon. Chinook diets were similar at three of the four sites, where *N. mercedis* was not as prevalent in stomachs. Both diet analysis and bioenergetics analysis suggested that the absence of an energy rich prey item such as *N. mercedis* in Chinook diets may diminish growth (Sobocinski 2004, ID176). *N. mercedis* is a preferred prey item and is also nutritionally valuable to rearing and emigrating Chinook Salmon. The authors indicated that availability of this prey species in habitats might be a limiting factor for Chinook growth at the Deepwater Slough monitoring sites (Sobocinski 2004, ID176).

9.2.3 Feeding behavior and life stages

The studies summarized above highlight some of the differences in feeding behavior among species, life stages, and habitats. However, some species and life stages exhibit more dramatic differences in feeding strategies depending on life stage and food availability. For example, Lamprey are filter feeders for 2-10 years in rivers during their larval life stage (personal communication, Ben Clemens, ODFW). Therefore, Lamprey are dependent on different food sources during different life stages and are distinct from salmon and trout species with respect to the food requirements and feeding behavior. In estuarine and nearshore habitats during their outmigration, Lamprey present another dynamic target species interaction. Lamprey transition from filter feeder to parasitic feeding on fish flesh during their estuary/nearshore rearing and emigration life stages and may feed on salmon and trout (Beamer et al. 2015, ID008). Therefore, salmon and trout represent potential prey species for Lamprey, while Lamprey represent a potential predator for salmon and trout during estuary and nearshore life stages. Lamprey do not actively feed during upriver adult migrations and holding, but Walleye Pollock are key prey during the marine feeding phase of Lamprey (personal communication, Ben Clemens, ODFW).

General feeding behavior and preferences for juvenile salmon are described in the previous section. Some species (Chum, Pink) may spend little time in freshwater before migrating, while other species (Chinook and Coho) may express a range of freshwater rearing strategies from days, weeks, months, or overwintering life histories (Beamer et al. 2005, ID175). Furthermore, estuary and nearshore rearing and emigration patterns also vary among species and life histories, as noted in the previous section, with Chum and Chinook being the most reliant upon estuary and nearshore habitats for early growth (Congleton 1978, ID255; Congleton et al. 1981, ID256; Beamer et al. 2005, ID175). During adult migrations, holding, and spawning, salmon are assumed to not feed and die following spawning. However, Bull Trout and steelhead, with their range of life histories that include anadromous, resident, adfluvial, and iteroparity, may actively feed at a variety of sub adult and adult life stages. Therefore, the potential influence of food availability varies among target species, life histories, and life stages and habitats.

10.0 OTHER ANTHROPOGENIC FACTORS

10.1 Climate change

Climate change is a potential stressor for all of the factors described in this review, and some studies even provided evidence of changes in current conditions that were linked to climate change. Of the factors considered in this review, climate change was identified as a potential or current stressor for instream flows, sediment supply and transport, habitat availability and connectivity, LWD and riparian condition, water quality, competition and predation, and food availability. Climate change impacts on these factors are described in more detail in their respective section, but summaries are provided for each primary factor in the sections below.

10.1.1 Climate change and instream flows

Multiple studies indicated that climate change was a potential stressor for instream flows, and that some recent changes in instream flows were linked to climate change (e.g., Lee and Hamlet 2011, ID196; SWC 2011, ID113; Lee et al. 2016, ID417; Riedel and Larrabee 2016, ID155; Woodward et al. 2017, ID121; Rubenstein et al. 2018, ID411). Some studies suggested that snowpack and instream flows in the Skagit River may be more sensitive to PDO/ENSO driven climate variability than other Pacific Northwest rivers (Lee and Hamlet 2011, ID196). Glaciers also play a crucial role in the Skagit Rive basin's hydrology, and glacial retreat since 1900 has resulted in a 50 percent reduction in total glacial area (Lee and Hamlet 2011, ID196). Loss of glacial coverage has already impacted summer base flow on the Skagit River (Riedel and Larrabee 2016, ID155), and losses of ice in the basin are roughly equivalent to 100 years of freshwater consumption at current rates in the basin. These patterns may be exacerbated by climate change processes and result in further changes in the hydrological regime in the basin as a result of changing glacial inputs. Climate modeling scenarios predict warmer temperatures will result in more precipitation falling as rain in the cool season, resulting in reduced snowpack and a shift in runoff timing. Reduced snowpack will carry over into more extreme low flows in the summer (Lee and Hamlet 2011, ID196). These shifts were predicted to result in a transition from a mixed rain and snow basin with dual peaks in the winter and spring to a rain dominated basin with a single peak in the winter for both natural and regulated flow conditions (Lee et al. 2016, ID417). Beamer et al. (2005, ID005) indicated that climate variations influence survival of Chinook, and recovery planning should consider possible shifts in marine survival related to climate change or variations in climate patterns, including planning for "worst-case scenarios" in population recovery. Prolonged summer low flows may impose additional stress on cold-water fish species, such as salmon and trout (Lee and Hamlet 2011, ID196).

Changes in flow regimes are also predicted to influence flood hydrology in the basin (Lee and Hamlet 2011, ID196; Lee et al. 2016, ID417; Woodward et al. 2017, ID121). Lee et al. (2016, ID417) showed that climate change will cause substantial seasonal changes in both natural and regulated projected flow conditions. Floods are expected to increase in frequency and magnitude due to more winter precipitation and higher freezing elevations (Lee and Hamlet 2011, ID196; Woodward et al. 2017, ID121). The 100-year flood is projected to increase relative to historic baselines for both a natural and regulated scenario in both the 2040s and 2080s. Additionally, annual peak flows are projected to increase in magnitude and occur more frequently in the winter season. Alternative flood control operations that increase flood control storage were shown to be ineffective at mitigating higher flood risks in future climate change scenarios. Lee et al. (2016, ID417) also indicated that increased sediment supply and transport with climate change could increase bed elevations, and this would exacerbate flooding risks with climate change and shifts in the timing and magnitude of flood events in the lower Skagit River.

10.1.2 Climate change and sediment supply and transport

Many of the potential changes in sediment supply and transport processes with climate change were related to changes in instream flows and flow regimes described above. Given that glaciers impact overall hydrography patterns and sediment supply and transport, significant changes in glacial area and volume are predicted with climate change (Riedel and Larrabee 2016, ID155). The Sauk River is a major unregulated tributary to the lower Skagit River that is influenced by glacial inputs. Historical suspended sediment load (SSL) was approximately 40 percent lower than the 5-year mean annual historic yield reported by the USGS study in the Sauk River (Bandaragoda et al. 2020, ID379). Loss of snow and ice cover with climate change and resulting exposure of unconsolidated and fine sediments to overland flow would also increase predicted SSL in the Sauk River (Bandaragoda et al. 2020, ID379). Lee et al. (2016, ID417) also predicted a large shift in the timing of sediment loads and dramatic increase in sediment load with climate change, with the total sediment discharge from December to February at the Skagit River near Mount Vernon increasing by 376 percent. These shifts potentially impact estuary habitat formation and maintenance processes, which were identified as being sensitive to sediment supply and transport processes by several studies (e.g., Hood et al. 2016, ID142; Grossman et al. 2020, ID057). Hood 2015 (ID063) suggested that sediment-challenged salt marshes in Puget Sound are already showing impacts from twentieth century SLR. However, levees and channel modifications influence sediment supply and transport processes by increasing jet momentum, forcing much suspended sediment to bypass the tidal marshes and be exported from Skagit Bay (Hood et al. 2016, ID142). Increased flood control with increased flood risk under climate change could exacerbate this stressor on sediment supply and transport. While increased sediment loads may potentially benefit tidal marsh progradation rates and estuary habitat formation and maintenance processes, increased SSL may also negatively impact many aquatic species (Lee et al. 2016, ID417).

10.1.3 Climate change and habitat availability and connectivity

Climate related changes in habitat availability and connectivity in river habitats were linked to changes in primary drivers of habitat formation and maintenance processes, including instream flows and sediment and supply and transport processes described above. Instream flows, and particularly peak flows, are a primary driver of habitat formation processes (Smith 2003, ID376; Beechie et al. 2003, ID015; Smith 2005, ID177; Riedel et al. 2020, ID001), and studies linked climate change to changes in peak flow patterns (e.g., Lee and Hamlet 2011, ID196; Lee et al. 2016, ID417; Woodward et al. 2017, ID121). LWD recruitment and retention was identified as a primary driver of habitat formation and maintenance processes, and climate change was also identified as a potential driver of LWD recruitment and retention, through impacts of changes in basin and riparian vegetation composition and growth, increased fire disturbances, and changes in peak flow and instream flow regimes (USACE 2010 ID117).

Climate change linked impacts on sediment supply and transport may also influence habitat formation and maintenance processes in estuarine and riverine habitats of the Skagit River basin. Predicted changes in bed elevations linked to sediment supply and transport impacts may alter flood hydrology, habitat formation and maintenance processes in the lower Skagit River (Lee et al. 2016, ID417). Beamer and Wolf (2017, ID187) indicated that tidal marshes along Skagit Bay and the fringes of the Skagit estuary are sensitive to climate change and potential SLR, which could increase the rate of tidal marsh losses in the delta over time that have already been linked to climate change processes (Hood 2015 ID063). Relative SLR and sediment re-routing were identified as a driver of overall declines of natural progradation rates in the Skagit estuary (SWC 2021, ID430). USACE 2010 (ID117) also reported that climate change could result in losses of wetland function and habitat. Beamer et al. (2005, ID005) reported that a 45 cm increase in sea level due to climate change would cause an estimated 12 percent (235 ha) loss of tidal marshes in the vicinity of Fir Island, and an 80 cm increase would result in an estimated loss of 22 percent (437 ha) of tidal wetland habitat near Fir Island. This would translate to an estimated loss of rearing capacity of 211,000 and 530,000 Chinook smolts, respectively.

10.1.4 Climate change and LWD and riparian condition

As noted above, climate change was also identified as a potential driver of LWD recruitment and retention, through impacts of changes in basin and riparian vegetation composition and growth, increased fire disturbances, and changes in peak flow and instream flow regimes (USACE 2010 ID117). Climate change is expected to impact vegetation communities, specifically the composition of tree and vegetation communities, as a result of drier and warmer summers. Drought-susceptible species such as western red cedar may be more sensitive to climate change and forecasted future conditions will likely favor forest pest species, diseases, and wildfire (Lee and Hamlet 2011, ID196). USACE (2010 ID117) also reported that climate change could result in changes in basin and riparian vegetation composition which could impact LWD recruitment.

10.1.5 Climate change and water quality

Potential water quality impacts with climate change were identified by a number of studies, with most predicted influences on instream temperature and maximum temperatures during summer low flow conditions in particular. In addition, some studies have linked current changes in instream temperatures to climate change processes. For example, Austin et al. (2021, ID446) found significant increasing trends in daily maximum instream temperatures for the months of August - October at Mount Vernon (0.05 – 0.02°C/year from1963-2018), which they linked to climate change. Predicted changes in glacial coverage, snowpack, and the timing, duration, and magnitude of precipitation events with climate change scenarios could result in altered temperature patterns, especially with respect to increased duration of low flow conditions (e.g., Lee and Hamlet 2011, ID196). Bandaragoda et al. (2020, ID379) predicted daily maximum temperature increases of 2-3°C for all future climate change scenarios in the Sauk River.

However, compared to the rest of the Pacific Northwest, increases in the Skagit River are expected to be somewhat lower than average (Lee and Hamlet 2011, ID196), and hydroelectric operations may influence risk for temperature changes. For example, Austin et al. (2021, ID446) found that temperatures have been increasing and the magnitude of increasing temperatures over time was linked to elevation and position relative to hydroelectric dams in the Skagit River. In August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches.

Several potential effects on target species were linked to climate change. Thompson and Beauchamp (2016, ID114) indicated that climate change has potential to alter the temperature regimes of tributaries in the Pacific Northwest, and temperature was found to be a significant factor limiting growth for target species. Chinook Salmon appear to be adapted to transition from large river estuaries to nearshore habitats as temperatures begin to exceed optimal metabolic thresholds. Under a climate change scenario, where SSTs increase by 2.2°C, Beamer et al. (2020, ID214) predicted a reduction in the average percent of optimal Chinook habitat across shore types from 16.5 percent to 0.3 percent. This could potentially cause a premature move to more favorable temperatures in nearshore habitats at the expense of increased predation risk and lower marine survival due to size selective mortality. Recent shifts in spawn timing for Coho and Chum were also linked to changes in instream temperatures, which were generally influenced by climate change and hydroelectric operations (Austin et al. 2021, ID446). Some climate change scenarios (NorWeST project) predict that August temperatures may reach 18-20 ºC in 24 km of the South Fork Skagit and in parts of Hansen, Day, and Finney creeks by the 2080s (Woodward et al. 2017, ID121). Areas of the Nookachamps may reach temperatures as high as 20–30 ºC (Woodward et al. 2017, ID121). These results suggested that instream temperatures may exceed thermal tolerances for target species and therefore influence survival, periodicity, and movement.

Climate change is also a potential stressor for nutrient and organic matter delivery to streams, with increased nutrient runoff to Skagit Bay and increased frequency of harmful algal blooms and hypoxia, or low dissolved oxygen, events (Lee and Hamlet 2011, ID196). In addition, linkages between instream flows and climate change are assumed to potentially influence the timing, duration, and magnitude of organic matter and nutrient inputs and cycles in riverine habitats. Similarly, changes in land use patterns, wastewater, and surface water runoff with increasing urban development are expected to negatively influence organic matter and nutrient inputs and cycles (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Redman et al. 2005, ID100). As noted above, potential climate change impacts on riparian vegetation could be a stressor on organic matter and nutrient inputs (USACE 2010 ID117; Lee and Hamlet 2011, ID196), which could impact leaf-litter and detritus-based food webs that influence food availability for target species (Beechie et al. 2010, ID017; USACE 2010 ID117).

Climate change influences on instream flow conditions and SLR processes were also identified as potential stressors on salinity patterns in the Skagit estuary (Khangaonkar et al. 2016, ID334). The results of a 3-D hydrodynamic analysis of circulation and transport in the Skagit River estuary, including the interaction between the interconnected basins of Skagit Bay, Padilla Bay, and Saratoga Passage, showed that expected SLR and lower summer flows in the future will increase salinity in the nearshore environment of the Skagit estuary and result in possible upstream salinity intrusion, but the magnitude of change is predicted to be relatively small. An increase in salinity of ~1 psu in the nearshore environment and a salinity intrusion of approximately 3 km further upstream is predicted in the Skagit River (2008 compared to 2070) (Khangaonkar et al. 2016, ID334). This shift in salinities may further reduce optimal juvenile salmonid habitats that Beamer et al. (2020, ID214) described with respect to potential thermal pressures from climate change.

Glacial melting is a primary source of turbidity in the Skagit River system, with seasonal melting contributing glacial flour or suspended fine sediments to reaches downstream of glaciated basins (Gislason 1980, ID406). The linkage between glacial extent and potential and contemporary climate change indicates that turbidity will be potentially influenced by climate change as well

(Lee et al. 2016, ID417; Riedel and Larrabee 2016, ID155; Bandaragoda et al. 2020, ID379). Changes in turbidity were linked to impacts on primary and secondary productivity (Gislason 1980, ID406), as well as predation risk and incubation mortality for target species (Woodward et al. 2017, ID121).

10.1.6 Climate change and competition, predation, and food availability

Climate change was identified as a potential stressor on competition, predation, and food availability. As noted above, potential climate change impacts on riparian condition, nutrient and organic matter inputs, and detritus-based food webs could have impacts on target species (e.g., Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Redman et al. 2005, ID100; Beechie et al. 2010, ID017; USACE 2010 ID117; Lee and Hamlet 2011, ID196). Instream temperatures are also a stressor on primary and secondary productivity (e.g., Redman et al. 2005, ID100; Beechie et al. 2010, ID017), as well as a potential influence on invasive species that can influence competition, predation, and food webs (e.g., Beamer et al. 2005, ID175; Lawrence 2008, ID071; Redman et al. 2005, ID100). Instream temperatures also influenced inter- and intraspecific competition with temperatures strongly influencing early growth that sets the stage for competition among target species during rearing and emigration life stages (e.g., Thompson and Beauchamp 2014, ID054; Thompson and Beauchamp 2016, ID114).

10.2 Hatcheries

Multiple studies evaluated potential impacts of hatchery releases and management strategies on target species in the study area. These are generally described in the Competition and predation section. The Marblemount Hatchery operated by WDFW produces Chinook, Coho, and steelhead (Beamer et al. 2005, ID175; Pflug et al. 2013, ID154; Austin et al. 2021; ID446). Austin et al. (2021; ID446) indicated that Skagit River summer and Cascade River spring Chinook populations are the most impacted by naturally spawning hatchery origin fish. The Upper Skagit Tribal Hatchery produces Chum, and raceways in the Swinomish Channel are operated by the SRSC (Beamer et al. 2005; ID175). Beamer et al. (2005; ID175) provided a description of general principles for hatchery resource management plans and strategies in the basin, and this section focuses on hatchery interactions.

The primary stressors related to hatchery releases are competition, predation, and mixing of hatchery and natural origin fish during migration and spawning, and these stressors are influenced by the size at release and timing of releases (e.g., Beamer et al. 2005, ID175; Redman et al. 2005, ID100; Pflug et al. 2013, ID154; Austin et al. 2021, ID446). Recent studies have shown that hatchery-natural steelhead hybrids have reduced reproductive success, and Pflug et al. (2013, ID154) reported that hybrid steelhead juveniles were detected in all sampled locations in Skagit tributaries. They speculated that hatchery adults spawn throughout the basin and significant mixing has occurred with the natural spawning population. One key issue with respect to hatchery management was that managers do not have effective tools to prevent hatchery origin adults from spawning outside the hatchery, and the temporal segregation strategy (segregated spawn timing) does not appear to be effective at preventing temporal and spatial overlap with natural spawners in the system or undesired genetic and ecological interactions (Austin et al. 2021, ID446).

Although several aspects of hatchery releases influence natural origin target species and life stages, no studies identified hatchery related stressors as limiting factors (e.g., Beamer et al. 2005, ID175;

Greene et al. 2021, ID056). For example, the Skagit Chinook Recovery Plan indicated that hatchery fish predation in rivers affects freshwater rearing life stages, but this was determined to be a non-limiting factor for Chinook Salmon (Beamer et al. 2005, ID175). Estuary rearing habitat was identified as a limiting factor (Beamer et al. 2005, ID175), and hatchery interactions have been noted in the Skagit estuary (e.g., Beamer et al. 2005, ID005; Greene et al. 2021, ID056). Greene et al. (2021, ID056) found that local juvenile Chinook densities regularly exceeded estimated capacity in the Skagit estuary, with > 60 percent of observations exceeding 95 percent of the estimated capacity annually. Beamer et al. (2007, ID007) reported an influx of hatchery fish from other river systems to Skagit Bay nearshore beach habitat that peaked in July, but they reported that juvenile hatchery Chinook Salmon from other systems were not extensively using Skagit vegetated delta habitat. Greene et al. (2021, ID056) also concluded that hatchery origin Chinook had a negligible effect on the habitat capacity exceedance frequency in the Skagit estuary compared to other Puget Sound estuaries.

10.3 Fisheries

Commercial and recreational fisheries are a long-standing factor influencing fish populations in the Skagit River basin. Unlike climate change and hatcheries, the impacts of fisheries are not described in many of the preceding sections. There are two primary aspects to fisheries that can have potential effects on target fish species—managed fisheries (e.g., commercial, recreational, and Indian Tribe fisheries) and illegal fishing (poaching). The primary effect of fisheries on target species is direct mortality from take, but indirect mortality has also been documented (Beamer et al. 2005, ID175). Fisheries are typically focused on adult life stages, and therefore primarily affect the abundance of adults migrating and spawning in the Skagit River.

Commercial fishing, and its associated canneries, began in the late 1890s (Smith 2003, ID376). Hatchery practices and a marked indicator stock of Chinook are intended to provide information to support management of harvest rates, and potentially useful information on marine survival rates (Beamer et al. 2005, ID175). The Skagit Chinook Recovery Plan also provides an analysis of harvest management actions to evaluate the degree to which harvest management actions could achieve wild production goals under a range of marine survival scenarios (Beamer et al. 2005, ID175). The analysis suggested that recovery goals for escapement can be met or nearly met by exploitation rates alone for some populations, but that recruitment of juveniles and productivity fell short of recovery goals. This indicated that reduced exploitation in combination with other management actions, like restoration of freshwater rearing habitat, are needed to meet recovery goals (Beamer et al. 2005, ID175).

Marine survival was identified as a limiting factor for Chinook salmon in the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175), and marine survival is partly tied to fisheries exploitation, but also greatly influenced by large scale climatic processes, regimes, and climate change (e.g., Greene et al. 2005, ID050). The Skagit Chinook Recovery Plan describes the potential impacts of exploitation rates under a variety of marine survival scenarios, which is consistent with recommendations to manage fisheries in the context of potential variations in marine conditions that can significantly influence productivity (Beamer et al. 2005, ID175; Greene et al. 2005, ID050).

Puget Sound Indian Tribes and WDFW (2017, ID085) described trends in exploitation rates associated with fisheries. This report indicated that *although there has been no discernable long-term trend in total annual exploitation rate for the Skagit Spring Chinook MU, there was a sharp drop in the total exploitation rate beginning in 1995 where the total exploitation rate averaged below 19 percent through fishing year 2016.* They attributed this trend partially to ...*reductions in Areas 5, 6, and 8 sport, as well as West Coast Vancouver Island troll fishery reductions that began in 1994. They also report that total exploitation rates for the Skagit Summer/Fall Chinook MU exhibited a declining trend from 1992 - 2002 followed by an increasing trend through 2011, finally leveling out at an average of 40 percent through year 2016*. Exploitation occurs through multiple fisheries, and using 10-year periods, exploitation of *Skagit Spring Chinook MU have averaged 11 percent in northern fisheries (Alaska and Canada) and 10 percent in southern US fisheries, and …exploitation rates on Skagit summer/fall Chinook MU have averaged 27 percent in northern fisheries and 18 percent in southern US fisheries*.

The Skagit Chinook Recovery Plan indicates that poaching, or illegal take, of fish reduces seeding levels and spawner survival, and poaching was identified as a limiting factor for Chinook (Beamer et al. 2005, ID175). The plan also indicated that *state, Tribal, and federal biologists have historic information and data that report and document the illegal take of salmon in the Skagit River, and it appears that, for several species, significant numbers are killed by illegal fishing activities*. The plan acknowledges the difficulty of quantifying the impacts of poaching due to the illegal nature of the activity, but they provide an estimate of *10 percent or more (possibly up to 50 percent for Suiattle River Chinook in some years), of the Chinook escapement, depending on the stock*. Given current legal exploitation rates at the time of the Skagit Chinook Recovery Plan (20-50 percent), they estimated that *5 percent to 40 percent of the total recruitment is taken illegally, depending on the stock, and that total exploitation rates could actually range from about 28 percent to 75 percent.*

10.4 Aquaculture

Aquaculture facilities and practices, including net pen fish facilities and shellfish aquaculture, can have a variety of potential effects on factors and target species, (Redman et al. 2005, ID100). Aquaculture facilities can have ecological effects due to "operational leakage" from damaged holding pens (Redman et al. 2005, ID100), and Greene et al. (2021, ID056) also identified aquaculture releases as a potential stressor on density dependent processes in delta habitats. Aquaculture can be a source of introduction for diseases and non-native species as well as possible increased nutrient loading, contributing to eutrophication and hypoxia, and reduced native habitat cover, in the case of shellfish aquaculture (Redman et al. 2005, ID100). Shellfish aquaculture can potentially degrade benthic habitat and introduce exotic species (Redman et al. 2005, ID100). Therefore, aquaculture has the potential to influence competition and predation, food availability, and water quality factors.

10.5 Beaver management

Several studies identified declines in beaver populations as an important stressor on habitat formation and maintenance processes, instream flows, water quality, and riparian conditions (Beechie et al. 2003, ID015; Beamer et al. 2005, ID175; Roni et al. 2006, ID104; Beechie et al. 2010, ID017; USACE 2010 ID117; Hood 2012, ID144). Beavers are ecosystem engineers that physically alter habitats and create slow-water refuge and rearing habitats that are important to target species and life stages. Historically, beaver ponds occupied a minimum of 8 percent of tributary length in the Skagit River basin within terraces (Beechie et al. 2001, ID365), and losses of beavers and the habitats they create have been linked to declines in capacity or productivity for some species. For example, removal of beaver ponds, diking, ditching, and dredging of floodplains and deltas has isolated or obliterated approximately 50 percent of Coho Salmon winter rearing habitat in both the Skagit and Stillaguamish basins. In the Skagit River basin, tributaries have lost more than 30 percent of their potential Coho smolt production (Beechie et al. 2001, ID365). In tributary reaches, ponds and wetlands (including those associated with beavers) are key habitats for Chinook (yearling in particular) and steelhead and critical for Coho (Beechie et al. 2003, ID015; Beamer et al. 2005, ID004). Restoration and protection of beavers and their habitats are necessary to address the losses of habitat process and rearing capacity for target species (e.g., Beamer et al. 2005, ID175; Beechie et al. 2010, ID017; Hood 2012, ID144).

Beavers are not just important ecosystem engineers in freshwater non-tidal habitats, they are also important in the Skagit's delta or estuary habitats (Beamer et al. 2005, ID175; Hood 2012, ID144). Tidal scrub-shrub habitat distributions were strongly related to beaver dam distributions in Skagit tidal marshes, which are important rearing habitats for juvenile Chinook (Beamer et al. 2005, ID175). Beaver dams in tidal channels also create low-tide pools with three times the area of tidal channels without beavers, which also increases potential residence time in tidal channels compared to channels that completely drain without beaver dams. This could increase growth potential, but also potentially increase predation risk from avian or other predators (Beamer et al. 2005, ID175). Hood (2012, ID144) found that seven fish species were caught in low-tide pools, including threatened juvenile Chinook, whose densities averaged 3.2 times higher in low-tide pools than shallows.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT D

LIFE STAGE FACTORS TABLES AND INITIAL ASSESSMENT OF RELATIVE IMPORTANCE

1.0 OVERVIEW

The following tables provide a summary of the life stage factors information synthesized from the sources identified in the SY-01 Synthesis and Integration of Available Information on Resources in the Lower Skagit River (Synthesis Study). The life stage factor tables (LSF Tables) are organized by factor, with some factors aggregated into one group. The factors included in the LSF Tables were identified during Steps 1 and 2 from the reviewed literature and in coordination with LPs during work group meetings (April 28, 2022; July 14, 2022; August 11, 2022; October 6, 2022). The information presented for each factor represents a summary of the information synthesized from the literature for each factor in the life stage factors narratives.

For each factor, the LSF Tables provide information on sensitivities and biological responses as well as information to support an initial assessment of relative importance (described below). In addition, a notes section for each factor provides supporting information. The following sections describe the information presented in the LSF Tables with respect to sensitivities, biological responses, and the initial assessment of relative importance. See Section 2.4 for example table, and the following sections for a description of the components of the table that include sensitivities, biological responses, and an initial assessment of relative importance.

2.0 LIFE STAGE FACTORS TABLES

2.1 Sensitivities

Sensitivities describe linkages between factors and management actions. Management actions include non-flow and flow actions, including flow regulation, water uses, restoration and protection, land uses and cover, hatcheries, and fisheries, as described below. Climate includes climate change and water year type, as described below. Factors that are potentially influenced by each management action or climate component are categorized as a Yes (☑) while those that are not were categorized as a No (☐). Indirect sensitivities (⊡) are also included as an option to indicate factors that may be indirectly influenced by a management action or climate.

Management Actions:

- **Flow Regulation (Flow Reg.)** – Includes flood control, power generation, life stage flows from any hydropower facilities.
- **Water Uses** – Includes river or groundwater withdrawals or diversions not related to hydropower.
- **Restoration & Protection (Rest. & Prot.)** – Includes restoration or protection of habitats.
- **Land Uses & Cover** – General land use or management, including roads, levees, forestry, agriculture, and riparian conditions.
- **Hatcheries** – Hatchery programs, release strategies, and hatchery interactions.
- **Fisheries** – Commercial, Tribal, and recreational fisheries of target or non-target species.

Climate:

- **Climate Change** – Includes changes in precipitation regime, glacial coverage, global warming, sea level rise, or other potential climate change impacts; and
- **Water Year Type (WY Type)** – Includes river or groundwater withdrawals or diversions not related to hydropower.

2.2 Biological responses of target species and life stages

The biological responses section of the LSF Tables provides information on the target species and life stages that are influenced by the factor. This information is organized by species groups (Salmon, Trout, or Lamprey) and key life stages (spawning to migration, incubation to emergence, rearing to outmigration, and estuary rearing and emigration to nearshore rearing and emigration). Both the spatial extent and type of biological responses are identified for each species group and life stage and are linked to the factor, as described below. The species groups were defined in coordination with LPs during workgroup meetings (April 28, 2022; July 14, 2022; August 11, 2022; October 6, 2022) and include:

Target Species Groups:

- **Salmon** – Chinook, Coho, Chum, Pink, and Sockeye Salmon;
- **Trout** – Bull Trout and Steelhead; and
- **Lamprey** – Pacific Lamprey.

Key life stages were derived from conceptual life cycle diagrams developed for each species group that reflect transitions between life stages and habitats and can be related to factors influencing these life stages. For the LSF Table, the life stages include the following:

Life Stages:

- **Migration to Spawning (MIGR → SPWN)** – adult migration, holding, and spawning;
- **Incubation to Emergence (INCU → EMER)** – incubation and emergence;
- **Rearing to Outmigration (REAR → OUTM)** – juvenile rearing and outmigration; and
- **Estuary to Nearshore (ESTU → NEAR)** – juvenile estuary and nearshore rearing and emigration.

The spatial relevance or extent of a factor is also identified but are aggregated to primary spatial strata for the study area for the Synthesis Study, which includes mainstem, tributary, estuary, and nearshore habitats, as described below.

Spatial Extent:

- **Mainstem (MAIN)** – mainstem reaches of the lower Skagit River (Reaches R7 – R13);
- **Tributary (TRIB)** – tributaries to the lower Skagit River, including Baker and Sauk River;
- **Estuary (ESTU)** – estuary reaches (reaches R14-R15); and
- **Nearshore (NEAR)** – nearshore habitats of Skagit and Padilla Bay.

The biological responses indicate how the factor is related to or influences biological responses for the target species group and life stage. These are generalized into several categories of biological responses based on the conceptual life history models developed during Step 2 in coordination with LPs (April 28, 2022; July 14, 2022; August 11, 2022). Potential biological responses described in the LSF Tables include movement, periodicity, habitat, growth, and survival, as described below.

Biological Responses:

- **Movement (MOV)** – influences movement from one habitat to another, including migration;
- **Periodicity (PRD)** – influences the timing or duration of habitat use, including rearing, or migration;
- **Habitat (HAB)** – influences the types of habitats used, or occupancy/abundance (e.g., capacity);
- **Growth (GRW)** – influences growth or condition factor, including diet or metabolic pathways; and
- **Survival (SRV)** – causes direct mortality (e.g., predation or stranding) or indirect mortality (e.g., disease or parasites, delayed mortality from fishing).

The biological responses section also provides information on limiting factors and linkages to Project operations. If a factor was identified as a limiting factor in a study, this is indicated by a "Yes" with the specific species group identified in parentheses (e.g., S for Salmon). Some studies also evaluated factors and determined they were not a limiting factor, and these are indicated with a "No" with the specific species group identified. A "-" denotes cases where no studies provided information on whether or not a factor is limiting for a particular species group and life stage. For Project operations, a "Yes" indicates that flow regulation and Project operations at the Skagit River hydropower facilities were identified as potential stressors or drivers of a factor that could influence the species group or life stage. The spatial extent of that potential influence is identified in parentheses. An indirect linkage may also be identified, and these are indicated with a "~Yes~" value. Similar to limiting factors, a "-" represents no information.

Limiting Factors:

- **Yes** – factor was identified as a limiting factor for a target species and life stage;
- **No** – factor was identified as not limiting to a target species and life stage; or
- "-" – no information identifying a factor as limiting or not limiting.

Project Operations:

- **Yes** – Project operations at the Skagit River hydropower facilities were identified as a potential stressor on the factor and target species and life stage;
- **~Yes~** – Project operations are potentially linked to the factor, but may indirectly influence the factor and species group and life stage; or
- "-" – no information identifying the factor as being linked to Project operations.

2.3 Initial Assessment of Relative Importance Approach

Scoring or assigning relative importance or priorities is a common problem in resource management. Many possible approaches have been used that range from the more subjective (e.g., professional opinion) to more quantitative and objective approaches (e.g., scoring and weighting approaches) (Weber et al. 2006; Turpin et al. 2022). To support identification of key factors for the Synthesis Study (Step 3), key factor criteria were first developed in coordination with LPs during work group meetings (July 14, 2022; August 11, 2022; October 6, 2022) to identify factors that are relevant to the target species and the study area for the Synthesis Study and can be influenced by management actions.

Key Factor Criteria:

(1) Is the factor relevant to one or more of the Synthesis Study target species or life stages?

(2) Is the factor a limiting factor to one or more of the Synthesis Study target species and life stages?

(3) Is the factor relevant to one or more of the study area for the Synthesis Study strata?

(4) Can the factor be influenced by one or more flow or non-flow management actions?

(5) Can the factor be influenced by Project operations?

(6) Is the factor sensitive to climate change or water year type?

These key factor criteria questions can be used to evaluate factors identified in the Synthesis Study by using a simple scoring framework based on Yes/No answers. However, factors may influence multiple target species groups or life stages, or a subset of these, and factors may be identified as limiting to more than one species group or life stage. Similarly, factors may potentially be influenced by one or more management actions or sensitive to one or more aspects of climate. Therefore, simple Yes/No scoring limits the ability to differentiate the relative importance of factors that have broader effects on target species groups and life stages as well as linkages to management actions and climate.

The ability to look at multiple effects of factors in a composite assessment is a common element to scoring or evaluating the relative importance of factors, and weighting is often used to identify gradients or levels of potential influences or strengths of association (e.g., Weber et al. 2006; Turpin et al. 2022). In addition, the ability to integrate feedback from stakeholders or workgroups and transparency are key elements to scoring approaches. Therefore, a simple weighted scoring framework was developed and reviewed with LPs in work group meetings (November 23, 2022) to support an initial assessment of relative importance based biological, climatological, and management action linkages. These were then used to develop an aggregate score that can be used to evaluate the relative importance of factors and support identification of key factors (Step 3). This provides a more quantitative and transparent assessment of relative importance compared to more subjective approaches (e.g., scoring based on professional opinion), and the scoring criteria can easily be adapted to address assessment needs. These scoring components are described in more detail in the following sections, and the scores for each factor can be found in the LSFs Tables (Table 1 - Table 15) as well as summarized in Table 16. An example LSF Table is provided in Section 2.4, which shows the components of the biological, management, and climate scores as described below.

2.3.1 Biological Score

The biological score (S_B) includes three components; (A) number of target species groups that the factor influences, (B) the number of life stages the factor influences, and (C) the number of species and life stages for which the factor limits productivity (Equation 1). Both target species and life stage scores were weighted based on the number of target species groups and life stages (as whole integers) divided by the possible number of target species groups (n = 3) and life stages (n = 4). Given that limiting factors describe factors that have been found to limit the productivity of a species and life stage, as opposed to simply having a potential influence on the species or life stage, limiting factors identified in the literature were summed for each species group and life stage (as whole integers). The weighted species group and life stage scores were then added to the limiting factors sum to assign the factor a biological score (Equation 1), which increases the influence of limiting factors on the biological score.

Equation 1. Biological score equation

$$S_B = \frac{A}{3} + \frac{B}{4} + C$$

Example: If a factor influences migration and spawning and the rearing and outmigration life stages of Salmon and Trout species, and the factor limits the rearing and outmigration life stage for Salmon, the biological score would be calculated as 2.2 (2/3 + 2/4 + 1).

2.3.2 Management Score

The management score (S_M) also includes three components; (A) number of study area strata that the factor operates at when influencing target species groups and life stages, (B) the number of management actions that were linked to the factor, and (C) the number of target species and life stages that are potentially influenced by Project operations (Equation 2). Both the study area strata and management actions components were weighted based on the number of strata (n = 4) and management actions (n = 6). Study area strata were scored using whole integers, while the management score included sensitivities that were identified as indirect as opposed to a simple Yes/No. For management actions that have an indirect influence on the factor, a value of 0.5 was added to the management action component of the management score. Similar to limiting factors in the biological score, the number of spatial strata that were linked to Project operations were summed to increase the weight of factors that have a greater potential to influence target species groups and life stages from Project operations (Equation 2). For indirect linkages to Project operations, a value of 0.5 was used.

Equation 2. Management score equation

$$S_M = \frac{A}{4} + \frac{B}{6} + C$$

Example: If a factor was influenced by flow regulation, restoration, and land uses, with water uses having an indirect effect on the factor, (A) would equal 3.5. If the factor influences target species groups and life stages in mainstem and tributary habitats, but not in the estuary or nearshore habitat strata, (B) would equal 2. If Project operations directly influences the factor in mainstem habitats, (C) would equal 1. The total management action score would then equal 2.5 (0.9 + 0.6 + 1).

2.3.3 Climate Score

The climate score (S_C) includes one component that was weighted to a half-scale compared to the other scoring components (Equation 3). A value of one was added for each climate change (A) and water year type (B) sensitivity identified. Climate change and water year type sensitivities also included indirect sensitivities, and these were added as 0.5 for each indirect sensitivity. The sum was then scaled to one half the weight of other scoring components by dividing the sum by four (Equation 3).

Equation 3. Climate score equation

$$S_C = \frac{A + B}{4}$$

Example: If a factor was influenced by climate change but only indirectly influenced by water year type, the climate score would equal 0.4 (1.5/4).

2.3.4 Aggregate Score

The aggregate score was derived by summing each scoring component (Equation 4). This scoring framework results in a minimum score of approximately 1.0, assuming that the factor is relevant to at least one target species group, life stage, spatial strata, and management action. Assuming a factor is relevant to all three target species groups, all four life stages, all four spatial strata, all six management actions, and both climate sensitivities, the aggregate score would equal 4.5 (excluding limiting factors and Project operations components). This represents a baseline score for factors that satisfy all key factor criteria. Factors that were identified as limiting factors or potentially linked to Project operations would additively increase this baseline score.

Equation 4. Aggregate score equation

$$S_T = S_B + S_M + S_C$$

Example: Using the previous examples for biological scores (S_B = 2.2), management scores S_M = 2.5, and climate scores (S_C = 0.4), the aggregate score would equal 5.1 (2.2 + 2.5 + 0.4).

2.4 LSF Tables

The following LSF Tables were developed as described in the previous sections. These LSF Tables provide a summary of the sensitivities and biological responses that were identified for each factor and an initial assessment of relative importance as described in the previous sections. The following table is an example that provides more detail on how the LSF Tables are configured and the information they provide (Figure 1).

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors **Yes (☑), No (☐), Indirect (⊡)**		***Species***	***Life Stages***	***Spatial Extent***	***Biological Response(s)***	***Limiting Factor***	***Project Operations***	***Criteria***	***Score***	***Criteria***	***Score***
Factor	***Management Actions***		****Possible values describe below****						Species Groups	**≤ 3**	Study Area Strata	≤ 4
	☐ Flow Reg.	☐ Land Uses & Cover	S = Salmon	MIGR → SPWN = Migration to Spawning	MAIN = mainstem	MOV = movement	Yes = identified as limiting factor	Yes = linked to Project	Life Stages	**≤ 4**	Management Actions	≤ 6
	☐ Water Uses	☐ Hatcheries	T = Trout	INCU → EMER = Incubation to Emergence	TRIB = tributary	PRD = periodicity	No = found not to be limiting	~Yes~ = indirectly linked to Project	Limiting Factor	**Count**	Project Operations	**Count**
	☐ Rest. & Prot.	☐ Fisheries	L = Lamprey	REAR → OUTM = Rearing to outmigration	ESTU = estuary	HAB = habitat	(-) = no information	(-) = no information	Biological Score	Sum	Management Score	Sum
	Climate		ALL = All Species	ESTU → NEAR = Estuary & nearshore rearing and emigration	NEAR = nearshore	GRW = growth			Climate Sensitivity	≤ 2	***Aggregate Score***	***Sum***
	☐ Climate Change	☐ WY Type				SRV = survival			Climate Score	Sum/4		
	Notes: Summary of information that supports the values in the life stage factors table for the factor.											

Figure 1. Example LSF Table that shows the information synthesized for each factor. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡) in the Sensitivities section.

Values included in the Biological Responses of Target Species and Life Stages section are shown. The Initial Assessment of Relative Importance section provides the scoring components for the biological, management, and climate scoring components that are summed for the aggregate score. Each scoring component is based on the sum of each element above it (except for the climate score which was divided by 4), with the possible values shown for each element.

Table 1. Instream flow factors (1 of 2) and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
General flow	***Management Actions***		ALL	MIGR → SPWN	MAIN, TRIB	HAB, MOV, PRD	-	Yes (Main)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg.	☑ Land Uses & Cover	ALL	REAR → OUTM	MAIN, TRIB	HAB, MOV, PRD	-	Yes (Main)	Life Stages	4.0	Management Actions	4.0
	☑ Water Uses	☐ Hatcheries	ALL	ESTU → NEAR	ESTU, NEAR	HAB, MOV, PRD	-	~Yes~ (ESTU)	Limiting Factor	0.0	Project Operations	1.5
	☑ Rest. & Prot.	☐ Fisheries							Biological Score	2.0	Management Score	3.2
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***5.7***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Instream flows are relevant to all target species and life stages, and influences the timing and duration of habitat uses. Instream flows are relevant in tributary and mainstem reaches, to a lesser extent in the estuary and nearshore habitats. Instream flows are linked to flow and non-flow management actions, with instream flows in mainstem reaches being most directly linked to Project Operations along with unregulated tributary inputs.											
Peak flow	***Management Actions***		ALL	INCU → EMER	MAIN, TRIB	SRV	Yes (Salmon)	Yes (Main)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg.	☑ Land Uses & Cover	S, T	MIGR → SPWN	MAIN, TRIB	MOV, PRD	-	Yes (Main)	Life Stages	4.0	Management Actions	3.5
	⊡ Water Uses	☐ Hatcheries	S, T	REAR → OUTM	MAIN, TRIB	MOV, PRD	-	Yes (Main)	Limiting Factor	1.0	Project Operations	1.5
	☑ Rest. & Prot.	☐ Fisheries	S, T	ESTU → NEAR	ESTU, NEAR	MOV, PRD	-	~Yes~ (ESTU)	Biological Score	3.0	Management Score	3.1
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***6.6***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Peak flows negatively related to incubation survival for Salmon and Trout (presumed for Lamprey), and movement and periodicity for other life stages of Salmon and Trout. Flow regulation has reduced mainstem peak flows. Tributaries identified as impaired for peak flows. Project Operations only linked to mainstem peak flows, but identified as an influence in estuary. Reductions in peak flows can reduce egg to fry mortality, but also has potential negative effects on habitat forming processes.											
Min flow	***Management Actions***		ALL	INCU → EMER	MAIN, TRIB	SRV	-	Yes (Main)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg.	⊡ Land Uses & Cover	ALL	MIGR → SPWN	MAIN, TRIB	HAB, MOV, PRD	-	Yes (Main)	Life Stages	4.0	Management Actions	3.0
	☑ Water Uses	☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	HAB, MOV, PRD	-	Yes (Main)	Limiting Factor	0.0	Project Operations	1.5
	⊡ Rest. & Prot.	☐ Fisheries	ALL	ESTU → NEAR	ESTU, NEAR	HAB, MOV, PRD	-	~Yes~ (ESTU)	Biological Score	2.0	Management Score	3.0
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***5.5***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Minimum flows are strongly influenced by climatological processes and flow regulation, unregulated tributary inputs, and groundwater and water withdrawals or diversions. Minimum flows can affect all target species, especially those with extended freshwater rearing life stages, and can influence life history expression, the timing and duration of rearing, and direct mortality through redd dewatering during the alevin stage. For Late Autumn/Winter spawners like Chum and some Coho there is also a risk of redd freezing that can occur during low flows.											

Table 2. Instream flow factors (2 of 2) and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (þ), No (¨), or Indirect (§). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Down-ramping	***Management Actions***		ALL	INCU → EMER	MAIN	SRV	-	~Yes~ (Main)	Species Groups	3.0	Study Area Strata	1.0
	☑ Flow Reg.	⊡ Land Uses & Cover	ALL	REAR → OUTM	MAIN	SRV	-	~Yes~ (Main)	Life Stages	2.0	Management Actions	3.0
	☑ Water Uses	☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.5
	⊡ Rest. & Prot.	☐ Fisheries							Biological Score	1.5	Management Score	1.3
	Climate								Climate Sensitivity	1.0	***Aggregate Score***	***3.0***
	⊡ Climate Change	⊡ WY Type							Climate Score	0.3		
	Notes: Downramping is directly related to flow regulation, although unregulated tributary inputs are identified as a muting factor affecting downramping. Downramping can potentially affect all target species and life stages similar to minimum flows, but is focused on the incubation and early emergence and rearing life stages through direct mortality associated with stranding and redd dewatering. The only documented downramping impacts in the Synthesis Study Area were linked to flow regulation on the Baker River.											
Tidal Inundation	***Management Actions***		S, T	ESTU → NEAR	ESTU, NEAR	HAB, MOV, PRD	-	~Yes~ (ESTU)	Species Groups	2.0	Study Area Strata	1.0
	⊡ Flow Reg.	☑ Land Uses & Cover							Life Stages	1.0	Management Actions	3.0
	⊡ Water Uses	☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.5
	☑ Rest. & Prot.	☐ Fisheries							Biological Score	0.9	Management Score	1.3
	Climate								Climate Sensitivity	1.5	***Aggregate Score***	***2.5***
	☑ Climate Change	⊡ WY Type							Climate Score	0.4		
	Notes: Tidal inundation is a primary factor affecting habitat formation and maintenance processes in estuary and nearshore habitats. Tidal inundation is influenced by instream flows and therefore indirectly influenced by Project operations. Climate change was linked to tidal inundation through sea level rise and changing river flow regimes. Habitat use, movement, and periodicity for Salmon and Trout were linked to gradients in tidal forcing and inundation, including the duration, magnitude, and frequency of tidal flooding, landscape connectivity, salinity gradients, and marsh and tidal channel habitat types and connectivity. See habitat availability and connectivity for more information habitat extent and habitat connectivity in estuary and nearshore habitats.											

Table 3. Sediment supply and transport factors (sediment supply and transport and deposition and substrate factors combined) and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (þ), No (¨), or Indirect (§). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Supply & Transport & Deposition & Substrate	***Management Actions***		ALL	INCU → EMER	MAIN, TRIB	SRV	Yes (S, T)	Yes (Main)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg.	☑ Land Uses & Cover	ALL	REAR → OUTM	MAIN, TRIB	HAB, GRW	-	Yes (Main)	Life Stages	4.0	Management Actions	3.0
	☐ Water Uses	☐ Hatcheries	S, T	ESTU → NEAR	ESTU, NEAR	HAB, GRW	Yes (S)	Yes (ESTU)	Limiting Factor	2.0	Project Operations	2.0
	☑ Rest. & Prot.	☐ Fisheries	ALL	MIGR → SPWN	MAIN, TRIB	HAB	-	Yes (Main)	Biological Score	4.0	Management Score	3.5
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***8.0***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		

Notes: Sediment supply and transport influences habitat formation and maintenance processes, as well as primary and secondary productivity, in habitats used by all target species and life stages. Sedimentation and erosion were identified as limiting factors for Chinook and Steelhead (Finney Creek). Fine sediment deposition and erosion (redd scour) can reduce incubation survival for all target species, and sediment processes were identified as impaired in tributaries to the lower Skagit River but not the mainstem Skagit River. Excessive fine sediment loading was linked to land uses and cover, riparian conditions, roads, and underlying geology in combination with instream flow and climatological drivers. In the estuary, reduced sediment supply and deposition were identified as stressors to estuary habitat formation and maintenance processes, and estuary habitat extent was identified as a limiting factor for Chinook. Retention of sediments in reservoirs have reduced sediment supply to the lower Skagit River and estuary by 70%, and channel modifications and levees have increased transport of sediments through the estuary to the nearshore.

Table 4. Habitat extent and connectivity factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

<table>
<tr><th rowspan="2">Factor</th><th colspan="2">Sensitivities</th><th colspan="6">Biological Responses of Target Species and Life Stages</th><th colspan="4">Initial Assessment of Relative Importance</th></tr>
<tr><th colspan="2">Stressors
Yes (☑), No (☐), Indirect (⊡)</th><th>Species</th><th>Life Stages</th><th>Spatial Extent</th><th>Biological Response(s)</th><th>Limiting Factor</th><th>Project Operation</th><th>Criteria</th><th>Score</th><th>Criteria</th><th>Score</th></tr>
<tr><td rowspan="7">Habitat Extent</td><td colspan="2">Management Actions</td><td>ALL</td><td>INCU → EMER</td><td>ALL</td><td>HAB, MOV, PRD, GRW</td><td>-</td><td>~Yes~ (Main)</td><td>Species Groups</td><td>3.0</td><td>Study Area Strata</td><td>4.0</td></tr>
<tr><td>☑ Flow Reg.</td><td>☑ Land Uses & Cover</td><td>ALL</td><td>REAR → OUTM</td><td>MAIN, TRIB</td><td>HAB, MOV, PRD, GRW</td><td>Yes (S)</td><td>~Yes~ (Main)</td><td>Life Stages</td><td>4.0</td><td>Management Actions</td><td>4.0</td></tr>
<tr><td>☑ Water Uses</td><td>☐ Hatcheries</td><td>ALL</td><td>ESTU → NEAR</td><td>ESTU, NEAR</td><td>HAB, MOV, PRD, GRW</td><td>Yes (S)</td><td>-</td><td>Limiting Factor</td><td>2.0</td><td>Project Operations</td><td>0.5</td></tr>
<tr><td>☑ Rest. & Prot.</td><td>☐ Fisheries</td><td>ALL</td><td>SPWN → MIGR</td><td>MAIN, TRIB</td><td>HAB, MOV</td><td>-</td><td>~Yes~ (Main)</td><td>Biological Score</td><td>4.0</td><td>Management Score</td><td>2.2</td></tr>
<tr><td colspan="2">Climate</td><td colspan="6"></td><td>Climate Sensitivity</td><td>2.0</td><td rowspan="2">Aggregate Score</td><td rowspan="2">6.7</td></tr>
<tr><td>☑ Climate Change</td><td>☑ WY Type</td><td colspan="6"></td><td>Climate Score</td><td>0.5</td></tr>
<tr><td colspan="12">Notes: Freshwater and estuary rearing habitat extents were identified as limiting factors for juvenile Chinook, and density dependent survival and life history expression were linked to freshwater and estuary rearing habitat extent. Freshwater and estuary rearing capacity limitations were linked with increased production of smaller and earlier migrating fry migrants with low marine survival. Increased freshwater and estuary rearing opportunity increases growth and survival. Access to pocket estuary habitats can offset delta rearing capacity limitations to some degree by providing increased growth and refuge opportunity. Loss of floodplain, estuary, and pocket estuary habitat extents were identified as restoration priorities to address rearing habitat limitations. Restoration strategies in freshwater habitats include restoration of connectivity (barriers and floodplain) as well as habitat formation and maintenance processes, which were linked to flow regulation and reduced peak flows that can be a primary driver of habitat processes. Restoration was identified as largest source of current change in estuary habitat extent, but climate change and sediment supply and transport processes were identified as stressors to estuary habitat formation and maintenance processes.</td></tr>
<tr><td rowspan="7">Habitat Connect-ivity</td><td colspan="2">Management Actions</td><td>ALL</td><td>INCU → EMER</td><td>ALL</td><td>HAB, MOV</td><td>-</td><td>~Yes~ (Main)</td><td>Species Groups</td><td>3.0</td><td>Study Area Strata</td><td>4.0</td></tr>
<tr><td>⊡ Flow Reg.</td><td>☑ Land Uses & Cover</td><td>ALL</td><td>REAR → OUTM</td><td>MAIN, TRIB</td><td>HAB, MOV</td><td>Yes (S)</td><td>~Yes~ (Main)</td><td>Life Stages</td><td>4.0</td><td>Management Actions</td><td>3.0</td></tr>
<tr><td>⊡ Water Uses</td><td>☐ Hatcheries</td><td>ALL</td><td>ESTU → NEAR</td><td>ESTU, NEAR</td><td>HAB, MOV</td><td>Yes (S)</td><td>-</td><td>Limiting Factor</td><td>2.0</td><td>Project Operations</td><td>0.5</td></tr>
<tr><td>☑ Rest. & Prot.</td><td>☐ Fisheries</td><td>ALL</td><td>SPWN → MIGR</td><td>MAIN, TRIB</td><td>HAB, MOV</td><td>-</td><td>~Yes~ (Main)</td><td>Biological Score</td><td>4.0</td><td>Management Score</td><td>2.0</td></tr>
<tr><td colspan="2">Climate</td><td colspan="6"></td><td>Climate Sensitivity</td><td>1.0</td><td rowspan="2">Aggregate Score</td><td rowspan="2">6.3</td></tr>
<tr><td>⊡ Climate Change</td><td>⊡ WY Type</td><td colspan="6"></td><td>Climate Score</td><td>0.3</td></tr>
<tr><td colspan="12">Notes: Connectivity is a primary stressor on habitat extent, and influences the extent of accessible or functional habitat and therefore influences habitat capacities and movement. Levees and dikes, water crossing structures and fish passage barriers, and dams were identified as influencing carrying capacities for salmon by limiting migrations during adult and juvenile life stages. Disconnection and isolation of floodplain and estuary habitats is a primary factor influencing habitat extent for target species and life stages, and therefore connectivity was identified as an indirect limiting factor for freshwater and estuary rearing habitat. Habitat accessibility can also be influenced by instream flow and flow regimes, and flow regulation was linked with changes in habitat formation and maintenance processes that influences off-channel habitat connectivity and formation processes. Restoration priorities identified for riverine, estuarine, and nearshore habitats included restoration of floodplain connectivity and tidal connectivity to tidal marsh and pocket estuary habitats, as well as fish passage barriers. Landscape connectivity was also identified as an important factor that influences the distribution and density of juvenile Chinook in estuary and nearshore habitats, with outmigrants being split between the North and South Fork distributaries. With approximately 3x more estuary habitat in the South Fork of the Skagit Estuary, density dependent rearing capacity pressure may be greater in the North Fork of the Estuary.</td></tr>
</table>

Table 5. Large woody debris (LWD) and bank condition factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
LWD Recruit-ment & Retention	***Management Actions***	ALL	SPWN → MIGR	MAIN, TRIB	HAB, MOV, SRV	-	~Yes~ (Main)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg. ☑ Land Uses & Cover	ALL	INCU → EMER	MAIN, TRIB	HAB, SRV	-	~Yes~ (Main)	Life Stages	4.0	Management Actions	3.5
	⊡ Water Uses ☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	HAB, MOV, GRW, SRV	-	~Yes~ (Main)	Limiting Factor	0.0	Project Operations	0.5
	☑ Rest. & Prot. ☐ Fisheries	ALL	ESTU → NEAR	ESTU, NEAR	HAB, MOV, GRW, SRV	-	~Yes~ (Main)	Biological Score	2.0	Management Score	2.1
	Climate							Climate Sensitivity	1.0	***Aggregate Score***	***4.3***
	⊡ Climate Change ⊡ WY Type							Climate Score	0.3		
	Notes: Land uses and cover, riparian condition, channel migration, instream flows and flow regulation are primary drivers of LWD recruitment and retention. LWD recruitment and retention, as well as habitat formation processes are a function of the size and abundance of LWD which is influenced by land cover and the proximity and age structure of trees to the active channel. Historical LWD removal and retention of LWD by reservoirs have reduced LWD abundance in the lower Skagit River and Estuary. LWD is a primary driver of habitat formation and maintenance processes for target species and life stages, including formation of pool habitats for rearing and holding, spawning gravels through formation of pool-rifle habitat units, activation and formation of off-channel habitats, and tidal marsh vegetation establishment processes. LWD can also provide cover and reduce predation, and increase food availability by increasing primary and secondary productivity. Riparian planting and LWD supplementation are primary restoration strategies to address impaired LWD recruitment and retention.										
Hydro-modified Banks & Channel Edges	***Management Actions***	ALL	REAR → OUTM	MAIN, TRIB	HAB, MOV, SRV	Yes (S)	~Yes~ (Main)	Species Groups	3.0	Study Area Strata	4.0
	⊡ Flow Reg. ☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	HAB, MOV, SRV	-	-	Life Stages	3.0	Management Actions	2.5
	☐ Water Uses ☐ Hatcheries	ALL	SPWN → MIGR	MAIN, TRIB	HAB, MOV	-	~Yes~ (Main)	Limiting Factor	1.0	Project Operations	0.5
	☑ Rest. & Prot. ☐ Fisheries							Biological Score	2.8	Management Score	1.9
	Climate							Climate Sensitivity	1.0	***Aggregate Score***	***4.9***
	⊡ Climate Change ⊡ WY Type							Climate Score	0.3		
	Notes: Hydromodifications and bank edge conditions were linked to habitat quality for target species and habitat formation and maintenance processes as well as connectivity and channel migration (e.g., levees and bank armoring). Hydromodifications were identified as a limiting factor for Chinook, limiting parr production through reduced freshwater rearing capacity. Juvenile salmon densities were higher in habitats with natural bank edges, but natural cover (e.g., LWD and riparian) can increase rearing capacities for hydromodified bank edges. Habitat assessments indicated that hydromodifications of channel edges are prevalent throughout the lower Skagit River, estuary, and nearshore. Hydromodifications can also reduce flood risk. Climate change is an indirect stressor on hydromodifications and bank conditions through influences on instream flows and potential SLR, and flow regulation is indirectly related to bank conditions through instream flows.										

Table 6. Riparian condition factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Riparian Condition	***Management Actions***	S	MIGR → SPWN	MAIN, TRIB	HAB	Yes (S)	-	Species Groups	3.0	Study Area Strata	4.0
	⊡ Flow Reg.; ☑ Land Uses & Cover	ALL	REAR → OUTM	MAIN, TRIB	HAB	Yes (S)	-	Life Stages	4.0	Management Actions	3.0
	⊡ Water Uses; ☐ Hatcheries	S, T	ALL	ALL	GRW, MOV, SRV	-	-	Limiting Factor	2.0	Project Operations	0.0
	☑ Rest. & Prot.; ☐ Fisheries							Biological Score	4.0	Management Score	1.5
	Climate							Climate Sensitivity	1.5	***Aggregate Score***	***5.9***
	☑ Climate Change; ⊡ WY Type							Climate Score	0.4		
	Notes: Riparian conditions were identified as a limiting factor for Chinook Salmon, influencing the extent and quality of spawning and juvenile rearing habitat and thereby limiting capacity. Impaired riparian conditions and functions (shade and cover, and recruitment of insects and LWD) were identified for tributary, lower Skagit River, estuary, and nearshore reaches. Effects on Chinook of impaired riparian conditions were primary associated with reduced LWD recruitment and its influence on habitat formation processes for spawning habitats, as well as instream shading and cover. Management actions, including land uses and restoration and protection were linked to riparian conditions, and riparian habitats are sensitive to climate change and instream flow conditions. Instream water quality, and especially temperatures, and food availability as well as cover were linked to riparian condition that can influence growth, movement, and direct mortality.										

Table 7. Instream temperature water quality factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operations*	*Criteria*	*Score*	*Criteria*	*Score*
Instream temp general	***Management Actions***	ALL	ALL	ALL	ALL	-	~Yes~ (MAIN,ESTU)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg. ☑ Land Uses & Cover							Life Stages	4.0	Management Actions	4.0
	☑ Water Uses ☐ Hatcheries							Limiting Factor	0.0	Project Operations	1.0
	☑ Rest. & Prot. ☐ Fisheries							Biological Score	2.0	Management Score	2.7
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***5.2***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Flow regulation can influence overall temperature patterns through regulation of instream flows and release of reservoir waters. Studies suggested that flow regulation influences on instream temperatures can extend to the estuary, but is mediated by unregulated tributary inputs. Water uses (irrigation and diversions) can influence instream temperatures, and restoration and land uses and cover can influence instream temperatures through riparian shading and influences on instream flows and hydrological processes. Climate change was also identified as a potential stressor on instream temperatures, particularly through alteration of glacial coverage, hydrological regimes, and global warming. Instream flows can influence instream temperatures, with lower flows generally increasing instream temperatures, and therefore instream temperatures are sensitive to water year type. Instream temperatures were identified as a critical water quality parameter for target species and life stages, with instream temperatures potentially influencing growth and survival, movement and periodicity, and habitat capacities and use.										
Instream temp max	***Management Actions***	ALL	MIGR → SPWN	MAIN, TRIB	HAB, PRD, SRV, MOV	Yes (S)	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg. ☑ Land Uses & Cover	ALL	INCU → EMER	MAIN, TRIB	SRV, PRD, GRW	No (S)	~Yes~ (MAIN)	Life Stages	4.0	Management Actions	4.0
	☑ Water Uses ☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	ALL	Yes (S)	~Yes~ (MAIN)	Limiting Factor	2.0	Project Operations	1.0
	☑ Rest. & Prot. ☐ Fisheries	S, T	ESTU → NEAR	ESTU, NEAR	ALL	-	~Yes~ (ESTU)	Biological Score	4.0	Management Score	2.7
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***7.2***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Many of the same drivers, stressors, and sensitivities for general instream temperatures apply to maximum instream temperatures. Maximum temperatures were generally evaluated with respect to summer low flow periods, although maximum temperatures during other seasons can influence other life stages (e.g., incubation duration). Many tributaries to the lower Skagit River were identified as having impaired water quality due to high instream temperatures, which were linked to riparian conditions, land uses and cover, and reduced instream flows. In the mainstem, maximum instream temperatures are moderated by flow regulation and cold-water reservoir releases. Increasing trends in summer maximum temperatures have been detected, but proximity to the Project moderates temperatures with cold water releases. High water temperatures were identified as a limiting factor for Chinook, but not during incubation life stage. Life histories with extended rearing in freshwater (e.g., yearlings) are more sensitive to maximum instream temperatures, and tributary spawning and rearing populations were also identified as having higher potential exposure to high instream temperatures. High water temperatures can also create thermal barriers to migration, and influence overall periodicity of life stages as well as survival, metabolic rates, and growth.										
Instream temp min	***Management Actions***	ALL	MIGR → SPWN	MAIN, TRIB	PRD	-	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg. ☑ Land Uses & Cover	ALL	INCU → EMER	MAIN, TRIB	PRD, GRW	-	~Yes~ (MAIN)	Life Stages	4.0	Management Actions	4.0
	☑ Water Uses ☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	PRD, GRW	-	~Yes~ (MAIN)	Limiting Factor	0.0	Project Operations	1.0
	☑ Rest. & Prot. ☐ Fisheries	S, T	ESTU → NEAR	ESTU, NEAR	ALL	-	~Yes~ (ESTU)	Biological Score	2.0	Management Score	2.7
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***5.2***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Minimum instream temperatures are also influenced by the same management actions and climate processes as described for general instream temperatures. Warmer mainstem temperatures in Oct-Dec were linked to flow regulation, and increased temperatures typically causes earlier emergence timing that could influence early survival if juveniles emerge before food is available. However, no significant differences in emergence timing were detected associated with Project associated increases in instream temperatures during incubation. Cooler temperatures can also increase rearing duration for larval Lamprey, and slow early growth rates for Salmon and Trout. Cold water releases from the Project were identified as a moderating factor for shifts in spawn timing compared to other nearby systems.										

Table 8. Dissolved oxygen, nutrient and organic matter, and pH water quality factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Dissolved Oxygen	***Management Actions***	S, T	MIGR → SPWN	MAIN, TRIB	HAB, PRD, SRV, MOV	-	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	⊡ Flow Reg. ☑ Land Uses & Cover	ALL	INCU → EMER	MAIN, TRIB	SRV, PRD, GRW	-	~Yes~ (MAIN)	Life Stages	4.0	Management Actions	3.0
	☑ Water Uses ☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	ALL	-	-	Limiting Factor	0.0	Project Operations	0.5
	⊡ Rest. & Prot. ☐ Fisheries	S, T	ESTU → NEAR	ESTU, NEAR	ALL	-	-	Biological Score	2.0	Management Score	2.0
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***4.5***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Temperatures and nutrient inputs are a primary drivers of dissolved oxygen (DO) concentrations, and DO can vary diurnally with primary productivity. Flow regulation and instream flows can influence DO and temperatures, and water uses or stressors that reduce instream flows and temperature in general can influence instream DO. Climate change and water year type can influence DO through increasing temperatures and reduced instream flows. Flow regulation was cited as generally increasing DO with the mainstem being highly oxygenated, but release of sub-thermocline water can reduce DO if sub-thermocline have depressed DO. Tributaries to the Skagit and floodplain and estuary sloughs were identified as having impaired DO. Hypoxia can cause stress and mortality during adult migrations, incubation, juvenile rearing, and estuary and nearshore rearing and emigration. Gravel permeability and deposition of fine sediments can reduce DO during incubation, which may delay embryo development or reduce survival to emergence or size at emergence.										
Organic Matter and Nutrients	***Management Actions***	ALL	REAR → OUTM	MAIN, TRIB	GRW	No (S)	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	☑ Flow Reg. ☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	GRW	-	~Yes~ (ESTU)	Life Stages	2.0	Management Actions	5.0
	☑ Water Uses ⊡ Hatcheries							Limiting Factor	0.0	Project Operations	1.0
	☑ Rest. & Prot. ⊡ Fisheries							Biological Score	1.5	Management Score	2.8
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***4.8***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Nutrients and organic matter loading and cycles are considered important aspects of water quality, with nutrient cycles being a primary driver of primary productivity that support target species during rearing life stages. Land uses, underlying geology, groundwater and surface water processes, instream flows, and riparian conditions are primary drivers of nutrient and organic matter inputs and cycles. However, nutrients and carcass productivity were not identified as limiting salmon productivity. Fisheries and hatcheries can indirectly influence carcass abundance instream. Release of low nutrient waters from reservoirs can influence nutrient levels, but this appears to be limited to reaches closer to dams. Excess loading from land and water uses can cause water quality impairments that can lead to eutrophication and hypoxia that can reduce survival for Salmon and Trout, which are described for the dissolved oxygen factor. Water quality impairments with respect to excessive nutrient and organic matter loading were identified in the lower mainstem Skagit, some tributaries, and estuary and nearshore habitats that were linked to urban and agricultural runoff, wastewater treatment, septic systems, and other land uses and point and non-point sources. Climate change was identified as a potential stressor on nutrient and organic matter cycles that could result in increased frequency of harmful algal blooms and hypoxic events.										
pH	***Management Actions***	S, T	ESTU → NEAR	ESTU, NEAR	GRW	-	-	Species Groups	2.0	Study Area Strata	2.0
	⊡ Flow Reg. ⊡ Land Uses & Cover							Life Stages	1.0	Management Actions	1.5
	⊡ Water Uses ☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	⊡ Rest. & Prot. ☐ Fisheries							Biological Score	0.9	Management Score	0.8
	Climate							Climate Sensitivity	1.5	***Aggregate Score***	***2.0***
	☑ Climate Change ⊡ WY Type							Climate Score	0.4		
	Notes: Declining trends in pH have been identified in marine waters linked to climate change and ocean acidification, or linked to reduced dissolved oxygen concentrations. The mainstem Skagit was generally described as a low pH river, and several reaches in the lower Skagit River and lower Skagit tributaries were identified as not meeting state water quality standards for pH. Studies indicated that implications for reduced pH for fish species were unclear, but declining pH was generally linked to declining water quality and ocean acidification may affect marine and estuary food webs.										

Table 9. Turbidity and salinity water quality factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Turbidity	***Management Actions***		ALL	INCU → EMER	MAIN, TRIB	SRV	~Yes~ (TRIB)	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	⊡ Flow Reg.	☑ Land Uses & Cover	ALL	REAR → OUTM	MAIN, TRIB	SRV, GRW	-	~Yes~ (MAIN)	Life Stages	3.0	Management Actions	2.5
	⊡ Water Uses	☐ Hatcheries	S, T	ESTU → NEAR	ESTU, NEAR	HAB	~Yes~ (ESTU)	~Yes~ (ESTU)	Limiting Factor	1.0	Project Operations	1.0
	⊡ Rest. & Prot.	☐ Fisheries							Biological Score	2.8	Management Score	2.4
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***5.7***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Turbidity is primarily driven by sediment supply and transport processes, and is therefore linked to instream flow and processes that influence instream flows (including climate change, flow regulation, and land uses). Glacial melt is a primary source of turbidity, and the Sauk River is a primary source of turbidity. The effects of turbidity on fishes are reported as complex, with elevated levels potentially being deleterious effects on fish survival and behavior. Turbidity is an indicator of fine sediment loading, and fine sediment supply and retention were identified as a limiting factor on tidal marsh formation and maintenance processes. Elevated turbidity can reduce primary productivity that would affect growth, and fine sediments measured by turbidity can reduce survival during incubation as described for the sediment supply and transport factors. Elevated turbidity in the lower Sauk River was cited as a potential limiting factor for incubation survival, and degradation of water quality as measured by turbidity was identified as a principle issue of concern for salmonids in several tributaries to the lower Skagit River. However, elevated turbidity can also reduce predation risk and act as a substitute for cover.											
Salinity	***Management Actions***		S, T	ESTU → NEAR	ESTU, NEAR	ALL	-	~Yes~ (ESTU)	Species Groups	2.0	Study Area Strata	2.0
	⊡ Flow Reg.	⊡ Land Uses & Cover							Life Stages	1.0	Management Actions	2.5
	⊡ Water Uses	☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.5
	☑ Rest. & Prot.	☐ Fisheries							Biological Score	0.9	Management Score	1.4
	Climate								Climate Sensitivity	2.0	***Aggregate Score***	***2.8***
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Salinity is primarily relevant to estuary and nearshore habitats, but land uses and other stressors can potentially influence the conductivity of freshwater habitats. Salinities generally scale with instream flows, and therefore salinity is potentially influenced by flow regulation, water uses, climate change (both from changes in hydrological regimes and sea level rise), and water year type. Salinities in estuary habitats are influenced by the balance of instream flows, tidal inundation, and landscape connectivity. Restoration in the estuary can alter salinity patterns. Salinity is an important attribute of estuary and nearshore habitats, and intermediate salinity habitats support physiological transition to marine life stages. Salinity patterns have been linked to distribution patters for Salmon and Trout species, and some life histories and species may rear in mixohaline habitats for weeks to months.											

Table 10. Bacteria and pathogens and contaminants water quality factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Bacteria & Pathogens	***Management Actions***	ALL	ALL	ALL	SRV	No (S)	No (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	☐ Flow Reg. ☑ Land Uses & Cover							Life Stages	4.0	Management Actions	2.0
	⊡ Water Uses ⊡ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	☐ Rest. & Prot. ☐ Fisheries							Biological Score	2.0	Management Score	1.3
	Climate							Climate Sensitivity	1.0	***Aggregate Score***	***3.6***
	⊡ Climate Change ⊡ WY Type							Climate Score	0.3		
	Notes: Bacteria and pathogens were linked to a wide range of potential stressors, including runoff from non-point sources and point sources related to land and water uses. Aquaculture was reported as a potential source of bacteria and pathogens. Most studies that reported on bacteria or pathogens focused on fecal coliforms, and this is a water quality parameter that is monitored based on state standards. Patterns of fecal coliform were generally related to land use patters, and can covary with temperature, salinity, turbidity, and primary productivity. Flow regulation was hypothesized as a potential stressor on disease prevalence through altered thermal regimes, but this speculation was not supported and disease was identified as not limiting Chinook productivity. Bacteria and pathogens are presumed to primarily influence survival, but reported impairments for bacteria and pathogens were not linked to impacts on target species or life stages.										
Contam-inants	***Management Actions***	ALL	ALL	ALL	SRV, GRW	-	-	Species Groups	3.0	Study Area Strata	4.0
	☐ Flow Reg. ☑ Land Uses & Cover							Life Stages	4.0	Management Actions	1.5
	⊡ Water Uses ☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	☐ Rest. & Prot. ☐ Fisheries							Biological Score	2.0	Management Score	1.3
	Climate							Climate Sensitivity	0.5	***Aggregate Score***	***3.4***
	⊡ Climate Change ☐ WY Type							Climate Score	0.1		
	Notes: Altered hydrology associated with land uses and cover influence toxic loading in streams and estuaries, and both point and non-point sources of contaminants (including pesticides, heavy metals, and other toxic compounds) were identified in studies as potential sources of impairments in the lower Skagit River, some tributaries, estuary, and nearshore habitats. Contaminants can cause lethal and sub-lethal impacts to fishes that may include compromised immunology, increased mortality, and possible DNA damage. Contaminants can also impact target species and life stages by impacting primary and secondary productivity, reducing high quality prey items or through bioaccumulation of toxins. Climate change was cited as a potential stressor on contaminants with sea level rise increasing delivery of pollutants to Skagit estuary and Skagit bay.										

Table 11. Predation factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	***Species***	***Life Stages***	***Spatial Extent***	***Biological Response(s)***	***Limiting Factor***	***Project Operation***	***Criteria***	***Score***	***Criteria***	***Score***
Predation - avian & mammal	***Management Actions***	S, T	ALL	ALL	SRV	No (S)	-	Species Groups	2.0	Study Area Strata	4.0
	☐ Flow Reg. ☑ Land Uses & Cover							Life Stages	4.0	Management Actions	2.5
	☐ Water Uses ⊡ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	⊡ Rest. & Prot. ⊡ Fisheries							Biological Score	1.7	Management Score	1.4
	Climate							Climate Sensitivity	0.0	***Aggregate Score***	***3.1***
	☐ Climate Change ☐ WY Type							Climate Score	0.0		
	Notes: Predation from birds and marine mammals was found to not be a limiting factor for Chinook Salmon during freshwater, estuary, and nearshore life stages, but predation can increase mortality as well as stress and delayed mortality due to predator/prey interactions. Natural resource management policies were cited as factor that has contributed to increases in marine mammal abundances, and land uses, barriers, and hydromodifications were identified as factors that can increase local predator densities. Mammals (primarily California sea lions and Pacific harbor seals) were identified as potential predators on all life stages of Salmon and Trout, while avian predators (primarily cormorant and mergansers) primarily affect juvenile life stages. Aggregations of fish like hatchery releases were cited as a factor that can attract predators. No information on predation and climate linkages were identified, and flow regulation linkages with predation (avian predation associated with downramping and stranding) were focused on the Upper Skagit River.										
Predation - fish	***Management Actions***	S, T	ALL	ALL	SRV	No (S)	-	Species Groups	2.0	Study Area Strata	4.0
	⊡ Flow Reg. ☑ Land Uses & Cover							Life Stages	4.0	Management Actions	4.0
	⊡ Water Uses ⊡ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	⊡ Rest. & Prot. ☑ Fisheries							Biological Score	1.7	Management Score	1.7
	Climate							Climate Sensitivity	1.0	***Aggregate Score***	***3.6***
	⊡ Climate Change ⊡ WY Type							Climate Score	0.3		
	Notes: Predation risk and pressure among fishes were primarily linked to relative size structure and factors that infleunce co-occurence of species and life stages. Hatchery fish were identified as predators on Chinook, but predation on Chinook by hatchery fish was identified as a non-limiting factor for Chinook. Predation on target species by fishes can cause direct mortality as well as delayed mortality through predator avoidance behaviors. Target species themselves were identified as potential predators on other target species, most notably Bull Trout and Steelhead, and potentially Lamprey during estuarine and nearshore life stages. Other warm water or invasive species were also identidied as potential predators, and the abundance of these predators were linked to instream flows and water uses, land uses, and climate change.										

Table 12. Competition factors and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities: Stressors Yes (☑), No (☐), Indirect (⊡)	Species	Life Stages	Spatial Extent	Biological Response(s)	Limiting Factor	Project Operation	Criteria	Score	Criteria	Score
Compet-ition - spawning	***Management Actions***	S, T	MIGR → SPWN	MAIN, TRIB	HAB, PRD, MOV	No (S)	~Yes~ (MAIN)	Species Groups	2.0	Study Area Strata	2.0
	☑ Flow Reg.; ☑ Land Uses & Cover							Life Stages	1.0	Management Actions	6.0
	☑ Water Uses; ☑ Hatcheries							Limiting Factor	0.0	Project Operations	0.5
	☑ Rest. & Prot.; ☑ Fisheries							Biological Score	0.9	Management Score	2.0
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***3.4***
	☑ Climate Change; ☑ WY Type							Climate Score	0.5		
	Notes: Competition during spawning may occur among a target species or between target species. A primary factor in competition interactions is the co-occurrence of species and life stages with the same resource requirements. Availability and quality of spawning habitat can be influenced by instream flows (and therefore climate change and water uses) and flow regulation, and downramping was identified as a potential stressor on spawning habitats closer to hydroelectric facilities. Competition during spawning was determined to not be a limiting factor for Chinook based on the finding that at least three juvenile rearing life stages were identified as limiting. Some studies indicated evidence for some competitive interactions during spawning and holding based on the timing and distribution of spawners, and that superimposition should be monitored as an indicator for competition during spawning. However, competition during spawning may become more important as recovery actions address limiting factors for juvenile life stages and increase productivity and the abundance of returning adults. Hatchery fish hybridization with natural origin fish during spawning was cited as a concern, and hatcher strategies (e.g., temporal segregation) did not appear to be effective at reducing temporal overlap of hatchery and natural origin spawners.										
Compet-ition - rearing	***Management Actions***	S, T	REAR → OUTM	MAIN, TRIB	ALL	Yes (S)	~Yes~ (MAIN)	Species Groups	2.0	Study Area Strata	4.0
	☑ Flow Reg.; ☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	ALL	Yes (S)	~Yes~ (ESTU)	Life Stages	2.0	Management Actions	5.5
	☑ Water Uses; ☑ Hatcheries							Limiting Factor	2.0	Project Operations	1.0
	☑ Rest. & Prot.; ⊡ Fisheries							Biological Score	3.2	Management Score	2.9
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***6.6***
	☑ Climate Change; ☑ WY Type							Climate Score	0.5		
	Notes: Competition during juvenile rearing life stages can influence growth, habitat use and capacities, movement, periodicity, and survival through density dependent and size selective processes. Co-occurrence is a primary factor in competition, and juvenile hatchery fish as well as other target species were identified as competitors during rearing life stages. Freshwater, estuary, and nearshore rearing habitats were identified as limiting for Chinook, and therefore competition during these life stages were identified as a limiting factor. Restoration actions have focused on increasing rearing habitat extent during these life stages to increase capacity, and thereby reduce competition. Instream flows, flow regulation, climate change, and water uses were also identified as potential stressors on competition during rearing through influences on habitat extent as well as survival during the incubation life stage.										

Table 13. Food availability metrics and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		Species	Life Stages	Spatial Extent	Biological Response(s)	Limiting Factor	Project Operation	Criteria	Score	Criteria	Score
Primary Productivity	Management Actions		ALL	REAR → OUTM	MAIN, TRIB	GRW, SRV	No (S)	~Yes~ (MAIN)	Species Groups	3.0	Study Area Strata	4.0
	⊡ Flow Reg.	☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	GRW, SRV	-	-	Life Stages	2.0	Management Actions	3.5
	☑ Water Uses	☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.5
	☑ Rest. & Prot.	☐ Fisheries							Biological Score	1.5	Management Score	2.1
	Climate								Climate Sensitivity	2.0	Aggregate Score	4.1
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Photosynthesis drives primary production of algae and aquatic plants, and primary production and detritus-based food web were linked to organic matter and nutrient inputs. Therefore, riparian conditions influence both primary and secondary productivity via instream shading and photosynthesis as well as organic matter and nutrient inputs. Nutrient and salmon carcasses influence both primary and secondary productivity, although they were not determined to be a limiting factor for Chinook productivity. Land use and cover in general and in combination with altered hydrological regimes associated with development were linked to primary productivity. Altered hydrology associated with land uses and cover were influence nutrient loading that can lead to eutrophication and hypoxia in stream and estuary habitats. Reducing water level fluctuations by implementing a stable flow regime resulted in higher standing crop of periphyton and benthic insects, and primary productivity can be influenced by flow regulation or downramping, but it is unclear if this applied to the lower mainstem Skagit River. In the estuary, invasive plants were also identified as a stressor on primary productivity and estuarine food webs.											
Secondary Productivity	Management Actions		S, T	REAR → OUTM	MAIN, TRIB	GRW, SRV	No (S)	Yes (MAIN)	Species Groups	2.0	Study Area Strata	4.0
	☑ Flow Reg.	☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	GRW, SRV	Yes (S)	Yes (ESTU)	Life Stages	2.0	Management Actions	5.0
	☑ Water Uses	⊡ Hatcheries							Limiting Factor	1.0	Project Operations	2.0
	☑ Rest. & Prot.	⊡ Fisheries							Biological Score	2.2	Management Score	3.8
	Climate								Climate Sensitivity	2.0	Aggregate Score	6.5
	☑ Climate Change	☑ WY Type							Climate Score	0.5		
	Notes: Primary productivity drives secondary productivity, but a wide range of potential drivers and stressors interact with food webs and habitat processes that can influence secondary productivity and the availability of food for target species during rearing life stages. Juvenile salmon and trout rely on both aquatic and terrestrial invertebrate production for feeding during rearing life stages while larval Lamprey are filter feeders. Salmon and trout may also feed on other fishes during rearing life stages, while Lamprey become parasitic on fishes after metamorphosis during estuarine and nearshore life stages. During adult migrations, holding, and spawning, salmon and Lamprey are assumed to not feed and die following spawning. However, Bull Trout and Steelhead, with their range of life histories that include anadromous, resident, adfluvial, and iteroparity, may actively feed at a variety of sub adult and adult life stages. Prey availability was identified as a limiting factor for Chinook during estuarine and nearshore rearing life stages, but nutrient and carcass productivity levels were not identified as a limiting factor during freshwater rearing life stages. The relative abundance and diversity of aquatic benthic insects are used as indicators of ecosystem and food web health, and relative dominance and benthic invert taxa diversity were linked to land uses, disturbance, and water quality impairments. Instream flows, including peak flow events and downramping were identified as stressors on benthic invertebrate abundance and distribution. Implementation of stable flow regimes through flow regulation can increase standing crops of benthic insects, but it is unclear if this applies to the lower mainstem Skagit River. The upper Skagit River produces most of the fish biomass in the basin and this infleunces secondary production in the lower Skagit River.											

Table 14. Other anthropogenic factors (1 of 2) and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities	Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)	*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Climate Change	***Management Actions***	ALL	MIGR → SPWN	MAIN, TRIB	ALL	-	-	Species Groups	3.0	Study Area Strata	4.0
	☐ Flow Reg. ⊡ Land Uses & Cover	ALL	INCU → EMER	MAIN, TRIB	ALL	~Yes~ (S)	-	Life Stages	4.0	Management Actions	0.5
	☐ Water Uses ☐ Hatcheries	ALL	REAR → OUTM	MAIN, TRIB	ALL	~Yes~ (S)	-	Limiting Factor	1.5	Project Operations	0.0
	☐ Rest. & Prot. ☐ Fisheries	ALL	ESTU → NEAR	ESTU, NEAR	ALL	~Yes~ (S)	-	Biological Score	3.5	Management Score	1.1
	Climate							Climate Sensitivity	2.0	***Aggregate Score***	***5.1***
	☑ Climate Change ☑ WY Type							Climate Score	0.5		
	Notes: Climate change was identified as a potential stressor on numerous factors including instream flows, sediment supply and transport, habitat availability and connectivity, large woody debris and bank conditions, riparian condition, water quality, competition and predation, and food availability. Likewise, climate change was identified as a potential stressor on all target species and life stages with potential to influence movement and periodicity, growth and survival, and habitat capacities. Climate change processes were also linked to some contemporary patterns as well as predicted future impacts of climate change (e.g., loss of glacial coverage and changes in instream temperatures). Potential influences of climate change on the availability of habitat and habitat connectivity for habitats that were identified as limiting for Chinook salmon were also identified, including freshwater, estuary, and nearshore rearing habitats.										
Hatcheries	***Management Actions***	S, T	MIGR → SPWN	MAIN, TRIB	HAB, MOV	-	-	Species Groups	2.0	Study Area Strata	4.0
	☐ Flow Reg. ☐ Land Uses & Cover	S, T	INCU → EMER	MAIN, TRIB	SRV	-	-	Life Stages	4.0	Management Actions	1.5
	☐ Water Uses ☑ Hatcheries	S, T	REAR → OUTM	MAIN, TRIB	ALL	No (S)	-	Limiting Factor	0.0	Project Operations	0.0
	☐ Rest. & Prot. ⊡ Fisheries	S, T	ESTU → NEAR	ESTU, NEAR	ALL	No (S)	-	Biological Score	1.7	Management Score	1.3
	Climate							Climate Sensitivity	0.0	***Aggregate Score***	***2.9***
	☐ Climate Change ☐ WY Type							Climate Score	0.0		
	Notes: Hatchery management strategies and releases were identified as a potential stressor on target species through competition, predation, and mixing of populations. Size and timing of releases were identified as primary factors influencing interactions between hatchery and natural origin fishes during rearing life stages. Studies provided evidence of reduced fitness and genetic mixing of target species from naturally spawning hatchery origin adults, and hatchery management strategies were identified as not being able to effectively prevent co-occurrence of spawners and natural spawning of hatchery origin adults. No studies identified hatchery releases as a limiting factor to target species, and this was specifically examined for freshwater, estuary, and nearshore life stages and habitats. Hatcheries are designed in part to supplement abundance for recovery and fisheries, and therefore fisheries indirectly influence hatchery management strategies.										
Fisheries	***Management Actions***	S, T	MIGR → SPWN	MAIN, TRIB	SRV	Yes (S)	-	Species Groups	2.0	Study Area Strata	4.0
	☐ Flow Reg. ☐ Land Uses & Cover							Life Stages	1.0	Management Actions	2.0
	☐ Water Uses ☑ Hatcheries							Limiting Factor	1.0	Project Operations	0.0
	☐ Rest. & Prot. ☑ Fisheries							Biological Score	1.9	Management Score	1.3
	Climate							Climate Sensitivity	1.0	***Aggregate Score***	***3.5***
	☑ Climate Change ☐ WY Type							Climate Score	0.3		
	Notes: Fisheries primarily influence adult life stages and reduces marine survival as well as survival during adult migration and holding through commercial, recreational, and tribal fisheries. Given that fisheries are in part managed based on abundance of populations and marine survival, fisheries are sensitive to climate change. Marine survival was identified as a limiting factor for Chinook, which is partly tied to fisheries during ocean life stages. Poaching was identified as a limiting factor for Chinook, but quantification of impacts are difficult due to the illegal nature of poaching. Hatcheries provide supplementation for fisheries.										

Table 15. Other anthropogenic factors (2 of 2) and initial assessment of relative importance. Sensitivities to management actions and climate are identified as Yes (☑), No (☐), or Indirect (⊡). The biological, management, and climate scores are based on the sums of the elements above each component (except for the climate score that is divided by 4), and the aggregate score is the sum of the scoring components. See Figure 1 for more information on the format and values shown in the LSF Tables.

Factor	Sensitivities		Biological Responses of Target Species and Life Stages						Initial Assessment of Relative Importance			
	Stressors Yes (☑), No (☐), Indirect (⊡)		*Species*	*Life Stages*	*Spatial Extent*	*Biological Response(s)*	*Limiting Factor*	*Project Operation*	*Criteria*	*Score*	*Criteria*	*Score*
Aqua-culture	***Management Actions***		S, T	ESTU → NEAR	ESTU, NEAR	SRV, HAB	-	-	Species Groups	2.0	Study Area Strata	2.0
	☐ Flow Reg.	☐ Land Uses & Cover							Life Stages	1.0	Management Actions	0.0
	☐ Water Uses	☐ Hatcheries							Limiting Factor	0.0	Project Operations	0.0
	☐ Rest. & Prot.	☐ Fisheries							Biological Score	0.9	Management Score	0.5
	Climate								Climate Sensitivity	0.0	***Aggregate Score***	***1.4***
	☐ Climate Change	☐ WY Type							Climate Score	0.0		
	Notes: Limited information on aquaculture impacts was identified in the literature for net pen and shellfish aquaculture. Potential effects of operational leakage were identified through introduction of invasive species, disease, excessive nutrient loading, or competitive interactions during estuarine and nearshore life stages that are subject to rearing capacity limitations through density dependence.											
Beaver Manage-ment	***Management Actions***		S, T	REAR → OUTM	MAIN, TRIB	HAB, MOV, GRW	~Yes~ (S)	-	Species Groups	2.0	Study Area Strata	4.0
	☐ Flow Reg.	☑ Land Uses & Cover	S, T	ESTU → NEAR	ESTU, NEAR	HAB, MOV, GRW	~Yes~ (S)	-	Life Stages	2.0	Management Actions	3.0
	☑ Water Uses	☐ Hatcheries							Limiting Factor	1.0	Project Operations	0.0
	☑ Rest. & Prot.	☐ Fisheries							Biological Score	2.2	Management Score	1.5
	Climate								Climate Sensitivity	0.0	***Aggregate Score***	***3.7***
	☐ Climate Change	☐ WY Type							Climate Score	0.0		
	Notes: Historical beaver trapping and declines in beaver populations were identified as a stressor on current habitat conditions that limit freshwater rearing capacity and productivity for target species. Beaver removal was also associated with land uses given that beaver can be considered a nuisance for some land uses due to their damming behavior. Beaver are ecosystem engineers that physically alter habitats and create slow-water refuge and rearing habitats that are important to target species and life stages, and evidence for positive benefits for target species from beaver activity were identified in both freshwater and estuarine habitats. Significant reductions in Coho production and capacity were specifically linked to losses of beaver habitat in the Skagit, and beaver dams in estuary tidal channels were linked to increased growth potential by increasing the duration of rearing in tidal channels by maintaining water in channels that would otherwise drain during ebb tides. Restoration and protection of beavers and their habitats were identified as a necessary management action to address the losses of habitat process and rearing capacity for target species, and therefore beaver management was identified as an indirect limiting factor for Salmon given that freshwater and estuary habitats were identified as limiting production.											

Table 16. Key factor criteria and summary of initial assessment of relative importance. All biological, management, and climate scores were summarized from the LSF Tables for each factor (See Table 1 - Table 15). Factors are sorted by aggregate scores to support identification of key factors. The color ramp represents the range of scores from lowest (light green) to 50th percentile (medium green) to highest (dark green) for each scoring component and the aggregate score.

Factor	Relevant to one or more target species or life stages?	Limiting factor to one or more species or life stages?	Relevant to one or more spatial strata?	Can be influenced by management actions?	Can be influenced by Project operations?	Sensitive to climate change or WY type?	Biological Score	Management Score	Climate Score	Aggregate Score	Initial Assessment of Relative Importance
Sediment supply and transport	Yes	Yes	Yes	Yes	Yes	Yes	4.0	3.5	0.5	8.0	High
Instream temp max	Yes	Yes	Yes	Yes	~Yes~	Yes	4.0	2.7	0.5	7.2	High
Habitat extent	Yes	Yes	Yes	Yes	~Yes~	Yes	4.0	2.2	0.5	6.7	High
Peak flow	Yes	Yes	Yes	Yes	Yes	Yes	3.0	3.1	0.5	6.6	High
Competition - rearing	Yes	Yes	Yes	Yes	~Yes~	~Yes~	3.2	2.9	0.5	6.6	High
Secondary productivity	Yes	Yes	Yes	Yes	Yes	Yes	2.2	3.8	0.5	6.5	High
Habitat connectivity	Yes	Yes	Yes	Yes	~Yes~	~Yes~	4.0	2.0	0.3	6.3	High
Riparian condition	Yes	Yes	Yes	Yes	No	Yes	4.0	1.5	0.4	5.9	High
Turbidity	Yes	Yes	Yes	Yes	~Yes~	Yes	2.8	2.4	0.5	5.7	Moderate
General flow	Yes	No	Yes	Yes	Yes	Yes	2.0	3.2	0.5	5.7	Moderate
Min flow	Yes	No	Yes	Yes	Yes	Yes	2.0	3.0	0.5	5.5	Moderate
Instream temp min	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.7	0.5	5.2	Moderate
Instream temp general	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.7	0.5	5.2	Moderate
Climate change	Yes	Yes	Yes	No	No	Yes	3.5	1.1	0.5	5.1	Moderate
Hydromodified banks and channel edges	Yes	Yes	Yes	Yes	~Yes~	~Yes~	2.8	1.9	0.3	4.9	Moderate
Nutrients and organic matter	Yes	No	Yes	Yes	~Yes~	Yes	1.5	2.8	0.5	4.8	Moderate
Dissolved oxygen	Yes	No	Yes	Yes	~Yes~	Yes	2.0	2.0	0.5	4.5	Moderate
LWD recruitment and retention	Yes	No	Yes	Yes	~Yes~	~Yes~	2.0	2.1	0.3	4.3	Low
Primary productivity	Yes	No	Yes	Yes	~Yes~	Yes	1.5	2.1	0.5	4.1	Low
Beaver management	Yes	Yes	Yes	Yes	No	No	2.2	1.5	0.0	3.7	Low
Bacteria and pathogens	Yes	No	Yes	Yes	No	~Yes~	2.0	1.3	0.3	3.6	Low
Predation - fish	Yes	No	Yes	Yes	No	~Yes~	1.7	1.7	0.3	3.6	Low
Fisheries	Yes	Yes	Yes	No	No	Yes	1.9	1.3	0.3	3.5	Low
Competition - spawning	Yes	No	Yes	Yes	~Yes~	Yes	0.9	2.0	0.5	3.4	Low
Contaminants	Yes	No	Yes	Yes	No	~Yes~	2.0	1.3	0.1	3.4	Low
Predation - avian and mammal	Yes	No	Yes	Yes	No	No	1.7	1.4	0.0	3.1	Low
Downramping	Yes	No	Yes	Yes	~Yes~	~Yes~	1.5	1.3	0.3	3.0	Low
Hatcheries	Yes	No	Yes	No	No	No	1.7	1.3	0.0	2.9	Low
Salinity	Yes	No	Yes	Yes	~Yes~	Yes	0.9	1.4	0.5	2.8	Low
Tidal inundation	Yes	No	Yes	Yes	~Yes~	Yes	0.9	1.3	0.4	2.5	Low
pH	Yes	No	Yes	Yes	No	Yes	0.9	0.8	0.4	2.0	Low
Aquaculture	Yes	No	Yes	No	No	No	0.9	0.5	0.0	1.4	Low

2.5 Initial Assessment of Relative Importance

The aggregate scores (S_T) for each factor (Table 16) were used to classify factors into three categories of relative importance based on the ranges of aggregate scores (S_T) that included the following:

1. High ($S_T \geq 5.8$),
2. Moderate ($4.5 \leq S_T < 5.7$), and
3. Low ($S_T < 4.5$).

The aggregate scores as well as the component scores and answers to key factor criteria are summarized in Table 16. The aggregate scores ranged from 1.4 to 8.0 (Table 16), and aggregate scores generally increased as the number of key factor criteria were satisfied (Figure 2). Comparing the aggregate scores to the number of key factor criteria that were satisfied shows that the aggregate scores vary among the key factor criteria, which is reflective of the finer detail of information the scoring components provide.

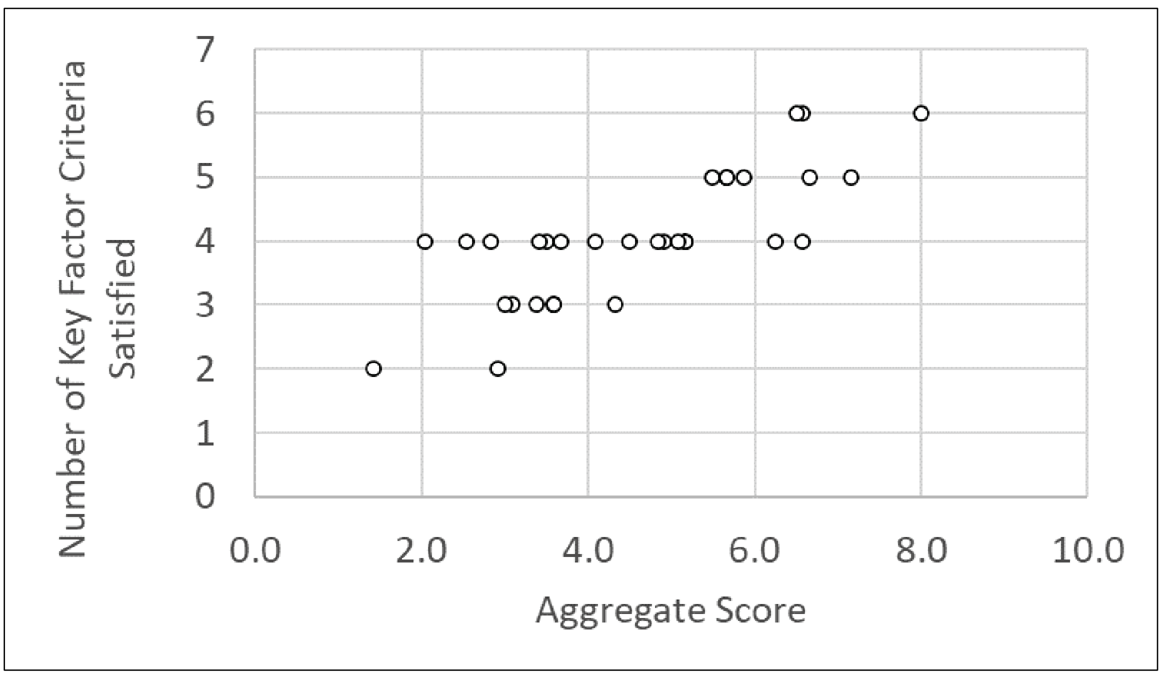


Figure 2. Aggregate scores from Table 16 compared to the number of key factor criteria questions that were satisfied (Yes's in Table 16). Each point represents a factor.

An aggregate score of 4.5 represented the baseline maximum score, which would include factors that are relevant to all three target species groups, all four life stages, all four spatial strata, all four management actions, and both climate sensitivities. This baseline maximum score was used to differentiate between factors that were classified as being of Moderate importance or Low importance. Factors that were identified as limiting factors or linked to Project operations would increase the baseline maximum score, and factors with an aggregate score of ≥ 5.8 (75th percentile) were identified as limiting factors to one or more species and life stages or linked to Project operations in one or more strata. These were classified as having a High relative importance. Factors with less than a 4.5 aggregate score were classified as having Low relative importance and would include factors that did not meet one or more of the key factor criteria, but may include factors that were identified as limiting to one species or life stage or linked to Project operations.

A total of eight factors were classified as being of High relative importance (Table 16). These included sediment supply and transport, instream temperature maximums, habitat extent, peak flows, competition during rearing, secondary productivity, habitat connectivity, and riparian conditions. These factors had the highest biological scores (average = 3.5), management scores (average = 2.7), and climate scores (average = 0.5).

An addition nine factors were classified as being of Moderate relative importance (Table 16). These included several water quality factors (turbidity, dissolved oxygen, general and minimum instream temperatures, and nutrients and organic matter), general and minimum instream flow, hydromodified banks and channel edges, and climate change. These factors scored less than the factors that were identified as having High relative importance for biological scores (average = 2.3), management scores (average = 2.4), and climate scores (average = 0.5).

The remaining 15 factors were identified as having Low relative importance and included LWD recruitment and retention, primary productivity, competition during spawning, beaver management, downramping, several water quality factors (bacteria and pathogens, contaminants, salinity, and pH), predation (avian, mammal, and fish), fisheries, tidal inundation, hatcheries, and aquaculture. These factors scored the lowest for biological scores (average = 1.5), management scores (average = 1.4), and climate scores (average = 0.2).

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT E

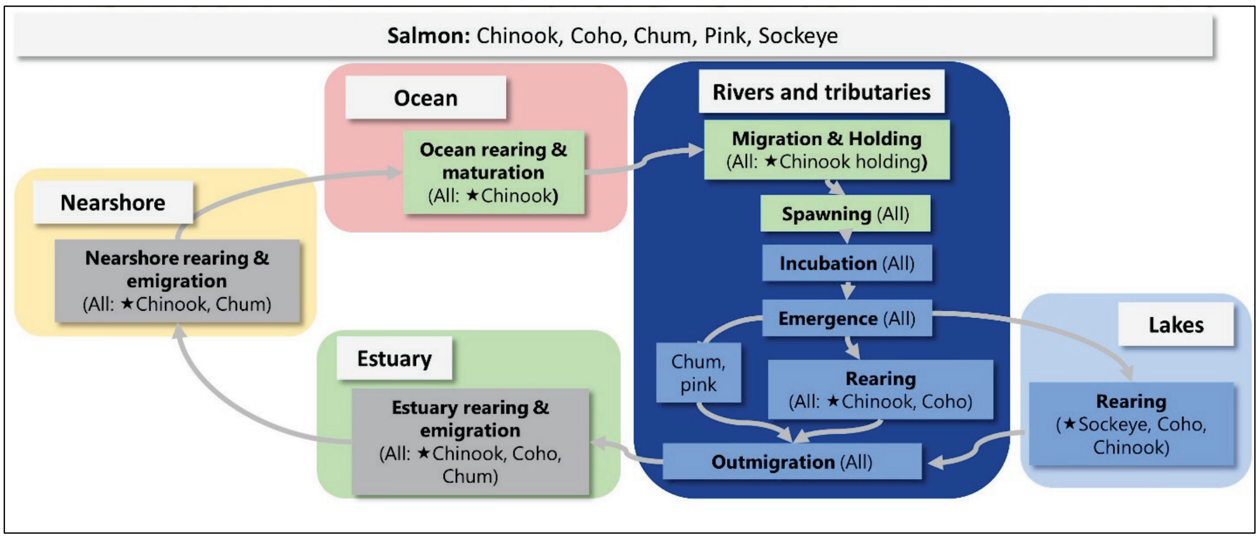
LIFE HISTORY MODELS

1.0 OVERVIEW

This Attachment provides conceptual life cycle diagrams and life history models that were developed for Step 2 in coordination with LPs and from literature synthesized during Step 1. The conceptual life stage diagrams and conceptual life history models were developed to support identification and interpretation of life stage factor information in Step 3. In coordination with LPs, the conceptual life cycle diagrams were developed at a species group level (Salmon, Trout, and Lamprey) and for aggregated life stages and transitions (generally grouped as adult migration, holding and spawning; incubation and emergence; rearing and outmigration; estuary rearing and emigration; and nearshore rearing and emigration).

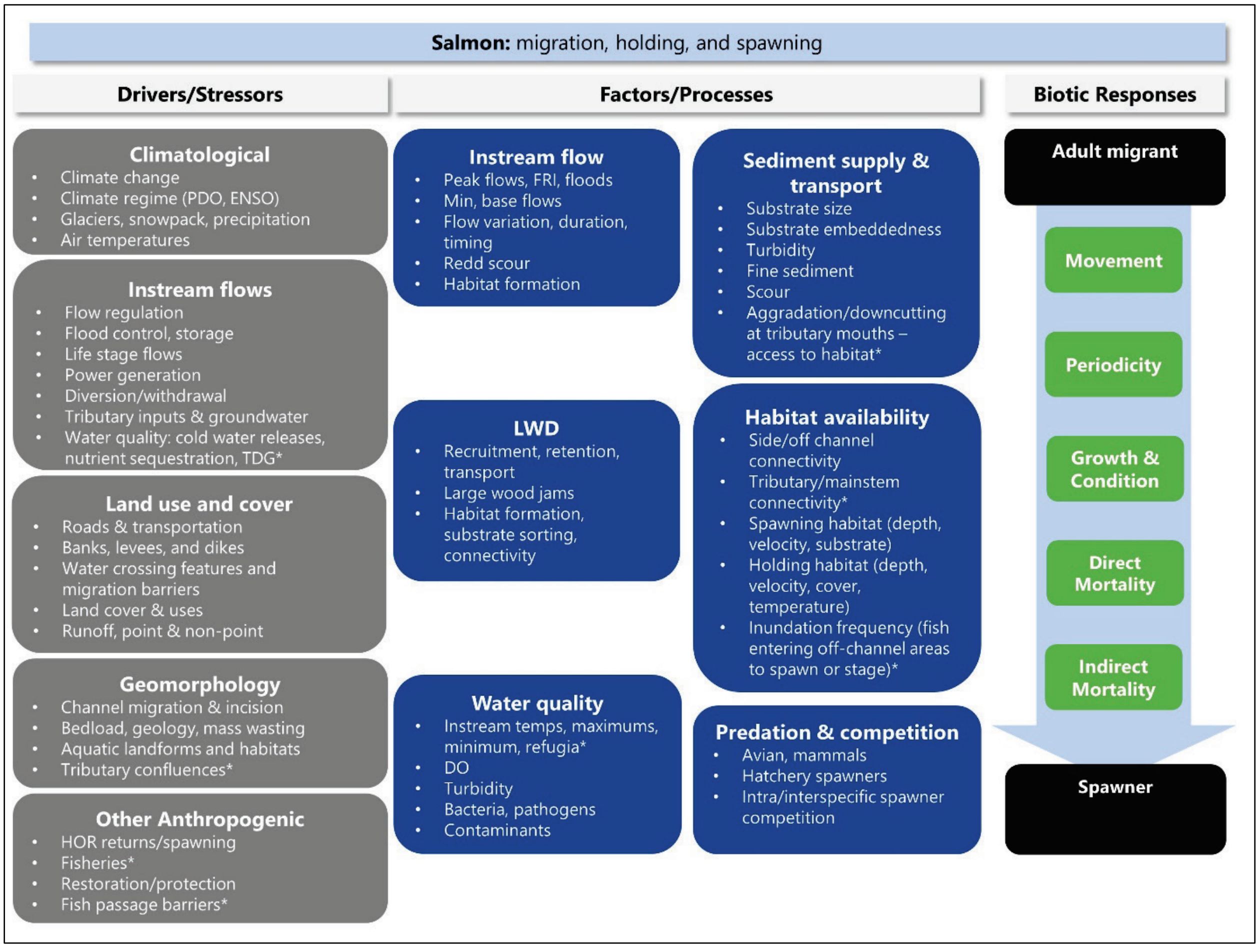
2.0 CONCEPTUAL MODELS

2.1 Salmon



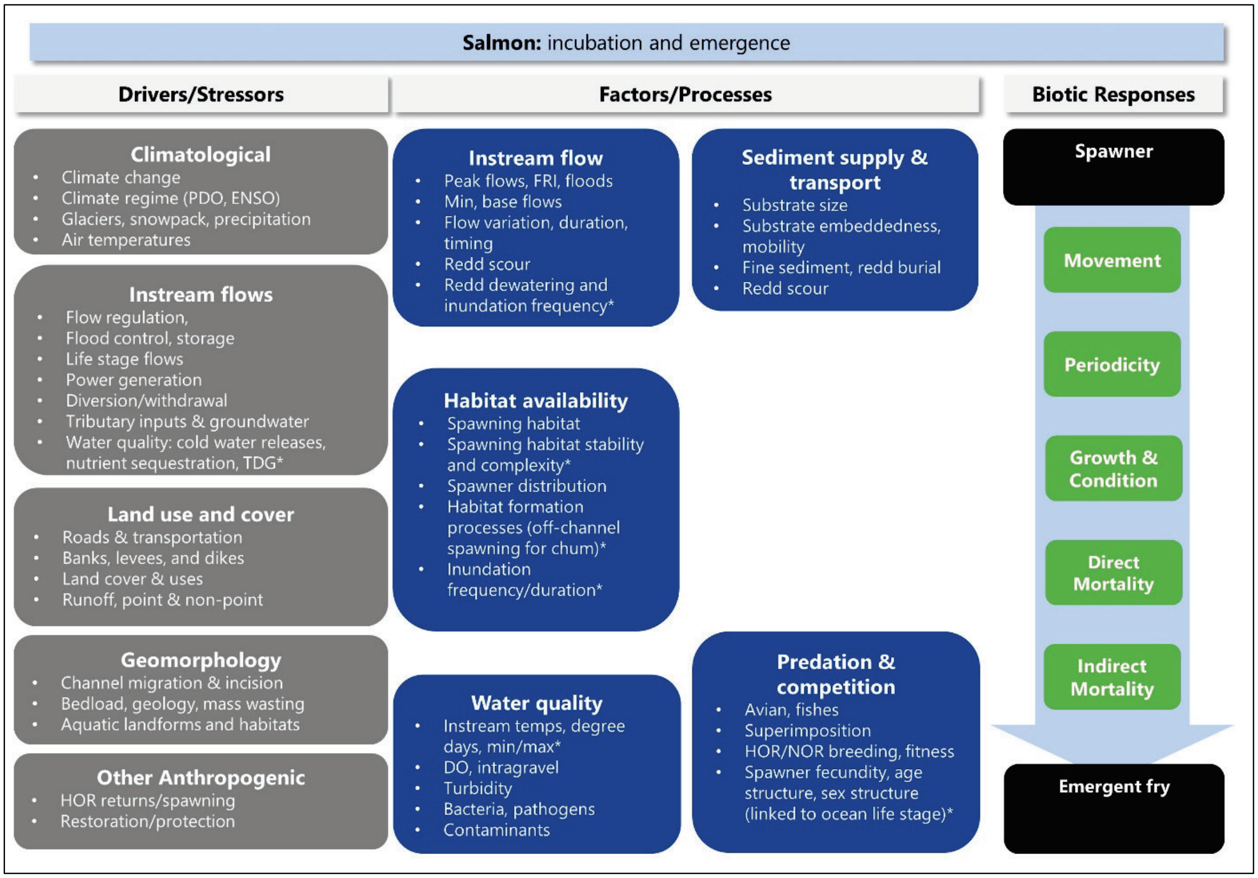
Note: Habitat strata are indicated by colored boxes with rounded edges, and life stages and transitions are identified by rectangular boxes with connecting arrows. Where applicable, specific species with the potential for extended residency are identified (★), or pathways specific to a species are identified as separate boxes. LH indicates a specific life history.

Figure 1. Conceptual life cycle diagram for Salmon species group.



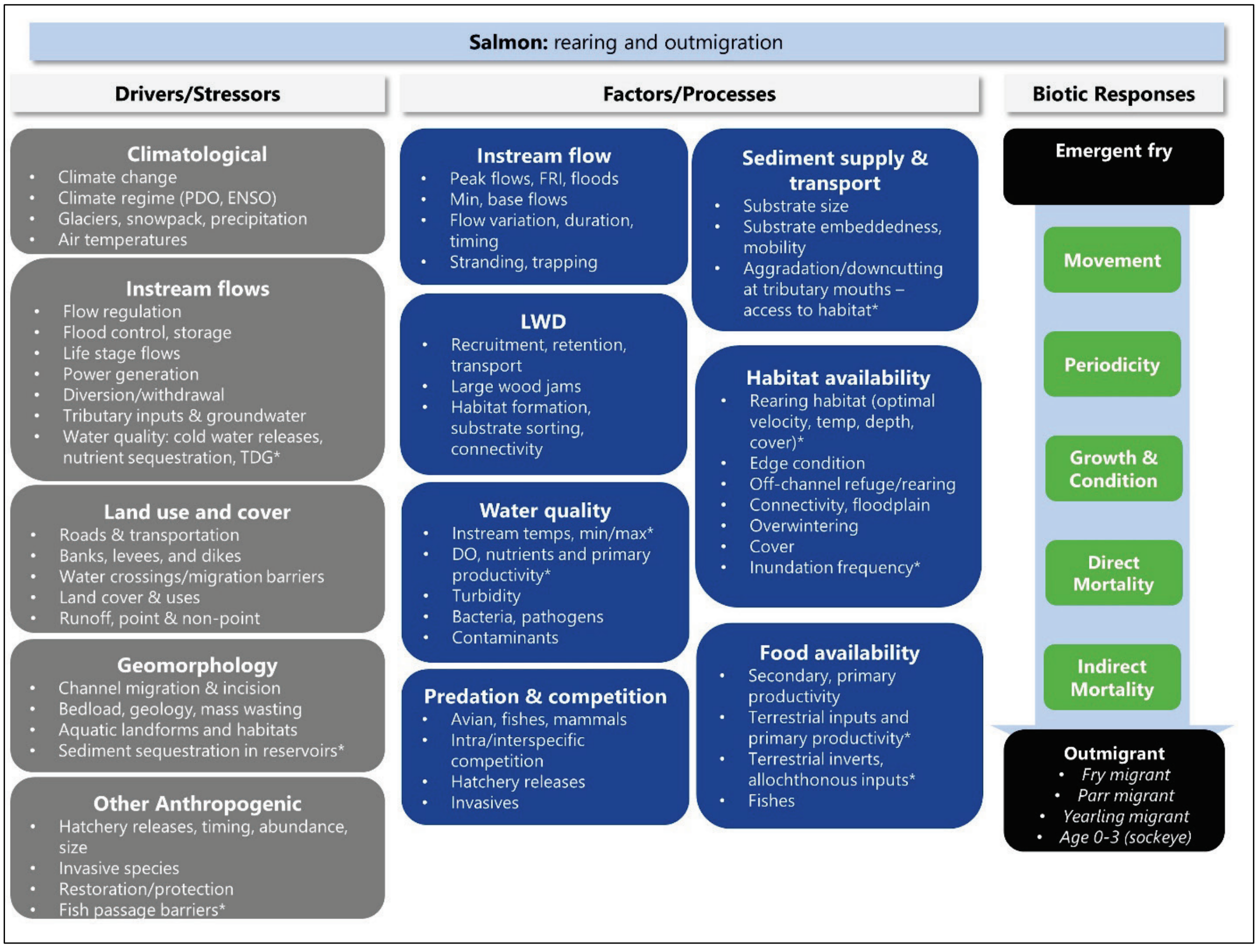
Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 2. Conceptual life history model for the Salmon species group for the migration, holding, and spawning life stages.



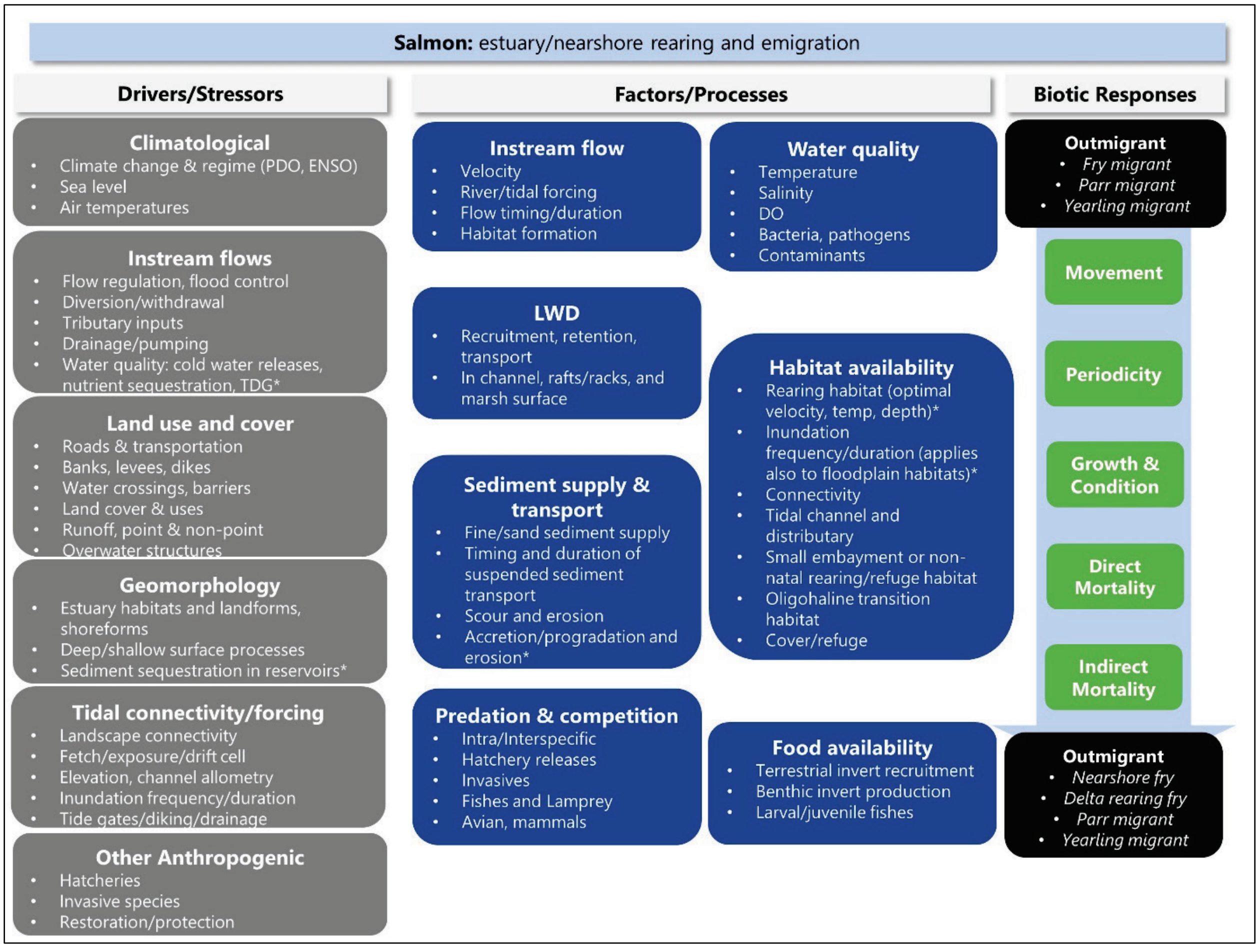
Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 3. Conceptual life history model for the Salmon species group for the incubation and emergence life stages.



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

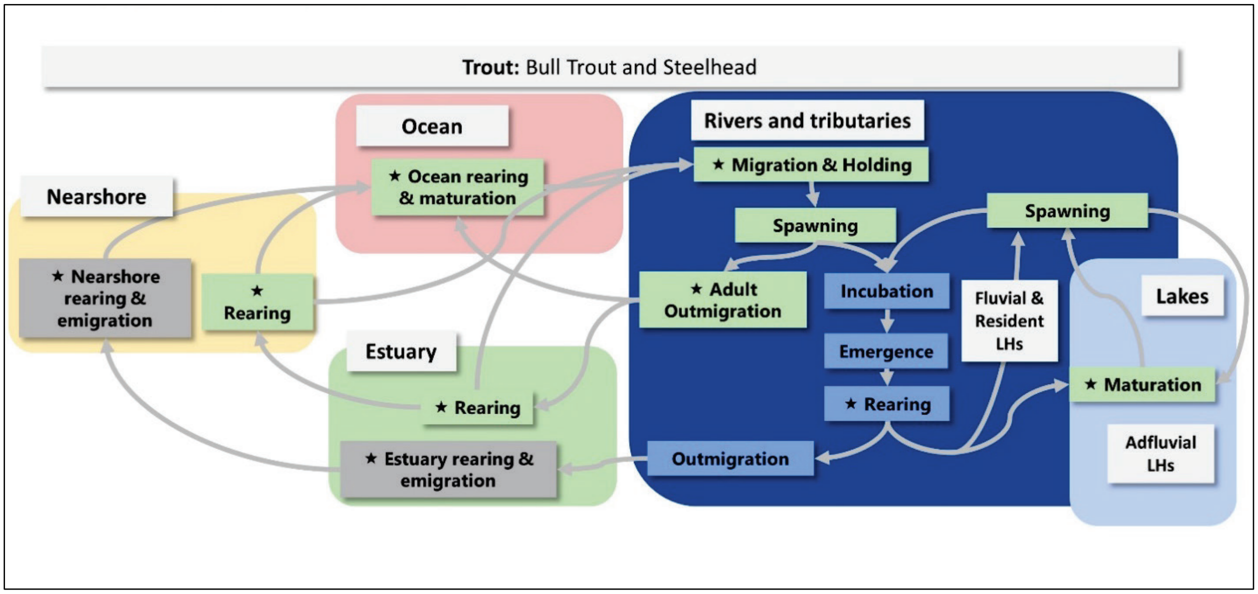
Figure 4. Conceptual life history model for the Salmon species group for the rearing and outmigration life stages.



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

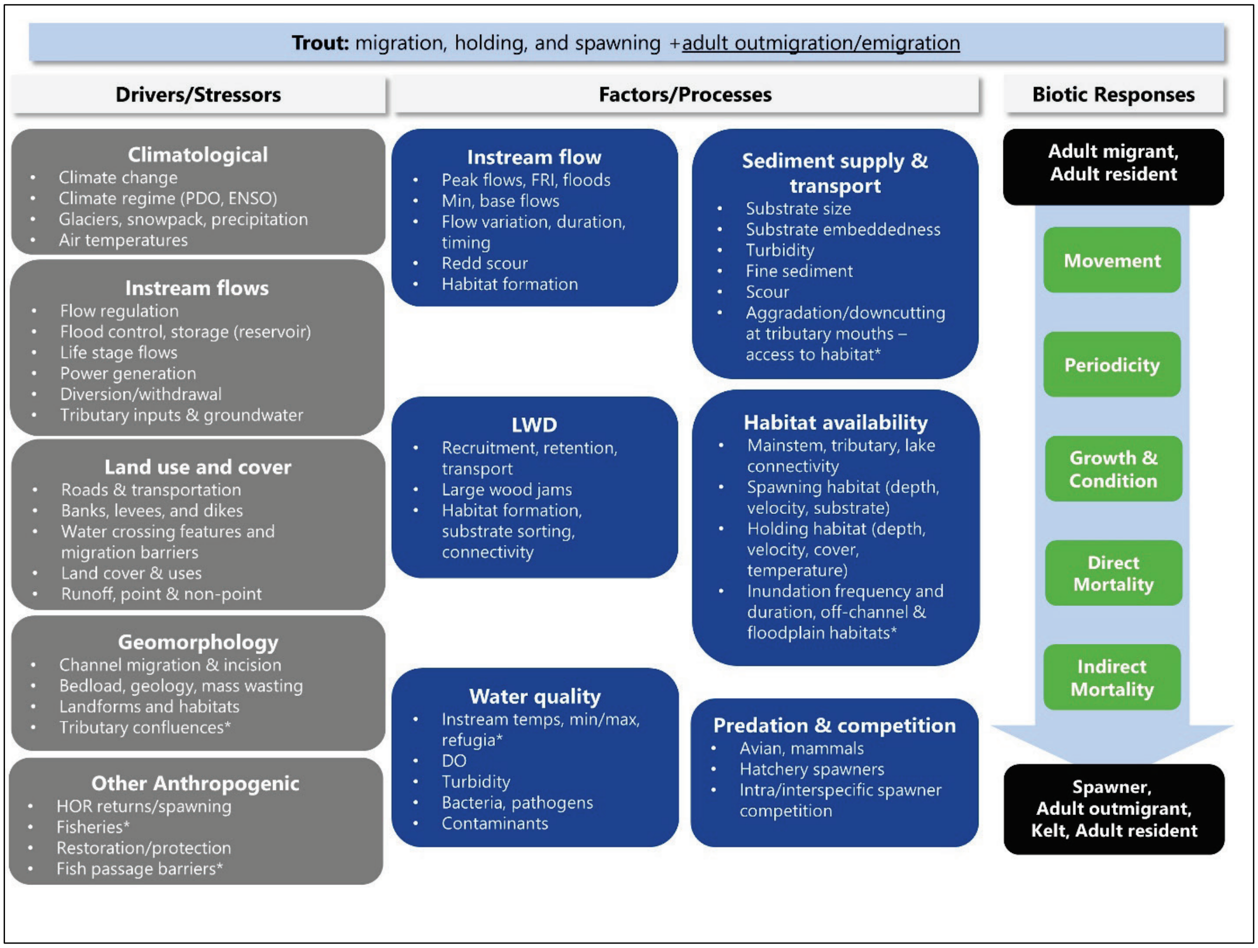
Figure 5. Conceptual life history model for the Salmon species group for the estuary/nearshore rearing and emigration life stages.

2.2 Trout



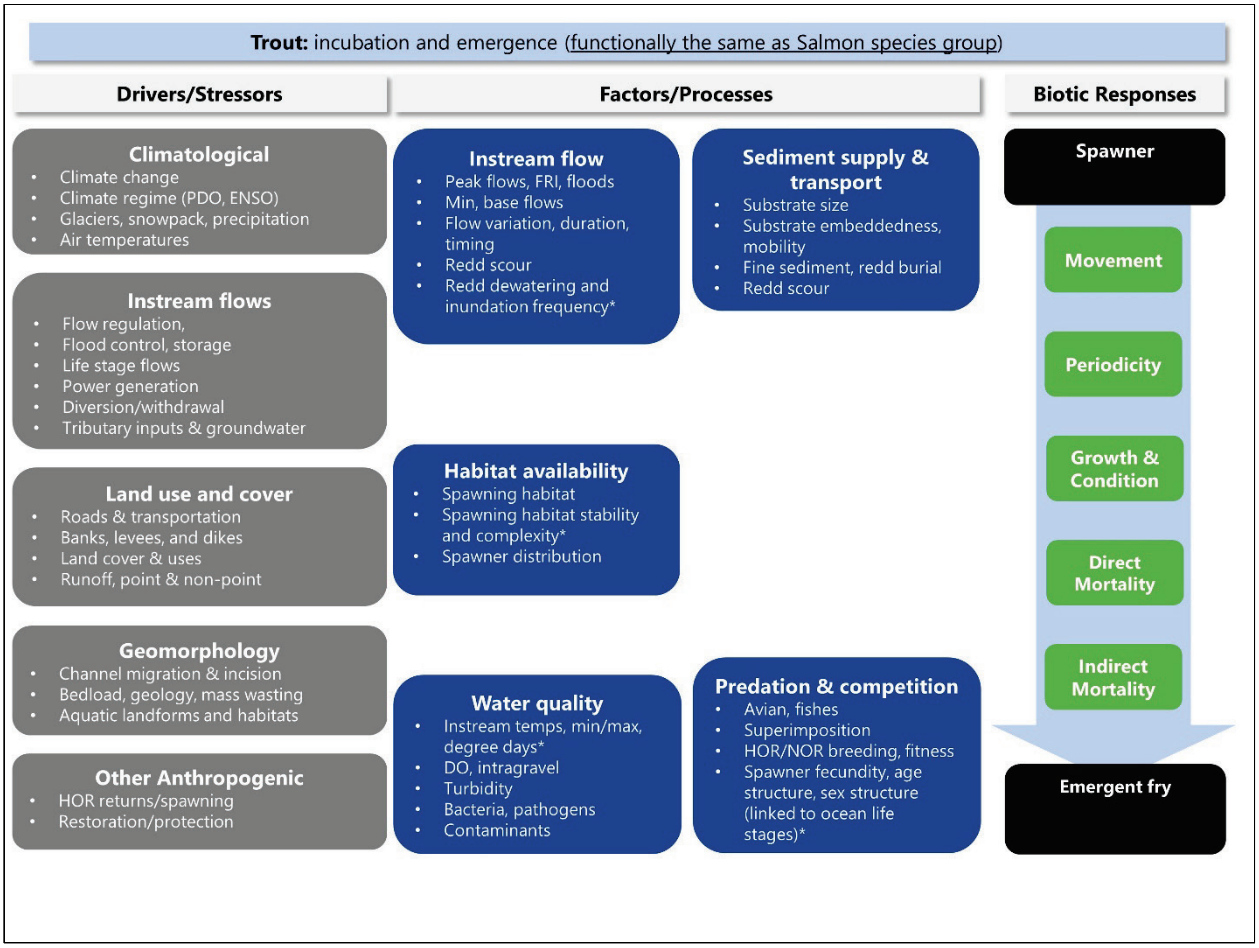
Note: Habitat strata are indicated by colored boxes with rounded edges, and life stages and transitions are identified by rectangular boxes with connecting arrows. Where applicable, specific species with the potential for extended residency are identified (★), or pathways specific to a species are identified as separate boxes. LH indicates a specific life history.

Figure 6. Conceptual life cycle diagram for Trout species group.



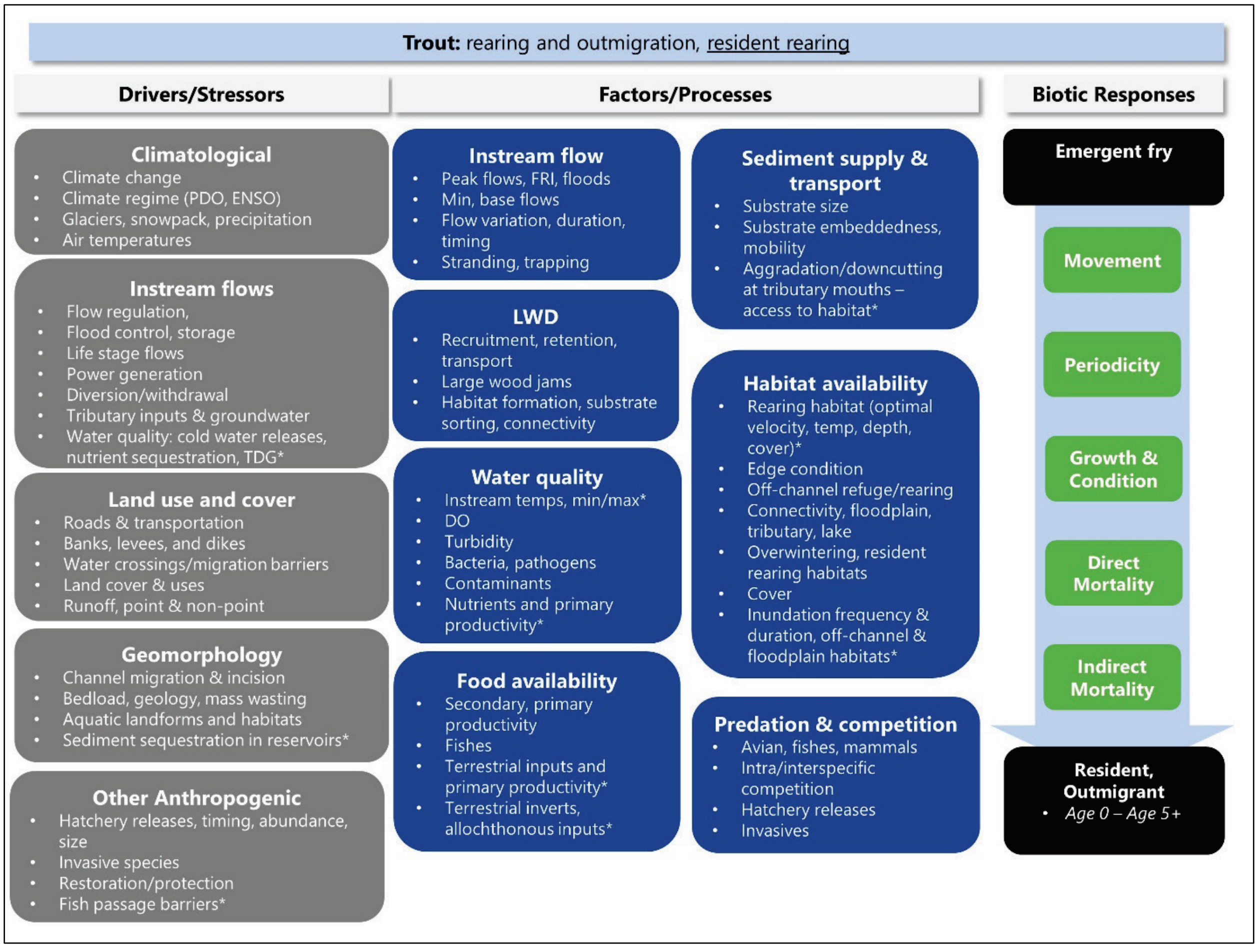
Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 7. **Conceptual life history model for the Trout species group for the adult migration, holding, spawning and adult outmigration/emigration life stages.**



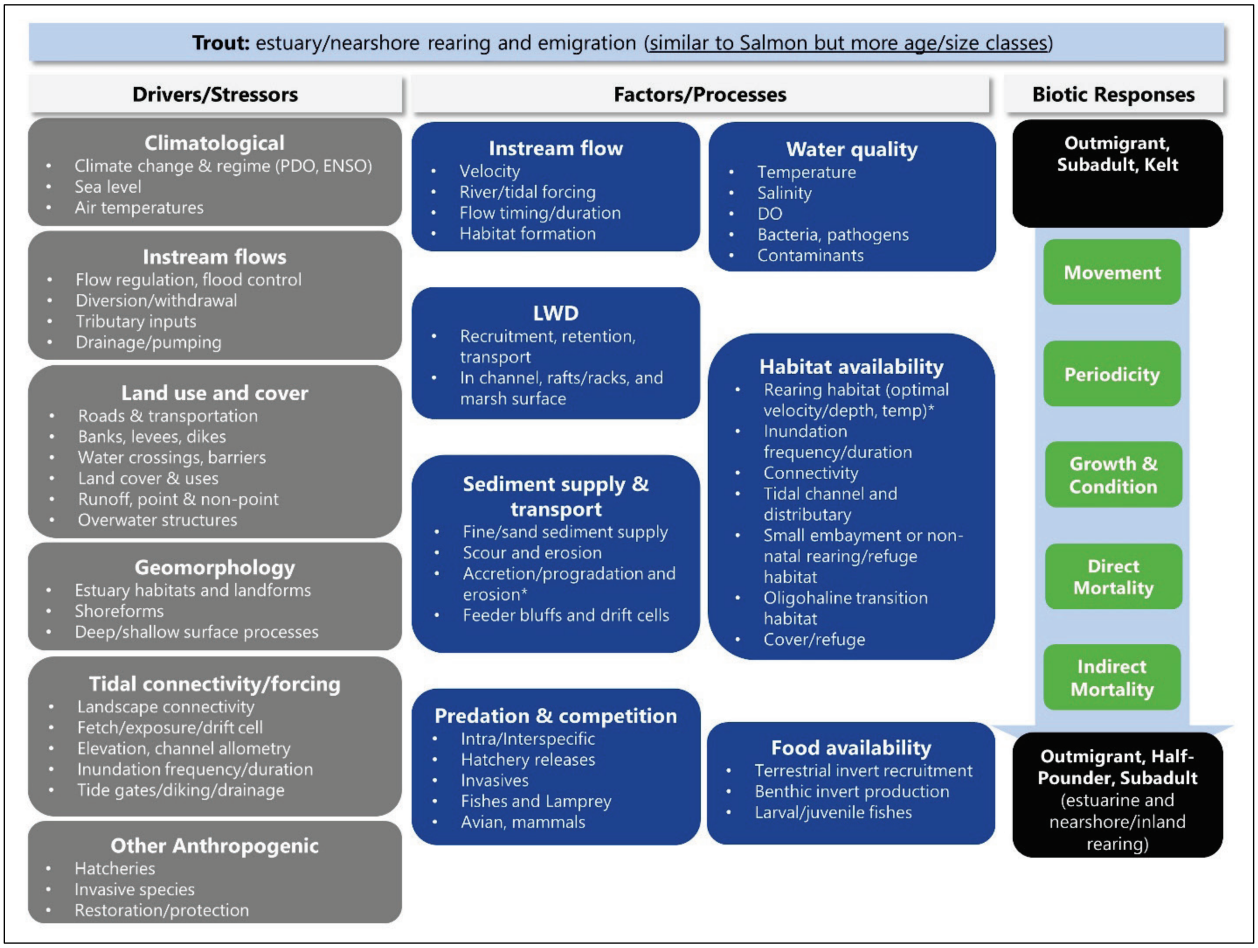
Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 8. Conceptual life history model for the Trout species group for the incubation and emergence life stages.



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

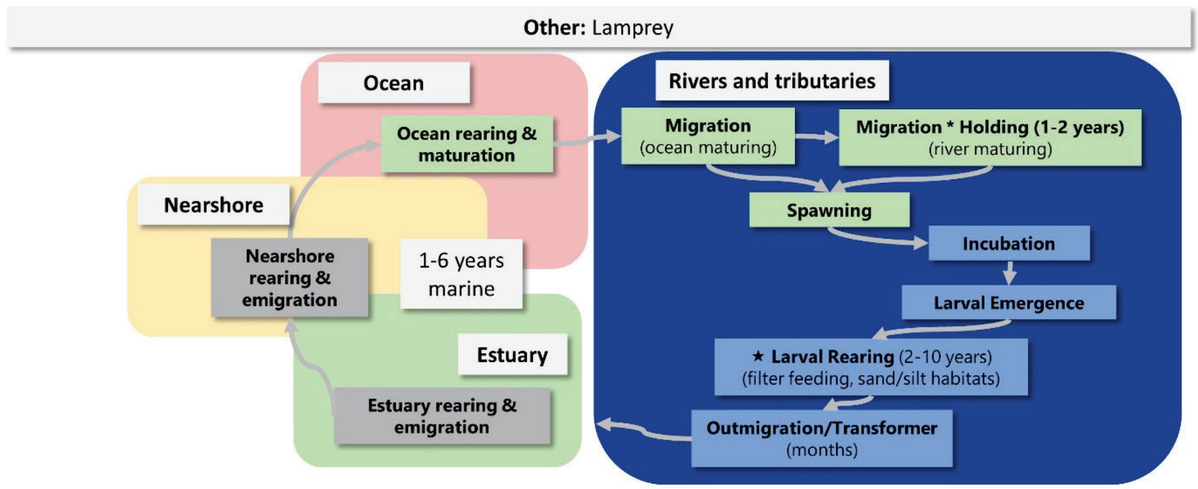
Figure 9. Conceptual life history model for the Trout species group for the rearing and outmigration, and resident rearing life stages.



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

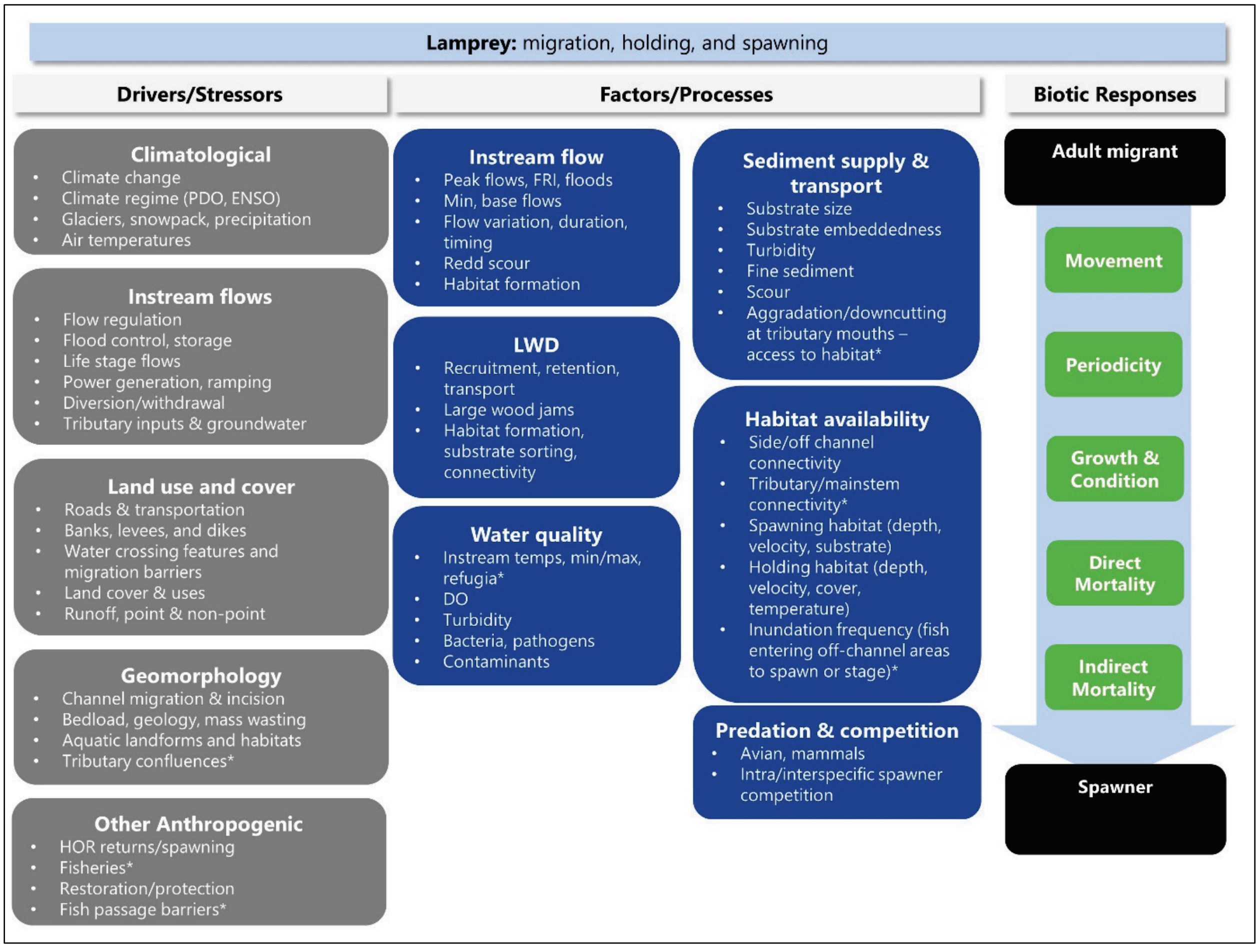
Figure 10. Conceptual life history model for the Trout species group for the estuary/nearshore rearing and emigration life stages.

2.3 Other: Lamprey



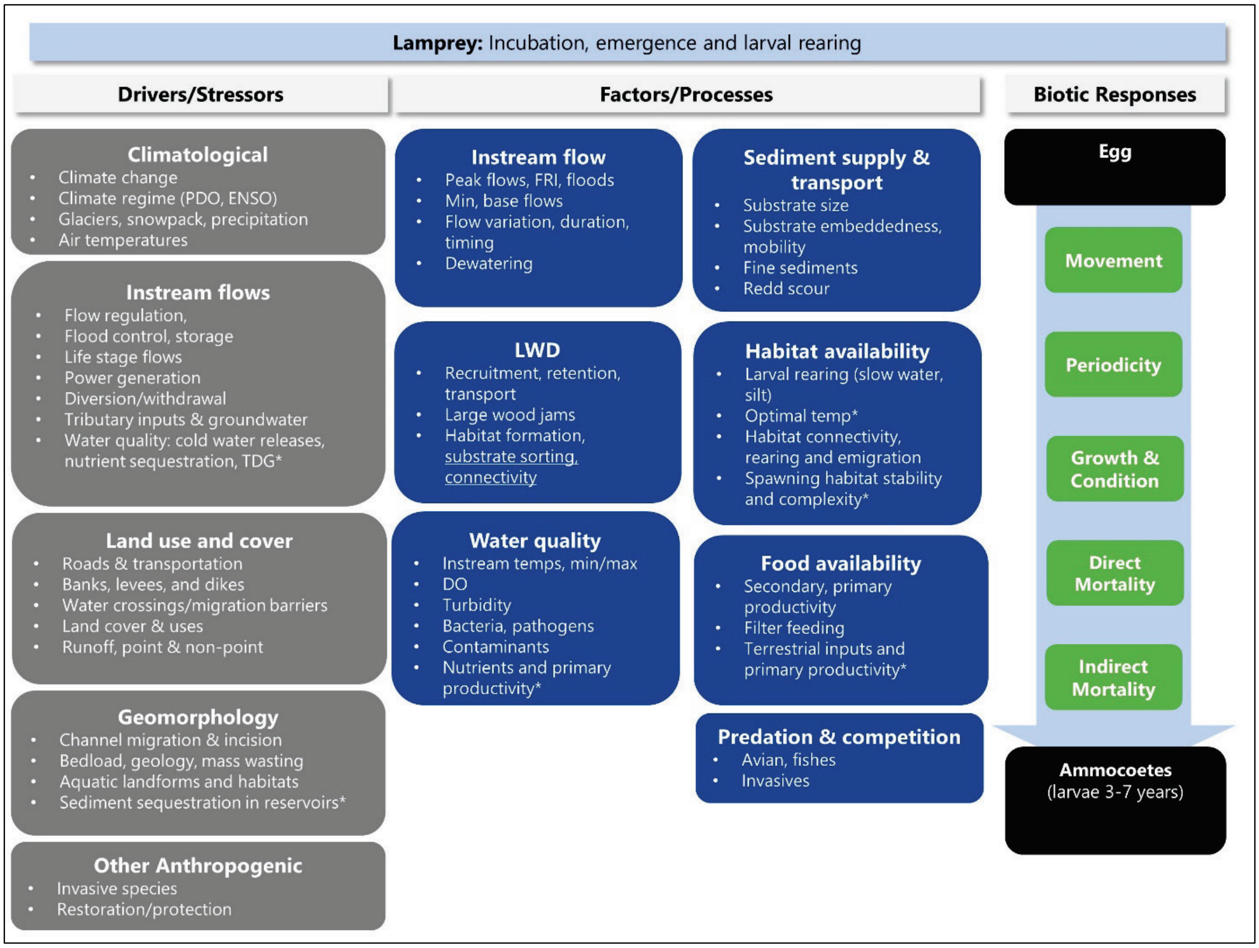
Note: Habitat strata are indicated by colored boxes with rounded edges, and life stages and transitions are identified by rectangular boxes with connecting arrows. Where applicable, specific species with the potential for extended residency are identified (★), or pathways specific to a species are identified as separate boxes. LH indicates a specific life history.

Figure 11. Conceptual life cycle diagram for Other (Lamprey) species group.



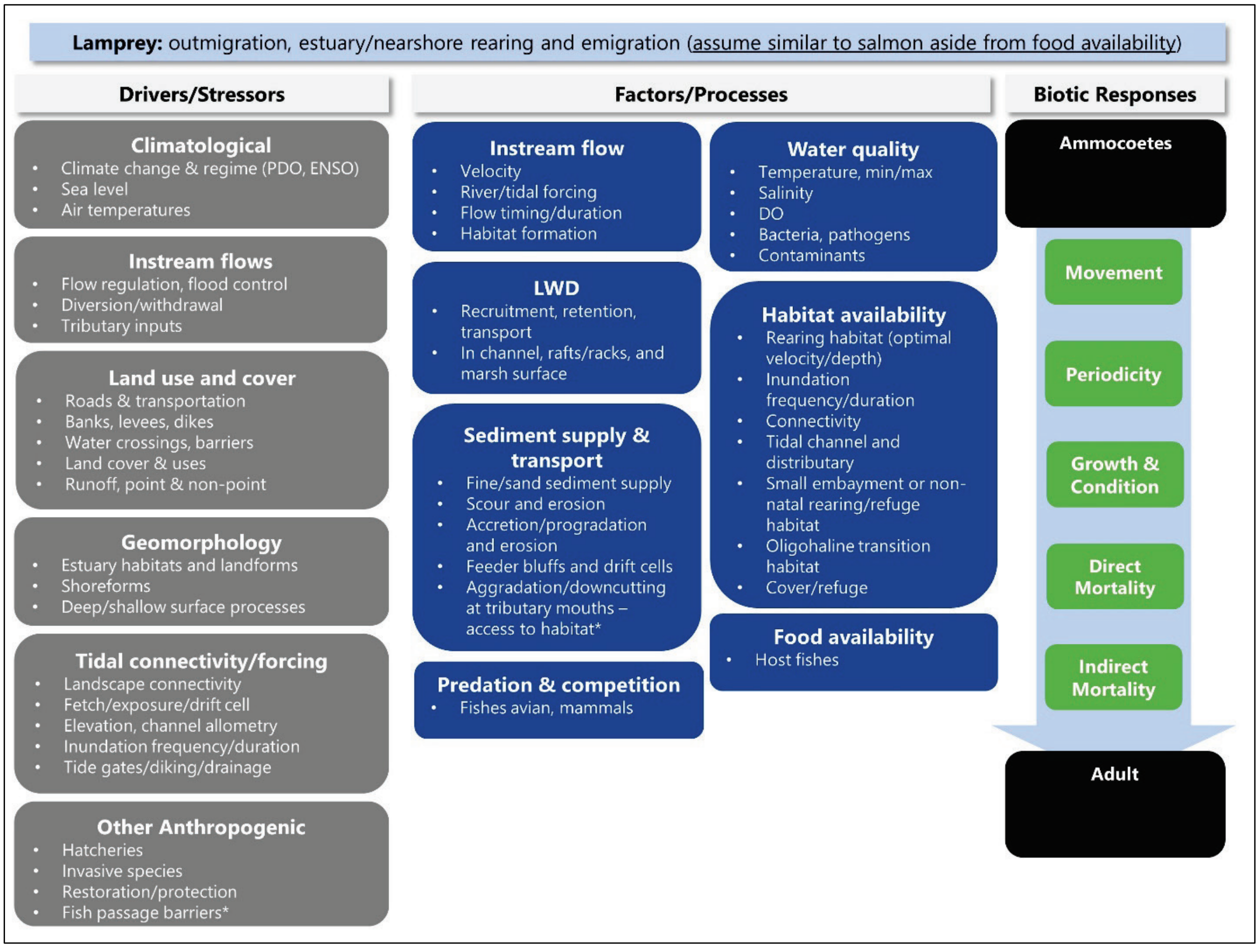
Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 12. Conceptual life history model for the Lamprey species group for the adult migration, holding, and spawning life stages.



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 13. **Conceptual life history model for the Lamprey species group for the incubation, emergence, and larval rearing life stages.**



Note: Drivers/Stressors and Factors/Processes identified in the conceptual life history models were developed in coordination with LPs and from the reviewed literature.

Figure 14. Conceptual life history model for the Lamprey species group for the outmigration, estuary/nearshore rearing and emigration life stages.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT F

TIER 1 ANNOTATED BIBLIOGRAPHIES

1.0 OVERVIEW

This Attachment provides annotated bibliographies for sources categorized as Tier 1. For each identified source, a brief summary of the source (Summary) and a narrative of how the information supports the SY-01 Synthesis and Integration of Available Information on Resources in the Lower Skagit River (Synthesis Study) objectives (Information Relevant to Skagit River Relicensing) are provided. A header is provided for each source that gives a high-level summary of the key information for each reference including the source type, topics, species, life stages, and reaches covered; whether spatial or quantitative data are provided; and whether Project Related data or information are provided. The *Linkages to Hydroelectric Operations* field provides a list of the topics and keywords or species and life stages that are linked to Hydroelectric Project Operations in the source, and these represent a subset of the topics and keywords, or species and life stages included in the source. References are organized alphabetically. Each annotated bibliography contains a citation ID that can be used to easily navigate to annotated bibliographies using the navigation pane.

Example template for annotated bibliography

Reference	AFS Style Guide for References: https://fisheries.org/wp-content/uploads/2016/01/References.pdf. Use the "References" style in the Home tab to get the style correct for the references section								
Source Information	***Type***	Source Type	***Status***	Draft/ Final	***Quantitative Data***	Yes/No	***Spatial Data***	Yes/No	***Project Related***	Yes/No
Topics and Keywords	***Topic:*** keywords.									
Species and Life Stages	***Species:*** life stages.									
Reaches and Spatial extent	Reaches.									
Linkages to Hydroelectric Operations	***Topic****:* keywords.									

Summary: Brief description of the study.

Relevant Information: Information specifically relevant to the Synthesis Study.

2.0 TIER 1 ANNOTATED BIBLIOGRAPHIES

Austin et al. (2021) (Unique Identifier: 446)

Reference	Austin, C.S., T. E. Essington, and T. P. Quinn. 2021. In a warming river, natural-origin Chinook salmon spawn later but hatchery-origin conspecifics do not. Canadian Journal of Fisheries and Aquatic Sciences 78(1):68–77.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related*** Yes
Topics and Keywords	***Fish and Habitat:*** Fish: periodicity, hatchery, life history, fecundity, abundance, status and trends; Habitat: instream flow, climate change; Monitoring: abundance, water quality, data gaps. ***Water Quality and Productivity***: temperature. ***Hydroelectric Operations***: flow regulation.								
Species and Life Stages	***Chinook***: spawning, incubation, emergence, outmigration. ***Chum***: spawning. ***Coho***. Spawning.								
Reaches and Spatial extent	Skagit Watershed, including Sauk River, other Sauk River tribs; Day Creek, Finney Creek, Jackman Creek and other lower Skagit tribs; and Skagit River Reaches R10-R7 and US of R7.								
Linkages to Hydroelectric Operations	***Water Quality and Productivity***: temperature.								

Summary: This study used time series of spawner and redd abundance surveys, going back to the 1950s, and instream temperatures to evaluate patterns of timing for spawning and emergence for natural origin Chinook Salmon populations in the Skagit Watershed. Populations considered included Skagit Spring, Suiattle Spring, Cascade Spring, Sauk Spring, Sauk Summer, Skagit Summer, and Skagit Fall Chinook. They modeled median timing of redd counts as an index of spawn timing for natural origin Chinook and found that timing has shifted later in the last 2-6 decades for five out of the six populations and that these shifts are related to increasing trends in instream temperatures during the spawning period. They also found that hatchery influenced natural origin populations have shifted spawn timing as well, but the shift was towards an earlier spawn timing and coincides with a shift towards earlier egg take for propagation among hatchery broods and earlier timing for hatchery origin spawners. Their findings have implications for population resiliency and recovery planning in the face of climate change, with increasing temperatures likely resulting in continued shifts in run timing.

Information Relevant to Skagit River Relicensing: This study provides relevant information to the Synthesis Study, including quantitative data on Chinook populations that utilize mainstem and tributary habitats within the Study Area for the Synthesis Study. They report on periodicity and shifts in periodicity for the timing of spawning as well as estimated emergence timing and the linkages of these patterns to temperature patterns and hatchery influences in the Skagit Watershed based on long time series of data (2-6 decades, going back to the 1950s for some populations). They found that temperatures have been increasing and that the magnitude of increasing temperatures over time are linked to elevation and position relative to hydroelectric dams in the Skagit River. The populations spawning in the mainstem Skagit River had the lowest rate of change relative to adjacent rivers, and they associate this pattern with the cooler and less variable hypolimnetic water released by the dams. Collectively, their findings are relevant to salmon recovery and planning from a climate change, hatchery practices, and Hydroelectric Operations perspectives given these factors are linked to spawn timing patterns in the Skagit Watershed through the results of this study. However, they also indicate that more research is needed to *"...determine the energetic consequences of juvenile salmonid emergence at different* *developmental states and times as climate change drives riverine thermal regime change,"* along with more long-term monitoring of temperatures at the sub-basin scale to support more detailed analysis of the linkages between spawn timing and temperature patterns. Relevant quantitative data from this study are described in more detail below.

<u>Fish and Habitat</u>: Information on spawner and redd survey methods, spatial extent, temporal period of record, mean annual redd counts, variation in mean redd abundance (CV), median spawn data of year, and the trend in median spawn date (change in days per year and S.E.) are provided for each population in Table 3. This includes redd abundance and trend data for Skagit Fall spawners in the mainstem river within the Study Area for the Synthesis Study (river km 39-108, or Reaches R10-R1), Day Creek (river km 0-3.5), Finney Creek (river km 0-6.7), and Jackman Creek (river km 0-0.08); and the Sauk River and its tributaries. For Skagit Fall Chinook populations, median spawn timing has increased at a rate of 0.14-0.84 days/yr while the timing for Sauk River Chinook populations has increased 0.09-1.18 days/yr for mainstem and tributary spawners aside from South Fork Sauk River and Dan Creek tributary spawners which had an earlier shift in timing of -0.05—0.30 days/yr. Scatter plots of median spawn date for each population are provided that show the trends over time (Figure 5), but data would need to be requested given the density of points precludes extraction from the provided plots. They also note that spawn timing of Chum and Coho Salmon are getting later in the Skagit Watershed in citing other studies, and this further supports their hypotheses that increasing temperatures are linked to salmon spawn timing.

Dates of estimated peak juvenile emergence based on spawn timing and temperature data varied among populations, from mid-January to late-March, with peak emergence for Skagit River fall, Sauk River Spring, and Sauk River Fall occurring in March and in late January for the Sauk River tributary Suiattle River Spring population. These were estimated based on median spawn date, linear regressions of fecundity (eggs per female), thermal development relationships, and population specific water temperature data from USGS gaging stations. Emergence dates, days from fertilization to emergence, and mean water temperature on emergence date are provided for each population in Table 6. They also indicate that shifts in temperatures of 1°C can result in a shift in emergence timing by a month, and that earlier spawn timing populations (e.g., the Hatchery spring population) emerged as much as 72-days earlier due to thermal exposure associated with their spawn timing.

<u>Water Quality and Productivity</u>: In August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Skagit River Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches. Differences in temperatures were explained primarily by elevation and position relative to hydroelectric dams, but they identify a need for more long-term temperature monitoring data at the sub-basin scale (including tributaries) to better understand temperature patterns and sources of variation at watershed and sub-basin scales. Figure 3 shows a scatter plot of increasing mean daily August maximum temperatures for the mainstem Skagit River at the USGS Marblemount gage (river km 127) upstream of the Study Area for the Synthesis Study, but trends are also reported for the Mount Vernon USGS gage (river km 26) from 1963-2018. They found that daily maximum temperatures in the mainstem Skagit River at Mount Vernon show a significant increasing trend in August – October of 0.05 – 0.02°C/yr, respectively. Mean monthly temperatures for August – October are also reported in Table 5 for USGS gages located on the Upper and Lower Sauk River and the Suiattle River, as well as the lower Skagit River.

Bandaragoda et al. (2015) (Unique Identifier: 416)

Reference	Bandaragoda, C., C. Frans, E. Istanbulluoglu, C. Raymond, and L Wasserman. 2015. Hydrologic Impacts of Climate Change in the Skagit River Basin. Final Report Prepared for Skagit Climate Science Consortium. Available at: http://www.skagitclimatescience.org/wp-content/uploads/2016/04/UW-SC2_SkagitDHSVM-glacierModel_FinalReport_2015.pdf									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Yes
Topics and Keywords	*Geomorphology:* climate change, change, aquatic habitats and landforms. *Modeling Tools:* hydrology, climate change. *Fish and Habitat:* Habitat: instream flow, climate change; Fish: climate change. *Hydroelectric Operations:* flow regulation.									
Species and Life Stages	NA									
Reaches and Spatial extent	Reaches R1-R13, Sauk River, Other Sauk River tributaries, Finney Creek, Jordan Creek, Jackman Creek, Nookachamps Creek, and other Upper Skagit River tributaries.									
Linkages to Hydroelectric Operations	*Hydroelectric Operations:* flow regulation. *Fish and Habitat:* Habitat: instream flow.									

Summary: This final report includes projections of naturalized streamflow based on a coupled glacio-hydrology model (DHSVM) at Skagit River Hydroelectric Project reservoir locations (Ross, Diablo, Gorge) and at sixteen tributaries using future climate change scenarios. The future streamflow projections are a collaboration between Seattle City Light, Swinomish Indian Tribal community, and the Sauk-Suiattle Indian Tribe administered by the Skagit Climate Consortium and the University of Washington (UW). The model domain included the entire Skagit River basin at 150 m (492 ft) digital elevation model (DEM) with nested models of 50 m (164 ft) resolution of selected basins (Thunder Creek and Cascade River) that have major glacier ice cover at their high elevations. The DHSVM model was calibrated using historical meteorological data and observed ice extent between 1960-2010 and corrections were conducted using empirical data, naturalized flows at reservoirs, and observed stream gauges. Future projects were calculated using Global Climate Model's 30-year period starting from 2010 to 2099.

The authors highlight the changes applicable to 2050. In glaciated high elevation basins, the current conditions of approximately 100 km^2 (39 square miles) of glacier ice are projected to decrease to less than 50 km^2 (19 square miles) by 2050. Tributary contributions, as measured by the August 90 percent exceedance probability between Newhalem to Marblemount are currently approximately 350 cfs and by 2050 could decrease to approximately 230 cfs (35 percent decrease). The South Fork Sauk River is predicted to decrease by 80 percent, from 14 cfs to 3 cfs for the August 90 percent streamflow. This represents a significant change in salmon habitat during a critical period.

The Sauk River currently has a bimodal annual hydrograph and is projected to progressively lose the summer peak (from snowmelt) and increase winter peak (from rainfall); by 2099 the Sauk River annual hydrograph is projected to have a single peak consistent with hydrograph timing of rain-dominated systems. The impacts of this shift will be most apparent in the August change where the decrease would be approximately 60 percent.

The lowest flows are currently 2000 cfs at the Gorge dam and predicted to decrease approximately 500 cfs in each 30-year period, to lower than 500 cfs in August by the end of the century.

Information Relevant to Skagit River Relicensing: The authors highlight the changes applicable to 2050. In glaciated high elevation basins, the current conditions of approximately 100 km^2 (39 square miles) of glacier ice are projected to decrease to less than 50 km^2 (19 square miles) by 2050. Tributary contributions, as measured by the August 90 percent exceedance probability between Newhalem to Marblemount are currently approximately 350 cfs and by 2050 could decrease to approximately 230 cfs (35 percent decrease). Little change was detected for Skagit Lowland tributaries that are currently and will remain rain dominated systems. The South Fork Sauk River is predicted to decrease by 80 percent, from 14 cfs to 3 cfs for the August 90 percent streamflow. This represents a significant change in salmon habitat during a critical period. The changes predicted throughout the system include less glacial coverage and more of a rain-dominated system throughout the entire basin. The decrease in August flows is concerning for salmon habitat. This underlines the need for climate change to be considered in all future flow and operational scenarios.

Bandaragoda et al. (2020) (Unique Identifier: 379)

Reference	Bandaragoda, C., S. Lee, E. Istanbulluoglu, and A. Hamlet. 2020. Hydrology, stream temperature, and sediment impacts of climate change in the Sauk River basin. Prepared by Hydroshare for Sauk-Suiattle Indian Tribe and Skagit Climate Science Consortium. Available at: http://www.hydroshare.org/resource/e5ad2935979647d6af5f1a9f6bdecdea								
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology:* climate change, change, aquatic habitats and landforms, sediment supply and transport. *Modeling Tools:* hydrology, climate change, sediment. *Fish and Habitat:* Habitat: climate change; Fish: climate change. *Water Quality and Productivity:* temperature.								
Species and Life Stages	NA								
Reaches and Spatial extent	Sauk River, other Sauk River tributaries.								
Linkages to Hydroelectric Operations	NA								

Summary: The study explored how low streamflows and peak annual flood streamflow in the Sauk Basin and tributaries are projected to respond to climate change using a coupled glacio-hydrology model (Distributed Hydrology Soil Vegetation Model, DHSVM) with highlighted discussions on 20 model output locations. The two climate change models that were used include Representative Concentration Pathways (RCP) 4.5 Ensemble and RCP 8.5 Ensemble. The Sauk River near Sauk is projected to have significantly more increases in wintertime (November-January) streamflow and decreases in summer time (July-September) streamflow. The Sauk River currently has a bimodal annual hydrograph but is projected to lose the summer peak from snowmelt and increase the winter peak from rainfall. By the end of the century the Sauk River annual hydrograph is projected to have a single peak consistent with rain-dominated systems. The impact will be most apparent in the August flow changes as future scenarios consistently give from around 50 percent to 90 percent declines toward the end of the century. High flows and peak events are projects to substantially increase by 2050, with statistically significant peak events (e.g., 100-year flood) expected to increase 20-30 percent for a moderate warming climate change scenario (RCP 4.5) and increase by 40 percent for high warming scenarios (RCP 8.5).

Historic daily maximum temperature during summers were 17.8°C (64.0°F), 19.2°C (66.6°F), and 17.4°C (63.3°F) at the Sauk River above Suiattle, Sauk River near Darrington, and the White Chuck River, respectively. Daily maximum temperature is projected to increase by 2-3°C for all scenarios and sites. The Sauk River near Darrington shows the largest increase in maximum temperature and the White Chuck River the least.

Mean annual suspended sediment load (SSL) estimates were obtained using historical (1960-2010) and future modeled streamflows in suspended sediment rating curve for lower and middle Sauk locations. Historical SSL was approximately 40 percent lower than the 5-year mean annual historic yield reported by the USGS study in the Sauk River, when stream streamflow is used directly without monthly bias correction. Monthly bias-corrected streamflow gave historical suspended load approximately 20 percent greater than the 5-year mean reported by USGS. The RCP 4.5 scenario models predict approximately twofold increase by the middle and much higher by end of the century. SSL gets consistently higher in the second half of the century in the worst-case RCP

8.5 scenario of climate change. Bias-corrected streamflow also results in consistent relative increases in SSL in lower Sauk for future climate scenarios. These results are limited by the assumption that sediment supply level does not vary and increases from the pro-glacial areas melting are not considered. Loss of snow and ice cover with climate and resulting exposure of unconsolidated and fine sediments to overland flow would also increase suspended sediment loads in the Sauk River.

Information Relevant to Skagit River Relicensing: The Sauk River provides a large load of sediment to the Study Areas for the lower Skagit River and Synthesis Study. The future changes in high flows and peak events will affect the Skagit River in terms of hydrology, temperature, and SSL. This report provides estimates of SSL and temperature that could enter the Skagit River in moderate to high warming climate change scenarios (RCP 4.5 and RCP 8.5). Although approximately 30 miles downstream of the Gorge, the confluence of the Sauk and Skagit River is an important area to understand. Both the Sauk and mainstem Skagit River are predicted to reduce in flow and increase in temperature over the century. This could be problematic to salmon that can be affected adversely by the August reduction in flows and increase in temperature.

Beamer and Henderson (1998) (Unique Identifier: 181)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. M., and R. A. Henderson. 1998. Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, northwest Washington. Report prepared for United States Army Corps of Engineers, Seattle District, Seattle, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: abundance, life history, rearing; <u>Habitat</u>: restoration, freshwater; <u>Monitoring</u>: abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: rearing, outmigration. Coho: rearing, outmigration, overwintering. steelhead (referenced as Rainbow Trout): rearing, outmigration, overwintering. Chum: rearing, outmigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Mainstem habitats from river mile 8.5 near Mount Vernon to river mile 85.2 near Marblemount along the mainstem Skagit River and Sauk River (Reach R14 – R7, US of R7, and Sauk River).</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This study evaluated paired sites with natural and hydromodified banks for an 80-mile stretch of mainstem habitats, from river mile 8.5 near Mount Vernon to river mile 85.2 near Marblemount along the mainstem Skagit River and Sauk River. They evaluated fish use and habitat trends by bank type while controlling for variation in mainstem channel types, life history patterns, and fish population levels. They found that natural banks had a higher percentage of area with wood, cobble, boulder, aquatic plants, and undercut banks compared to hydromodified banks. Wood cover increased along hydromodified banks with increasing time after hydromodifications were constructed, and bank gradient and streamflow discharge were correlated with water surface velocities of bank units. With respect to fish habitat use, juvenile Chinook and Coho abundance were significantly correlated (positive) with wood cover, explaining 82 percent and 62 percent of variance in species abundance, respectively. They found evidence for preference of riprap edges and some wood cover types among Rainbow Trout. Among wood cover types, abundances were greatest with rootwads compared to single logs for all species and life stages except subyearling Chum, which preferred aquatic plant and cobble cover. The authors indicate that their findings suggest integration of natural cover types in bank protection can mitigate some hydromodification impacts, and that the results of this study can be used to estimate potential restoration benefits.

Information Relevant to Skagit River Relicensing: The authors indicate that the cumulative effects of dams, dikes, dredging, bank protection, snag removal, and development have changed river and floodplain processes with consequences to biological resources that rely on the Skagit River and its floodplain. This study provides information that informs how one aspect of these impacts, bank protection, are related to juvenile fish habitat use patterns for a range of target species (Chinook, Coho, Chum, and Rainbow Trout) and life stages (freshwater rearing, outmigration, and overwintering) for the Synthesis Study. They focus on mainstem edge habitats of large rivers, which they postulate are used differently than smaller channel habitats. They provide a framework for classifying cover types for bank edge habitats with definitions, size thresholds, depth, velocities, and other physical criteria that could be used to support monitoring plans. Numerous summaries of relative abundance for target species and life stages are provided during peak spring outmigration (Chinook and Chum), summer rearing (Coho and Rainbow Trout), and overwinter rearing (Coho and Rainbow Trout) periods, although many are reported as relative densities and would therefore need to be used appropriately. In addition, many of the metrics and relationships identified in this report could be used to inform models of habitat conditions and fish use as well as potential responses to restoration actions.

Fish and Habitat: Numerous summaries of fish abundance metrics are provided with respect to different edge habitat types, including expected changes in fish abundance by cover type that are normalized to riprap edge types, which could be used to inform models of expected responses to restoration or habitat change (see Table 4). However, many of the reported densities are normalized to either standardized densities for grid points or based on riprap as shown below. Additional summary tables of abundance are provided for each species for each habitat unit in appendices, with extensive detail by habitat unit types, cover types, and species/life stages with means, variance, and sample size information. However, these are also primarily reported as fish per grid point sampled and could be converted to fish/m^2 based on reported grid spacings. Summary tables of cover percentages for edge cover types for hydromodified banks and natural banks are provided (means, standard deviation, and sample size), and water surface velocities among hydromodified and natural bank types are provided (means, standard deviation, and sample size) (see Tables 2-3). Multiple regression relationships are shown for habitat and fish abundance, including percent bank unit with no cover and gradient, and abundance (Chinook, Coho) with percent wood cover by edge type. Collectively, these data and relationships can be used to inform models of fish habitat characteristics and use. Detailed summary tables of habitat units sampled are provided in appendices that could be used to extract cover, edge type, and other metrics at the site scale and reach scales.

Beamer and Henderson 2004 (Unique Identifier: 160)

Reference	Beamer, E., and R. Henderson. 2004. Distribution, abundance, timing, and size of anadromous bull trout in the Skagit estuary. Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: periodicity, abundance, distribution, status and trends, size structure; Monitoring: abundance.								
Species and Life Stages	***Bull Trout:*** estuary rearing and emigration, nearshore rearing and emigration.								
Reaches and Spatial extent	Skagit Estuary and delta including Skagit Bay nearshore and subtidal habitats.								
Linkages to Hydroelectric Operations	NA								

Summary: This presentation provides summaries of the distribution, abundance, timing, and size of juvenile and subadult Bull Trout in the Skagit River delta and Skagit Bay from sampling efforts in 1995-2003. They employed a number of sampling methods (fyke nets and beach seining) to capture Bull Trout juveniles and sub adults in blind tidal channel, distributary channel, shallow intertidal, and intertidal/subtidal fringe habitats. They found that Bull Trout use blind tidal channels in deltas, but they may not use smaller/shallower tidal channel habitats or tidal channel habitats farther from distributary channels. They detected no trends in abundance in delta habitats and significant variation in the timing of presence in delta habitats among years. A significant increasing trend in abundance and length were detected for Bull Trout in Skagit Bay.

Information Relevant to Skagit River Relicensing: This presentation provides potentially important demographic information on Bull Trout in the Skagit River watershed, which is a target species for the Synthesis Study for which relatively few studies provide data on. Annual and monthly summaries of Bull Trout presence, distribution, abundance, and size structure for estuary and Skagit Bay habitats from multiple years (1995-2003) of sampling that provide quantitative data for a number of fish metrics for Bull Trout summarized below. However, the summaries as presented in the available slides do not provide any information on factors that are related to the presence, distribution, abundance, and size structure of juvenile Bull Trout.

Fish and Habitat: Significant variation in the periodicity and timing of juvenile Bull Trout delta habitat use was observed, with peaks typically in June and primary period of presence from April – August. Juveniles present in deeper intertidal/subtidal habitats year-round with peaks in May – June and a bi-modal pattern with the second peak in the fall in the most recent years of sampling. Bull Trout were present in intertidal/subtidal fringe habitats year-round but peaks in May and December, and Bull Trout were present in blind tidal channels April – August with peaks in June with presence being associated with depth. Bull Trout were not observed in habitats with depths < 0.3 m, they were infrequent in depths 0.3 – 1.0 m, and most frequent when depths > 2.5 m. Bull Trout densities were highest in spit habitats (2.69 fish/ha in May peak, range 0.1 – 0.23 fish/ha February to November) compared lagoon type pocket estuaries (0.17 fish/ha in July peak, not observed in any other months) or bluff beaches (1.01 fish/ha in June peak, range 0.04 – 0.28 fish/ha May - July) in Skagit Bay nearshore habitats. Average annual Bull Trout densities in Skagit Bay increased significantly from 1.5 – 2.8 fish/ha in 1995-1997 to 5.8 – 6.8 fish per/ha in 2001-2003.

No trends in abundance for Bull Trout in blind tidal channel habitats, significant increasing trends in abundance in Skagit Bay intertidal/subtidal fringe habitats; and significant increasing length frequency complexity in Skagit Bay. Bull Trout in blind tidal channels typically sub-adult with most 100 – 200 mm and some up to 400 mm fork length (FL); in Skagit Bay size ranges included larger fish with sizes ranging from 100 – 750 mm FL; and trimodal size structure was evident in most recent years of monitoring (1999-2003) indicating presence of sub-adult, first year spawner, and mature adults in Skagit Bay habitats.

Beamer and Larsen 2004 (Unique Identifier: 183)

Reference	Beamer, E. M., and K. Larsen. 2004. The importance of Skagit Delta habitat on the growth of wild ocean-type Chinook in Skagit Bay: implications for delta restoration. Report prepared by Skagit River System Cooperative and United States Geological Survey, Biological Resource Division.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, density dependence, growth, life history, size structure, periodicity, predation, survival, rearing; Habitat: restoration, limiting factors, estuary, pocket estuary, nearshore, capacity; Monitoring: abundance, scale or otoliths. ***Geomorphology and Landforms:*** estuarine habitats and landforms, change.								
Species and Life Stages	***Chinook:*** estuary rearing and emigration, outmigration, nearshore rearing and emigration.								
Reaches and Spatial extent	Skagit Bay and Skagit Estuary.								
Linkages to Hydroelectric Operations	NA								

Summary: This report provides a summary of ongoing research conducted by the Skagit River System Cooperative monitoring wild ocean type Chinook abundance in the Skagit delta. They found evidence for a density dependent relationship in the Skagit estuary that supports estuary restoration for improving ocean-type Chinook survival. The authors provide a description of four juvenile life histories based on delta monitoring data via beach seine and fyke trapping; (1) Delta Rearing Type 1, (2) Delta Rearing Type 2, (3) Delta Rearing Type 3, and (4) Fry Migrants. These life history strategies and patterns of abundance, growth, and residency are linked to restoration and recovery planning and used to support restoration of estuary and pocket estuary habitats to support Chinook recovery goals. Increased growth and size at bay entry are linked to increased survival to adult return through citations of other studies to support the importance of increasing delta rearing capacity in the Skagit River estuary.

Information Relevant to Skagit River Relicensing: This report provides relevant quantitative data as well as information on linkages between resource conditions and life stage factors affecting juvenile Chinook Salmon life stages. The data and analyses focus primarily on Skagit River estuary and nearshore habitats in Skagit Bay, but life history patterns and capacities are linked to freshwater migrant production from the Skagit River watershed. Their data support a density dependent hypothesis for estuary rearing habitat, with increasing fry migrant production as outmigrant abundance increases. This points to estuary rearing habitat as a potential limiting factor to overall production and survival of juveniles given that larger delta rearing migrants have higher marine survival. Density dependent patterns observed in the estuary suggests that delta rearing is limited when outmigrant abundance exceeds about 2.5 million (resulting in surplus production of fry migrants that bypass delta rearing habitat), and restoration could increase delta rearing capacity and therefore growth prior to entry to Skagit Bay and an assumed increase in survival to adult return. Pocket estuaries are identified as a potential benefit for exported fry migrants, but they also indicate the amount of pocket estuary habitat and restoration potential are insufficient to resolve the observed density-dependent patterns observed in the Skagit River estuary. They also found that juveniles experience better growth rates the longer wild sub-yearling Chinook spend rearing in delta habitats, and that that longer delta rearing life histories enter Skagit Bay later in the year (based on otolith analysis and microchemistry). In general, fish size at bay entrance positively influenced growth rates in Skagit Bay, and the authors suggests this could be related to adjustments to changes in food availability or salinity in transitioning from delta to bay habitats. Shorter residence times in Skagit Bay habitats observed for fry migrants were linked to increased mortality or emigration.

Fish and Habitat: The Skagit River estuary has lost 80 percent of historical delta habitat, and these losses are linked to density dependent estuary rearing habitat limitations in the Skagit River estuary. Wild Chinook freshwater outmigrant production estimates ranged from approximately 1-7 million (1992-2002), and juvenile densities in blind tidal channels increased with increasing outmigrant production from approximately 200-3,000 fish/ha with a density dependent relationship (density increases at a slower rate with increasing outmigrant production). The proportion of fry migrant production, or the number of juveniles that bypass rearing in delta habitats, increases when wild smolt outmigration abundance exceeds 2,500,000 based on monitoring data from RSTs and fyke trapping of tidal channels (1992-2002). Proportion fry migrant production is <10 percent at smolt production of <2,500,000 and increases to 20-40 percent with smolt production at 4-7 million (1996-2002). Four delta life histories are described including rearing duration and timing, and some information on growth, relative survival, and size. The following descriptions were provided in the report and are quoted here in italics to preserve the original context, with additional notes added based on reported data:

> *"**Delta Rearing Type 1**– These fish rear in delta habitat on average for 28.1 days and show a progression of habitat occupation on their otolith typical of "textbook" ocean-type Chinook: a freshwater residence period followed by a delta residence period followed by bay residence."* Bay growth rates ranged from ≈0.4-0.8 mm/day, with rearing duration in delta ranging from a few days to ≈60 days. Fork length at entry into Skagit Bay habitats ranged from ≈50-95 mm, with bay entry occurring from May – July and bay residence ranging from ≈5-40 days.

> *"**Delta Rearing Type 2**– These fish rear in delta habitat on average for 45.2 days and show a progression of habitat occupation on the otolith similar to Delta Rearing Type 1 fish, (a freshwater residence period followed by a delta residence period followed by bay residence). However, within the delta residence period there is a fast growth period followed by a slow growth period before bay residence occurs."* Bay growth rates ranged from ≈0.3-0.6 mm/day, with rearing duration in delta ranging from ≈20-100 days. Fork length at entry into Skagit Bay habitats ranged from ≈70-100 mm, with bay entry occurring from May – July and bay residence ranging from ≈10-45 days.

> *"**Delta Rearing Type 3**– These fish rear in delta habitat on average for 51.0 days and show a progression of habitat occupation on the otolith similar to Delta Rearing Type 1 fish, (a freshwater residence period followed by a delta residence period followed by bay residence). However, within the delta residence period there is a fast growth period followed by a slow growth period, and then followed by another period of fast growth before bay residence occurs."* Bay growth rates ranged from ≈1.0-1.3 mm/day, with rearing duration in delta ranging from ≈30-95 days. Fork length at entry into Skagit Bay habitats ranged from ≈70-130 mm, with bay entry occurring from May – August and bay residence ranging from ≈8-50 days.

> *"**Fry Migrants** – These fish do not rear for an extended period in delta habitat. They do not exhibit a delta region on their otolith. Migration to bay habitat is early in the year*

(usually February through April). On fry migrant otoliths we observe a freshwater residence period followed directly by bay residence." Authors note that these fish migrate to Skagit Bay habitats at a very small size (≈40 mm fork length), and experience poor growth in the bay. Bay growth rates ranged from ≈0.2-0.3 mm/day, with rearing duration in delta ranging less than ≈20 days. Fork length at entry into Skagit Bay habitats ranged from ≈35-45 mm, with bay entry occurring from February – April and bay residence ranging from ≈5-15 days.

Beamer and Pess (1999) (Unique Identifier: 380)

Reference	Beamer, E. M., and G. R. Pess. 1999. Effects of peak flows on Chinook (Oncorhynchus tshawytscha) spawning success in two Puget Sound river basins. Proceedings of American Water Resources Associations 1999 AWR Conference: Watershed Management to Protect Declining Species, Seattle, Washington.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: survival; Habitat: instream flow, limiting factors. ***Modeling tools:*** juvenile production.									
Species and Life Stages	***Chinook:*** incubation, migration.									
Reaches and Spatial extent	R1-R6, R7-15, Sauk River, Other Sauk River tribs, Other upper Skagit tribs.									
Linkages to Hydroelectric Operations	NA									

Summary: This source analyzed six stocks of Chinook in the Skagit (Cascade summer run, lower Skagit fall run, upper Skagit summer run, upper Skagit spring run, lower Sauk summer run, upper Sauk spring run, Suiattle spring run) and one stock in the Stillaguamish River to investigate the effects of peak flow on egg incubation and how this later impacted the production of returning adults. A log-Pearson Type III distribution transformation was applied to peak flood events to create flood recurrence interval (RI, years). These data were used to develop a Chinook adult to adult recruitment model and egg to migrant fry survival model that they used to demonstrate that Chinook stocks were unable to "replace" themselves if peak flow during the egg incubation period was equivalent to a 20-year event or larger. They conclude that the relationships between peak flow and recruitment rates (adult to adult and egg to fry) provide evidence of freshwater habitat limitations and sensitivity to peak flow events that have implications for fisheries harvest management and recovery planning.

Information Relevant to Skagit River Relicensing: This analysis provides evidence that freshwater habitat conditions are potentially constraining or limiting production rates for Skagit River Chinook stocks, including stocks in the lower Skagit River, Sauk River, and upper Skagit River populations. In addition, they found that populations are sensitive to peak flow events even when flooding is not severe (e.g., 2-year flood events), and that egg incubation survival limited production 30 percent of the time. A 20-year flood recurrence interval corresponded to a 5 percent Chinook egg to migrant fry survival rate. However, Chinook recruitment did not exceed a certain level for a given flow, suggesting that the bottleneck limiting production of Chinook stock is the egg to fry survival. When the model was applied to North Fork of the Stillaguamish River, Chinook egg to fry survival was found to be reduced from 10 percent to 5 percent for the two-year flood event. Every brood year of spawning Chinook has a 50 percent chance (instead of 10 percent) of being exposed to flow events that correspond to egg to fry survival rates where the stock is not able to replace itself. Plots of recurrence intervals and Chinook recruitment (adult to adult, and egg to fry) are provided, with exponential regression statistics that can be used to predict egg to fry migrant survival with recurrence interval based on flows at the Mt. Vernon gage. The modeled relationship was reported as:

$$S_{e \to m} = 0.1285 \cdot e^{-0.0446 \cdot x}$$

where $S_{e \to m}$ = egg to migrant survival, and x = flood recurrence interval in years at Mount Vernon.

Beamer and Wolf (2016) (Unique Identifier: 186)

<table>
<tr><td>Reference</td><td colspan="10">Beamer E., and K. Wolf. 2016. The influence of a naturally formed distributary channel on the distribution of juvenile Chinook salmon within the Skagit tidal delta. Report prepared for NOAA/WRCO SRFB Skagit HDM Project under agreement P104051-A102542-n/a by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, sediment transport and supply, estuarine habitats and landforms. Fish and Habitat: <u>Fish</u>: periodicity, life history, abundance; <u>Habitat</u>: limiting factors, restoration. Water Quality and Productivity: dissolved oxygen, temperature.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary and Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report provides an analysis of juvenile Chinook monitoring data in the Skagit River delta (2002 – 2015 fyke trapping and beach seining) to evaluate the impacts of a new avulsion (2006) in the North Fork region of the estuary that has created a new distributary connection and outmigration pathway to Skagit Bay. They test several hypotheses related to whether the new distributary has changed the distribution of juvenile Chinook within Skagit Bay. They found that the new distributary did not affect densities upstream of the new bifurcation, and no evidence of increasing densities downstream of the new bifurcation or in nearshore habitats in the bayfront. Therefore, they found that the new distributary was not a viable pathway for juvenile Chinook to reach bayfront marsh habitats near Fir Island, but they conclude that this new pathway is more likely to result in juveniles being exported to nearshore habitats in Skagit Bay as indicated by increased fry densities in nearshore habitats along the Whidbey Island shoreline across the bay. They also identify areas where rapid habitat changes are occurring as a result of changed water flow and sediment deposition patterns associated with the avulsion; including areas of distributary channel infilling and conversion to marsh/blind tidal channel habitat, and areas with less certain habitat change trajectories. They conclude by recommending continued monitoring at the estuary scale to continue evaluating these questions.

Information Relevant to Skagit River Relicensing: This study provides relevant quantitative data for the Skagit River estuary as well as linkages between habitat conditions and life history expression, and the effects of changes in habitat connectivity on habitat use patterns. The results presented in this report specifically look at the effects on a recent avulsion on observed densities in the Skagit Estuary, and they found that the avulsion had little effect on observed densities except for an increased export of fry migrants to nearshore habitats. They also identify areas where rapid habitat changes are occurring as a result of changed water flow and sediment deposition patterns associated with the avulsion and progradation rates; including areas of distributary channel infilling and conversion to marsh/blind tidal channel habitat, and areas with less certain habitat change trajectories. These areas are discussed in the context of climate change and sea level rise, and spatial data associated with these areas could be used to evaluate habitat vulnerability or resilience. The authors also provided a recommendation for continued monitoring of juvenile salmon habitat use in the Skagit River estuary to address the questions and uncertainties identified in their analyses. The authors also reiterate the findings of early investigations, which suggests freshwater and delta rearing habitat limitations influence life history expression and potential adult production for Skagit Chinook populations, and restoration of tidal delta habitats are presented as a means to alleviate this potential limitation. Relevant quantitative data for fish and habitat, geomorphology and landforms, and water quality and productivity are also provided as described below.

Fish and Habitat: Juvenile Chinook Salmon rear in natal tidal deltas for 0.5-2 months and averages 34.2 days (as cited from previous studies), and 5-40 percent of all juvenile Chinook outmigrants produced by the Skagit River are fry migrants. This life history expression is linked by the authors to freshwater and delta habitat rearing habitat limitations and density dependent processes. Outmigrant fry abundance estimates from WDFW RST monitoring ranged from 914,161 to 5,116,578 fry/yr, and this was used as a covariate in their analyses. Monthly (February – July, 2002 – 2015) mean densities (fish/ha) with one standard deviation are provided for five sites as bar plots. Skagit River peak daily flow at Mt Vernon for the period January through April ranged from 19,900 to 74,700 cfs for 2002 - 2015. Skagit River average daily flow at Mt Vernon for the period January through April ranged from 12,585 to 21,182 cfs for 2002 - 2015. These were used as covariates in their analysis. They found that peak and mean flow were not related to juvenile Chinook densities in the Skagit Delta but were related to nearshore densities along Whidbey Island shoreline.

Geomorphology and Landforms: The new distributary channel has widened since avulsion in 2006 at the bifurcation and at the narrowest point in the distributary, with the increase being described by exponential regressions. Channel widths have increased from 8 m at the bifurcation in 2006 to 108 m by 2015, and the narrowest width has increased from 2 m in 2006 to 56 m by 2015. During this same period, the length of the distributary channel through vegetated tidal wetland habitat has decreased from 1,228 m to 1,086 m (2006-2015), which the authors describe with a polynomial function. Cumulative restoration extent occurring within the South Fork tidal delta (channel area only) ranged from 8.10 to 38.03 hectares from 2002 - 2015. Total restored tidal footprint (channels and wetland) ranged from 93.7 to 183.4 hectares. Annual values are provided in a table. These were used as covariates in their analysis. The authors cite that progradation rates in the Skagit Delta have declined despite increasing timber harvest and subsequent landslides, and overall sediment delivery in the basin (see Hood et al. 2016 (ID142) for quantitative data).

Water Quality and Productivity: Low dissolved oxygen and high temperatures are cited as influencing juvenile Chinook absence/presence in the Skagit tidal delta as cited from Fisher Slough restoration monitoring studies, but quantitative data are summarized for those reports and only cited in this report. DO and temperature were strongly correlated with month, and therefore not used directly in their analyses.

Beamer and Wolf 2017 (Unique Identifier: 187)

Reference	Beamer, E., and K. Wolf. 2017. Skagit Chinook habitat monitoring status and trends: change in Skagit tidal delta habitat extent, 2004-2013. Report prepared by Skagit River System Cooperative, Research Program, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: status and trends, climate change, restoration; Monitoring: data gaps, restoration. ***Geomorphology and Landforms:*** sediment transport and supply, estuarine habitats and landforms.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Estuary, including Swinomish Channel.								
Linkages to Hydroelectric Operations	NA								

Summary: This report describes the results of habitat status and trends monitoring using remote sensing of aerial imagery to evaluate progress towards desired future conditions targets established by the 2005 Skagit Chinook Recovery Plan. The report includes data from 2004 and 2013 mapping efforts of vegetated marsh extent, sources of change from restoration, direct human modifications, and natural changes. They found that habitat area increased and that increases from restoration are outpacing losses from natural and human causes in the Skagit River estuary. However, they also found that the desired future conditions set in the Chinook Recovery Plan would not be reached until the year 2096 based on their measured rates of increase in habitat area. The authors also provide several scenarios and recommendations to increase the rate of change and increase resilience to sea level rise, including increasing restoration effort and incorporating sea level, storm surge, and sediment routing into an updated recovery strategy to account for natural losses of marsh habitats.

Information Relevant to Skagit River Relicensing: This report provides quantitative and spatial data on vegetated marsh extent for two time periods (2004 and 2013), and the data quantifies sources of change related to natural processes, human causes, and restoration efforts. The authors indicate that the results presented in this report apply only to the indicator "*Tidal delta habitat extent*" and do not account for specific changes in habitat types (e.g., channel and marsh types) or efforts that enhance marsh habitat but do not change total tidal marsh area. The authors indicate that sea level, storm surge, and sediment routing should be incorporated into an updated recovery strategy for the Skagit River estuary to address sources of (natural) habitat losses and improve habitat forming processes. This points to a data gap of understanding sediment routing and supply in the estuary as it relates to habitat formation and maintenance processes in the face of restoration, natural change, and potential future climate change. Available quantitative data and information for fish and habitat and geomorphology and landforms are summarized below.

Fish and Habitat: Quantitative data on habitat status and trends show a net increase of 83 hectares of marsh was observed between 2004 and 2013, with 122 ha increase from restoration and 18 ha increase from passive breaches and progradation; and losses of 0.4 ha from channel filling and levee repairs, 36 ha lost from invasive spartina removal, and 30 ha loss from natural erosion. Historic habitat extent for the estuary was reported as 11,438 ha, with desired future conditions set by the 2005 Chinook Recovery Plan as 4,233 ha (37 percent of historic extent). Current progress towards this recovery target is reported as 30.3 percent of historic extent or 81.9 percent of the desired future condition target. Restoration of a total of 122 hectares were reported for the Skagit River estuary between 2004 and 2013, at a pace of 13.6 ha/year. Annual restoration efforts varied, and they estimate restoration occurring at the slowest observed pace of 10.2 ha/yr would reach the desired future condition target by year 2106, while the fastest observed pace of 25.8 ha/yr would reach the target by year 2045. Natural losses of tidal marsh habitat predominately occurred along the Skagit Bay front or tidal marsh fringes, which the authors indicate are most sensitive to climate change and potential sea level rise effects that could increase the rate of tidal marsh losses in the delta over time.

Geomorphology and Landforms: Sediment supply and routing (transport) was identified as an issue of concern for erosion and progradation of marsh habitats, although no quantitative results are provided. The authors indicate that sediment supply and transport information are needed to understand habitat forming and maintenance processes in the delta. Spatial data from this study provide the spatial distribution and extent of marsh habitats for the Skagit River delta for two time periods, and continued monitoring will provide additional time steps. The data layers from this study could be obtained to evaluate changes over time with more recent mapping, which the SRSC has continued to develop.

Beamer et al. (1998) (Unique Identifier: 189)

Reference	Beamer, E., T. Beechie, and J. Klochak. 1998. A strategy for implementation, effectiveness, and validation monitoring of habitat restoration projects, with two examples from the Skagit River basin, Washington. Report prepared by Skagit System Cooperative for Mount Baker- Snoqualmie National Forest, Mount Baker Ranger District, Sedro Woolley, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration, barriers, capacity, limiting factors, instream flow, riparian; Fish: abundance, survival, distribution, life history, age structure; Monitoring: restoration, habitat, abundance. ***Modeling Tools:*** habitat, juvenile production. ***Land Use and Cover:*** roads, land cover, forestry. ***Geomorphology and Landforms:*** sediment transport and supply, large wood, slope, aquatic habitats and landforms. ***Water Quality and Productivity:*** turbidity, temperature, dissolved oxygen.									
Species and Life Stages	***Coho:*** migration, spawning, rearing, outmigration, overwintering. ***steelhead:*** rearing, outmigration, overwintering. ***Bull Trout:*** rearing. ***Chum:*** spawning, rearing, outmigration. ***Chinook:*** spawning, rearing, outmigration, overwintering.									
Reaches and Spatial extent	Finney Creek, Sauk River, Other upper Skagit tribs (Newhalem Creek, Illabot Creek), Other Sauk River tribs (Suiattle River, Falls Creek, Dan Creek, Lime Creek, Boundary Creek, Conrad Creek), Baker River (Little Park Creek).									
Linkages to Hydroelectric Operations	NA									

Summary: This report describes a restoration effectiveness monitoring approach for restoration actions implemented through the Aquatic Conservation Strategy of the Northwest Forest Plan, and includes examples of applying the approach. The approach was intended to serve as a framework that could be applied to future restoration actions and efforts. This approach includes three components: implementation monitoring, effectiveness monitoring, and validation monitoring which are intended to evaluate whether an action is completed as designed, had the desired effect on landscape processes, and had the desired effect on stream habitat and fish production, respectively. By understanding past and current conditions, hypotheses about desired outcomes can be developed and metrics and monitoring strategies can be identified to test hypotheses. They apply their approach to monitoring actions designed to reduce sediment production from forest roads in the Illabot Creek drainage, and to a fish passage improvement action on Little Park Creek in the Baker River basin. For the forest road sediment reduction example, they found that mass wasting has significantly increased due to forest roads in the Illabot Creek drainage, but overall land use has caused relatively little mass wasting compared to that from mature forests and naturally unvegetated areas. For the fish passage improvement example, they found that velocities were always higher than design velocities at specified flows, and that carrying capacity for Coho is limited by the availability of summer rearing habitat.

Information Relevant to Skagit River Relicensing: This report provides a framework for monitoring and evaluation restoration actions that could be applied to future restoration actions in the Study Area for the Synthesis Study. The study references several restoration actions that were implemented as part of the Aquatic Conservation Strategy of the Northwest Forest Plan on tributaries that are included in the Study Area for the Synthesis Study. These include actions in the Finney Creek tributary to the lower Skagit River, Little Park Creek that is a tributary to Baker River, and several tributaries to the Sauk River and Suiattle River (Dan Creek, Falls Creek, Boundary Creek, Conrad Creek, and Lime Creek). Descriptions of the restoration actions (e.g., miles of road removed, fish passage improvements, and revegetation) along with project costs are provided. They apply the restoration effectiveness monitoring framework to only two of tributary systems (Illabot Creek and Little Park Creek) and some detailed monitoring data and results from these examples are potentially relevant to the Synthesis Study.

The monitoring framework provides information to support monitoring of sediment supply and transport, effects of increased sediment supply to habitat processes and salmonids, testable hypotheses for sediment impacts and linkages to processes, and monitoring approaches and metrics to evaluate hypotheses and restoration action effectiveness. This information can be used to support development of conceptual life history models and hypotheses for factors affecting resource conditions for the Synthesis Study. They also describe field and remote sensing methods used to evaluate responses to restoration, and habitat-based fish production models to understand probable impacts of a restoration action on fish production. The habitat-based models were based on previous works and included a model for juvenile Coho and steelhead that use areas of different habitat unit types and corresponding average densities and estimated survival to life stages to estimate production capacity at reach and watershed scales. These are linked to restoration effectiveness evaluation through estimated changes in habitat areas to evaluate potential limiting factors, capacity, and restoration responses.

This report also includes several appendices which provide examples of restoration treatment types and specific actions, results from preliminary watershed assessments for selected watersheds within the Skagit River basin, prioritization and scoring approaches used to rank restoration projects in the Skagit Watershed, monitoring strategies and detailed habitat survey results for Illabot Creek, detailed smolt trap data from Little Park Creek from 1997 (includes daily catches of Coho, average fork lengths, water temperatures, and catches of trout [Rainbow and Cutthroat]). The watershed assessments include Finney Creek, Suiattle River, and Sauk River that are included in the Study Area for the Synthesis Study. These assessments provide a lot of potentially useful information including principal issues of concern, species distribution and use types (including some life history and age structure information), current habitat conditions, desired future conditions, processes, and recovery strategies for each of these systems. In Finney Creek, they identify degradation of water quality and riparian areas due to erosion and mass wasting, decline of fish stocks (linked to loss of historical spawning and rearing habitat, increased temperatures and turbidity, and loss of riparian shade), and impacts of private property as principal issues of concern. In Suiattle River, decline of fish stocks, loss of historical spawning and rearing habitat, turbidity and riparian conditions, and degradation of water quality due to erosion and sedimentation are identified as principal issues. In the Sauk River, degradation of water quality and riparian areas, mass wasting, decline of fish stocks, loss of spawning and rearing habitat, and increased stream temperatures and turbidity are identified as principal issues.

<u>Fish and Habitat</u>: Flood recurrence intervals for 2 – 100-year events are described for the Sauk River and Newhalem Creek using USGS stream gages, but these were derived from data through 1997 and would likely need to be updated with more recent data. Smolt production estimates (averages with standard deviation, sample size, and coefficient of variance) are provided for twelve western Washington stream systems, including three tributaries in the Skagit River basin (Seed Orchard, Mannser, and Etach/Red Cabin Creek). Mannser and Etach/Red Cabin Creeks are tributaries to the lower Skagit River (reach R11) with reported average annual Coho smolt production of 13,141 (4,734 SD) and 6,913 (4,608 SD) based on 9 and 8 years of monitoring,

respectively. It is not readily apparent what reach See Orchard Creek is associated with, but average annual production estimates were 1,129 smolts (353 SD) based on 8 years of monitoring. Variation in stream flow explained interannual variation in production for 4/12 tributary systems included in their analysis, although none of these were the Skagit River tributaries. All monitoring data were obtained from the Skagit River System Cooperative, and additional data or information could be requested for these production estimates. Current and historic habitat conditions, water quality, sediment transport and supply, riparian conditions, and land use patterns are described for Finney Creek, Sauk River, and Suiattle River in Appendix 2 with some quantitative data provided.

Peak adult counts and cumulative redd counts for 1995-1998 are provided for reaches of Little Park Creek upstream of the fish passage improvement project; and peak counts of Coho adults, total Coho redds, and Coho fry planting abundances for 1992-1998 return years for Little Park Creek, as well as adult Coho escapement to Baker Lake. They use habitat-based models to estimate Coho smolt capacity for Little Park Creek at 7,223 with summer habitat limiting capacity and 21,587 if winter habitat is limiting. Detailed smolt trap data from Little Park Creek from 1997 are provided in Appendix 7 (includes daily catches of Coho, average fork lengths, water temperatures, and catches of trout [Rainbow and Cutthroat]). Fish distributions, life history variations, and age structure are generally described for target species and life stages for Finney Creek, Sauk River, and Suiattle River in Appendix 2. Limited spatial data are provided for some habitat and land use metrics that could be extracted from coarse resolution maps, as well as some quantitative data that are tied to reaches that could be used to develop spatial data.

Beamer et al. (2000) (Unique Identifier: 190)

Reference	Beamer, E., T. Beechie, B. Perkowski, and J. Klochak. 2000. River basin analysis of the Skagit and Samish basins: tools for salmon habitat restoration and protection. Report prepared by Habitat Restoration and Protection Committee of the Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat***: Habitat: barriers, instream flow, freshwater, estuary, riparian, restoration, data gaps; Fish: distribution, data gaps. ***Hydroelectric Operations:*** flow regulation, flood control. ***Geomorphology and Landforms:*** floodplain connectivity, slope, floodplain, sediment supply and transport, aquatic habitats and landforms, large wood, data gaps. ***Land Use and Cover:*** land cover, banks and shoreline, roads, data gaps. ***Water Quality and Productivity:*** temperature, dissolved oxygen, bacteria, data gaps.									
Species and Life Stages	***All Anadromous Species:*** migration, rearing, outmigration.									
Reaches and Spatial extent	Skagit Watershed; including the Skagit Estuary and Reaches R7-13, and US of R7; Sauk River and other Sauk River tribs; Finney Creek, Nookachamps Creek, Jackman Creek, Hansen Creek, Gilligan Creek, Day Creek, and other lower Skagit River tribs; and Baker River.									
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flow regulation, flood control.									

Summary: This report provides describes the first phase of application of the Skagit Watershed Council's Salmon Habitat Restoration and Protection Strategy. This strategy includes two major objectives:

- *"identify where and to what extent the landscape processes that form and sustain salmon habitat are degraded in the Skagit and Samish River basins," and*
- *"identify specific actions to restore and protect salmon habitat in these habitats, focusing on efforts to address the causes of habitat degradation rather than the symptoms."*

A combination of remotely sensed and field collected data are used to address land scape processes that include riparian functions, sediment supply, peak and low flows, channel and floodplain interactions, water quality, and migration barriers. They apply functional criteria to the data layers and identify impaired processes and provide an overview of the limitations for their approaches, the methods used to identify impairments to processes, data layers considered, and the next steps and future work needed to improve the analyses. In this first phase, they identified over 400 individual potential projects that were classified into five categories; sediment reduction, riparian, isolated habitat, protection, and feasibility studies. The results of this first phase are intended to inform the Skagit Watershed Council's development of an Action Plan, which they define as *"…a long-term strategic plan for the scientifically based and cost-efficient restoration and protection of salmon habitat in the Skagit and Samish River basins."* The final section of this report provides detailed information on prioritization of projects identified in this report, feasibility studies, and monitoring and includes cost effectiveness estimates for a number of the landscape process impairments identified in their analysis.

Information Relevant to Skagit River Relicensing: This report provides relevant information on resource conditions in the Skagit Watershed, including the Study Area for the Synthesis Study, the

Skagit Estuary, and target tributaries to the lower Skagit River. Numerous spatial data products were produced that provide spatial data for locations of distribution of anadromous and non-anadromous streams, anadromous fish passage barriers (including features that need to be assessed), aquatic habitats and landforms (predicted channel types), peak flow function ratings and impervious surface cover, sediment supply ratings and supply rates, forest road risk group ratings, riparian buffer width ratings, stream bank hardening and dike/levee distributions, connected and disconnected estuary floodplain/wetland habitat, water quality impairment ratings (dissolved oxygen, fecal coliform, fish habitat, and temperature), and their final ratings of habitats as degraded, important, isolated, key, secondary, and unknown. In addition, supplemental or supporting tables for many of the metrics and data layers were developed and presented (e.g., see Table 2-8-2). The report also identifies numerous data gaps and monitoring needs as next steps in a "Future Work" section for each of the landscape process analyses they completed. However, this report was completed in 2000 and timeframes of 1-3 years were identified for many of the next steps, therefore, it is likely that some of these data gaps and monitoring needs have already been addressed and these would need to be linked with later reports and sources to determine the status of these data gaps.

<u>Fish and Habitat</u>: The anadromous fish zone was delineated to describe the natural extent of salmon migration, including natural and artificial barriers, but the distribution was not specific to salmon species. Maps of anadromous fish distribution and fish passage barriers and their status are provided (Figure 2-1), but approximately 70 percent of the barriers identified in their analysis were unconfirmed or there was low certainty for barrier classifications. This represents a data gap and monitoring need identified by the authors that will likely require field surveys to address. Distributions were also based on slopes from digital elevation models, and they indicate that field surveys or higher resolution remote sensing are needed to improve slope estimates for tributaries. A subsample of water crossing features indicated that 14 percent of features did not meet passage criteria, and therefore they estimate they will find approximately 150 more features blocking fish passage with additional surveys. Based on their analysis, they found that 44 percent of the historical channels remain accessible to anadromous salmon in their study area.

Riparian habitat impairments were identified from remote sensing land cover data, and field surveys of 234 sites to validate classifications of seral stage from remote sensing. Maps of riparian condition ratings are provided based on predicted riparian widths based on seral stage classifications (Figure 2-11), and proportions of anadromous stream length by riparian impairment classification are provided for many tributaries and mainstem reaches included in Study Area for the Synthesis Study (Figures 2-12 and 2-13). Continued field surveys of riparian condition and field inventories are recommended to improve identification or riparian impairments, and a map showing areas where riparian inventories have been completed at the time of this report is provided in Figure 2-14 that can be used to inform future monitoring.

Maps of current and historical estuary habitat are provided (Figure 2-17), including channels blocked to fish use and water crossing features in the Skagit Estuary. This mapping extends to Padilla Bay and the Swinomish Channel as part of their Samish River study extent.

Instream flows are identified as important landscape processes and impervious surface cover is used as a proxy for identifying potential impairments to hydrology in lowland habitats, but the authors recommend incorporation of field-collected hydrologic records and field-verification of hydrological modeling to more accurately evaluate peak flow impairments. Impairments from peak flows in mountain basins are linked to road densities and rain-on-snow events.

The authors provide summaries of changes in peak flows and recurrence intervals pre- and post-flood storage in the based USGS gage data near Mount Vernon and Sedro Woolley. Since flood storage capacity and flow regulation, the number of floods between 2-yr and 100-yr return periods have been reduced by about 50 percent since the construction of upper Skagit River and Baker River dams. Pre-dam floods approached or exceeded 200,000 cfs while floods in the post-dam era have not exceeded 200,000 cfs. However, the authors recommend long-term monitoring of unregulated sub-basins in the Skagit Watershed to help evaluate peak flow impairments and a map of mountain basins with likely impairments to peak flows is provided that could be used to help identify sub-basins for long-term monitoring, which includes tributaries to the lower Skagit River (Figure 2-7).

Land Use and Cover: Peak flow impairments in lowland habitats were assessed based on impervious land cover with impervious cover ≤ 3 percent classified as function with respect to hydrology, moderately impaired with 3-10 percent impervious cover, and impaired where impervious cover was >10 percent. This is presented as a means to predict potential hydrological process impairments with respect to peak flow where hydrological data are not available. In mountain basins, peak flow impairments are linked to extension of drainage networks due to road densities and rain-on-snow events. Improved road inventories, especially in state and private lands, are identified as a data gap and monitoring need to support evaluation of sediment process impairments in the Skagit Watershed.

Bank hardening data are presented and used to classify floodplain process impairments, with 45.6 kilometers of hydromodified edge length identified upstream of the Skagit Delta and 50.9 km of hardened banks in the mainstem upstream of the Skagit Delta (Figures 2-15a and 2-15b). Stream bank hardening prevents channel migration and reduces LWD recruitment, and their methods indicate that the data layer they developed contains a number of potentially useful attributes for bank conditions including edge types, levee presence, hydromodification types, placement years, riparian stand types, and riparian buffer widths. The authors indicate that the SRSC has completed bank inventories for all large river main channel areas of the Skagit, but no reference to mapping tributary channels or intervals for updating these data are provided.

Geomorphology and Landforms: Maps of predicted channel types (cascades, step-pool, forced pool riffle or plane-bed, pool-riffle, and other) are provided for all freshwater reaches within the salmonid distribution (Figure 2-3). Sediment supply and transport processes were evaluated based on field measurements and spatial modeling, and included ratings of functioning (<100 $m^3/km^2/yr$ or <1.5x natural rate) or impaired (>100 $m^3/km^2/yr$ or <1.5x natural rate) and maps of ratings and supply rates are provided in Figures 2-8 and 2-9. Field-based sediment budgets are identified as a data gap and monitoring need for the Skagit Watershed, with budgets having only been completed for 12 percent of the basin area as of the date of this report. Development of screening tools and data for surface erosion and sedimentation for low-slope areas are also identified as a data gap and monitoring need for evaluating sediment processes impairments.

Water Quality and Productivity: Water quality impairments were identified based on Washington Department of Ecology's Candidate 1998 Section 303(d) Impaired and Threatened Water Bodies listings, and they provide a map of listing parameters for dissolved oxygen, fecal coliform, fish habitat, and temperature (Figure 2-18). They recommend including maps of known point and non-point sources that may contribute to water quality impairments to identify areas of potential concern, and support identification of sites to monitoring for water quality.

Beamer (2000) (Unique Identifier: 191)

Reference	Beamer, E. M., R. E. McClure, and B. A. Hayman. 2000. Fiscal year 1999 Skagit River Chinook restoration research. Report prepared for Northwest Indian Fisheries Commission by Skagit System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** large wood, estuarine habitat and landforms, change, sediment transport and supply. ***Modeling Tools:*** adult returns. ***Fish and Habitat:*** Habitat: instream flow, freshwater, estuary, ocean, limiting factors, status and trends, capacity, restoration, climate change; Fish: abundance, life history, diet, condition, density dependence, survival, growth, rearing, periodicity, size structure, status and trends, harvest; Monitoring: abundance, scales or otoliths.								
Species and Life Stages	***Chinook:*** spawning, incubation, emergence, outmigration, estuary rearing and emigration, ocean.								
Reaches and Spatial extent	Skagit Estuary, Skagit Bay, Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: The Skagit Chinook Restoration Study started in 1995 and the intent of the study was to model the production of Skagit River origin Chinook according to discrete Chinook life-stages and habitat preferences to evaluate proposed restoration actions, and test assumptions about Chinook limiting factors. The authors identified Chinook life history patterns from various habitat types within the Skagit River and estuary through patterns on Chinook otoliths. The authors estimate capacity and survival during spawning, freshwater rearing, and estuary rearing, and survival to adult return. This Skagit Chinook Restoration Study used fish density, life history, and habitat data collected from the Skagit specifically to build the model. The model framework is based on isolated life stages and testable hypotheses, which supports improvements to life stages without the need to revise the whole model. Limitations of the model include the lack of nearshore habitat and a wide variance in population estimates of juvenile Chinook at specific sites within the Skagit Estuary. The results of this study support the idea that Chinook production in the Skagit is constrained by (1) lower than expected egg to fry survival and (2) density dependence during the estuarine rearing life stage. This analysis indicated that restoration of peak flow and sediment supply to “functioning” levels would provide limited benefits unless estuary capacity was also increased, and they identify estuary restoration as the first priority to increase capacity and adult production in the Skagit River.

Information Relevant to Skagit River Relicensing: This study provides relevant quantitative data for fish and habitat, and geomorphology and landforms topics of interest as well as modeling tools that can be used to support future restoration, status and trends, and development of conceptual life history models or life stage factors affecting survival. The results of this study indicated that restoration of peak flow and sediment supply to “functioning” levels would provide limited benefits unless estuary capacity is also increased. This report includes production curves for Skagit ocean-type Chinook under 1999 habitat conditions (Figure 11), maximum restoration to increase freshwater survival (Figure 12), maximum restoration of estuarine blind channels (Figure 13), and both (Figure 14) that display the limited benefits provided by restoration of peak flow and sediment supply alone and the significant benefits provided by estuary and freshwater survival restoration.

Fish and Habitat: The analyses and data presented in this report provides estimates of capacity for freshwater and estuary habitats, as well as linkages of capacity to limiting factors. The authors state that, for flow-adjusted escapements from 1989 to 1998, freshwater capacity did not affect river smolt production (no evidence yet). Sub-yearling Chinook use of stream edge habitat with natural wood cover is over five times greater than their use of riprap cover. Within freshwater habitat of the Skagit River, 97 kilometers of stream edge had been modified along the large main river channels. These lines of evidence are used to suggests that freshwater capacity will likely constrain production at some point, but habitat inventories and continued monitoring are needed to support evaluation of freshwater rearing habitat limitations on freshwater Chinook capacity and productivity. However, this question has been addressed in subsequent analyses and freshwater rearing habitat capacity has been found to limit life history expression and production of outmigrants in the Skagit River (e.g., Beamer et al. 2005 ID005).

While a basic assumption is that there is some relationship between the number of spawning salmon and resulting recruitment, and they found evidence that increasing escapement does tend to result in increasing freshwater outmigration (Figures 4 and 9) but that egg to fry survival is mediated by peak flows and sediment. They found that the factor with the greatest effect on freshwater survival was peak flows occurring during egg deposition to emerged fry, and egg to fry survival was reduced by increases in peak flows and sediment supply. Figure 6 shows the relationship between flood recurrence interval during egg incubation and egg to migrant fry survival with an exponential regression that can be used to estimate egg to migrant survival under a range of flows. The authors provide maps showing peak flow and sediment supply impairments for all sub-basins in the Skagit Watershed that are related to freshwater survival (Figures 7 and 8).

They also determined estuarine habitat capacities based on the available data and they found that there was a density-dependent relationship between the abundance of river smolts and estuary rearing smolts. The average resident period for Skagit juvenile Chinook is 34.2 days based on previous analyses, and using the Beverton-Holt parameters between potential occupants and observed occupants, Ocean-type Chinook smolt capacity in blind channel habitat, assuming infinite outmigration size, was calculated at 21,916 fish per hectare. With 117.7 ha of blind channel habitat in 1999, total estuarine capacity was estimated at 2.6 million at infinite smolt outmigration. The marine survival rate of a Chinook Salmon (leaving the estuary to adult recruitment), in adult equivalent recruitment, had a mean of 2.6 percent with a range of 1.6 percent to 3.9 percent. Estimated estuary capacity combined with a 2.6 percent marine survival, estimated maximum adult recruitment under 1999 estuary habitat levels was about 67,000 adults. Annual Chinook catches in the Skagit Bay alone during the 1930's came close to 50,000 in some years, which means that total recruitment was likely much higher and that capacity has been significantly reduced since that time with gradual habitat losses and estuary habitat increasingly limiting productivity.

In 1999, juvenile Chinook were present in Skagit Bay in February and had essentially left Skagit Bay by late October (were absent or seldom taken by beach seining). Peak abundance of juvenile Chinook Salmon occurred in both February and in mid-June. In 1995-1998, peak abundance of juvenile Chinook Salmon occurred between May and July. Table 2 provides a summary of recovery efficiencies for different sites and tidal gage heights, which can be used to inform expansions of catches in similar habitats or from similar sampling methods. The lengths of juvenile Chinook generally increased throughout the sampling season, and a table that summarizes average juvenile fork length by year and month is provided based on the sampling effort (Table 5). The authors also noted substantial numbers of other species of fish, particularly sandlance, smelt, and herring in the catches. There were some observations of salmon with juvenile sandlance or herring protruding from their mouths, but no formal analysis has been completed to determine if salmon utilize these forage fish.

Geomorphology and Landforms: A map showing sub watersheds classified as functioning, impaired, or missing data based on sediment supply over estimated natural rates is provided for the entire Skagit watershed (Figure 8). A map showing current habitat (circa 1991) and historical (circa 1880) locations of channels, major wetlands, and limits of estuarine habitat zones are provided for historic conditions, which includes the main Skagit Delta and Padilla Bay or Samish lobes of the geomorphic delta (Figures 1 and 10). Under historic conditions, the Skagit River Delta had large areas of estuarine and freshwater habitat.

Modeling Tools: Table 1 provides inputs, sources of data, and analytical methods used to generate initial inputs and outputs for Chinook Restoration Analysis Model. Equations are provided that would support application of the model or integration of model components into future life cycle modeling efforts. The model was developed to the *"…(1)the likely effects of different proposed restoration actions can be evaluated; and (2) our assumptions about Chinook limiting factors can be tested."* However, the model does not include nearshore habitat that may influence Chinook productivity, and this will be addressed in future monitoring efforts (e.g., Beamer et al. 2005 ID005).

Beamer et al. (2000) (Unique Identifier: 192)

Reference	Beamer, E. M., J. C. Sartori, and K. A. Larsen. 2000. Skagit Chinook life history study progress report number 3. Report prepared for Non-Flow Coordination Committee, Seattle City Light, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: freshwater, estuary, nearshore; Fish: distribution, rearing, life history, age structure, periodicity; Monitoring: scale or otoliths.									
Species and Life Stages	***Chinook:*** spawning, rearing, estuary rearing and emigration, nearshore rearing and emigration									
Reaches and Spatial extent	R10-13, US of R7, Sauk River.									
Linkages to Hydroelectric Operations	NA									

Summary: This report summarizes progress made by the Skagit Chinook Life History Study during 1999. This report includes visual and quantitative analysis results of otolith samples, identification of naturally induced transition checks or points on otoliths, and identification of juvenile life history types. The study focuses on identifying specific ocean-type Chinook life history types in the Skagit river Chinook. Juvenile Chinook otolith samples were collected from the upper Skagit River (US of R7), middle Skagit River (Reach 10-11), lower Skagit River (Reach 12), Skagit Bay (R13), Skagit estuary, and lower Sauk River. Results from juvenile Chinook otolith samples were collected in 1995 and reported later in 1998 and 1999. This report represents results from samples collected from adult Chinook at spawning grounds and juvenile Chinook in nearshore habitat of Skagit bay. This report also summarizes Chinook juvenile life history types and estuarine residence period. In addition to logical life history types of freshwater to estuary to bay (FEB) and freshwater to bay (FB), results from this report identified three atypical life history types; freshwater to estuary to freshwater to bay (FEFB), freshwater to estuary to freshwater to estuary to bay (FEFEB), and estuary to freshwater to bay (EFB). The report also shares revision and priorities of future work and the protocol for otolith preparation is also reported in the appendix.

Information Relevant to Skagit River Relicensing:

Juveniles: 151 otolith samples from juvenile Chinook were collected between February 29 and September 20 in 1996 within the Skagit Bay. 138 of the 151 were visually analyzed. All samples revealed time spent in the bay. All five life history types were identified in the 1996 samples. Atypical samples (FEFB and FEFEB) were most represented at the end of June to the beginning of July and end of July to beginning of August. Table 1 provides percent of juvenile Chinook by life history type and sample year. The 1995 sampling season was from May 11 to August 31 which may explain the difference in results between the two years.

All developmental microstructural patterns (A, B, C, D) were represented among the 1996 samples. Patterns A and B were the most abundant among the bay samples and were similar for both 1995 and 1996. Patterns A and B peaked from mid-June to mid-July. Pattern D peaked at the end of June into mid-July. The microstructural patterns made up the following percent of the samples for 1996: A=29 percent, B=35 percent, C=19 percent, D=17 percent. For 1995: A=29 percent, B=35 percent, C=13 percent, D=23 percent.

Quantitative analysis was performed on 112 of the 138 samples used in the visual analysis. The authors note that they summarized linear distances, mean incremental widths, and increment counts were entered in a database. The authors report the increment lengths, in microns, associated with each habitat type and use these results to estimate estuarine residence period by life history type in Table 2. This analysis also revealed that average FEFB and FEFEB life history types, in 1995, reared 1.8 and 2.1 times longer in estuarine habitat than the average FEB life history type.

Adults: Visual analysis was performed on 26 of 31 adult Chinook otolith samples collected in 1997. Samples were collected from early June to late October and including the Upper Sauk River and Upper Skagit River (US of R7). Bay region was excluded from this analysis and consistent identification of the first annulus was not possible. Early life histories were identified, and the results were as follows; FEB type represented 69 percent, FEFB type represented 15 percent, FEFEB type represented 15 percent. This adult typical:atypical ratio is similar to the juvenile typical:atypical ratio from the Skagit Bay samples in 1995.

Developmental check patterns A, B, C, D were represented throughout the samples. The microstructural patterns made up the following percent of the samples; A=19 percent, B=43 percent, C=19 percent, D=19 percent. Pattern A was observed only on the Sauk and Suiattle samples. Patterns B and D were observed on samples collected from the Upper Skagit mainstem (US of R7). Pattern C was observed on samples collected from Day creek (R11). The authors hypothesis that developmental check pattern C is the norm.

Quantitative analysis was performed on 24 of the 26 adult samples. Bay region was excluded from this analysis as well and consistent identification of the first annulus was not possible. Radial distances, mean incremental widths, and incremental counts were recorded and entered into a database. Appendix 1 reports the protocol used for adult otolith preparation.

Beamer et al. (2005) (Unique Identifier: 004)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. M., B. Hayman, and D. Smith. 2005. Linking freshwater rearing habitat to Skagit Chinook salmon recovery: Appendix C of the Skagit Chinook recovery plan. Report by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: abundance, periodicity, life history, density dependence, size structure, growth, survival, data gaps, hatchery; <u>Habitat</u>: freshwater, limiting factors, capacity, connectivity; <u>Monitoring</u>: abundance. Hydroelectric Operations: flow regulation. Geomorphology and Landforms: change, slope, floodplain, side and off-channels, floodplain connectivity, aquatic habitats and landforms. Modeling Tools: habitat, juvenile production.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: incubation - outmigration, rearing, overwintering.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Watershed, including Sauk and other Sauk River tribs (Suiattle River).</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Hydroelectric Operations: flow regulation. Fish and Habitat: <u>Fish</u>: life history. Chinook: overwintering.</td></tr>
</table>

Summary: This report is an appendix to the 2005 Skagit Chinook Recovery Plan and focuses on the linkages between freshwater rearing habitat and Chinook Salmon recovery. The report provides an overview of the life histories of juvenile Chinook, specifically including parr and yearling migrants, their habitat preferences, and how freshwater habitat conditions are limiting production in the Skagit River watershed. They found that parr and yearling histories consistently contribute to returning adult populations of Chinook in Skagit and conclude that these life histories are important to recovery planning in the Skagit Watershed. They developed estimates of historic and current habitat conditions to evaluate changes in freshwater rearing habitat conditions (historical to current circa 1995) and developed estimates of habitat capacities and impacts to capacities from hydromodifications and loss of floodplain connectivity. The results are described in the context of restoration and recovery planning, providing support for their premise that increasing freshwater habitat rearing capacity (through restoration) could address density dependent patterns observed in juvenile Chinook abundance and life history patterns. They also provide restoration strategies and modeling tools that can be used to support recovery and restoration planning to address the freshwater habitat limitations they identified. Recommended restoration strategies to address freshwater rearing habitat limitations for yearling life histories in the Skagit River watershed included restoring habitat access, reconnecting side channels, and restoring the natural process of habitat formation though channel migration. For parr life histories, they recommend addressing hydromodifications and restoration or removal of other floodplain disturbances (e.g., dikes and levees, riprap) that hinder river movements, reduce formation of backwaters and other complex edge habitats that freshwater rearing parr prefer, and increasing connectivity to off-channel floodplain habitats important for refuge and rearing.

Information Relevant to Skagit River Relicensing: This report provides a lot of relevant information for the Synthesis Study including quantitative data supporting the finding that freshwater rearing habitats are limiting juvenile Chinook parr and yearling freshwater rearing capacity in the Skagit Watershed. Metrics describing periodicity, life histories, size structure, growth, survival, capacity, density dependence, and hatchery interactions are provided, as well as metrics and modeling tools describing the potential linkages between these fish metrics and changes in habitat conditions that can inform restoration planning and evaluation in the basin. Spatial data were also developed that that could be requested to support future analyses. Spatial data delineated includes mainstem channel habitat, connected floodplain, shadowed floodplain, isolated floodplain, hydromodifications, floodplain channels, restoration projects, and gaps in habitat opportunity. They also identify several important data gaps and monitoring needs including improving our understanding of yearling movement patterns and habitat preferences in freshwater habitats, understanding how straying of unmarked hatchery Chinook and flow management in the Upper Skagit River influences yearling productivity, yearling capture efficiencies at rotary screw traps used to monitoring juvenile production, and improved estimates of floodplain habitat losses from historical reconstructions. We noted that a lot of information presented in this Appendix is also covered to some extent in Appendix D of the 2005 Skagit River Chinook Recovery Plan (Beamer et al. 2005, ID005), and therefore we focus on the relevant information and quantitative data that are unique to this Appendix in the summaries below.

Fish and Habitat: Summaries of life history and periodicity for juvenile Chinook are provided for parr and yearlings, which rely on freshwater rearing habitat to a greater extent than other juvenile life histories (e.g., fry migrants, delta rearing fry migrants). Parr migrants emerge from egg pockets and rear for a couple months in freshwater habitats before migrating downstream at an average FL of 75 mm (57-92 mm FL) in May to June, where they move to Skagit Bay habitats through delta habitats relatively quickly. Yearling migrants overwinter in freshwater, but their movement patterns and habitat preferences are largely unknown. Yearlings migrate out of freshwater at an average size of 120 mm (92-154 mm FL) typically from late March through May, and do not rear extensively in delta habitats before emigrating to deeper subtidal or offshore habitats in Skagit Bay.

Parr migrant production has averaged approximately 1.3 million parr per year (1997-2002) and is not related to total outmigrant production, whereas much more variation in early migrant production (fry migrant) is observed as a function of total outmigrant abundance. Using a Ricker function, they estimate freshwater rearing capacity is reached when total juvenile production reaches approximately 4.5 million, with parr production leveling off and fry migrant (early migrant) production increasing as total production increases. Regression and scatter plots are provided showing these relationships. They also provide capacity estimates for parr rearing habitat based on habitat and edge types based on published densities/capacities and regressions and assumptions of habitat areas, with detailed tables provided that can be used to support modeling of capacities and habitat in the lower Skagit River study area. The authors indicate that these tools were applied to potential restoration projects in the Skagit Watershed and the results are described in Chapter 10 of the 2005 Skagit River Chinook Recovery Plan.

Yearling migrant production estimates have ranged from about 40 to 180 thousand smolts with an average of 107 thousand. However, they indicate that yearling capture efficiencies are limited and estimates of yearling production are potentially biased and could be refined with future research into capture efficiency of yearling migrants. Detailed annual summaries of yearling production and population estimates are provided for each population for 1994-2000 brood years. Average annual contributions to adult escapement from yearling migrants varied among populations with higher contributions among spring-run populations; 2.6 percent in upper Skagit summer run, 17.8 percent in lower Skagit fall-run, 50.3 percent in upper Cascade spring-run, 44.3 percent in upper

Sauk spring-run, and 51.3 percent in Suiattle spring-run Chinook. They noted a large decline in yearling contributions in the upper Skagit summer population that they indicate coincides with changes in Skagit River Hydroelectric Project flow management (in the mid-1980s and 1991 associated with the last relicensing) and cessation of unmarked hatchery releases but identify this as an area of future study to better understand mechanisms and processes influencing the decline. They also found a negative relationship between adult escapement and yearling productivity (yearling smolts per spawner) and suggests this is evidence of yearling rearing habitat limitations.

Geomorphology and Landforms*:* Historical reconstruction and estimates of current habitat extent from aerial imagery are provided, with detailed metrics and summaries of 31 mainstem reaches provided in Chapter 10 of the 2005 Skagit Chinook Recovery Plan. They found that 31 percent of floodplain area has been isolated, over 98 km of hardened stream banks for mainstem Skagit River reaches (> 50 m bankfull width channels), and an average reduction of 28.6 percent in the effective floodplain compared to historical conditions. The found approximately 2x higher density of off-channel habitats in connected floodplains compared to isolated or shadowed floodplains, and that floodplain gradient and effective floodplain width were significant predictors of off-channel habitat extent among reaches. Regression equations for estimating mainstem edge and off-channel habitat areas in large river floodplains, as well as average widths of bank edge, bar edge, and off-channel habitats and assumed parr capacities for mainstem habitat types (natural backwater, hydromodified backwater, natural bar, hydromodified bar, natural bank, hydromodified bank, mid-channel, and off-channel) from published values. Collectively, these are used to estimate current capacities for parr rearing and as a modeling tool to support restoration planning.

Hydroelectric Operations: A decline in the abundance and proportion of yearlings in the Upper Skagit summer population was linked to changes in flow management related to relicensing agreements (in the mid-1980s and 1991) and cessation of unmarked hatchery releases. The linkage is demonstrated by plots showing the decline coinciding with these events, but they indicate that more research is needed to evaluate the changes in yearling abundance and proportions from this population. In addition, it is unclear if the decline in the abundance of yearlings and proportion of yearlings in the returning Upper Skagit Summer population would be linked to differences in yearling abundance in the lower Skagit River within the Study Area for the Synthesis Study based on their reported results. No linkages were described for other populations including lower Skagit River fall or Sauk tributary populations.

Beamer et al. 2005 (Unique Identifier: 005)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook Salmon populations. Supplement to Skagit Chinook Recovery Plan.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Links</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> status and trends, estuary, nearshore, pocket estuary, restoration, instream flow, capacity, climate change; <u>Fish:</u> abundance, density dependence, competition, survival, growth, rearing, predation, life history, age structure, size structure, sex structure, periodicity, status and trends, hatchery, harvest, climate change, data gaps, movement. Water Quality and Productivity: salinity. Modeling Tools: connectivity.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: spawning, estuary rearing and emigration, nearshore rearing and emigration, rearing, outmigration, overwintering, ocean.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary and Skagit Bay, some information on upstream reaches R1-R13.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Fish and Habitat: life history. Chinook: overwintering.</td></tr>
</table>

Summary: This report is an appendix to the 2005 Skagit Chinook Recovery Plan and the authors synthesize information from over a decade of research on estuary habitat use, life history variation, estuary habitat loss, marine survival, restoration responses, and climate change impacts. One of the objectives of this report is to predict the potential benefits of restoration projects for recovering Chinook Salmon in the Skagit River. The authors hypothesize that the Skagit estuary is critical to the survival of wild Chinook Salmon populations in the Skagit, provide data and lines of evidence that support this hypothesis, and describe how estuary habitats are related to a diversity of Chinook abundance and demographic parameters. In addition, they present models and data that support evaluation and prioritization of restoration strategies.

Information Relevant to Skagit River Relicensing: The information presented in this report represents a foundational reference, with extensive references and quantitative information on several topics regarding Chinook Salmon relevant to the Synthesis Study objectives. The data and information presented in this report have been used to develop multiple peer-reviewed publications that were also considered in this synthesis, and numerous references to relevant sources are provided. The analysis and information presented in this report are primarily focused on the Skagit Estuary and nearshore (pocket estuary) habitats in Skagit Bay, but information and quantitative data are presented that link abundance and demographic patterns to upriver population abundance and demographic patterns as well as restoration strategies. The authors present several key findings that are relevant to the Synthesis Study objectives including:

All six Chinook populations in the Skagit River express delta rearing and fry migrant life history strategies and can be found rearing in Skagit delta and pocket estuary habitats, and therefore, all six stocks utilize Skagit delta and estuary habitats for emigration as well as rearing for certain life histories.

Freshwater rearing capacity in reaches upstream of the estuary limits the production of late migrants and excess production results in the expression of fry or early migration life histories that emigrate to estuary and nearshore habitats.

> Density dependence influences the timing of emigration, duration of rearing, size at entry, and expression of life histories and thereby use of delta, estuary, nearshore, and pocket estuary habitats.
>
> Delta and pocket estuary habitat extent has decreased and become more fragmented, and restoration opportunities exist for both delta and pocket estuary habitats.
>
> Current (circa 2005) delta habitats are limiting the abundance and size of juvenile Chinook that the delta can support through density dependent processes, and this potentially limits marine survival rates or survival at later stages based on size selective mortality.
>
> Restoration of pocket estuary habitat can partially mitigate the density dependence and survival impacts for fry migrants, which is influenced by freshwater water rearing capacity limitations.
>
> Increasing delta and pocket estuary habitat extent and connectivity should be a component of the Skagit Chinook Salmon population recovery plan, and these restoration actions would address density dependent patterns and increase the abundance of juveniles produced, survival to subsequent life stages, and increase population resilience through maintenance of life history diversity.
>
> Climate variations influence survival, and recovery planning should consider possible shifts in marine survival related to climate change or variations in climate patterns, including planning for “worst-case scenarios” in population recovery.

The finding that freshwater rearing capacity and density dependent processes drive expression of fry and early migrant life histories suggests that management actions focused on increasing adult escapement need to be paired with actions that increase freshwater rearing capacity and estuary rearing capacity given that delta rearing capacity is currently limiting. The authors develop landscape and local connectivity models, and a quantitative model for estimating capacities and production by life history type based on adult abundance, smolt production, and estuary capacity based on both the quantity and connectivity of estuary habitats under different restoration and marine survival or climate change scenarios. These models and data are used to support development of estuarine habitat restoration strategies that include both connectivity and habitat area to support Chinook Salmon recovery planning.

This report provides extensive quantitative information of juvenile life history types, size ranges, periodicity, habitat use, and mechanisms controlling or related to the expression, survival, and growth of life history types including: (1) fry migrant; (2) tidal delta rearing migrants; (3) parr migrants; and (4) yearlings. Differences in hatchery and wild juvenile Chinook densities, size, and periodicity are also presented. This information can be used to support development of conceptual life history models for Chinook Salmon in the study area. Quantitative and spatial data on changes in the extent (quantity) and connectivity of delta, estuary, and pocket estuary habitats from historic (circa 1860s) to modern times (circa 1991), as well as with climate change (sea level rise) are also presented. In addition, measurements of channel density, allometric relationships, widths, edge areas, channel areas, and optimal Chinook habitat area (based on water depth and velocity) as well as distance between pocket estuary habitats are also presented in the context of juvenile Chinook abundance and life history patterns.

The authors indicate that declines in yearling life history expression among Upper Skagit populations coincided with cessation of unmarked hatchery releases and changes in flow management associated with the Skagit Project relicensing (in 1980 and 1991), but they identify this as a potential area of future study to evaluate how the correlation is related to Hydroelectric Operations, straying rates, and hatchery practices. Summaries of salinities, water depths, and surface velocities are provided for a number of locations or pathways in the estuary but are not summarized here.

Fish and Habitat: Current tidal delta rearing capacity is estimated to be reached when freshwater outmigrant abundance exceeds 5.1 million in the lower river. Accounting for differences in estuary habitat use among life histories, they estimate a net tidal delta rearing capacity for tidal delta rearing migrants at 2,249,581 fish. Net loss of 72.8 percent tidal delta estuarine habitat area from historic 1860s (11,483 ha) to 1991 (3,118 ha) is reported for status and trends, which includes the areas most relevant to Skagit River Chinook from Padilla Bay to Camano Island. Open distributary channel densities were 11.6 m channel length/ha of wetland for historic conditions and 39-41.2 m/ha for current conditions. Area of open tidal channels declined by 30.4 percent from historic (1860s) to current (2000), with 20.7 percent loss of edge area and 94.6 percent loss of blind tidal channel area, which translates to a 87.9 percent loss of preferred Chinook delta rearing habitat. The authors estimate 68 percent of historical pocket estuaries are no longer accessible to juvenile salmon as a result of land disturbances, with all current (n=27) pocket estuaries having some modifications that have reduced usable fish habitat for a net reduction in pocket estuary habitat area of 80 percent. Distance to the nearest pocket estuary was unchanged from historic to current conditions, at 0.96 km from natal river mouth. However, the number of pocket estuaries within 9.5 km (the distance a juvenile Chinook can travel in one ebb tide) has declined by 50 percent from historic (n=18) to current (n=9) conditions. Within 25 km of the natal river mouth, the number of accessible pocket estuaries under current conditions (n=14) was 42 percent of historic (n=33). Spatial data for pocket estuary locations and habitat maps for a number of pocket estuaries are provided.

Potential areas, open water channel area, connectivity scores, and smolt capacity are provided for a number of potential restoration projects. Collectively, these would increase delta area by 1,114 ha and increase rearing capacity by 1,352,791 smolts annually. Potential pocket estuary restoration projects are also described, with potential areas for habitat and channels, connectivity scores, and smolt capacities. These projects would increase pocket estuary rearing capacity from 73,393 to 221,264 smolts annually.

The report also indicates that a 45 cm increase in sea level due to climate change would cause an estimated 12 percent (235 ha) loss of tidal marshes in the vicinity of Fir Island, and an 80 cm increase would result in an estimated loss of 22 percent (437 ha) of tidal wetland habitat near Fir Island. This would translate to an estimated losses of rearing capacity of 211,000 and 530,000 smolts, respectively. Spatial data of habitat under both sea level rise scenario are available, and include marsh type.

Numerous metrics on periodicity, abundance, life history, length, movement, growth, density-dependence, and survival are reported for Chinook. Mean monthly unmarked Chinook densities peaked in April in tidal delta habitats (≈3.5 log +1 fish/ha), in March to May for shallow intertidal habitats (≈1.5 log +1 fish/ha), in June in intertidal subtidal habitats (≈1.75 log +1 fish/ha), and in July to September in offshore surface waters (≈1.0 log +1 fish/ha). In contrast, marked Chinook densities peaked in June in tidal delta (≈1.0 log +1 fish/ha), intertidal shallow (≈0.3 log +1 fish/ha), and intertidal subtidal habitats (≈1.0 log +1 fish/ha), and in July in offshore surface waters (≈0.9 log +1 fish/ha). Mean monthly densities with standard error are available for each habitat type for both marked and unmarked juvenile Chinook. This report provides the following descriptions for four primary juvenile life history types.

> ***Fry Migrants*** – *"These fry emerge from egg pockets and migrate quickly downstream to Skagit Bay. Fry migrants do not rear extensively in tidal delta habitat so no tidal delta rearing structure is observed on their otolith. They enter Skagit Bay usually in February and March, at an average fork length of 39 mm (observed range from otoliths is 30-46 mm fork length). Some fry migrants take up residence in pocket estuary habitat (Beamer et al. 2003). These areas are thought to provide fry migrants with a survival or growth advantage over other nearshore habitats."* Based on genetic analyses, fry migrants contribute to ≈20 percent of upper Skagit, ≈18 percent of lower Skagit, ≈20 percent of Cascade River, ≈15 percent of Suiattle, ≈10 percent of upper Sauk, and ≈15 percent of lower Sauk populations.

> ***Tidal Delta Rearing Migrants*** – *"Tidal delta rearing fry emerge from egg pockets and migrate downstream at the same time as fry migrants. Instead of directly entering Skagit Bay, they reside in tidal delta habitat for a period ranging from several weeks up to several months, reaching an average size of 74 mm fork length (observed range from otoliths is 49-126 mm fork length). The average tidal delta residence period for tidal delta rearing Chinook Salmon in 1995 and 1996 (combined) was 34.2 days (Beamer et al. 2000b). Following the tidal delta rearing period, these fish migrate to Skagit Bay, usually starting in late May or June. We observe a tidal delta rearing region on their otolith. Beamer and Larsen (2004) further defined several life history sub-strategies for tidal delta rearing Chinook Salmon based on movement patterns and overall residence period within the tidal delta."* Based on genetic analyses, tidal delta rearing migrants contribute to ≈22 percent of upper Skagit, ≈20 percent of lower Skagit, ≈12 percent of Cascade River, ≈7 percent of Suiattle, ≈15 percent of upper Sauk, and ≈22 percent of lower Sauk populations.

> ***Parr Migrants*** – *"These fry emerge from egg pockets and rear for a couple of months in freshwater to achieve a similar size as their tidal delta rearing cohorts over the same time period. Following freshwater residence, parr migrants move through the tidal delta and into Skagit Bay, usually starting in late May or June at the average size of 75 mm fork length (observed range from mainstem trapping is 57-92 mm fork length). Parr migrants do not reside in tidal delta habitats. We observe an extended freshwater rearing region and no tidal delta rearing region on their otolith. Some of these fish may reside in off channel habitat within the large river floodplain areas of the Skagit River (Hayman et al. 1996)."* Based on genetic analyses, parr migrants contribute to ≈22 percent of upper Skagit, ≈8 percent of lower Skagit, ≈45 percent of Cascade River, ≈15 percent of Suiattle, ≈15 percent of upper Sauk, and ≈0 percent of lower Sauk populations.

> ***Yearlings*** – *"These fry emerge from egg pockets and rear in freshwater for a period over one year. Movement patterns and habitat preferences within freshwater are largely unknown. Yearlings migrate to the estuary generally from late March through May at the average size of 120 mm fork length (observed range is 92-154 mm fork length). Yearlings do not reside in tidal delta habitats for an extended period of time like tidal delta rearing migrants. Yearlings seem to pass through tidal delta habitats, possibly lingering briefly, on to nearshore areas. Yearlings are rarely found in shallow intertidal environments, but are most commonly detected in deeper subtidal or offshore habitats. Residence in nearshore areas of Skagit Bay by yearlings appears to be shorter than ocean type life*

histories." Based on genetic analyses, yearling migrants contribute to ≈8 percent of upper Skagit, ≈0 percent of lower Skagit, ≈25 percent of Cascade River, ≈25 percent of Suiattle, ≈25 percent of upper Sauk, and ≈18 percent of lower Sauk populations.

Residence time decreases and average fork length decreases as freshwater smolt population increases. These relationships are shown as scatter plots with regressions from 1992-2002 data. The proportion of wild juvenile Chinook that do not rear in the estuary (fry migrant abundance in nearshore) increases as outmigrant production increases, with the authors identifying a threshold of 2.5 million where the proportion fry migrant production increases (15-40 percent fry migrants) compared to about 10 percent fry migrant production at <2.5 million outmigrants. The relationship is shown as a linear regression with 1992-2002 data. Juvenile Chinook can travel 9.5 km from a natal delta in one ebb tide cycle, which is relevant to connectivity and accessibility or potential use of pocket estuary habitats by displaced fry migrants.

Freshwater outmigrants expressing an early migrant life history increases with increasing outmigrant abundance, indicating freshwater limitations on rearing capacity. The proportion of early migrants increases from 40-50 percent at about 2 million outmigrants to over 80 percent when outmigrant production reaches about 6 million – a linear regression and scatter plot are provided for this relationship. In contrast, late or parr migrant abundance remains relatively stable with increasing outmigrant production at an average of 1,320,419 from 1997-2002 (a scatter plot is provided for these data).

Marine survival estimates are provided for 1974-1997, and were classified into two regimes based on marine conditions and derived or estimated for each life history type as shown in Table 4.1. These were used to estimate adult contributions of each life history type, with adult production ranging from as low as 4,159 adults under very poor marine conditions to as high as 57,895 adults under favorable marine conditions accounting for variations in marine survival among life history types (see Table 4.2).

Modeling Tools: A landscape connectivity model was developed and tested using abundance data, this model is shown in the snapshot below. Note that distance to pocket estuary along the shoreline is added for nearshore habitats. The model is described in the report, with landscape connectivity described as a function of distributary channel order and distance. Daily average juvenile Chinook densities increase as a function of this landscape connectivity metric until a connectivity value of approximately 0.035, after which the relationship appears to level off. At connectivity values greater than 0.035, average densities were 11,200 fish/ha in blind tidal channels. Connectivity scores are available as spatial data. Scatter plots of subyearling densities and connectivity scores are provided. Local connectivity also described observed densities, with densities increasing with increase depth of water at high tide at channel mouths, which defines local access to habitats. Densities increased from 0 to 7-10 fish/ha as depths increased from 1 to 4.5 ft. Scatter plots of depth and subyearling densities are provided.

Beamer et al. (2005) (Unique Identifier: 175)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., R. Bernard, B. Hayman, B. Hebner, S. Hinton, G. Hood, C. Kraemer, A. McBride, J. Musslewhite, D. Smith, L. Wasserman, and K. Wyman. 2005. Skagit Chinook recovery plan 2005. Report prepared by Skagit River System Cooperative and Washington Department of Fish and Wildlife.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Links</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, history, slope, floodplain, side and off-channels, floodplain connectivity, substrate and sediment, sediment transport and supply, large wood, nearshore habitats and landforms, aquatic habitats and landforms, estuarine habitats and landforms. Water quality and Productivity: temperature, nutrients, dissolved oxygen, turbidity, salinity. Modeling Tools: life cycles, habitat, hydrology. Land Use and Cover: floodplain, banks and shoreline, forestry, agriculture, commercial, urban, roads. Hydroelectric Operations: flow regulation, downramping, flood control, life stage flows, stranding. Fish and Habitat: <u>Habitat:</u> instream flow, riparian, wetlands, beaver, barriers, freshwater, estuary, pocket estuary, nearshore, ocean, connectivity, limiting factors, status and trends, capacity, restoration; <u>Fish:</u> abundance, distribution, density dependence, genetics, predation, competition, survival, hatchery, harvest; <u>Monitoring:</u> restoration, habitat, sediment, flow.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: Full life cycle. All Anadromous species: NA.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">US of R7, R7 to R11, Skagit Watershed, Sauk River, Suiattle River, Cascade River, Baker River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Hydroelectric Operations: flow regulation, downramping, flood control, life stage flows, stranding.</td></tr>
</table>

Summary: This report contains the full Skagit Chinook Recovery Plan prepared by Skagit River System Cooperative and the Washington Department of Fish and Wildlife. This plan aims to provide a detailed pathway by which Skagit Chinook populations can recover to sustained numbers that meet recovery goals. The report identifies factors limiting production of Chinook as seeding level, degraded riparian zones, poaching, current hydroelectric operations, sedimentation and mass wasting, flooding, high water temperatures, hydromodification, water withdrawals, loss of delta habitat and connectivity, loss of pocket estuary habitat and connectivity, availability of prey species, and illegal habitat destruction and degradation. These limiting factors are addressed, in depth, for each Chinook population. Harvest management actions have previously been successful at limiting impacts on Skagit Chinook, but alone cannot achieve the recovery goals for recruitment and productivity. There are no additional changes to artificial Chinook production in this plan as there are already resource management plans under review by NOAA fisheries. Current hatchery programs within the Skagit River will continue as configured, but this plan does detail proposed and possible hatchery operations and releases for Chinook and non-Chinook hatchery programs. This plan provides 56 recommendations related to habitat protection and proposes a list of research actions that need to take place to fill data gaps. Each of the six Chinook stocks are described in detail as well as the life history strategies of fry migrants, delta rearing migrants, parr migrants, and yearlings. This report assumes that the ocean is not at carrying capacity and therefore changes in juvenile production will result in corresponding changes in adult recruitment. The plan includes a list of detailed harvest management actions including implementation, verification, backup actions, fishing locations, seasons, regulations, and enforcement. This plan also makes recommendations for residential use, public use, hydropower use, and commercial use of stream flows. Recommendations are made to improve water quality and sediment through forest and agricultural practices along with numerous recommendations to maintain and improve stream channel complexity, riparian areas and wetlands, estuary and nearshore habitat, and fish passage and access as well as parameters that should be incorporated into a long-term monitoring strategy. All types of habitat restoration projects are covered through a summary, purpose statement, targeted populations, estimated cost, timeframe, expected results, monitoring, and backup actions. Overall, this report represents a pathway that will meet the regional expectations of Chinook recovery. This plan defines biologically-based recovery goals, identifies what is known about factors that limit production of Skagit River Chinook, and proposes actions that will restore Skagit River Chinook to optimum levels.

Information Relevant to Skagit River Relicensing: This report focuses on the plan for Chinook Salmon recovery and does not contain large amounts of quantitative data but does provide a somewhat comprehensive list of actions that should be taken or could be taken to move toward recovery of Skagit River Chinook. This report contains a lot of historic values for habitat extent and Chinook population status. For each section of the report, there are careful considerations and recommendations made for the distinct Skagit Chinook populations. This report provides detailed analysis of factors limiting Chinook production in the Skagit watershed. There are many limiting factors detailed in the report including dam operations, which are described in the Hydroelectric Operations section. Data gaps identified in this report include sources of sediments impacting egg to fry survival, the role of beavers in the tidal delta, the ecology of forage fish as it relates to salmon during nearshore rearing, the role of predation by seals and birds in limiting Chinook productivity, and further refinement of our understanding of Chinook rearing and survival in nearshore habitats including the impacts of specific land uses. The actions in this plan assume the following estimates of maximum sustainable yield (MSY). MSY for Skagit summer and fall Chinook is between 10,000 and 15,000. MSY for Skagit spring Chinook is between 1,500 and 2,000. MSY exploitation rate estimates for Skagit Chinook summer and falls is about 50 percent and springs is around 40 percent. Tables 4.1 and 4.2 contain the plan's recovery goals at average and high marine survival, respectively. The Indian Tribes also specify their harvest goals at 500 springs and 20,000 summer and falls in the near-term and at 1,000 springs and 30,000 summer and falls in the long-term. Chinook catches in the Skagit Bay and River have declined from 40,000 in 1935 to a few hundred in 2000. While spawning escapements have been relatively stable from 1983 to present, total adult recruitment has decreased significantly.

Note that multiple appendices are cited in the report that provide detailed information on specific topics. These were reviewed as separate sources and annotated bibliographies were developed for each appendix as appropriate; (SRSC and WDFW [2005] [Unique Identifier: 304], Beamer et al. [2005] [Unique Identifier: 305], Beamer et al. [2005] [Unique Identifier: 004], Beamer et al. [2005] [Unique Identifier: 005], Hayman [200] [Unique Identifier: 309]).

<u>Fish and Habitat</u>: This report provides a detailed history and summary of limiting factors in each population of Chinook Salmon in Section 5.3. Seeding levels appear to be adequate but were evaluated for each population separately. Seeding levels are of intermediate status for the Lower Sauk Summers, Upper Sauk Springs, and Upper Cascade Springs. Degraded riparian zones were evaluated for each population and it is found that the Lower Skagit Falls experience heavily degraded riparian areas, the Upper Skagit Summers experience significantly degraded riparian areas, the Lower Sauk Summers experience heavily degraded riparian areas in some areas, the Upper Sauk Springs experience Moderate riparian degradation, the Suiattle Springs experience

significant riparian degradation, and the Upper Cascade Springs experience little riparian degradation. Poaching was found to have significant impacts on all populations and the Suiattle Springs population is believed to suffer greater impacts than others. Other limiting factors include sedimentation and mass wasting in Section 5.3.5, flooding in Section 5.3.6, high water temperatures in Section 5.3.7, hydromodification in Section 5.3.8, water withdrawals in Section 5.3.9, loss of delta habitat and connectivity in Sections 5.3.10 and 5.3.11, loss of pocket estuary habitat and connectivity in Sections 5.3.12 and 5.3.13, availability of prey fish species in Section 5.3.14, illegal habitat destruction in Section 5.3.15 and high seas survival in Section 5.3.16. Factors evaluated and assumed not significant include hatchery fish predation, river temperatures during incubation, small hydro projects, nutrient and carcass and productivity levels, bird predation, competition and predation, disease, hatchery competition, and marine mammal predation. A spawning fish barrier survey completed in 2000 identified over 600 barriers to fish passage.

Table 13.1 contains information on the programmed annual releases of Chinook Salmon in the Skagit River Basin. Table 16.2 details the change in exploitation rates from 1983 to 1989 for Spring Chinook and Summer/Fall Chinook. Scale samples from spawning grounds since 1992 from summer and fall spawning grounds, and since 1986 from spring spawning grounds give the following mean percent of yearlings by populations; Lower Skagit falls = 17.8 percent; Upper Skagit Summers = 2.6 percent; Suiattle springs = 51.2 percent; Upper Cascade springs = 50.3 percent, Upper Sauk springs = 44.5 percent; Lower Sauk = 9.1 percent.

Hydroelectric Operations: Dam operations include downramping that has been limited to less than two inches per hour and cannot be met at the Baker River Project, but Baker River dam improvements were planned for 2012. The Lower Skagit Falls are largely affected by the Baker Lake Hydroelectric Dam that has inundated a total of 68.8 miles of anadromous habitat. Downramping from the Baker dams may cause water levels to drop in the mainstem Skagit River faster than seven inches per hour. Upper Skagit Summers have lost riverine side channels due to the loss of floods that can create new side channels. All other stocks are affected as fry when they migrate and rear in the Skagit mainstem.

Geomorphology and Landforms; Land Use and Cover: The total area of large river floodplain in the Skagit Basin is approximately 14,293 hectares. 31 percent of the total floodplain area is either isolated or shadowed from natural riverine processes. Historic wetland area of the non-tidal delta was approximately 5,733 hectares and has been reduced to 67 hectares. Historic lower floodplain forest area was 12,297 hectares and has been reduced to 314 hectares. The historic habitat area of the Skagit delta that is exposed to tidal and river hydrology was 11,483 and has been reduced to 3,118 hectares. The historic habitat area of pocket estuaries was 340.7 hectares and has been reduced to 47.5 hectares. Reach 7 through 11 contain 6,451 hectares of floodplain with 37 percent isolated or impaired from roads, hydromodification, or other floodplain structures. The mainstem channel length is 68.7 km in this reach and the off-channel habitat length is 118.5 km. The average floodplain width in this reach is 1,173 meters, but the effective width is only 739 meters due to floodplain impairment. Figure 10.5 contains spatial information covering floodplain connectivity and habitat for Reaches 7 through 11. Reaches US of R7 from R7 to Diobsud Creek has 2,473 hectares of floodplain with 48 percent isolated or impaired from roads, hydromodifications, or other floodplain structures. The mainstem channel length is 30.9 km and the off-channel habitat length is 43.8 km. The average floodplain width in this range is 877 meters, but the effective width is only 453 due to floodplain impairment. Figure 10.6 contains spatial information covering floodplain connectivity and habitat for the range US of R7 from R7 to Diobsud Creek. Range US of R7 from Diobsud Creek to Newhalem has 405 hectares of floodplain with 28 percent isolated for impaired from roads, hydromodifications, or other floodplain structures. The mainstem channel length is 16.3 km and the off-channel habitat length is 10.6 km. The average floodplain width in this range is 266 meters and the effective width is 192 meters due to floodplain impairment. Figure 10.7 contains spatial information covering floodplain connectivity and habitat for the range US of R7 from Diobsud Creek to Newhalem. This report contains these same statistics for the following rivers; Cascade River (Marble Creek to Kindy Creek), Sauk River (mouth to Suiattle River), Sauk River (Suiattle River to Whitechuck River), Sauk River (Whitechuck River to the Forks), and the Suiattle River (mouth to Milk Creek).

Figure 9.1 contains spatial data that indicates whether sediment supply call is functioning or impaired for each watershed. Table 9.1 contains a list of unpaved roads that are likely to be improved through the RMAP provision of the Forest and Fish agreement. Figure 9.2 contains spatial data that indicates the predicted sediment supply call for each watershed after RMAP.

Table 10.1 contains a summary of large river floodplain and habitat conditions for Skagit River Basin. Table 10.2 contains a summary of edge habitat conditions and hydromodifications for each rearing range. Table 10.3 identifies priority river reaches identified in floodplain habitat. Figure 10.2 contains spatial data that displays the historic extent of forested floodplain, palustrine wetland, and mainstem and floodplain channels compared to 1991.

Beamer et al. (2005) (Unique Identifier: 305)

Reference	Beamer, E., B. Hayman, and S. Hinton. 2005. Appendix B: linking watershed conditions to egg-to-fry survival of Skagit Chinook salmon in Skagit Chinook recovery plan. Report prepared by Skagit River System Cooperative and Washington Department Fish and Wildlife.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Geomorphology and Landforms:*** change, slope, floodplain, substrate and sediment, sediment transport and supply, large wood, climate change, scour. ***Water Quality and Productivity:*** dissolved oxygen. ***Modeling Tools:*** habitat, juvenile production. ***Land Use and Cover:*** land cover, roads. ***Fish and Habitats:*** Habitat: instream flow, freshwater, status and trends, restoration, climate change, capacity; Fish: survival, abundance, distribution; Monitoring: habitat, abundance. ***Hydroelectric Operations:*** flow regulation, flood control.									
Species and Life Stages	***Chinook:*** spawning, incubation, emergence, outmigration.									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Hydroelectric Operations	***Fish and Habitats:*** Habitat: instream flow.									

Summary: This report describes the basis for watershed restoration actions presented in the Skagit Chinook Recovery Plan that improve egg to fry survival for Chinook Salmon. This report contains the methods used to calculate the estimated change in egg to migrant fry survival before and after watershed restoration. There was a strong negative relationship between peak flows and Chinook Salmon egg to migrant fry survival. The movement of streambed material during peak flows can affect the egg to migrant fry survival by increasing fine sediment deposition and infiltration around and into the egg pocket. This reduces water movement around and through the egg pocket and lowers dissolved oxygen, and fine sediment deposition can also prevent fry emergence. Peak flows may also reduce habitat availability for age-0 Chinook. The authors recommend that actions should not seek to eliminate flood events but should evaluate the sediment or floodplain processes and find where an impairment causes a stream channel to become destabilized and contribute to sediment supply. This report also summarizes the effects of watershed landscape processes on spawning habitat capacity, egg incubation success, and fry emergence success including the status of peak flow and sediment supply and the effect of sediment supply on scour. The authors estimate productivity of Skagit Chinook Salmon under current (2005) watershed conditions through a migrant fry per spawner measurement. The authors propose that regulatory actions already in place and restorations of forest road systems will lead to restored sediment supply a hydrology functions in the Skagit River Basin. The authors predict that the actions listed in the Skagit Chinook Recovery Plan for egg to fry survival can change all impaired watersheds to functioning levels, but that egg to fry survival could become lower in the future if watershed conditions stay the same, due to climate change. Therefore, restoration of impaired watersheds is a high priority for the Skagit Chinook Recovery Plan.

Information Relevant to Skagit River Relicensing: This report provides relevant information on egg to fry survival across the entire Skagit River watershed, the factors that affect survival and limit productivity in the watershed, and actions to address these limiting factors. It focuses heavily on the effects of sediment supply and hydrologic changes on Chinook Salmon survival. The authors also provide several models to predict Chinook smolt/spawner ratios. Quantitative data as well as information related to topics of interest are described in more detail below.

Geomorphology and Landforms: Data to identify the flood history for unregulated mountain sub-basins in the Skagit watershed is very limited. Figure 7 displays the status of sediment supply for watersheds and Chinook Salmon spawning ranges. Sites with higher sediment supply have depths of scour that are 15 to 20 cm greater than scour depths in sites with low sediment supply. Figure 8 displays scour depth as a function of sediment supply and streampower for several river basins including the Skagit River Basin. In the sources used by this report, there are insufficient data to estimate sediment supply for individual sites. The authors predict that, in Skagit Chinook habitats, the effects of sediment supply may be smaller in larger streams. Changes to hydrologic or sediment regimes are known to effect salmonid survival, but the relationship between these changes and salmonid populations has not been well documented.

Water Quality and Productivity: Reductions in gravel permeability reduce water movement around and through the egg pocket and lower dissolved oxygen levels which may delay embryo development, lead to early emergence, and decrease emergent fry size.

Modeling Tools: The authors provide their model for predicting migrant fry per spawner in section 5 of this report. The model describes an ever-decreasing predicted survival with increasing flood recurrence interval. The authors also provide their model to convert their survival rate to a productivity value. For brood years 1989-2002, the authors predict a rate of 341 smolts/spawner (95 percent CI: 306-376). Table 10 contains information on the contribution of Chinook spawners to migrant fry production among functioning and impaired habitats and spawning populations. The authors provide a model that was used to estimate spawner to migrant fry productivity at properly functioning conditions in section 5.2. They estimate that productivity would be 435 smolts/spawner (95 percent CI: 390-480).

Land Use and Cover: The authors used vegetation cover class to estimate the relative increase in sediment supply due to land use like timber harvest and roads and share these results in Table 3.

Fish and Habitat: Figure 2 displays how flood magnitude is related to egg to fry migrant survival. At flood levels less than a 2-year event, egg to migrant survival tends to have higher variance with overall higher survival. For events over a 2-year recurrence interval, egg to migrant fry survival decreases with less variance in the pattern. This information enables the prediction of egg to migrant fry survival for any stream and flood recurrence. Figure 4 is a spatial display of the peak flow hydrology and status within the Skagit River watershed. Hydrology is classified as low risk functioning, sensitive functioning, impaired, or likely impaired. Watersheds were determined to be impaired when the 2-year flood magnitude equals or exceeds the natural 5-year flood magnitude. Data to identify changes in peak flow are very limited and this study was only able to use six USGS gages due to a lack of gages with long periods of record. Figure 5 displays peak flows for the lower Skagit River in CFS. Before flood storage capabilities like reservoirs, floods in the lower Skagit River commonly approached or exceeded 200,000 cfs. A flood has not approached 200,000 cfs since Hydroelectric Operations and flood storage in the basin. The number of floods between the 2-year and 100-year return period has been reduced by ~50 percent since dams were built on the Skagit and Baker Rivers. In the Skagit and Stillaguamish Rivers, larger flood events supply much more sediment to stream channels than smaller flood events. Figure 11 displays the relationship between predicted Chinook egg to fry survival and stream bed scour depth and conveys that a relatively small increase in scour depth will result in a relatively large increase in egg mortality.

Figure 3 shows the spatial distribution of the spawning ranges for the six different Skagit Chinook Salmon stocks including the Lower Skagit Falls, Upper Skagit Summers, Lower Sauk Summers, Upper Sauk Springs, Upper Cascade Springs, and Suiattle Springs. Table 6 contains data from redd surveys that are categorized by habitat type in the Skagit River Basin. Table 7 provides examples of changed channel slope, channel type, and Chinook Salmon spawning potential for two alluvial fan areas in the Skagit River Basin; Illabot Creek and Big Creek. Table 8 contains information on the percentage of escapement that spawns in impaired or functioning habitat by population. This information could be used in the model provided by the authors. The authors predict that the egg to migrant fry survival rate in impaired habitat is 3.5 percent and in functioning habitat is 21.4 percent. Figure 13 displays a positive linear trend between age 0+ migrants and escapement for brood years 1989 through 2002.

Beamer et al. (2007) (Unique Identifier: 007)

Reference	Beamer, E., C. Rice, R. Henderson, K. Fresh, K., and M. Rowse. 2007. Taxonomic composition of fish assemblages, and density and size of juvenile Chinook salmon in the greater Skagit River Estuary field sampling and data summary report. Report prepared for Department of the Army Seattle District Corps of Engineers, Seattle.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, salinity. ***Fish and Habitat:*** Habitat: estuary, pocket estuary, nearshore, connectivity; Fish: abundance, distribution, growth, rearing, life history, size structure, periodicity, status and trends, hatchery; Monitoring: habitat, abundance, scale or otolith, genetics.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration, nearshore rearing and emigration. ***Coho:*** estuary rearing and emigration, nearshore rearing and emigration. ***Pink:*** estuary rearing and emigration, nearshore rearing and emigration. ***Chum:*** estuary rearing and emigration, nearshore rearing and emigration. ***Bull Trout:*** estuary rearing and emigration, nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary, Padilla Bay, Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: This report summarizes thousands of fish catch records from beach seine, fyke trap, and surface trawl sets across habitat types and season from 1996 to 2003 in the Skagit Estuary and Skagit Bay. This report provides detailed information on juvenile salmon density and fish use, influences of connectivity and spatial arrangement of habitats, size and origin, and influences of temperature and salinity among Skagit Bay, Skagit Tidal Delta, Swinomish Channel, and Padilla Bay habitats. The results of this study provide a baseline description of monthly fish assemblages and factors related to these patterns, and they suggest that the results can be used to predict responses to management actions based on changes to habitat. The authors conclude that collecting monthly fish assemblage data over a period of one year is adequate for understanding monthly fish assemblage by habitat type, but if study goals are fish population size related and not fish assemblage related, then one year of data will not be adequate to understand fish abundance and habitat type relationship.

Information Relevant to Skagit River Relicensing: This report provides relevant quantitative data on fish and habitat, and water quality and productivity metrics for the Skagit River estuary and for numerous target species and life stages. Spatially and temporally intensive sampling of Skagit Estuary, Skagit Bay, and Padilla Bay habitats provides a valuable dataset that can be used to describe periodicity, abundance, size structure, distribution, and other fish and habitat metrics as well as inform status and trends. The authors also provide in depth methods for each type of fish sampling method used in this study and monitoring program, including small beach seine, large beach seine, Puget Sound beach seine, fyke trap, and surface trawls. Much of the information and data presented in this report has been integrated into future analyses and reports as monitoring has continued in the Skagit Estuary and its nearshore habitats to evaluate restoration effectiveness through implementation of the Skagit Chinook Recovery Plan.

Fish and Habitat: Juvenile Chinook Salmon take up residence within the vegetated sections of the Skagit River Delta and often enter the blind tidal channels when flooded. The general pattern for early migrating juvenile Chinook shows them to be shoreline oriented and accumulate within pocket estuaries. Later in the year starting in June, juvenile Chinook Salmon slowly move offshore to deeper habitats. The overall seasonal pattern of juvenile Chinook abundance across habitat types found in this report are similar to previous results: a general downstream and offshore transition over time with declining densities. One exception to this can be seen in pocket estuaries where early fry migrants begin to appear in the winter. The Skagit Bay tends to have higher densities and earlier appearance of juvenile Chinook than Padilla Bay. The authors attribute the early appearance of wild fish in the Skagit Bay to the presence of the Skagit River as a source of fish. Through the juvenile hatchery Chinook origin study, the authors found that all 23 fish collected in the Skagit delta blind and distributary channels were of Skagit origin. These results suggest that juvenile hatchery Chinook Salmon from other systems are not extensively using Skagit vegetated delta habitat. There was an influx of hatchery fish from other river systems to the Skagit Bay nearshore beach habitat that peaked in July. In Padilla Bay nearshore beaches and delta flats had no fish originating from rivers south of the Skagit. The juvenile hatchery Chinook origin results are provided in Figure 44, with composition of catches from other basins including Nooksack, Samish, Snohomish, Stillaguamish, and Chilliwack basins.

Figures 45 through 52 provide information on fish assemblage composition across years. Basic fish assemblage patterns were consistent within habitats across years. The authors found that basic habitat type had the strongest relationship with assemblage compositions, but in some months like June, the inclusion of salinity made for the strongest effect. An MDS plot and ANOSIM global R statistics test are also provided for each year/habitat/salinity combination in Figure 53 and Table 33, respectively. Table 34 provides the percent contribution, based on relative abundance, of various species to taxonomic similarity for fish assemblages in four habitat types by month for the years 1996 through 2003. Fish assemblage similarity for Chinook, Chum, Coho, and Bull Trout are provided for the Skagit River Delta, Skagit Bay, Swinomish Channel, and Padilla Bay for many habitat types and salinity regimes in Tables 7 through 31. These results use a SIMPER test based on relative abundance for all months combined. Accompanying plots show temporal patterns of average fish per set among sampling areas in average fish per set by species (Figures 2 through 26). Table 6 of the report includes the percentage of individual taxa contributing to top 90 percent of taxonomic similarity by habitat type for the entire study area and for each sub-area. Figures 28 and 29 provide information that compares juvenile Chinook per hectare in Skagit Bay, Padilla Bay, and Swinomish Channel by month and Table 32 provides a summary of the relationships between Skagit Bay, Padilla Bay, and Swinomish Channel that had significant differences in densities of juvenile Chinook.

Lengths of juvenile Chinook over time and by habitat type are similar to previous results. Small sub yearlings (~45mm) begin to appear in winter and increases in mean size were not observed until April and May. Skagit and Padilla Bay show similar size structure. Overall, mean length increases with downstream, seaward transition through habitats and time. Exceptions include the abrupt increase in mean length in some estuarine habitats when yearling migrants (>100mm) show up in April or May, and in pocket estuaries that are only occupied by smaller sub yearling Chinook in February through May. Figure 30 displays fork length of juvenile Chinook by habitat type, and Figures 31 through 34 display fork length of juvenile Chinook by location, habitat type, and month. Figures 35 through 43 display the fork length of juvenile Chinook by location, month, and status (marked vs unmarked). Many of the figures are boxplots and can be used to extract information on the distribution of sizes among juvenile Chinook in Skagit Estuary and nearshore habitats.

Water Quality and Productivity: Temperature and salinity were collected at the time of each sampling event during this study, but data are not reported at that level in this report. Differences in salinity regime were empirically derived for each site using graphical analysis to bracket the 10th and 90th percentiles around the median. Salinity regimes were defined as: 0-15 ppt, 5-25 ppt, and >20ppt. The salinity result and sampling method are provided for 91 sample sites in Table 2.

Beamer et al. (2010) (Unique Identifier: 202)

Reference	Beamer, E., J. Shannahan, K. Wolf, E. Lowery, and D. Pflug. 2010. Freshwater habitat rearing preferences for stream type juvenile Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) in the Skagit River basin: phase 1 study report. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	*Type*	Study	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology:* side and off-channels, large wood, log jam, aquatic habitats and landforms. *Fish and Habitat:* Habitat: status and trends; Fish: abundance, periodicity, distribution. *Water Quality and Productivity:* temperature.									
Species and Life Stages	*Chinook:* rearing. *steelhead:* rearing. *Coho:* rearing.									
Reaches and Spatial extent	Reaches R1-R14, Finney Creek, Sauk River, other Sauk River tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: This study was conducted to better understand the decline of Chinook and steelhead salmonoid species in the Skagit River basin. The study's purpose is to identify seasonal and habitat type preferences in the Skagit River basin for these salmonoid species in order to inform restoration efforts. This study is split into two parts. Phase 1 of this study is designed to assess the feasibility of the proposed sampling design. Results from Phase 1 informs Phase 2, which will implement a larger scale effort of this assessment that aims to identify seasonal and habitat type preferences, and recommendations for Phase 2 are provided in this report. This document reports on Phase 1 of this study.

This study assembled a habitat database of the Skagit River basin in GIS. This habitat database was organized by a nested scale habitat classification scheme. These classifications began with large scale habitat definitions including "Large mainstem," "Small mainstems or tributaries," and "Floodplain channels." The smaller unit scale definitions included "Pool," "Riffle," "Bar," "Bank," and more. These delineated habitat units then had representative reaches selected based on factors of space, time of year, and habitat type. These representative reaches were then assessed in the field and pilot level fish observation data was collected. This fish data was then used to conduct a statistical power analysis to inform Phase 2 of this study. The field methods implemented in Phase 1 of this study were then refined based on experience in the field as well as the results of the power analysis conducted to inform the minimum effort required for Phase two of this study.

The results of Phase 1 of this study found detectable differences in fish assemblage abundance for all three factors that were hypothesized to determine fish assemblage abundance. These three factors are space, season, and habitat type. The power analysis conducted in Phase 1 found that in general juvenile Chinook data is the limiting factor in making a robust enough sample size to be statistically significant. Overall, a doubling or tripling of efforts conducted in Phase 1 would be sufficient to create statistically significant results in Phase 2.

Information Relevant to Skagit River Relicensing: This study provides data on the location and distribution of habitat unit types in the Skagit River during 2007, and focusses on the freshwater reaches of the lower Skagit River, the upper Skagit River, Sauk River, and a few target tributaries for the Synthesis Study. These include summaries of habitat quantities by their space and habitat type strata that include small mainstem and tributary channel lengths, large mainstem perimeter/edge length and area, and floodplain (secondary channel) channel areas. These habitat unit types follow a nested scale habitat definition scheme that begins with channel type and fines down to individual habitat unit types. In addition to habitat unit delineations, this study also delineated locations that large log jams were interacting with the low flow channel in 2007 and they developed descriptive statistics showing the number of logs in log jams by log jam length. This data will help inform changes in habitat unit type and large wood abundance and distribution that are being reported on in the Skagit River Relicensing GE-04 Geomorphology study report. Descriptive summaries of periodicity are provided that were used to inform the sampling design, as well as spatial data on the distribution of different Chinook populations and life stages in the Skagit River watershed. Summaries of water temperatures by season and location are provided, including Finney Creek and Sauk River locations. Percent presence and average abundance estimates by season and geographic area are provided for juvenile Chinook, steelhead, and Coho during rearing stages.

Beamer et al (2015) (Unique Identifier: 008)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., A. McBride, K. Wolf, A. Hook, and W.G. Hood. 2015. Skagit monitoring pilot project: methods and results for estuarine and nearshore habitat targets identified in the 2005 Skagit Chinook Recovery Plan. Report prepared by Skagit River System Cooperative, La Conner, WA.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Draft</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: sediment transport and supply, climate change. Land Use and Cover: banks and shoreline, forestry. Fish and Habitat: <u>Habitat:</u> estuary, pocket estuary, connectivity, status and trends, limiting factors, data gaps; <u>Monitoring:</u> restoration, habitat, abundance. Modeling Tools: habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration, nearshore rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary, Skagit Bay, Padilla Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: Conclusions drawn from numerous Skagit studies demonstrate that wild Skagit Chinook salmon populations should benefit from tidal delta and pocket estuary habitat restoration and improved migration pathways within and between estuarine habitats, because the Skagit delta and pocket estuary habitats are more fragmented and sparce than historically and the current delta habitat conditions are limiting the number, size, and location of juvenile Chinook Salmon. This paper summarizes the methods and results for estuarine and nearshore habitat targets that were identified in the 2005 Skagit Chinook Recovery Plan. To monitor habitat extent and change over time, this project created GIS polygon-based indicators for natal Chinook Estuaries that represent tidal delta habitat extent, distributary and blind channel area, and tidal delta progradation rate. The report shares Skagit tidal delta fragmentation and connectivity topics, conditions, suggested measurements, and next steps that include the Skagit river tidal delta and pocket estuaries. They also report a decision matrix for determining functional habitat related to hydrologic processes in tidal deltas and pocket estuaries. Lastly, this report shares recommendations for future research and data gaps within the Skagit tidal delta.

Information Relevant to Skagit River Relicensing: This report provides relevant information for the Skagit Estuary in the form of spatial data on the extent of tidal delta habitats, connectivity, and change. In addition, the authors provide analyses and narratives that describe the linkages between resource conditions and trends with processes and factors that can be used to support the Synthesis Study. Linkages are also described in a results chain model that can be used to describe the linkages between actions, pressures, and responses in the Skagit Estuary, water quality and sediment, and nearshore habitat. They also identify many data gaps and monitoring needs that are relevant to the Synthesis Study and ongoing research in the Skagit Estuary, which include: developing spatial data for unvegetated habitats and submerged aquatic vegetation extent in the Skagit Estuary that are known to be changing but not currently captured by mapping protocols; develop spatial data for the 2015 time period (note this has already been done at the time of the Synthesis Study); map shoreline armoring, overwater structures, and marine riparian extent for all years (note this is already being done or has been completed); and map drift cell dynamics for all years. Relevant quantitative data for land use and cover, fish and habitat, and geomorphology and landforms are described below, but the report contains numerous tables and spatial data that can be extracted to support additional analyses.

Geomorphology and Landforms: The tidal delta progradation rate was calculated for the North Fork, South Fork, and Central Fir Island. The progradation rates are plotted along with Skagit Basin landslide rates, sediment delivery, and Western Washington timber harvest for 1920 to late 2000s. All three progradation rates trend negative as well as landslide rate, sediment delivery, and timber harvest (forestry). The authors report that a relative sea level rise and sediment routing within the tidal delta are responsible for the decline in the formation of tidal delta habitat, providing support for a potential linkage between these processes.

Fish and Habitat: The importance of indicators and measures of progress towards recovery goals are stressed by the authors, and they report tables that link indicators among programs including the Skagit Chinook Recovery Plan and the Puget Sound Partnership Common Indicators program. In tracking progress towards recovery, they report relative contributions of actions towards targets identified in the Skagit Chinook Recovery Plan as 61 percent from habitat protection, 6 percent from upper watershed process restoration, 7 percent from freshwater rearing and restoration, 23 percent from estuary restoration, and 3 percent from local nearshore restoration. In addition, they provide monitoring data from multiple sites to address the need to define and clarify indicators and targets that are based on "functional" conditions, including hydrological muting and comparisons to reference or desired conditions (e.g., allometry), and they present a decision matrix for classification of functional condition (see Tables 4.1-4.2). A chapter describing indicators in more detail is also provided, but the chapter is noted as not being complete. However, information is provided describing how habitat status and trends indicators are summarized, and recommendations for additional development or monitoring and data gaps.

Maps of tidal delta habitat extents by types are provided for 2004, and habitat extent by estuarine wetland zones and habitat type by hectares and habitat were classified into system types, subtypes, shoreline types, and habitat types and summarized in tabular form. The Skagit River tidal delta had 3,384.65 hectares of habitat exposed to tidal and riverine hydrologic processes in 2004, which is primarily controlled by the presence and distribution of levees and dike infrastructure in the Skagit Estuary. In 2004, the Skagit tidal delta had 109.14 hectares of blind channel and 859.11 hectares of distributary channel.

A GIS point layer was developed that represents all outlet mouth locations of blind tidal channel networks within the Skagit river tidal delta and pocket estuaries. Landscape connectivity was calculated for all 643 GIS points. For Skagit tidal delta blind channels, average landscape connectivity is 0.02752. The landscape connectivity has been calculated for several sub-sections of the tidal delta as well and further delineation could take place if the original GIS data was obtained. Additional connectivity values are as follows: Central Fir Island (0.02119), North Fork Delta (0.03941), South Fork Delta (0.02945), Stanwood-Camano (0.01314), Swinomish Channel/ S. Padilla Bay (0.00953), Skagit bay Pocket Estuaries (0.01419). These landscape connectivity metrics have been demonstrated to be correlated with fish densities and can be used to evaluate restoration responses and habitat status and trends, as well as support restoration planning. A table describing current habitat fragmentation and connectivity issues, desired recovery conditions, historical conditions, suggested measures of progress, and next steps are provided to support future monitoring and restoration needs in the Skagit Estuary.

The authors report that they found 24 pocket estuaries accessible to juvenile salmon in the Whidbey Basin in 2005 and have classified them into system types, subtypes, shoreline types, and habitat types, seen in Table 3.3, and summarized habitat area by type in Table 3.4. They report that 14 of the 24 pocket estuaries have documented juvenile salmon presence results that can be found in other referenced papers that are listed in Table 3.2 of the report. Based on their mapping, they report "*total pocket estuary habitat accessible to juvenile salmon for the Whidbey Basin in 2004-2006 was 63.30 hectares of channel and impoundment combined and a total of 238.30 hectares of habitat exposed to tidal hydrology."* Maps of pocket estuary habitat developed in this study can be used to evaluate habitat status and trends. Distances between pocket estuaries and natal deltas are also described, which are used to support the hypotheses that fragmentation and distance (or connectivity) influence the accessibility or potential benefit of pocket estuaries to residual fry migrants that exceed the delta rearing capacity.

Modeling Tools: Results chain models are provided that link actions, processes, and responses for multiple factors and habitats and responses including results chain models for: (1) Skagit tidal delta restoration strategies, (2) Skagit nearshore restoration strategy, (3) habitat protection through water quality, quantity, and sediment processes, and (4) estuarine and nearshore habitat structure (see Figures 1.2-1.5).

Beamer et al. (2016) (Unique Identifier: 212)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., G. Hood, and K. Wolf. 2016. Habitat and juvenile Chinook benefit predictions of candidate restoration projects within the Skagit tidal delta. Memorandum to NOAA Restoration Center, The Nature Conservancy, and Washington Department of Fish and Wildlife.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: floodplain connectivity, side and off-channels. Modeling Tools: hydrology, juvenile production, habitat, connectivity. Land Use and Cover: banks and shoreline, floodplain. Fish and Habitat: <u>Habitat:</u> estuary, pocket estuary, connectivity, capacity, restoration; <u>Fish:</u> abundance, distribution, rearing; <u>Monitoring:</u> restoration, habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration, outmigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary (including Swinomish Channel), Padilla Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This memo describes the results of the Skagit Hydrodynamic Model project where several predictions are made for 23 candidate delta restoration projects that include potential channel habitat formed, landscape connectivity, and juvenile Chinook benefit expressed as carrying capacity (for a subset of the projects, 18/23). Midpoint juvenile Chinook Salmon carrying capacity estimates for individual projects, if constructed, ranged from a low of 3,000 (South Fork Setback) to a high of 275,000 (Avon-Swinomish Bypass) fish per year. The authors used several variations of an allometric regression model to predict outcomes in restoration marshes. Offsite impacts were estimated using hydrodynamic modeling results. The authors used landscape connectivity to help predict juvenile Chinook benefits and interpret juvenile Chinook monitoring results, and most of the report focuses on predicted channel areas and how that could impact juvenile Chinook carrying capacities for potential projects.

Information Relevant to Skagit River Relicensing: This report provides a lot of measured and modeled quantitative data that could be relevant to the Synthesis Study. This report describes modeling tools that can be used to predict outcomes of restoration projects based on allometric relationships, which could also be used to evaluate expected conditions in current tidal marsh extent. In addition, tools for estimating carrying capacity for projects based on channel areas and landscape connectivity are described with predicted carrying capacity estimates provided for many of the candidate restoration sites considered in this analysis. The analyses and data are focused on juvenile Chinook Salmon during estuary rearing and emigration life stages and includes information on a number of potential restoration sites within the Skagit River delta. In addition, annual juvenile Chinook outmigrant abundance estimates are summarized in the report.

<u>Fish and Habitat</u>: The authors provide an appendix that contains Chinook Juvenile abundance data for each site at a range of years that could be extracted for the Synthesis Study, which includes annual fish densities at a site (fish/yr/ha), annual Skagit River outmigrant size (~2002-2015), annual landscape connectivity scores, and whether outmigration levels are above or below estimate carrying capacity for the Skagit tidal delta. The carrying capacity used was based on a regression analysis of outmigration data by fry and parr life history types through 2015 that suggests tidal delta rearing carrying capacity is achieved at an outmigration of 3.9 million Chinook fry. The

authors include maps of potential projects areas and report having created a 2013 fish migration pathway GIS layer used to derive landscape connectivity scores for project sites. They also report that a GIS layer was created that contains logical fish access points based on historic channels.

For each monitoring site and year combination, they calculated the season-long density of juvenile Chinook Salmon and density was divided by an average residence time of 35 days for individual juvenile Chinook Salmon rearing in Skagit River tidal delta habitat. Juvenile Chinook Salmon carrying capacity predictions were standardized by predicting carrying capacity for a one-hectare area to directly compare to the fish monitoring results. The restoration predictions and associated Chinook carrying capacities are summarized in tables with estimates of accessible habitat area.

Modeling Tools: Allometric models to predict channel surface area, channel outlet count, and channel length based on marsh area, mean tide range, channel surface areas, channel outlet counts, and channel lengths are described that can be used to predict outcomes of potential restoration projects. The multiple regression equations are reported as follows:

- Total channel surface area: R2 = 0.85; p << 0.0001; logAC = 1.412logAM + 0.67T -4.288
- Total channel outlet count: R2 = 0.67; p << 0.0001; logOC = 0.602logAM + 0.391T -1.000
- Total channel length: R2 = 0.87; p << 0.0001; logLC = 1.176logAM + 0.584T 0.093

where AM = marsh area; T = mean tide range; AC = channel surface area; OC = channel outlet count; and LC = channel length.

Methodologies for estimating carrying capacities for restoration sites are provided with summary tables of estimated carrying capacity (average, low, and high estimates) and predicted channel areas for each site. The modeling results suggests that their carrying capacity model over-estimates carrying capacity for sites with landscape connectivity higher than 0.0881 and lower than 0.0234.

Beamer et al. (2017) (Unique Identifier: 010)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., R. Henderson, C. Ruff, and K. Wolf. 2017. Juvenile Chinook salmon utilization of habitat associated with the Fisher Slough Restoration Project, 2009 - 2015. Report prepared for The Nature Conservancy, Mount Vernon, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: estuarine habitats and landforms. Water Quality and Productivity: temperature, dissolved oxygen. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat:</u> barriers, estuary, connectivity, status and trends, restoration; <u>Fish:</u> abundance, rearing, periodicity, movement, size structure, life history; <u>Monitoring:</u> restoration, habitat, abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration, outmigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report focuses on the Fisher Slough restoration project located in the South Fork Skagit River tidal delta near the town of Conway. Restoration at Fisher Slough included improved fish passage in 2009 with installation of a new floodgate, and a dike setback in 2011 to increase carrying capacity and provide floodwater storage. This report addresses restoration effectiveness questions including: whether tidal habitat increased following the dike setback; if restoration influenced water temperature and dissolved oxygen; if juvenile Chinook Salmon presence was influenced by water temperature, dissolved oxygen, depth, and velocity; and if the dike setback and floodgate operation influence juvenile Chinook Salmon abundance, density, and size? Floodgates at Fisher Slough are managed for flood and irrigation control and fish use with three operational periods; Fall/Winter Flood Control Period (October 1 – February 28/29), Spring Juvenile Chinook Migration Period (March 1 – May 31), and Summer Irrigation Period (June 1 – September 30). In this report, monitoring results from 2009-2013 and 2015 are presented. Relationships between juvenile Chinook abundance and the effect of the dike setback, floodgate operation, and the abundance of Chinook fry migrants are explored using generalized additive models. The combination of dike setback and current floodgate operation led to an increase in the smolt carrying capacity of Fisher Slough by 21,823 estuary rearing Chinook Salmon smolts per year, which represented an order of magnitude increase (10x) in habitat use by juvenile Chinook Salmon to the 55.7 acres of tidal wetland habitat. Juvenile Chinook abundance in Fisher Slough upstream of the floodgate increased significantly in years 2012-2013 following the dike setback relative to years 2009-2011 prior to the dike setback, and they conclude that floodgate operation and dike setback actions are important factors resulting in the increased habitat use observed at Fisher Slough.

Information Relevant to Skagit River Relicensing: This report focuses on monitoring data from 2009-2013 and 2015 to describe differences in environmental variables before and after restoration efforts, and provides quantitative data that are potentially relevant to the Synthesis Study. Floodgate replacement or enhancement projects along with dike setbacks or removal are common restoration strategies for estuary habitats, and the results of monitoring studies like this report provides provide potentially useful information on the potential impacts of restoration with respect to juvenile Chinook Salmon habitat use, capacity, or productivity. Quantitative data describing fish and habitat as well as water quality and productivity are provided in figures and tables, as well as the results of analyses designed to evaluate responses to restoration (dike setback and floodgate replacement) and potential linkages between fish habitat use and restoration. Potentially relevant quantitative data and results are generally described below, but more detailed data could be extracted from the report if needed. Spatial data for restoration design and digital elevation models are shown that could also be used to evaluate changes over time at the site. In addition, earlier reports focused on previous monitoring years are also available with additional information on this restoration project and restoration effectiveness monitoring activities and results.

Fish and Habitat: Sampling was conducted once per month in February and twice per month starting in March and through the summer (2009-2013, and 2015). Juvenile Chinook abundance in Fisher Slough upstream of the floodgate increased significantly in years 2012-2013 following the dike setback relative to years 2009-2011 prior to the dike setback. Prior to dike setback, abundance estimates at Fisher Slough were not consistent with what would be expected at the site based on monitoring data in the Skagit Estuary, but abundance was consistent with other sites after completion of the setback. Juvenile Chinook abundance in Fisher Slough above the floodgate for pre-dike setback was 630 fish compared to 6,592 fish for years post-dike setback. Mean fork length of juvenile Chinook rearing in Fisher Slough was significantly higher following the dike setback (a 5.2 mm increase based on least squares means of pre- versus post-dike setback). Mean fork length was also significantly higher in April, May, and June. Wild juvenile Chinook population size upstream of the floodgate was estimated at 8,236 in 2009, 37,999 in 2012, 48,166 in 2013, and 6,813 in 2015. Wild juvenile Chinook carrying capacity upstream of the floodgate was estimated at between 27,459 and 16,950 in 2009, and between 38,773 and 23,935 in 2012, 2013, and 2015. Average Chinook residence time in delta habitats was reported as 35-days based on previous studies, and this was used to support estimates of the abundance of juvenile Chinook that used Fisher Slough habitats from monitoring data. Overall, juvenile Chinook Salmon presence upstream of the Fisher Slough floodgate was not influenced by variability in water depth, velocity, DO, or temperature for the years 2009 – 2013, but the addition of data from 2015 reveal that differences in both water temperature and DO upstream of the floodgate did influence juvenile Chinook presence/absence patterns.

Annual estimates of total wild subyearling Chinook Salmon outmigration production for the Skagit River are reported, ranging from 1.13 to 5.64 million fish over the six-year monitoring period at Fisher Slough (2009-2013, 2015). The fry migrant component of these outmigrant years ranged from 50 percent to 90 percent of the total subyearling outmigration population, with a low of 0.80 million and a high of 4.60 million fry migrants. Depending on the year, landscape connectivity explains 36 percent to 74 percent of the variation in seasonal juvenile Chinook Salmon density at Skagit River delta long-term monitoring sites.

The authors indicate water velocities were monitored to support evaluation of passage at the floodgate and habitat use. They report 0.89 ft/sec as the critical fatigue swimming speed for small Chinook fry, and 1.1 ft/sec is a recommended maximum water velocity for structures like floodgates to enable salmon fry less than 60 mm in fork length to migrate upstream. These thresholds were considered to evaluate measured velocities, but the authors found in previous analyses that passage opportunity was best explained by the duration that floodgates were open during tidal cycles and dropped water velocity metrics from the analyses.

<u>Water Quality and Productivity</u>: Seven environmental variables were collected at each site on each sampling date or with continuous water sensors that include water temperature, salinity, dissolved oxygen, water velocity, vegetation, substrate, and the depth of the water sampled. Salinity, vegetation, and substrate are not included in the analysis of Chinook presence because they did not vary enough to influence juvenile Chinook Salmon within Fisher Slough. Detailed results and quantitative data are presented for temperature and dissolved oxygen with temporal patterns, restoration influences, flood gate influences, and recommendations discussed.

Maximum daily temperature upstream of the Fisher Slough floodgate in 2015 was 2.5 to 5.9 °C warmer than every other year, and maximum daily temperatures upstream of the Fisher Slough floodgate are reported in boxplots for each year and each month within years. River water tends to be colder than tributary water and the period when water temperatures are high coincide with the period when tributary inflow is the lowest. This suggests that Skagit River water has a stronger influence on water temperature than tributary inflow during these high temperature months. Changes in temperature patterns at the Fisher Slough site were linked to the dike setback, with new sources of warm water from blind channels that are shallow and unshaded. However, the setback also increased the volume of tidal water exchange that increased cooling effects linked to the dike setback. The authors suggest leaving floodgate doors open during times when water temperatures can approach the lethal limit for juvenile Chinook Salmon and when juvenile Chinook Salmon are still present. They also recommend floodgates only be closed after times when water temperature has peaked, when flows are still low, and when juvenile Chinook Salmon are not present, so most likely in September of each year. Chinook presence/absence was not explained by difference in water temperature prior to 2015, but it was in 2015. Overall, juvenile Chinook were present in water that was 4.8°C cooler in 2015. In 2015 there was a difference of 4.8°C between no Chinook presence and confirmed Chinook presence. Modeled threshold water temperatures for presence/absence of Chinook could be pulled from Figure 5.1, but to acquire accurate temperatures, data may need to be requested from the author.

Generally, dissolved oxygen levels at Fisher Slough are higher in the spring and decrease during the summer and early fall. DO was not strongly correlated to tributary flow, but models including tributary flow and Skagit River flow metrics were better at explaining DO in Fisher Slough, and they found that higher tributary flow generally resulted in lower DO in Fisher Slough. Longer times of floodgate opening equates to higher DO in Fisher Slough in late spring and summer. The minimum daily DO upstream of the Fisher Slough floodgate in 2015 was 1.3 mg/L lower than in 2012 but not different than DO concentrations observed in 2013. Minimum daily DO are reported in boxplots by year and among months. They found that the dike setback resulted in no affect changes in average DO concentrations, but minimum DO concentrations were reduced after the dike setback. The processes driving changes in temperature after the dike setback are linked to the changes in DO. Chinook presence/absence was not explained by differences in DO prior to 2015, but it was in 2015. In 2015 there was a difference of 1.6 mg/L DO between no Chinook presence and confirmed Chinook presence. Overall, juvenile Chinook were present in water with DO 1.65 mg/L higher in 2015. Modeled threshold DO for presence/absence of Chinook could be pulled from Figure 5.2, but to acquire accurate measurements, data may need to be requested from the author.

Beamer et al. (2019) (Unique Identifier: 013)

Reference	Beamer E., C. Greene, and M. LeMoine. 2019. Skagit River Estuary Intensively Monitored Watershed annual report for 2019. Report prepared for the Washington State Salmon Recovery Funding Board Monitoring Panel, Olympia.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and habitat:*** Habitat: estuary, nearshore, connectivity, capacity, restoration, limiting factors; Fish: abundance, rearing, periodicity, growth, size structure, density dependence, life history, data gaps; Monitoring: restoration, abundance.									
Species and Life Stages	***Chinook:*** rearing, estuary rearing and emigration, nearshore rearing and emigration. ***Chum***: migration, spawning, estuary rearing and emigration.									
Reaches and Spatial extent	Skagit Watershed with an emphasis on the Skagit Estuary and Swinomish Channel; Other upper Skagit River tribs (Cascade River), Sauk River and Other Sauk River tribs (Suiattle River).									
Linkages to Hydroelectric Operations	NA									

Summary: This is an annual report for the Skagit River Estuary Intensively Monitored Watershed (IMW) that is designed to monitor responses to restoration related to implementation of the Skagit Chinook Recovery Plan. The Skagit Chinook Recovery Plan goal for estuary habitat restoration is to address limiting factors for estuary rearing habitat to increase connectivity of estuary habitats and increase juvenile Chinook Salmon carrying capacity by 60 percent, from 2.25 to 3.6 million smolts. Skagit River Estuary IMW monitoring began in 1994 and restoration treatments began in 2001, and the IMW seeks to answer two general questions: (1) do Chinook Salmon exhibit limitations during estuarine life stages related to capacity and connectivity, and (2) has estuary restoration resulted in population or system scale responses? These questions are addressed in this report based on IMW monitoring data using BACI (Before-After-Control-Impact) and BA (Before-After) analyses. Opportunistic effectiveness monitoring results are also presented to evaluate whether restoration projects increase utilization of estuary habitats. The authors also leverage IMW monitoring data to evaluate the causes of Skagit Chum Salmon declines and produced the first multi-stage model for natural origin Chum in the Puget Sound region. They found that Skagit River Chum Salmon population trends are driven by marine survival rather than freshwater productivity, although they indicate that parsing estuary and marine survival is difficult with the available monitoring data and they identify this as an area of potential future study. In addition to summarizing the results of monitoring thus far, the authors make recommendations for future directions for the IMW project including continued implementation of the study design that includes:

1. *"Annual monitoring at local scale (restoration project) and population scale (Skagit estuary) of juvenile fish, including metrics for abundance, timing, and body size. Fish monitoring should include specifically designed elements for sub-system level treatment effects*."
2. "*Update estuary habitat conditions and connectivity as necessary. Restoration is ongoing in the Skagit estuary. Changes to habitat conditions should be measured post restoration projects. Natural changes to the estuary should be updated approximately every five years*."

Information Relevant to Skagit River Relicensing: This report provides relevant information from an ongoing intensive monitoring program focused on the Skagit River estuary and nearshore habitats including responses to restoration projects, but most of the report is formatted based on project reporting requirements or responses to monitoring program questions. The ongoing monitoring is focused primarily on juvenile Chinook, but this report includes some preliminary findings for evaluating the potential causes of declining Chum Salmon abundances. The results of this preliminary Chum study were presented to City Light and will be available in a future report (Ruff et al. in prep), but they indicate additional research is needed to parse out the effects of estuary conditions on marine survival (which they identify as being more related to declining population trends rather than freshwater conditions).

Chinook Salmon responses have tracked the findings of a previous annual report (2016) and are only described in general in this report. In general, they found that all monitored projects in all years after restoration had juvenile Chinook Salmon present. However, restoration sites with muted hydrology or limited connectivity performed poorer than projects that restored connectivity to a greater extent. The BACI analyses revealed that juvenile Chinook densities have decreased with increasing restoration as a result of increased habitat opportunities, and the length of residence in the estuary has increased with increasing restoration. Some support was also found for reduced frequency of fry migrants in marine habitats and increased smolt to adult return rate (SAR) with increasing restoration. Collectively, these findings support the hypotheses and questions addressed by the Skagit River IMW and Skagit River Chinook Recovery Plan that estuary restoration can address limiting factors and increase habitat capacity and productivity to support salmon recovery. Links to previous reports are provided, but this annual report summarizes the findings of previous year's reports. They also mention a future report that has since been published that evaluated density dependent patterns in more detail and included data from multiple systems (see Greene et al. 2021, ID056). In addition, proposed schedules for testable hypotheses for restoration responses are provided for major geographical areas within the Skagit River delta (Table 3).

<u>Fish and Habitat:</u> Abundance and periodicity patterns are described from multiple monitoring methods including outmigrant trapping, fyke trapping, beach seining, and nearshore surface trawling. The results of the 2019 monitoring year are primarily described, but plots showing previous year's results are provided that could be used to extract time series data. Outmigrant trapping on the mainstem of the Skagit (1 site; daily in Feb-Jul): Juvenile Chinook Salmon outmigration estimates in the Skagit estimate the natural origin subyearling Chinook Salmon population size of 1,801,632 fish (CV = 13.88 percent). The life history type fractions of the subyearling outmigration were 72.4 percent fry and 27 percent parr. The total subyearling Chinook Salmon outmigration in 2019 was approximately 1.65 million fewer fish than the overall average outmigration of 3,455,290 fish for the 26-year period of record. Fyke trapping in the tidal delta and Swinomish Channel (10 sites; biweekly in Feb-July, monthly in Aug): In April they estimate over 8,000 juvenile Chinook Salmon per hectare of blind tidal channel. By July, densities in tidal delta habitat were low, averaging only 193 fish per hectare. The geometric mean annual density in 2019 was 53.4 fish per hectare compared to the overall average of 249 fish per hectare. While the 2019 density was significantly lower than the overall average, they show that it is not historically uncommon for fish densities to be as low as 50 fish per hectare. Beach seining in the Skagit Bay shore and Swinomish Channel (128 sites; biweekly in Feb-Aug, monthly in Sep-Oct): In 2019, unmarked juvenile Chinook Salmon were present in the Skagit bay nearshore habitat throughout the sampling period with a peak from May through June. Geometric mean annual density of unmarked juvenile Chinook Salmon in nearshore habitat (index sites) in 2019 was 4.1 fish per

hectare compared to the 5.5 fish per hectare overall average. The peak of juvenile Chinook Salmon in nearshore habitat was in June where densities reached past 300 fish per hectare and can be seen in Figure 3. In Figure 4, the report shares their yearly results of unmarked juvenile Chinook Salmon densities based on large net beach seine in the Skagit Bay. Kodiak/Surface trawling in the Skagit Bay neritic (60 sites; monthly in Apr-Oct): In 2019, unmarked juvenile Chinook in Skagit Bay neritic habitat displayed much higher abundance in July, and lower abundance in August. In Figure 6, the report also shares their yearly results of annual densities of unmarked juvenile Chinook Salmon in neritic waters of Skagit Bay. Abundance of Chum Salmon have declined since 2004, and they reference spawner surveys, smolt trap monitoring, and beach seine data as being used to develop multi-stage models for Chum, but these data are not presented in this report.

Overall, the Skagit River estuary is gaining more habitat than it is losing (due to natural and anthropogenic causes). Increases include some natural progradation and 653 acres of restoration projects, and restoration was identified as the primary source of changing estuary habitat extents during the monitoring period. An additional 398 acres of planned restoration projects are described in the report, with general information including summaries of available monitoring data and implementation dates (planned or actual). Monitoring data for the most recent restoration project on Fir Island Farms are also shared in this report. Prior to restoration of Fir Island Farms (Reach 13), wild juvenile Chinook abundance for inside habitat of Fir Island Farms was estimated at 118 in 2015 and 566 in 2016. Following restoration, wild juvenile Chinook abundance was estimated at 50,522 in 2017 and 11,124 in 2018.

Beamer et al. (2020) (Unique Identifier: 214)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, C. M. Greiner, J. S. Barber, C. P. Ruff, and K. Wolf. 2020. Climate vulnerability assessment for habitat and associated fisheries in the inland waters of northern Washington State. Report prepared for Skagit River System, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Modeling Tools: climate change, habitat. Land Use and Cover: banks and shoreline, pocket estuary, climate change. Fish and Habitat: <u>Habitat:</u> estuary, nearshore, pocket estuary, climate change; <u>Fish:</u> life history, size structure, periodicity, rearing, growth, predation, climate change. Water Quality and Productivity: temperature, salinity, climate change.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: spawning, outmigration, estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary, Skagit Bay, and Padilla Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: Human land use and climate change is thought to influence the suitability of marine habitats of fish and shellfish. The authors developed a qualitative tool for assessing habitat risk to wave energy and sea level rise for the inland waters of northern Washington, including Whidbey Basin, Admiralty Inlet, Bellingham Bay, Samish Bay, and portions of the Strait of Juan de Fuca, Strait of Georgia, and San Juan Islands. They also created predictive models for sea surface temperature using landscape features and observations. The authors compared their model predictions of sea surface temperature (SST) with literature-based estimates of thermal tolerance for juvenile Chinook Salmon. They then assessed how habitat availability for Chinook Salmon may change under future climate change by applying a 2.2°C increase in SST across the study area. They also found that large river estuaries (Skagit estuary) and human-modified shore types were projected to be the least resilient to wave energy and sea level rise while barrier beaches, sediment source beaches, and rocky beaches were projected to the be the most resilient. The authors hope that this model can be used to inform prioritization of habitat protection measures while considering future climate change predictions.

Information Relevant to Skagit River Relicensing: This report provides potentially relevant quantitative data and modeling tools that could be used to inform the development of conceptual life history models and factors affecting life stage transitions and resource conditions in the Study Area for the Synthesis Study. This study and the modeling tools include the Skagit River estuary as well as nearshore habitats in Skagit Bay and Padilla Bay, as well as adjacent systems and nearshore habitats in the Whidbey Basin. Spatial data were produced that could be used to summarize inputs and outputs by shore types or other spatial units, but results are mostly summarized at their study area scale. The proximity of a site to large rivers influences mean salinity for all shore types and the presence of direct freshwater inputs to pocket estuaries results in significantly reduced salinity. The authors would like to describe predicators for various salinity metrics beyond using mean or maximum salinity vales. This could be used to address broader questions that may link climate change predictions to changes in nearshore salinity that would be biologically relevant to fish species.

<u>Fish and Habitat:</u> Based on known thresholds for juvenile Chinook Salmon growth, current condition in most nearshore habitats within the study area provide optimal growth conditions especially pocket estuary and rocky beach shore types located farther from rivers. By July and August, SSTs within all the river and pocket estuarine habitats exceed those that would be considered metabolically favorable for juvenile Chinook Salmon, potentially explaining why juvenile Chinook leave estuaries for more marine waters at this time of year. Under a climate change scenario, where SSTs increase by 2.2°C, the authors predict a reduction in the average percent of optimal Chinook habitat across shore types from 16.5 percent to 0.3 percent. This could potentially cause a premature move to more favorable temperatures in nearshore habitats at the expense of increased predation risk.

Periodicity and size structure are described for juvenile Chinook life stages (Table 2) with fry (<60 mm) being distributed in the tidal delta and blind channel habitats of large river and pocket estuaries from February to August. Fry use shallow intertidal reaches in large river and pocket estuaries from February to July. Chinook Salmon parr (60-150 mm) use intertidal/ subtidal reaches in all shore types from February to August, intertidal/subtidal reaches in pocket beaches from April to August, and surface waters in neritic zones from June to November. Under current July/August SST conditions, all large river and pocket estuarine habitat (Skagit estuary) temperatures exceeded those that would be metabolically favorable for juvenile Chinook Salmon. These results suggest that growth opportunity for juvenile Chinook Salmon is dependent on an individual's ability to time their rearing and migration behavior such that they utilize each habitat type when temperature and food availability are optimal. Chinook Salmon appear to be adapted to transition from large river estuaries to nearshore habitats as temperatures begin to exceed optimal metabolic thresholds. Monthly plots of mean densities (with Standard Error) for marked and unmarked juvenile Chinook by habitat type from Beamer et al. (2005, ID005) are provided to show this pattern. Specifically, in the Skagit River estuary, Chinook fry reach peak densities between March and May, after which they move to the nearshore marine habitats of Skagit Bay where temperatures are more favorable for growth (Beamer et al. 2005).

Under the climate change scenario July/August SST conditions, only a small percentage of rocky beach shore types remain optimal for Chinook Salmon growth. In general, the nearshore habitats most conducive to Chinook growth under the climate change scenario are pocket and rocky beach shore types along with some sediment source beaches or barrier beaches. Skagit Chinook Salmon spawn timing has shifted later as water temperature during spawning has increased (Austin et al. in review). The shift appears to be an adaptive response at the population level that maintains fry emergence timing from shifting to earlier in the year when freshwater and estuarine fry rearing conditions would be less favorable.

<u>Water Quality and Productivity, Land Use and Cover, and Modeling Tools:</u> Optimal thermal conditions are described for Chinook fry and parr life stages (Table 10) as optimal surface temperatures (11-14°C), less than optimal surface temperatures (14.1-16°C), stressful surface temperatures (16.1-20°C), and negative growth surface temperatures (≥20.1°C). There are no data showing the salinity threshold of Chinook Salmon fry, but Chinook Salmon parr have a salinity threshold of greater than 15 PSU and less than 27 PSU. Maps of predicted current and climate change SST temperatures are provided that could be used to extract quantitative data for nearshore habitats in the Study Area for the Synthesis Study. The predicted mean sea surface temperature (SST) under existing conditions for the Skagit estuary was between 16.1 and 17°C in July/August, Skagit Bay was between 13.1 and 16.0°C with the north end being the coldest, and Padilla Bay

ranged between 13.1 and 18.0°C with most of the bay being between 14.1 to 15.0°C. Predicted mean sea surface temperatures under a future climate change scenario (2.2°C rise in sea surface temperature) for the Skagit estuary are between 18.1 and 19°C in July/August, Skagit Bay was between 15.1 and 19.0°C with the coldest temperatures in the north end, and Padilla Bay was between 16.1 and 20°C with most of the bay being between 18.1 and 19°C.

Maps showing spatial data for the shoreline showing rating scores and results from the model that could be extracted, including nearshore habitats within the Study Area for the Synthesis Study. In general, wave and sea level rise resilience scores are displayed as not very resilient in the Skagit estuary, Skagit Bay, and Padilla Bay. The maximum geomorphic response score predicts an extremely low resistance to erosion in the Skagit estuary, Skagit Bay, and the majority of Padilla Bay. The maximum existing human score is displayed as having a high percentage of armored shoreline on the East side of the Skagit Bay, but a low percentage of armored shoreline in the Skagit estuary. The Padilla Bay is displayed as having moderate percent of armored shoreline in most of the bay, with some high percentage of armored shoreline on the Northeast shore. The authors indicate that their shoreline model was based on a dataset from 2011 and many of the results for land use and shoreline armoring are over 20 years old, but state that new datasets will soon be available.

Beamer (2014) (Unique Identifier: 218)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. 2014. Summary of juvenile Chinook salmon life history diversity and distribution. Report prepared by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: life history, growth, density dependence, size structure, rearing; <u>Habitat</u>: capacity, pocket estuary, estuary, nearshore; <u>Monitoring</u>: abundance, genetics, scale and otoliths.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: rearing, overwintering, outmigration, estuary rearing and emigration, nearshore rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary, Skagit Bay, Skagit Watershed and Sauk River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This brief paper summarizes the results of research and long-term monitoring in the Skagit River system (Brood Years 1993 – 2008) to support the development and implementation of the Skagit Chinook Recovery Plan. They provide a description of five life history strategies, and briefly describe population dynamics that contribute to their expression and distribution of juvenile Skagit Chinook life histories and life stages in shoreline habitats of the Salish Sea. The data presented primarily focuses on the Skagit River estuary and nearshore habitats of Skagit Bay, but freshwater outmigrant production of juvenile salmon from the Skagit Watershed, including Sauk River, are presented. Since all six Skagit Chinook Salmon populations produce fry migrants and tidal delta rearing migrants, juvenile life history expression of Skagit Chinook Salmon is likely caused by phenotypic pressures such as habitat opportunity, environmental disturbances and density dependence instead of any kind of genetic based reason. Skagit origin Chinook Salmon were the most common Chinook Salmon in shoreline habitat of the Whidbey Basin. Skagit origin Chinook were approximately 80 percent of the juvenile Chinook Salmon in pocket estuaries and small streams associated with Skagit Bay, 60 percent in Port Susan, and 40 percent in Possession Sound.

Information Relevant to Skagit River Relicensing: This brief report provides descriptions of life history diversity, factors controlling expression of life histories, as well as important descriptive information on periodicity, size structure, relative abundance, growth, and habitat capacities. Data presented are primarily for the Skagit River estuary and Skagit Bay, but information on freshwater production of juvenile Chinook and relative contributions among Skagit Watershed basins and populations, including the Sauk River, are presented. This information and data can support the development of conceptual life history models as well as understanding factors affecting resource conditions in the Study Area for the Synthesis Study. Potentially useful information and quantitative data are described in more detail below.

<u>Fish and Habitat:</u> The Skagit River produces 1-7+ million wild Chinook Salmon outmigrants each year (1993-2008 brood years). Five life history variations are described with respect to timing (periodicity), rearing, and size structure patterns. Percent composition of these life history types are shown among populations (Lower Sauk, Upper Sauk, Suiattle, Cascade River, Lower Skagit, and Upper Skagit). Expression of life history patterns are linked to density dependent processes

occurring during freshwater and estuary rearing and emigration life stages. Skagit Bay tidal delta rearing capacity is estimated at 2.25 million tidal delta rearing juvenile Chinook per year. Fry emigrating to estuary habitats in excess of this rearing capacity respond by moving downstream to Skagit Bay and bypass rearing in the delta. Parr migrant abundance has averaged approximately 1.2 million per year and is related to density dependent process in freshwater habitats. Yearling life history abundance has ranged from 6,000 – 97,000. The following descriptions and data for each life history type are provided:

> ***Fry migrants*** emerge from egg pockets and migrate quickly to Skagit Bay. Fry migrants make up approximately 5 percent to over 40 percent of the juvenile Chinook Salmon in Skagit Bay each year. Fry migrants appear to be using pocket estuaries and small streams as an alternative nursery habitat, much like the Skagit tidal delta is used by juvenile Chinook Salmon, and these are described as a sub life history of the fry migrant strategy. (Enter Skagit Bay in February and March. Average fork length of 39mm, range of 30-46 mm).
>
> ***Tidal Delta Rearing Migrants*** emerge as fry from egg pockets and migrate downstream at the same time as fry migrants, but instead of entering Skagit Bay, they reside in tidal delta habitat for weeks to months. Enter Skagit Bay in May and June with an average fork length of 74mm (49-126 mm), and average rearing duration in tidal delta was 34.2 days.
>
> ***Parr migrants*** emerge as fry from egg pockets and rear for several months in freshwater and reach a size like the tidal delta rearing group. Parr migrants do not reside in tidal delta habitats but may rear in off channel habitats of floodplains. Parr migrants make up about 15 percent to over 60 percent of the sub yearling outmigration each year. Enter Skagit Bay in May and June with an average fork length of 75mm (57-92 mm).
>
> ***Yearlings*** emerge from egg pockets and rear in freshwater for a period over one year. Yearlings do not reside in tidal delta habitats. Yearling abundance has ranged from 6,000 to 97,000. Enter Skagit Bay in March, April, and May with an average fork length of 120mm (92-154 mm).

Percent of catch by habitat type (Skagit tidal delta, pocket estuary, and small stream) are provided by month. Use of pocket estuaries and non-natal streams of Whidbey Basin occurs from January to May, and these habitats appear to be used primarily by fry migrants as alternative nursery habitat. Box plots of growth rate for juvenile Chinook Salmon are provided in pocket estuary, small stream, tidal delta estuarine emergent marsh (EEM), tidal delta forested riverine tidal (FRT), and tidal delta scrub shrub (SS) habitats are provided, with median, 25th – 75th percentiles, 5th – 95th percentiles, and outliers (see Figure 3). Median growth rates were the highest in tidal delta estuarine emergent marsh habitats compared to all other habitat types considered. Growth rate data like these can be used to inform bioenergetic models to inform salmon recovery.

Beechie et al. (1994) (Unique Identifier: 337)

Reference	Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14(4):797-811.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: capacity, status and trends, barriers; Fish: distribution, periodicity, survival. ***Land Use and Land Cover:*** land cover.									
Species and Life Stages	***Coho:*** incubation, rearing, emergence, overwintering, outmigration.									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Summary: To develop a restoration strategy for the Skagit River Basin, the authors estimated changes in smolt production of Coho Salmon since European settlement began in the Skagit River basin, based on changes in the summer and winter rearing habitats. They estimated that the Coho Salmon smolt production capacity of summer habitats have been reduced from 1.28 million smolts to 0.98 million (-24 percent) and that the winter habitats have been reduced from 1.77 million to 1.17 million smolts (-34 percent). Hydromodification, agriculture, and urbanization accounts for 73 percent of summer habitat losses and 91 percent of winter habitat losses. Blocked fish access on small tributaries accounted for 13 percent of summer habitat losses and 6 percent of winter habitat loss, whereas forestry activities were attributed with 9 percent and 3 percent of summer and winter habitat losses, respectively.

Information Relevant to Skagit River Relicensing: The study focused on the entire Skagit River watershed, including the Study Area for the Synthesis Study, and juvenile life stages of Coho Salmon. However, the data are summarized at a watershed scale and original data and spatial data would potentially need to be requested to develop summaries of quantitative data for the Study Area for the Synthesis Study. The quantitative data provided include areas and percentages by land ownership; historical and current estimates of habitat unit areas and lengths (side-channel sloughs, distributary sloughs, small tributaries, large tributaries and main stem, lakes and reservoirs, and ponds) with modifications (hydromodification, culverts, dams); estimates of changes in production among habitat unit types and seasons and modifications; as well as estimates of usable area equivalents, which is a scalar for habitat unit types that are usable to juvenile salmonids, and scalars for parr densities, survival to smolt life stage, and total potential smolt production per unit area or length by habitat unit types are provided for both summer and winter seasons (see Table 2). These data are presented at a basin scale, but many of the habitat unit types are applicable to the habitats found in the Study Area for the Synthesis Study.

Beechie et al. (2001) (Unique Identifier: 365)

<table>
<tr><td>Reference</td><td colspan="10">Beechie, T. J., B. D. Collins, and G. R. Pess. 2001. Holocene and Recent Geomorphic Processes, Land Use, and Salmonid Habitat in two North Puget Sound River Basins. Pages 37-54 in J. M. Dorava, D. R. Montgomery, B. B. Palcsak, and F. A. Fitzpatrick, editors. Geomorphic Processes and Riverine Habitat. American Geophysical Union, Washington D. C.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Book</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Links</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, history, channel migration, channel incision, slope, floodplain, substrate and sediment, side and off-channels, large wood. Fish and Habitat: <u>Habitat:</u> capacity, freshwater, beaver, data gaps; <u>Fish:</u> rearing. Land use and Cover: agriculture, forestry.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Coho: rearing, overwintering.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R11, R12, R13, Skagit Watershed, Sauk River, Baker River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> capacity.</td></tr>
</table>

Summary: To develop a restoration strategy for the Skagit and Stillaguamish river basins, the authors summarize and recount the geomorphic processes that formed the rivers, the dramatic changes that took place, the anthropogenic alterations, and ultimately the impact these changes have had on the salmonid species in the systems, specifically, the habitat available to Coho Salmon smolts. Voluminous lahars from Glacier Peak created an extensive low-gradient delta on the Skagit River, which developed abundant habitats in wetlands and distributary channels. Removal of beaver ponds, diking, ditching, and dredging of floodplains and deltas has isolated or obliterated approximately 50 percent of Coho Salmon winter rearing habitat in both the Skagit and Stillaguamish basins. This research aims to understand the interplay of Holocene landscape evolution, geomorphic processes, land use, and salmonid habitat to provide context for developing habitat restoration programs.

Information Relevant to Skagit River Relicensing: Much of this study is focused on geomorphic history and processes of change related to habitat capacity and Coho smolt rearing at a watershed scale, but they do provide information on several focus areas that include the town of Lyman and the Sauk River that are within the Study Area for the Synthesis Study (Reach R11). Many of the processes described can affect conditions and processes in the downriver reaches. This source provides a lot of potentially useful information on changes in rearing capacity, and they conclude that most of the lost capacity is related to losses of slough habitats in the Skagit estuary and beaver pond habitats that have occurred over the last 150-years.

<u>Geomorphology and Landforms</u>: In 16,000-ybp The Skagit River at Lyman (Reach 11) was only about 10 m above sea level at ice retreat, placing the river mouth 4 km downstream of Lyman, or about 35 km upstream of its present-day location. This puts the 16,000-ybp Skagit River mouth within Reach 11. (This data is partially visualized with a line chart in Figure 4. In 12,500-ybp the Skagit river mouth was approximately 5 km upstream of its present-day location. This puts the 12,500-ybp Skagit River mouth within Reach 13. In 5,500-ybp the mouth of the Skagit River had moved up valley to approximately 12 km upstream of its present-day location. This puts the 5,500-ybp Skagit River mouth still within Reach 13. Around 5,500-ybp Glacier Peak erupted and at least one lahar reached the mouth of the Skagit River. It deposited 3 meters of dacitic debris near Lyman,

in Reach 11, which explains the valley floor elevation of only a few meters above the present river elevation. Deposits up to 18 meters thick near the present-day delta shoreline indicate that much of the delta downstream of Sedro Wooley (Reach 12 and 13) was created during this eruption. This study estimates extension of the mainstem Skagit River during this eruption at 15 kilometers. These lahars are assumed to have reduced the quality of salmonid rearing habitats for at least 30 years in the mainstem Skagit and Sauk Rivers. The study illustrates the historic valley cross sections of Reach 11 and the Lower Sauk River in Figure 6.

The authors estimate that, over the last 5,500 years, the Skagit River has exported more than three billion cubic meters of sediment to the delta (including sub-tidal areas). Channels in bedrock terrain are comprised of 78 percent streams that are steeper than 0.02 and only 4 percent have a slope of less than 0.03. Streams on bedrock and steeper than 0.02 and with bankfull width less than 15 meters have very little spawning gravel available, mostly because average basal shear stress is high enough that median particle size of the bed surface tends to be cobble or larger. Channels in terraces are less steep than those in bedrock with 70 percent of channels being less than 0.02 and 22 percent of channels being greater than 0.03. Streams on terraces and with bankfull width less than 15 meters are typically used by Coho Salmon, steelhead Trout, and Cutthroat Trout. Channels in alluvium are comprised of 62 percent streams that are less than 0.01 and at least 75 percent have a slope of less than 0.03. The Skagit and Sauk river typically migrate laterally across the alluvium, resulting in meandering or anastomosing channel patterns. These side channels account for at least 44 percent of channel length in the Skagit and Sauk River floodplains prior to European settlement. The authors estimate that much (more than half) of the 150-ybp habitat area in the Skagit River basin was located on the deltas and floodplains.

Fish and Habitat: Historically, beaver ponds occupied a minimum of 8 percent of tributary length in the Skagit River basin within terraces. Historical and current rearing habitat capacities are provided by habitat type for Coho. In the Skagit River basin, tributaries have lost more than 30 percent of their potential Coho smolt production. Similar estimates of the change for mainstem channels cannot be made, because there is insufficient data in the literature to quantify Coho Salmon use of habitats in large rivers. 45 percent of the floodplain side-channel habitat has been isolated or obliterated in the Skagit River basin. Isolation of 75 percent of distributary slough area in the Skagit delta has eliminated much of the winter habitat capacity for Coho smolts. Culverts and other stream crossing structures have reduced rearing capacity by 6 percent in the Skagit River basin, and the construction of two dams on Baker River have reduced Coho winter rearing habitats by about 5 percent, although they estimate this is offset by increased rearing capacity within the reservoir habitats. They indicate that the upper Skagit River dams do not block passage to historical anadromous habitat and therefore do not influence capacity change estimates. Smolt densities, survival, and potential production estimates by habitat type and season are provided, but these were derived from sources already included in the Synthesis Study (Beechie et al. 1994, ID337).

Land Use and Cover: The four main land uses that alter rates of geomorphic processes and subsequently affect the quantity or quality of fish habitat in the Skagit watershed are agriculture, forestry, rural residential development, and hydropower dams. Agricultural and rural residential areas are almost exclusively within the floodplains and deltas and overlap more than 59 percent of the historical range of salmon. In the Skagit River basin, almost all tributaries in agricultural lands are low-slope channels, and pool areas are much less than in reference sites or in streams with other adjacent land uses. Table 3 provides percent pool habitat by land use type and gradient classes that can be used to estimate habitat areas for tributary habitats. Much of these differences in pool areas are likely due to channel dredging or increased supply of sediments from pastures and croplands. In forest lands in terrace tributaries, reduced wood recruitment has caused the greatest reductions in pool areas in moderate-slope streams (0.02-0.04). Reductions in pool areas in rural areas are similar to those in forestry areas. In channels where the bankfull width is greater than 24 meters (main stem Skagit and Sauk), total pool area has decreased by more than 35 percent. In large channels like these, key pieces more than 1 meter in diameter are needed to create stable jams, which in turn create more and deeper pools. Logging has reduced recruitment of trees large enough to form these pools in large channels.

Beechie et al. (2003) (Unique Identifier: 015)

Reference	Beechie, T. J., E. A. Steel, P. Roni, and E. Quimby (editors). 2003. Ecosystem recovery planning for listed salmon: an integrated assessment approach for salmon habitat. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-58, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat***: Fish: abundance, growth, survival, distribution; Habitat: instream flow, restoration, limiting factors, capacity, status and trends, barriers, riparian. ***Geomorphology and Landforms:*** sediment supply and transport, floodplain, large wood, floodplain connectivity, change, side and off-channels. ***Modeling Tools:*** life cycle, habitat. ***Land Use and Cover:*** land cover, roads. ***Water Quality and Productivity:*** secondary productivity, temperature, dissolved oxygen, turbidity, contaminants. ***Hydroelectric Operations:*** flood control, flow regulation.									
Species and Life Stages	***All anadromous species.***									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Hydroelectric Operations	***Fish and Habitat:*** Fish: distribution; Habitat: barriers, instream flows. ***Geomorphology and Landforms:*** floodplain connectivity, side and off-channels									

Summary: The Endangered Species Act (ESA) requires that a recovery plan be developed for all species listed as threatened or endangered, and this technical memorandum supplements prior guidance documents with information specific to habitat recovery planning to support. The report is divided in to five sections that are described in the executive summary.

- *An Assessment Approach for Habitat Recovery Planning*: presents a conceptual framework for understanding relationships among land uses, watershed functions, habitat conditions, and biota. The framework relies on principles of watershed and ecosystem management and organizes the habitat-related questions that each recovery plan should attempt to answer.
- *Analyses for Phase I Recovery Planning*: Setting Recovery Goals: discusses assessments that help identify important habitat losses and set recovery goals.
- *Analyses for Phase II Recovery Planning*: Identifying Ecosystem Restoration Actions: presents more detailed assessments to conduct within individual watersheds for identifying causes of habitat loss or degradation.
- *Prioritizing Potential Restoration Actions within Watersheds*: describes how to use Phase I and Phase II information together to help prioritize actions.
- *Managing Uncertainty in Habitat Recovery Planning*: discusses how uncertainty can affect planning decisions and provides guidance and examples for identifying and quantifying types of uncertainty.

The executive summary provides a good description of each of these sections, and the report also includes three appendices; Appendix A Issues of Scale in Habitat Recovery Planning, Appendix B Estimating Chinook Salmon Spawner Capacity of the Stillaguamish River, and Appendix C Restoration of Habitat-Forming Processes: An Applied Restoration Strategy for the Skagit River.

Information Relevant to Skagit River Relicensing: Although most of this report is not focused on the Skagit River watershed or the Study Area for the Synthesis Study in particular, the report primarily provides information that can inform the development of conceptual life history models and the identification of factors affecting target species for the Synthesis Study. The sections of the report are described in more detail below to highlight how they may inform the Synthesis Study in an applied sense. However, Appendix C Restoration of Habitat-Forming Processes: An Applied Restoration Strategy for the Skagit River also provides information directly relevant to the Study Area for the Synthesis Study and is an applied example analysis for their Phase II recovery planning. This appendix describes the "*Skagit Watershed Council's habitat protection and restoration strategy, directed at restoring the disturbed habitat-forming processes instead of attempting to build specific habitat conditions, as well as applications of the methods and preliminary results*." Among the sections of the report, this appendix provides the most directly relevant quantitative information for the Study Area for the Synthesis Study.

The Assessment Approach for Habitat Recovery Planning section provides a conceptual framework for habitat recovery planning that describes landscape processes that create or sustain habitats, and how recovery planning focused on "*preserving or restoration landscape processes should provide food quality salmon habitat over the long term*." The Phase I section describes analyses that help identify "*how habitat changes might have altered the abundance, survival, population growth rate, spatial structure, and life history diversity of ESUs or individual populations*." The methods described are for ESU level analyses and are intended to provide information at a broad scale using existing data and the report indicates that "*consistent methodologies applied across an entire ESU enable comparisons of results among populations or watersheds*." Correlation analyses using existing geospatial data are identified as a means to "*identify relationships among natural landscape attributes, land uses, and salmon populations (e.g., the Salmonid Watershed Analysis Model or SWAM)*." Comparisons to historical habitat conditions "*can help assess potential productivities and capacities of salmon populations, identify where large habitat losses have occurred, and help identify which habitat losses might have large effects on ESU viability*." At the watershed-scale, the report indicates that similar analyses can be conducted "to ascertain relationships among landscape attributes, land uses, and salmon viability." Three existing modeling tools are described that include the simplified limiting factors model, the ecosystem diagnosis and treatment (EDT) model, and the dynamic life cycle model. The report indicates that "*all three approaches compare current and historical habitat conditions but differ in their data requirements and representation of the salmon life cycle*."

The Phase II analyses described in the report are designed to "*identify causes of habitat loss or degradation and identify ecosystem restoration actions*." The analyses include inventories and assessments to identify altered ecosystem processes that include distributed processes (sediment supply and transport, flow), reach-level processes (floodplains and riparian), and other ecosystem functions (e.g., barriers, flow diversion). The purpose of these analyses is "*to identify the natural landscape processes active in a watershed, the effects of land use on natural processes, and the causal relationships between land use and habitat conditions*" and "*a list of habitat restoration actions can be prepared for each watershed of an entire ESU*" using the results. The Prioritizing Potential Restoration Actions within Watersheds and Managing Uncertainty in Habitat Recovery Planning provides more information on how to apply the Phase I and Phase II results to prioritize actions and inform management and planning decisions. The sequencing of Phase I and II assessments are shown in Figure 3.

Fish and Habitat: A conceptual model showing the linkages among landscape processes, land uses, habitat chances, and biological responses is shown in Figure 1. This model supports the development of conceptual life history models in a conceptual sense but does not provide information linking specific processes and responses. A conceptual model for how restoration influences landscape controls and watershed processes is shown in Figure 14, and a table of restoration actions with typical response times, longevity, and variability and probability of success is provided in Table 10. The hierarchal strategy for prioritizing specific restoration activities is shown in Figure 15 that is generic, but a prioritization sequence diagram is also provided in Figure 16 that compares Coho and Chinook Salmon given differences in their life history diversity.

The report is not generally specific to any species, but emphasis is placed on Chinook Salmon in various analyses, figures, and examples used throughout the report. A plot of Chinook redd densities (redds/km) by habitat types (forced pool-riffle, pool-riffle, plane-bed, and step-pool) by bankfull width is shown Figure B-2, which was developed from Skagit River data from Montgomery et al. (2009, ID 081). However, the data are presented at a basin scale and not specific to the Study Area for the Synthesis Study. Historical distributions of salmon are shown for the whole Skagit River basin in Figure C-2. Appendix C notes that upstream migration has been blocked by the Baker River hydroelectric projects but trapping and hauling are used to maintain Coho and Sockeye passage. Table C-2 provides a list of reach-level habitat types for tributaries, main rivers, and estuaries with classifications for each species (Chum, Coho, Chinook, steelhead, and Pink Salmon) for the importance of the habitat type (key = critical habitat required for the persistence of a dominant life history type for at least one life stage, secondary = does not provide critical habitat for any life stage and is not preferred by the majority of life stages). Figure C-8 shows a map of the basin with subbasins classified based on the amount of key habitat identified in the analysis, with detail on important, isolated or degraded, and key habitats shown for the lower Skagit River and Estuary. Riparian conditions are shown for the basin in Figure C-5, and the locations of hydromodifications and manmade barriers are shown for the lower Skagit River in Figure C-7.

Geomorphology and Landforms: Regional differences in dominant ecosystem processes and functions are described in Table 2. This table identifies processes more specifically (including sediment supply and transport, flood hydrology, low flow hydrology, riparian functions, habitat connectivity, estuary function, and biological integrity), but is not geographically specific to the Study Area for the Synthesis Study and would therefore inform the development of conceptual linkages between watershed processes and functions and drivers. Coarse and fine scale habitat types from freshwater to estuary environments are provided in Table 3. A diagram of watershed processes that links controls (land uses, vegetation, geology, climate, morphology) to processes (sediment supply, hydrologic regime, organic matter inputs, nutrient/chemical inputs, light/heat inputs) to habitat effects and fish population responses is provided in Figure 11. Figure 12 shows the results of sediment supply and transport analyses that were applied in the Skagit Watershed and shows mass wasting hazard areas and modeled sediment supply rates for the lower Skagit River watershed and upper drainages of the basin. Detailed descriptions of the methods and thresholds used to evaluate landscape processes and functional condition is provided in Table C-1. Figure C-4 shows sediment supply ratings for the basin, with mass wasting hazard ratings and forest road inventory data.

Land Use and Cover: Figure C-2 provides a map of land uses within the basin that include agricultural, national park, national forest, commercial forest, rural, and urban/industrial land uses. Functional ratings for peak flows are shown for the basin in Figure C-3. Figure C-4 provides a map of forest road inventory data, as well as mass wasting events tied to vegetative state. Figure C-7 shows the location of hydromodifications, including hardened or diked streambanks, for the lower Skagit River and Estuary.

Modeling Tools: Three existing modeling tools are described that include: the simplified limiting factors model, the ecosystem diagnosis and treatment (EDT) model, and the dynamic life cycle model. The EDT model is "*complex and greatly relies on expert opinion for input data, whereas the other approaches are simpler models based primarily on measured data*." The simplified limiting factors model "*has the least complete representation of the salmon life cycle, allowing only life stage capacities to change*." In contrast, the EDT model "*allows both life stage capacities and survivals to change*." The dynamic life cycle model "*allows life stage capacities and survivals to change and can examine population growth rates over time in response to habitat actions*." These models can be used to identify areas where habitat changes have most impacted salmon viability, or identify limiting factors, as well as supporting predictions of how salmon populations will respond to restoration or recovery planning actions. The generalized life cycle model framework is shown in Figure 7, with a diagram showing the linkages among life stage transitions, habitat conditions affecting those transitions, and human actions that alter habitat conditions or survival that can inform the development of conceptual life history models.

Water Quality and Productivity: Table 9 describes 10 metrics of the B-IBI (Index of Biological Integrity) and predicted responses (and direction) to human disturbance that can inform development of conceptual life history models. Temperature effects on salmon life stages including growth and survival are generally described, but not specific to the Study Area for the Synthesis Study. Similarly, the links between water quality parameters like dissolved oxygen, nutrients, contaminants, and turbidity are also described to provide context to the linkages between water quality and salmonid life stages.

Hydroelectric Operations: Table C-3 provides a summary of flood return periods and the magnitude of peak flows before and after flood storage, which shows an approximate 50 percent reduction in the magnitude of peak flows at the Sedro-Woolley and Mount Vernon USGS gages since flood storage capacity was added to Baker River and the upper Skagit River. This reduction in peak flow magnitude is linked by the authors to a probable reduction in channel-floodplain processes that form and maintain off-channel habitats.

Beechie et al. (2005) (Unique Identifier: 014)

Reference	Beechie, T. J., M. Liermann, E. M. Beamer, and R. Henderson. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society 134(3):717-729.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow, freshwater, data gaps, limiting factors; Fish: abundance, distribution, life history, periodicity. ***Geomorphology and landforms:*** substrate and sediment, large wood, aquatic habitats and landforms. ***Land Use and Cover:*** banks and shoreline.									
Species and Life Stages	***Chinook:*** rearing, outmigration, overwintering. ***Coho:*** rearing, overwintering. ***steelhead (rainbow):*** rearing, overwintering. ***Chum:*** rearing, outmigration.									
Reaches and Spatial extent	R1-R14.									
Linkages to Hydroelectric Operations	NA									

Summary: In this study, the authors categorized six habitat units in the mainstem of the Skagit River (>100m bank-full width) which included midchannel pools, riffles, and glides, as well as channel margin bank edges, bar edges, and backwaters to analyze how juvenile salmon use those habitats. Chinook, Coho, steelhead, and Chum were collected through electro-fishing during February through June and September to October to capture the various life history strategies of salmonids (i.e., to capture out-migration peaks of ocean-type salmonids like Chinook, Chum, and Pink, they sampled February through June) from 1993 to 1998. Midchannel units were too difficult to sample because they were deeper and faster than channel margin habitat types and consequently capture and detection rates were lower for electrofishing and snorkeling. low capture rates and water velocities were too fast for snorkeling), but they did find that midchannel habitat units were deeper and faster than channel margin habitat types. Within the edge unit types, the backwater units had the lowest velocities as well as more complex cover. Juvenile Chinook Salmon and Coho were highest in bank and backwater units in the winter. During the summer, Coho densities were significantly different in the different edge unit habitat types. Microhabitat selection between velocity, depth, and cover type of channel margin habitat types was similar to habitat use in small streams.

Information Relevant to Skagit River Relicensing: This study provides useful quantitative and descriptive information of juvenile salmon habitat use along channel margin habitat types of the mainstem Skagit River from Reach R1-R14 (excluding the estuary). Additionally, this study provides quantitative data on the characteristics of different habitat types, including velocities, substrate type, cover type (wood, aquatic plants, cobble/boulder, and or no cover), and depth; and the relative densities of juvenile salmon occupying those habitats. Collectively, the data presented in this report provides quantitative information that can support evaluating the effects of habitat change or restoration from reach to watershed scales. The authors also point to a data gap for juvenile salmon use of large river midchannel habitat types due to the difficulties of sampling with traditional methods (electrofishing and snorkeling) due to depth and velocities. This data gap as noted by the authors *"...inhibits our ability to predict how habitat restoration actions in large rivers might contribute to recovery of salmon listed under the Endangered Species Act."*

<u>Fish and Habitat:</u> Proportions of velocity class (high >45 cm/s, moderate 15-45 cm/s, and low <15 cm/s), substrate type (mud/detritus, sand, gravel, cobble, boulder, bedrock), and cover type (wood, aquatic plants, cobble/boulder, no cover, and other) for edge types (bar, bank, backwater) by season (winter, spring, and summer) are provided (see Figure 4). Bars and banks sample points had 40-75 percent low water velocity while backwater sample points had 100 percent low water velocity (< 15 cm/s). Depths were significantly different across all habitat types and bars had shallower depths on average (mean = 0.41 m, SD = 0.15) compared to mean depths of 0.71 m (SD = 0.18) and 0.70 m (SD = 0.17) for bank and backwater habitats, respectively. Banks had the most abundant wood cover, while bar edges were dominated by cobble/boulder and backwaters were more mixed in cover types.

Relative densities are reported in box plots for each species and age class for edge unit types, velocity class, and cover types, but these are presented as cube-root transformed fish per point standardized by year. Therefore, the relative densities reported from this study would primarily be useful in comparisons between habitat types, velocities, substrate, and cover to support restoration planning or prioritization, evaluation of habitat status and trends, or comparisons of scenarios for change of time based on changes in habitat type, cover, substrate, or velocity. For this summary, we describe the general patterns but the relative density data can be extracted from the boxplots to support the Synthesis Study. Fish use of channel margin edge unit types (bank, bar, and backwaters) differed among seasons and species. In the winter, bank units had higher densities than bar units for all species as well as coho densities in the summer. Chinook, Coho, and Chum had higher densities in backwaters. In contrast, Rainbow Trout densities were similar in bar and backwaters. Chinook, Chum, and winter Coho Salmon were highest in low-velocity points compared to winter Rainbow Trout and summer Coho Salmon had comparable in low and medium-velocity points. Juvenile Coho Salmon selected low to moderate velocities in the summer but avoided bar units (even though they had 40 percent low velocity points) because bar habitats had no cover or it was cobble and boulder coverage. Age-0 and age-1 or older steelhead were evenly distributed along edge habitat types in the summer and evenly distributed across all velocity classes. Chinook and Chum occupied low-velocity areas and used all cover types.

Beechie et al. (2006) (Unique Identifier: 016)

Reference	Beechie, T. J., C. M. Greene, L. Holsinger, and E. M. Beamer. 2006. Incorporating parameter uncertainty into evaluation of spawning habitat limitations on Chinook salmon (Oncorhynchus tshawytscha) populations. Canadian Journal of Fisheries and Aquatic Sciences 63(6):1242-1250.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: limiting factors, capacity, barriers; Fish: survival, distribution. ***Modeling Tools:*** adult returns. ***Geomorphology and Landforms:*** aquatic habitats and landforms, slope. ***Hydroelectric Operations***: flow regulation.									
Species and Life Stages	***Chinook:*** migration, spawning.									
Reaches and Spatial extent	Skagit Watershed including R7-R13, R1-R6, Sauk River, Other upper Skagit tribs (Cascade), Other Sauk River tribs (Suiattle).									
Linkages to Hydroelectric Operations	***Geomorphology and Landforms:*** aquatic habitats and landforms.									

Summary: This study analyzed parameter uncertainty through a Monte Carlo model to assess habitat limitations on salmon spawning habitat capacity for six Puget Sound Chinook populations in the Skagit River watershed. They used DEMs, digital hydrography, and aerial photographs to delineate and characterize spawning reaches and available habitat, along with published data from the Skagit River and nearby watersheds to estimate spawning habitat capacities. They developed capacity estimates for small (5-25 m bankfull width) and large channels (> 25 m bankfull width) but excluded channels < 5 m bankfull width and assumed to not support consistent spawning for Chinook, and report capacities for each population that can be used to inform salmon recovery planning. They conclude that factors other than spawning capacity limit population size and that recovery of Skagit River Chinook populations does not need to focus on spawning habitat restoration and posit that their analysis provide a conservative estimate of spawner capacities for Skagit River Chinook populations.

Information Relevant to Skagit River Relicensing: This study provides data that were derived from studies within the Skagit River watershed as well as nearby systems to support estimation of spawner habitat capacity and limitations of spawning habitat on populations of Chinook in the Skagit River. They include the Sauk River and a major tributary to the Sauk (Suiattle) in their analysis, and most of the lower Skagit River (reach R7-R12) but excluded the lower mainstem below river kilometer 33 (reach R13) where fine-grained beds that are not used for spawning. They also assumed no spawning in the mainstem Suiattle due to high turbidity due to glacial melt during the spawning period. Development of spatial and remotely sensed data are indicated, but these data would need to be requested. They provide several regression models and data that can be used as modeling tools support spawner habitat capacities or estimates of habitat extent based on geomorphic relationships and potential Hydroelectric Impacts.

Fish and Habitat: Distribution statistics used to develop spawner capacity estimates are provided; with redd capacities ranging from 0.0 – 54.3 redds/km (10^{th} – 90^{th} percentiles) and a median of 6.1 redds/km (these are used to estimate capacities in small channels 5-25 m bankfull width), redd sizes ranging from 4.9 – 27.9 m^2 (10^{th} – 90^{th} percentiles) and a median of 14.1 m^2, and adults per redd ranging from 1.35 – 3.5 redds/adult (10^{th} – 90^{th} percentiles) and a median of 1.9 redds/adult.

Capacities for large channel (> 25 m bankfull width) were estimated from remote sensing of aerial imagery to delineate available spawning habitat with redds size and redds per female ranges applied to usable spawning habitat area estimates. Estimated large channel area, large side channel area, small channel length, and small side channel lengths are reported for each population, as well as spawner population and mean capacity estimates (see Table 4 and 5).

They conclude that spawner habitat capacities are not limiting recovery of Skagit River Chinook populations. They report outmigration survival (egg to outmigration) ranges from 10-16 percent in years with normal flooding intensity in the Skagit River basin and suggest that this indicates neither increases in fines or increased flooding would explain current population status to further support their conclusion that spawning habitat capacity or extent is not limiting recovery. However, they indicate that spawning habitat quality is not addressed in this analysis and habitat quality could potentially explain habitat constraints or limitations. In addition, habitat capacities at other life stages not addressed in their analysis could constrain or limit populations (e.g., freshwater rearing and nearshore or tidal delta rearing habitats), and they point to research identifying density dependent processes in delta rearing stages that could potentially limit production of Skagit River Chinook populations.

Information on potential spawning distribution are also provided, with assumptions that no spawning occurs in the lower mainstem Skagit River downstream of river kilometer 33 (reach R13), in the mainstem Suiattle due to high turbidity during the spawning period, in channels less than 5 m bankfull width, upstream of migration barriers based on channel slope (>0.04 m/m), and dams on Baker River and the Upper Skagit limiting adult spawning distributions.

Geomorphology and Landforms: Regression equations for calculating wetted widths for reaches from cumulative upstream reach length are provided for the Skagit River and Sauk River, with separate equations developed due to the influence of hydroregulation on the relationships. Regression models for bankfull estimating bankfull width from drainage area are also provided that could be used to support estimations of available habitat.

Beechie et al. (2010) (Unique Identifier: 017)

Reference	Beechie, T. J., D. A. Sear, J. D. Olden, G. R. Pess, J. M. Buffington, H. Moir, P. Roni, and M. M. Pollock. 2010. Process-based principles for restoring river ecosystems. BioScience 60(3):209-222.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** land cover, forestry, agriculture, urban, roads. ***Geomorphology and Landforms:*** channel migration, floodplain, large wood, aquatic habitats and landforms, sediment transport and supply, side and off-channels, floodplain connectivity, scour, channel incision, sinuosity, slope. ***Fish and Habitat:*** Habitat: riparian, freshwater, restoration, instream flow, beaver, barriers, connectivity; Fish: growth, diet. ***Water Quality and Productivity:*** temperature, nutrients, contaminants, primary productivity, secondary productivity.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: Rebuilding depressed anadromous fish populations requires restoration of habitats spanning entire watersheds because the life cycle of anadromous fish includes headwater spawning reaches, midriver spawning and rearing habitats, and delta and estuarine rearing habitats. The authors outline and illustrate four process-based principles that ensure river restoration will be guided toward sustainable actions that include; "*(1) restoration actions should address the root causes of degradation, (2) actions must be consistent with the physical and biological potential of the site, (3) actions should be at a scale commensurate with environmental problems, and (4) actions should have clearly articulated expected outcomes for ecosystem dynamics*." For the first principle, the authors suggest that restoration actions should address the root causes of degradation and correct human alterations by driving processes rather than correcting the symptoms of human alterations. For the second principle, restoration actions must be consistent with the physical and biological potential of the site, and these should be identified through historical analysis and by assessing disruptions to the primary driving processes to assist restoration planners in identifying appropriate target rates of watershed processes. For the third principle, the restoration actions should be at the same scale as the environmental problems. For example, reducing sediment supply requires actions distributed across the watershed whereas restoring wood recruitment to a small stream may require only a reach scale effort. For the fourth principle, restoration actions should have clearly articulated expected outcomes for ecosystem dynamics as some efforts can take decades before natural recovery. To support each of these principles, the authors provide tables and conceptual models that link ecosystem features to driving processes and restoration planning processes. Restoration actions taken at the watershed-scale can be difficult to implement and most often focus on headwaters and small tributaries while the most severe habitat and land-use changes are commonly in lowland floodplains and deltas. In cases where a river basin is heavily constrained, the balance of action types will likely trend toward habitat construction and partial restoration.

Information Relevant to Skagit River Relicensing: This source provides potentially useful broad-scale restoration recommendations that are generally applicable to any watershed. They also provide potentially useful information to inform conceptual life history models and hypotheses, as well as linkages between resource conditions and processes and drivers and these have been catalogued using relevant keywords in the data inventory (although these are not used quantitatively in this report). Some data specific to the Skagit River basin are presented, with the authors using the Skagit Watershed as an example of how land and water use constraints limit restoration options within a watershed. In the lowland floodplains and delta of the lower Skagit River (Reaches R12-R15), they indicate restoration will be mostly limited to small habitat construction projects (~65 percent) compared to full restoration or partial restoration projects. In the middle Skagit River (Reaches R10-R11), the authors estimate that restoration opportunities are a relatively even mix of habitat construction, partial restoration, and full restoration opportunities with mostly forestry and rural land uses. In headwater tributaries of the upper Skagit River, there are more opportunities for full restoration (~80 percent) with mostly forestry land uses. This source provides a map of spatial land cover data that were used in this example, which was made from high resolution land use data that breaks the watershed into 4 land uses: Urban, Agriculture, Forestry, Park/wilderness.

Beechie et al. (2017) (Unique Identifier: 018)

Reference	Beechie, T. J., O. Stefankiv, B. Timpane-Padgham, J. E. Hall, G. R. Pess, M. Rowse, M. Liermann, K. Fresh, and M. J. Ford. 2017. Monitoring Salmon Habitat status and trends in Puget Sound: development of sample designs, monitoring metrics, and sampling protocols for large river, floodplain, delta, and nearshore environments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-137, Seattle.								
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* aquatic habitats and landforms, estuarine habitats and landforms, log jam, sinuosity, floodplain, side and off-channels, floodplain connectivity. *Land Use and Cover:* land cover, banks and shoreline, floodplain. *Fish and Habitat:* Habitat: freshwater, estuary, nearshore, status and trends; Monitoring: habitat.								
Species and Life Stages	***Chinook:*** rearing, spawning. ***Chum*:** rearing, spawning. ***steelhead:*** rearing, spawning.								
Reaches and Spatial extent	Skagit Watershed (Reaches R1-R15), Sauk River, Skagit Estuary, Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: This report addresses the first stage of development of a habitat monitoring program for four salmon and steelhead spawning and rearing environments across the Puget Sound: large rivers, floodplains, deltas, and the nearshore. This program will be used to provide data for assessing habitat changes across each environment.

The goals of the first year of this monitoring effort are as follows:

(1) To develop a hierarchical sampling design to monitor habitat status and trends.

(2) To identify habitat metrics that are cost-effective and related to viable salmonoid population parameters.

(3) To develop protocols to measure those metrics.

(4) To test the satellite, aerial photography, and field methods for repeatability and reliability.

(5) To evaluate habitat status to assess the ability of each metric to detect habitat differences among our chosen land-cover strata.

These efforts will be used to refine the habitat monitoring program to ensure consistency and relevancy so that it may be used reliably in the future.

Results from the first year of monitoring are included in this report. These results include next steps on the refinement of the habitat monitoring program as well as the current status of habitat for the four salmon and steelhead spawning and rearing environments and include: development of nearshore mapping protocols, develop fish-habitat relationships, develop pilot projects with local watershed groups, retrospective analysis of remote sensing metrics to determine sensitivity to land use, and determining role of comanagers to integrate steelhead into the monitoring framework.

Information Relevant to Skagit River Relicensing: This report provides data on the 2017 status of salmon and steelhead habitat across Puget Sound's large river basins, which include the Skagit

River and its estuary and nearshore habitats. Additionally, it provides a guideline for a habitat monitoring program using remote sensing and field-based techniques that has been extensively reviewed and evaluated for improvements on consistency and reliability and includes lists of metrics that were identified for habitat status and trends monitoring and linkages with processes and pressures that influence these metrics (including links to salmon Viable Salmon Population parameters and sensitivity to scale and land use). This is relevant to the Synthesis Study as this methodology can be used to inform current aquatic habitat monitoring practices, as well as data from the monitoring program being used to support habitat status and trends monitoring. An online resource is also available for this monitoring program, additional reports, and spatial data products (see NOAA Salmon Habitat, ID315). Preliminary summaries of habitat status and trends monitoring metrics are reported from this phase, which are mostly reported at basin or major population group scales including the following data for each habitat strata:

Large river and floodplains: percent landcover, riparian buffer width, proportion disconnected floodplain, sinuosity, proportion bank types (natural bank, bar, and hydromodified bank edge), braid and side channel lengths, braid and side channel node densities, backwater area, and wood jam areas.

Deltas: percent landcover, areas by channel types, channel edge lengths, channel lengths, and channel node densities.

Nearshore: No data reported for nearshore metrics in this report.

Where reported at the basin scale, data for the Skagit Watershed could be extracted for some of the above metrics. However, spatial data are available that can be used to extract data specific to the Study Area for the Synthesis Study (see NOAA Salmon Habitat, ID315).

Beechie 1992 (Unique Identifier: 127)

Reference	Beechie, T. J. 1992. Delineation of hydrologic regions in the Skagit River basin. Report prepared by Skagit System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow. ***Modeling Tools:*** hydrology.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: This study analyzed USGS gage data in the Skagit River basin. The analysis resulted in five hydrologic regions. The paper delineated hydrologic regions in the Skagit River basin based on characteristic flow relationships, elevation, and precipitation; distinguished the primary hydrograph patters in the basin; and described within-region relationships between 50-year peak floods and drainage area. All the hydrological and sub-basin data used in this study were from Williams et al. 1985 USGS Streamflow Statistics, Report 84-114-B, and are through 1979.

Information Relevant to Skagit River Relicensing: The Skagit River basin was divided into five hydrologic regions with regions 1-4 being part of the Study Area for the Synthesis Study (these regions are roughly shown in a map in Figure 3). Summaries of potentially useful hydrographical parameters are provided for gages and regions (e.g., upstream drainage area, slope, elevation, precipitation, average annual flow, snowmelt period, 2-year average low flow, and 7-day average low flow), and includes data for a number of relevant tributaries (Nookachamps Creek, Day Creek, Baker River, and Sauk River as well as other tributaries to the Skagit River). However, some of these summaries would potentially need to be updated with more recent data if available., but the summaries do provide some potentially useful baselines for comparisons. They also developed a model that can be used to estimate 50-year peak flows at locations within the Skagit River basin, although this would potentially need to be updated to be used for current conditions.

Fish and Habitat: Instream flows in the lower elevations (regions 1 and 2) were a response to storm precipitation. Peak flows in the lower elevation regions occurred in the fall and early winter, with 50-year peak flows around 165 cfs/mi^2 in the fall and 255 cfs/mi^2 in the winter. In the higher elevation regions (regions 3, 4, and 5), the precipitation falls as snow and peak flows occur in the spring. The 50-year peak flow estimate in region 3 was 245 cfs/mi^2. In region 4, the 50-year peak flow estimate was 170 cfs/mi^2. Monthly mean flows for all gages with more than 10-years of data are also provided in bar plots in an appendix.

Modeling Tools: The 50-year peak flow estimates can be used to rapidly estimate the 50-year peak flows at locations on streams in the Skagit River basin. To estimate a 50-year peak flow for a small basin, multiply the estimated QPF50 (peak flood flow, 50-year recurrence interval) per unit areas from Table 5 by the drainage areas of the stream above the desired project location. If the drainage basin is near a boundary between two hydrological regions, one can interpolate between estimates of QPF50 (i.e., use an estimate between the two values).

Bowling et al. (2000) (Unique Identifier: 020)

Reference	Bowling, L. C., P. Storck, and D. P. Lettenmaier. 2000. Hydrologic effects of logging in western Washington, United States. Water Resources Research 36(11):3223-3240.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Land Use and Cover***: forestry, roads. ***Fish and Habitat***: Habitat: instream flow.								
Species and Life Stages	NA								
Reaches and Spatial extent	Sauk River; Other upper Skagit tribs (Newhalem Creek).								
Linkages to Hydroelectric Operations	NA								

Summary: This study compares three methods for analyzing long-term trends in streamflow characteristics (annual maxima series, peak over threshold, mean annual flow, and annual minima) associated with logging-related land uses (harvest and road construction) in 23 western Washington catchments, including two in the Skagit River basin: the Sauk River and Newhalem Creek. The three analysis approaches compared were: analysis of individual catchments, paired catchments, and model residuals. Statistically significant downward trends in annual streamflow minima are apparently explained by the Pacific Decadal Oscillation (PDO), rather than forestry practices, in the individual catchment analysis. Paired catchment analysis, which controls for climate variability by pairing heavily harvested catchments and less heavily harvested catchments with similar regional climate influences, was inconclusive but indicated a trend towards increases in annual streamflow minima possible resulting from forestry practices. The model residuals analysis compared observed changes in stream characteristics from forested catchments to a hydrologic model which simulates streamflow characteristics based on static climate and land-use patterns. Therefore, the simulated data acts as a stand-in for a true "Control" catchment and subtracts most of the influence of climatic and spatial variability from the analysis. The model residuals analysis method was most readily able to detect significant trends and was advantaged because it inherently controls for climatic and spatial variability. The authors conclude that 1) individual trends in streamflow characteristics are masked by a regional climate signal caused by the PDO, 2) removing the effects from climate by conducting paired catchment analysis indicates forestry practices are responsible for changes in streamflow characteristics, particularly at low-flow, 3) analyzing time-series residuals from hydrologic model simulations revealed increasing trends in peak flows (annual maxima series and peak over threshold) which was not detected with other methods. This is suggestive that the use of model simulations can improve detectability of statistically significant trends in noisy data.

Information Relevant to Skagit River Relicensing: This is a highly technical paper that describes challenges and limitations to detecting statistically significant trends in streamflow characteristics. The bulk of this study focuses on comparing the merits of three different approaches to isolate unbiased trends from streamflow data and causally link estimates to forestry practices. However, this study does provide several potentially useful summaries of forestry practices in the Sauk and

Newhalem basins and at other forested catchments in western Washington. Several tables include summaries of percent changes in immature forested area for several time periods (1930 to 1991, 1945 – 1991, and 1960 – 1991) and summarized data for forest road length and density for the basins considered in the analysis, including the Sauk and Newhalem Creek. Percent old growth by basin area summaries are also provided for each catchment, and scatter plots show that road density in a basin was strongly related to total area harvested. In addition, this study raises awareness of the difficulties of isolating the effects of changes in land-use resulting from forestry practices in time series data and provides a detailed comparison of three potential approaches to analysis. Similar challenges in statistical estimation could presumably arise during analysis of potential effects from Hydroelectric Operations.

Collins et al. (2002) (Unique Identifier: 418)

Reference	Collins, B. D., D. R. Montgomery, and A. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland Rivers. Can. J. Fish Aquatic Science 59:66-76.								
Source Information	*Type*	Study	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology:* large wood, log jam, change. *Land Use and Cover:* banks and shoreline, forestry.								
Species and Life Stages	NA								
Reaches and Spatial extent	Reach R13 -14, Skagit Estuary.								
Linkages to Hydroelectric Operations	NA								

Summary: This study examines the historic change of large wood function and distribution in Puget lowland rivers. The purpose of this study is to examine the statement that the influence of large wood decreases with increasing channel size. The authors of this study hypothesize that historic stream cleaning has greatly decreased the abundance of large wood in Puget lowland rivers and levee construction and riparian forest clearing has diminished the potential for lowland rivers to recruit wood. This combined effect suggests that the current condition of large wood loading in Puget lowland rivers is not representative of their historical condition.

The authors of this study examine this hypothesis by comparing the current condition of large wood distribution and function in reaches across three Puget lowland rivers. Two of these rivers, the Snohomish and Stillaguamish, have been heavily leveed, cleared, and logged. They are meant to represent conditions in a Puget lowland river that has been subject to extensive European settlement impact. The other river examined, the Nisqually River, contains reaches that have been largely untouched since European settlement. The study reaches in the Nisqually are meant to represent historic conditions of other Puget lowland rivers pre-European settlement. Additionally, the authors examined archival materials of wood distribution and function of these three rivers as well as other Puget lowland rivers, including the Skagit River, to provide insight into their historical condition.

Results from this study show significant differences in wood distribution and function between the Nisqually River and the Snohomish and Stillaguamish Rivers.

Archival materials of the Nisqually River suggest that the study reach is relatively unchanged from its mid-19th century condition. Present day large wood distribution is similar to the size distribution in 1873. Additionally, the present-day anastomosing channel planform in the Nisqually is similar to what is seen in historic aerial photos and historic maps. The historic distribution and function of large wood in the Nisqually is comparable to the historic conditions in the Stillaguamish. The Stillaguamish had comparable wood sizes to the Nisqually, abundant log jams, and an anastomosing channel planform according to archival materials. The Snohomish was dissimilar in that it did not have as much wood as the Nisqually and Stillaguamish. Additionally, it exhibited a single meandering planform as opposed to anatomizing. The authors note that the Snohomish does exist in a broad low-gradient valley created by Pleistocene subglacial runoff as opposed to the post-glacial incision dominated valleys that the Nisqually and Stillaguamish exist in. This could be the cause for the variation in historic conditions of these channels.

There are strong contrasts in wood distribution and function when comparing the Nisqually with the Stillaguamish and Snohomish River current day conditions. The Nisqually has 8 and 21 times more wood than the Snohomish and Stillaguamish, respectively. This difference is accounted for primarily from wood jams in the Nisqually which are much more abundant than in the Snohomish and Stillaguamish. Additionally, large wood was shown to have a greater impact on the overall aquatic habitat in the Nisqually forming 61 percent of pools versus 12 percent and 6 percent in the Stillaguamish and Snohomish respectively. The large wood in the Snohomish and Stillaguamish was also shown to lack long, large-diameter, pieces with rootballs which function in the Nisqually to initiate and stabilize log jams as key pieces.

The authors concluded that the present-day large wood conditions seen in most Puget lowland rivers is not representative of historic conditions. Large wood historically was one to two orders of magnitude more abundant pre-European settlement. This loss of large wood has been driven by human interaction.

Information Relevant to Skagit River Relicensing: This analysis focused primarily on the Nisqually, Snohomish, and Stillaguamish Rivers, but they discuss historic conditions of large wood distribution in the Skagit river and provide comparisons of present day and mid-19^{th} century large wood distribution conditions in Puget lowland rivers comparable to the Skagit river. This study cites archival materials circa late 1800s that describe a log raft on the Skagit river near Mt. Vernon as “nine meters deep, consisting of from five to eight tiers of logs, which generally ranged from three to eight feet in diameter and existed for at least a century,” this jam was reported to be “large enough to support live trees 0.6 to 1.2 meters in diameter.” This raft jam was greater than 1 kilometer long. Additional archival materials discuss the prevalence of tidal distributary channels that were reportedly characterized by “hundreds of miles of old channels that were choked with wood, filled with sediment, and abandoned.” The study also provides evidence that Puget lowland rivers had one to two orders of magnitude more wood abundance in the mid-19^{th} century, which can be used to inform evaluation or interpretation of large wood abundances estimates in the Study Area for the Synthesis Study.

Congleton et al. 1981 (Unique Identifier: 256)

<table>
<tr><td>Reference</td><td colspan="10">Congleton, J.L., S. K. Davis, and S. R. Foley. 1981. Distribution, abundance, and outmigration timing of chum and Chinook salmon fry in the Skagit salt marsh. Pages 153-163 in E. L. Brannon, and E. O. Salo, editors.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Proceedings</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: rearing, abundance, distribution, movement, growth, periodicity, size structure; <u>Habitat:</u> instream flow, estuary, connectivity; <u>Monitoring</u>: abundance, biotelemetry.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chum: outmigration, estuary rearing and emigration. Chinook: outmigration, estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This study was conducted between 1977 and 1979 in an undisturbed saltmarsh on the delta of the Skagit River to determine the distribution, abundance, and outmigration timing of Chum and Chinook fry. Saltmarshes are one of the shallow estuarine habitats used by Chum and Chinook Salmon fry for rearing, foraging, and refuge. In 1977, six areas of the marsh were surveyed to determine distribution, species composition, and relative abundance of juvenile salmon on several dates during the spring. Mark-and-recapture experiments were carried out in 1978 and 1979 to determine abundance and residence time of Chum and Chinook in a marsh channel 500 m north of Freshwater Slough. Downstream migrating Chum and Chinook fry were sampled in 1979 at Lundeen's Landing, 3.2 km upstream from the mouth of Freshwater Slough. Details are provided on calculations and results for densities and residence time estimates as well as size comparisons of Chinook and Chum in the lower Skagit River and the marsh. Based on the results of this study, the authors conclude that a large percentage of outmigrating Chum and Chinook utilize salt marsh habitats for rearing rather than migrating through the estuary directly to nearshore habitats.

Information Relevant to Skagit River Relicensing: The report provides quantitative data relevant to the Synthesis Study for Chum and Chinook during estuary rearing and emigration life stages and follows up on the results previously reported in Congleton (1978 ID255). Specifically, it provides population estimates of estuary rearing Chinook and Chum, and data on size structure and residence time for Chinook and Chum. This information provides data that describes the importance of the Skagit saltmarsh for rearing for juvenile salmonids and could be used to evaluate status and trends of estuary habitat use via comparisons of measured rearing densities for salt marsh habitats as reported in this study. This information can also be used to inform conceptual life history models for Chinook and Chum estuary rearing and emigration life stages. Results and quantitative data for topics of interest are described in more detail below.

<u>Fish and Habitat:</u> During the sampling period in 1979, Chum and Chinook Salmon fry increased in abundance in the lower Skagit River and adjacent saltmarsh from March to early May (see Figures 2-3 for time series of catches). Catch per unit effort for 1977 seine sampling in Skagit Marsh is provided in Table 1. Abundance of fry for both species peaked in Index Slough during the last week of April and first two weeks of May and similar timing was also observed in 1976,

1977, and 1978. Increases in fry abundance in the salt marsh closely followed increases in catch per unit effort (CPUE) at the upstream river site and corresponded with peaks in river discharge. Numbers of Chum and smaller Chinook fry declined at both the river and marsh sites after mid-May. Weighted mean residence times for Chinook fry in the salt marsh ranged from 2.4 to 3.8 days, and residence time in the lower river was only a few days. The instantaneous daily disappearance rates estimated for marked fish released into Index Slough in 1979 were 0.26 to 0.41 for Chinook and 0.35 to 0.69 for Chum (see Figure 6 for disappearance rates of marked Chum). Instantaneous daily rates of emigration were 0.16 to 0.31 for Chinook and 0.24 to 0.59 for Chum. Corresponding estimates of weighted mean residence times were 3.1 to 6.0 days for Chinook and 1.7 to 4.0 days for Chum Salmon. Based on these emigration rate and residence time estimates, approximately 49,000 Chum fry and 17,500 Chinook fry entered the marsh (16 ha drainage) in 1979. Scaling this estimate to the total area of the Skagit marsh accessible to outmigrating salmon fry (990 ha), they estimate approximately 3.1 million Chum fry and 1.1 million Chinook fry, or one third of the estimated number of migrants, used the marsh habitat for rearing rather than migrating directly to Skagit Bay in 1979.

Chum and Chinook fry sampled in Index Slough were larger than fry sampled concurrently at the river site (see Figures 4-5 for time series of mean fork lengths). Chum fry from the marsh site averaged up to 4-5 mm larger than Chum fry from the upstream river site, and Chinook fry averaged up to 6-7 mm longer. Growth may have been slow in the river because stomachs of fry from the river site contained less food than stomachs from fry at the marsh site (cited in the discussion, data not shown in this report).

Congleton (1978) (Unique Identifier: 255)

<table>
<tr><td>Reference</td><td colspan="10">Congleton, J. L. 1978. Feeding patterns of juvenile chum in the Skagit River salt marsh. Pages 141-150 in S.J. Lipovsky and C.A. Simenstad, editors. Gutshop '78: Fish Food Habits Studies Proceedings of the Second Pacific Northwest Technical Workshop. Washington Sea Grant, University of Washington, Seattle.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Proceedings</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Water quality and productivity: secondary productivity. Fish and Habitat: <u>Fish:</u> diet, periodicity, rearing.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chum: estuary rearing and emigration, nearshore rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This brief proceedings document describes the study of juvenile Chum feeding patterns in a Skagit River salt marsh. Chum stomach samples were taken at two-to-three-hour intervals within a twenty-four hour period at a salt marsh drainage channel on the Skagit River's south fork delta. Prey availability within the salt marsh was characterized by drift sampling the surface and bottom of the marsh water column during high and low slack tides. Dipteran adults and pupae made up the highest stomach weight composition (57.7 percent and 81.45 percent in 1978 and 1977, respectively). The large quantities of food found in the sampled Chum stomachs demonstrate marsh flats are important foraging habitat.

Information Relevant to Skagit River Relicensing: This study provides juvenile Chum feeding information in the Skagit Estuary salt marshes. Chum Salmon are among the most estuary reliant salmon species, with juvenile Chum rearing in estuary habitats from March to mid-May. The study provides quantitative information on diet composition, feeding chronology, drift composition data, as well as diel diet changes which provides some insight into how changing tides impact juvenile Chum feeding patterns. Given that this study provides data from 1977 and 1978, it could also provide reference information for Chum feeding patterns that could be used for comparing todays Chums feeding patterns with changes in estuary habitat that have occurred since the study (e.g., restoration, progradation, diking). The diet information presented here could also be used to support development of modeling tools (e.g., bioenergetics) for Chum in estuary habitats, and they provide data for both diet composition and prey availability that supports analysis of feeding preference in salt marsh habitats. The author indicates future studies should be performed to determine residence periods and growth rates for juvenile salmon in marsh habitats (see Congleton et al. 1981 ID256).

<u>Fish and Habitat:</u> The authors found that Chum fry fed mostly during periods of marsh submergence when they moved out of the marsh channels (where they reside during low tides) and onto the marsh flats. Feeding intensity greatly decreased when Chum were concentrated in low tide channel holding areas. The stomach content samples reached a maximum weight after three to four hours of a high tide and then declined. Detailed tables of drift catches among taxa (Table 3) for sampling dates, tide cycles, and time of day are provided along with diet composition for Chum (Table 1-2). In 1977, adult and pupae Diptera composed 81.4 percent of Chum stomach

weight in 1977. Chironomidae (family within the Diptera order) adults and pupae were 67.1 percent out of the 81.4 percent. The remaining stomach composition was miscellaneous insect parts, and the Ceratopogonidae pupae. In 1978, adult and pupae Diptera composed only 57.7 percent of stomach weights, broken down further by family, chironomids totaled 45.4 percent. The next highest prey weight was Oligochaeta which was 28.6 percent. They also found that while dipterans dominated diets among Chum fry, relatively small catches of dipteran adults and pupae in the drift samples suggests that chironomids are eaten from substrate rather than in the water column (e.g., bottom or from plant stems). Dipteran adult and pupae were hardly found in drift net samples (ranged between 0 to 17 individuals per average net catch). The study did find that catches were *"highest during receding flows in the late afternoon, indicating that drifting dipterans were derived from the marsh rather than from river water pushed into the marsh by the incoming tide."* Anisogammarus was more prevalent during the night (ranged 153 to 663 individuals per average drift net catch) but was highest in Chum stomachs *"following periods of low water"* regardless of night or day.

Connor and Pflug 2004 (Unique Identifier: 385)

<table>
<tr><td>Reference</td><td colspan="10">Connor, E. J., and D. E. Pflug. 2004. Changes in the distribution and density of pink, chum, and Chinook salmon spawning in the upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24(3):835-852.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat</u>: instream flow; <u>Fish</u>: periodicity, age structure, abundance, survival, status and trends, distribution, hatchery; <u>Monitoring</u>: abundance. Hydroelectric Operations: flow regulation, downramping, life stage flows.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Pink: spawning, incubation, emergence, rearing, outmigration. Chum: spawning, incubation, emergence, rearing, outmigration. Chinook: spawning, incubation, emergence, rearing, outmigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R7 – R8, R1 – R6, Sauk River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Fish and Habitat: <u>Habitat</u>: instream flow; <u>Fish</u>: abundance, survival, status and trends, distribution. Hydroelectric Operations: flow regulation, downramping, life stage flows. Chinook: spawning, incubation, outmigration. Pink: spawning, incubation, outmigration.
Chum: spawning, incubation, outmigration. Reaches: R7 – R8.</td></tr>
</table>

Summary: This study analyzed time series of the spatial distribution and abundance of Pink, Chum, and Chinook spawning in a 27-mile reach of the upper Skagit River with respect to implementation of flow management measures in 1981. Their study area was divided into three reaches: (1) Reach 1 from George Powerhouse downstream to Marblemount; (2) Reach 2 from Marblemount to Rockport and Sauk River confluence; and (3) Reach 3 downstream of Sauk River confluence to Baker River confluence. These flow management measures were intended to minimize redd dewatering during spawning and incubation periods and reduce fry stranding during emergence and outmigration life stages. Their study included analysis of changes in flows and spawner data during per-agreement (1950-1980), interim agreement (1981-1990), and final agreement periods (1991-2001), including comparing trends in spawner abundance with other nearby systems to support interpretation of patterns and their relationship to flow management measures. Their study design was a before-after impact comparison and they concluded that increasing minimum flows during incubation periods improved redd protection levels, and that fry stranding was reduced by reducing the number of downramping events and timing of downramping events during the daytime when fry are more vulnerable to stranding. They also found that spawner abundances increased with the flow measures, and that increases were strongest in the upstream most reaches closest to the Skagit Project.

Information Relevant to Skagit River Relicensing: The report provides quantitative data that are relevant to the Synthesis Study and specifically on Project Impacts. The study focused on reaches upstream of the Baker River confluence, and therefore is directly relevant to Reaches 7-8 in the Study Area for the Synthesis Study, but their analysis included Project impacts in reaches upstream of Reach 7. Their study area included a Reach 3 that includes all of the Study Area for the Synthesis Study Reach 8 and the downstream portion of Reach 7, and a Reach 2 that includes the upstream portion of Reach 7 at the Sauk River confluence. They also evaluated trends in populations in the Sauk River as a control for evaluating trends related to changes in flow regulation. Therefore, results summarized in this report are relevant to Reaches R7, R8, and Sauk River. The following summarizes quantitative data and metrics related to the Study Area for the Synthesis Study or general information.

Fish and Habitat: This report provides quantitative data on many metrics for fish and habitat, including average density of Chum and Pink spawners and Chinook redds by reach for pre (<1985) and post (>1985) periods; trends in escapement for odd-year Pink, fall-run Chum, and summer-fall run Chinook for upper and lower Skagit River (percent per year, mean, S.E.) for 1959-1981 and 1983-2001; and spawner densities by reaches. The following describes quantitative data for reaches within the Study Area for the Synthesis Study or general population demographic information (e.g., life histories, distribution, age structure), and we translate the author's reaches to the Study Area for the Synthesis Study reaches for consistency.

> ***Pink Salmon:*** Carcass densities significantly increased by 231 percent from 171 carcasses/mile pre-1983 to 566 carcasses/mile post-1983 in portions of reach R7. In contrast, carcass densities decreased (not statistically significant) by 46 percent in reach R8 and portions of R7 from pre-1983 at 222 carcasses/mile to 119 carcasses/mile post-1983. Pink Salmon are dominated by an odd-year return cycle. Pink spawn predominately (90 percent) in main-stem habitats, but mostly in upper Skagit River. Typically spawning age at age 2.
>
> ***Chum Salmon:*** abundance data were only available for portions of reach R7, where no significant differences in spawner densities were detected between pre- and post-1983 periods, with spawner densities of 247 and 288 fish/mile in even years and 93 and 70 fish/mile in odd years for pre- and post-1983 periods respectively. Chum Salmon are fall-run with cyclically high abundances in even years. Chum Salmon prefer to spawn in side channels, sloughs, and shallow, lower velocity, protected areas along the margins of the main channel. Typically spawning age at age 3 – 4.
>
> ***Chinook Salmon:*** Redd densities were significantly higher in portions of reach R7 in even years than odd years with average redd densities of 25 and 30 redds/mile in odd years in portions of reach R7 pre- and post-1985, respectively, compared to 18 and 47 redds/mile in even years pre- and post-1985 respectively. In portions of reach R8 and R7, redd densities were 12 and 13 redds/mile in odd and even years in portions of reach R7 pre- and post-1985, respectively. "Emergent fry in the study area exhibit an ocean-type life history, with most fry migrating to the ocean by the late spring or early summer." Run types include three spring runs, two summer runs, and one fall run. Typically spawning age at age 3 – 4.

Periodicity information is also presented based on summaries of other studies and are summarized here based on life stages. ***Adult spawning periods:*** Pink Salmon September – October (odd years), Chum Salmon November – December, and Chinook Salmon August – October. ***Incubation periods:*** Pink Salmon September – March, Chum Salmon November – May, and Chinook Salmon August – April. ***Emergence periods:*** Pink Salmon February – April, Chum Salmon March – May, and Chinook Salmon January – April. ***Outmigration period:*** Pink Salmon February – April, Chum Salmon March – May, and Chinook Salmon January – August.

Status and trends patterns for each species are analyzed and described in detail. Pink Salmon in the lower Skagit River changed from a negative trend of -2.5 percent per year in the 1959-1981 period, to a positive trend of 1.1 percent per year in the 1983-2001 period. Chum Salmon in the lower Skagit River had a trend of -12.5 percent per year 1974-1984 compared to no trend (0.0

percent per year) 1985-2001, and in the Sauk River trends were -8.8 percent per year 1974-2984 and -1.8 percent per year 1985-2001. Chinook Salmon had a trend of -3.3 percent per year 1974-1984 compared to -4.3 percent per year 1985-2001, and in the Sauk River trends were -5.1 percent per year 1974-2984 and -5.2 percent per year 1985-2001. Authors cite that releases of hatchery-reared spring Chinook do not appear to influence abundance of Chinook on spawning grounds, and little hatchery straying observed.

Hydroelectric Operations: Linkages with Skagit Hydroelectric Project operations were detected mostly in patterns of abundance and distribution in reaches upstream of the study area for the Synthesis Study with effects attenuating with distance downstream of the Project (which the authors attribute partly to the influence of unregulated tributaries entering the Skagit River with increasing distance downstream) and included; significant increase in Pink Salmon spawner abundance in Reach 7 and in upstream reaches; significant increases in Chum spawner abundance in reaches upstream of the study area but not in Synthesis Study reaches; significant increases in Chinook redds in Reach 7 and reaches upstream of the Study Area for the Synthesis Study; significant increasing trends in Pink and Chum post agreement that were greater than trends observed in other basins; and stable abundance of Chinook Salmon in the Study Area for the Synthesis Study compared to declining trends in unregulated basins of the Skagit River. Pink Salmon spawner densities increase as differences between spawning and incubation flows are reduced as indicated by a curvilinear lol-log regression with differences in average spawner and incubation flows with a two-year lag preceding the return year. For Chum Salmon, spawner abundance increase with increasing minimum flows but varies between odd- and even-years based on flows with a four-year lag preceding the return year. The authors link the observed changes in fish abundance metrics with distance from the Project to changes in egg-to-fry survival that are inferred from improved redd survival and stranding with implementation of the flow agreement, but these are interpretations of the data and not supported by monitoring data during these life stages.

The report summarizes flow for pre-(1909-1930) and post-Project periods (1981-2001) as well as for key Salmon life stages (spawning and incubation for Chinook, Chum, and Pink) as well as monthly statistics, and include metrics describing minimum and maximum life stage flows, and downramping limits/rates. However, all flow metrics and hydroelectric operations metrics summarized in the report are based on the U.S. Geological Survey (USGS) gauging station for the Skagit River at Newhalem (number 12178000) or the Skagit Hydroelectric Project, which are located upstream of the Study Area for the Synthesis Study. Therefore, none of the flow metrics or Hydroelectric Operations metrics reported in this study directly describe instream flow in the Study Area for the Synthesis Study.

Connor et al. 2015 (Unique Identifier: 413)

Reference	Connor, E., E. Lowery, D. Smith, K. Ramsden, B. Barkdull, B. Warinner, R. Hartson, and R. Brocksmith. 2015. Tributary assessment for potential Chinook salmon rearing habitat and recommendations for prioritizing habitat protection and restoration.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: capacity, freshwater, restoration, data gaps; Fish: rearing, abundance, distribution; Monitoring: abundance. ***Modeling Tools:*** juvenile production, habitat. ***Geomorphology and Landforms:*** slope, aquatic habitats and landforms, floodplain. ***Land Use and Cover:*** land cover.									
Species and Life Stages	***Chinook***: rearing, spawning.									
Reaches and Spatial extent	Sauk River, Day Creek, Nookachamps Creek, Finney Creek, Jackman Creek, other lower Skagit tributaries, other upper Skagit tributaries, other Sauk River tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: This study developed several alternative assessment and modeling approaches for identifying, estimating, and ranking tributaries in the Skagit River basin according to their intrinsic ability to support Chinook Salmon. They used spawner abundance observations from tributaries and a multiple regression approach, an intrinsic potential approach, and the percent of spawners contributed by tributary approach screen tributaries for rearing habitat. The three modeling approaches provided the same rankings of tributaries for spawning potential for the highest ranked streams. The authors then determined the rearing potential by identifying reaches with lower gradients and floodplains that were most likely to include habitat suitable for Chinook rearing. They considered stream segments to have suitable rearing habitat if they had a gradient of 4 percent or less and were classified as moderately confined or unconfined. They excluded tributaries that were less than 7.3 m (24 ft) in width from the analysis because they were less likely to support increased Chinook densities. For each tributary, they multiplied the length of the habitat that met the gradient and confinement criteria by the estimated channel width to get an estimate of the amount of rearing habitat that may be available.

Information Relevant to Skagit River Relicensing: The report provides quantitative data and modeling tools that are relevant to the Synthesis Study, and specifically data relevant to tributaries in the Study Area for the Synthesis Study. Specifically, it provides predictions of spawner abundance based on watershed variables for Skagit River tributaries in Table 1, intrinsic potential values, and rankings for Chinook spawner productivity in tributaries in Table 3, and percent of total spawners contributed by the tributaries for the six Chinook populations in the Skagit basin in Table 4. Table 5 provides the estimated relative rearing habitat area for tributaries, which is used to provide recommendations for incorporating the tributaries into the Tier 2 Target Area in the Skagit Watershed Council 2010 Strategic Approach. The information in this report can be used to assess the potential for future habitat and restoration for the benefit of Chinook spawning and rearing for tributary habitats in the basin. The habitat factors considered in their analysis could be used to inform the conceptual life history models for Chinook Salmon spawning and rearing life stages. Quantitative data for topics of interest are described in more detail below.

Fish and Habitat: This report provides quantitative data on metrics for fish and habitat. Specifically, it provides multiple regression predictions of Chinook spawner abundance using drainage area, forest canopy, spawning length, and basin slope from each tributary as predictor variables and ranks the tributaries according to the number of spawners that would be expected. Of relevance to the Synthesis Study, Finney Creek was ranked #2 with 185 potential spawners, Nookachamps was ranked #5 with 115 potential spawners, Day Creek was ranked #6 with 110 potential spawners, North Fork Sauk was ranked #7 with 106, and South Fork Sauk was ranked #8 with 90 potential spawners (see Table 1). Intrinsic potential (IP) values and rankings for Chinook spawner productivity in Skagit tributaries are provided in Table 3. The composite IP scores were calculated using the gradient IP, width IP, and mean basin IP for each tributary. The "Reach IP" value was then calculated by multiplying the IP score for each tributary category by the length (miles) of the tributary accessible to spawning Chinook Salmon. The rankings of tributaries from the IP method are shown in Table 3. From the top ten tributaries, the ones that are relevant to the Synthesis Study are Finney Creek, which was #2 with a reach IP value of 5.88; Day Creek at #5 with a reach IP value of 3.70; South Fork Sauk at #8 with a reach IP value of 2.29; and Nookachamps Creek at #10 with a reach IP value of 1.77.

The percent of total spawners contributed by tributaries for the six Chinook Salmon populations in the Skagit basin are provided in Table 4. The table contains the number of tributary spawners, average population run size, percent run in tributary, and the rank of the tributary. The top tributaries for spawning potential are identified by the screening criteria, which include Finney Creek as #2, Day Creek as #5, Nookachamps Creek as #6, and South Fork Sauk as #8. Finally, Table 5 presents the estimated rearing habitat area for pre-screened tributaries in the Skagit River. The table contains the drainage area, mean precipitation, estimated channel width, low gradient length, and an estimated amount of rearing habitat available in each tributary. The authors note that there were data limitations in terms of mismatches in the scale used to calculate gradient and a scale that was biologically relevant to fish. The use of more precise tools such as LiDAR or direct measures could be used to fill the data gaps. They also note the need for a complete dataset that identifies floodplains associated with tributaries.

Modeling Tools: The report provides models developed to predict potential spawners in tributaries and intrinsic potential in Skagit River tributaries. The regression model resulted in the following equation that could be used to predict the number of spawners supported by a tributary:

$$\text{Spawners} = -142.4 + (1.31 \times \text{Area}) + (18.47 \times \text{Length}) + (0.83 \times \text{Canopy}) + (1.14 \times \text{Basin Slope})$$

They used the IP methodology that has been used by NOAA, U.S. Forest Service, and others to identify the best streams in a large basin for salmon and steelhead production. A composite IP score was then calculated with the three variables for each tributary using the equation:

$$\text{IP} = (\text{Gradient IP} \times \text{Width IP} \times \text{Mean Basin Elevation IP})^{1/3}$$

The "Reach IP" value was then calculated by multiplying the IP score for each tributary category by the length (miles) of the tributary accessible to spawning Chinook Salmon.

Curran et al. (2016) (Unique Identifier: 373)

Reference	Curran, C. A., E. E. Grossman, M. C., Mastin, and R. L. Huffman. 2016. Sediment load and distribution in the lower Skagit River, Skagit County, Washington. U.S. Geological Survey Scientific Investigations Report 2016–5106. Available at: http://dx.doi.org/10.3133/sir20165106.									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Links
Topics and Keywords	*Geomorphology:* change, sediment transport and supply, substrate or sediment, climate change. *Modeling Tools:* hydrology, sediment. *Fish and Habitat:* Habitat: instream flow. *Water Quality and Productivity:* turbidity. *Hydroelectric Operations:* flow regulation.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	*Fish and Habitat:* Habitat: instream flow.									

Summary: The authors developed and evaluated regression models of sediment transport (sediment-rating curves) by utilizing 175 measurements of suspended-sediment load, made routinely from 1974 to 1993, and sporadically from 2006 to 2009. Five different regression models were evaluated. The five types of models they used were ordinary least squares, polynomial least squares, seasonal, time-interval, and flow-range. The flow-range model had the closest fit between estimated and measured suspended sediment concentrations (SSC). Using this regression model for 75 years of daily discharge (1941-2015), a mean annual suspended-sediment load in the Skagit River of 2.5 teragrams (1 Tg = 1 million metric tons) was estimated. Individual large floods accounted for as much as 40 percent of annual sediment delivery. In 2007, an extremely wet year an annual load of 4.5 Tg was measured from daily suspended-sediment samples collected with an automated sampler. For 2007, the flow-range rating curve overestimated the SSC by 6.7 percent, while the seasonal rating curve underestimated load by 11 percent.

A summer low-flow model showed poor correlation between SSC values estimated from discharge and measured SSC values. The poor correlation indicates that discharge is a poor surrogate for SSC during the summer low-flow period. A comparison of models for three-time intervals revealed an overall increase of 66 percent in the slope of the SSC to discharge relation between 1974-1976 and 2006-2009. The increase suggests changes in sediment supply, channel hydraulics, and/or basin hydrology.

Particle size was an important factor controlling sediment delivery and deposition. The percentage of fines generally increased with increasing discharge during the winter storm season. A continuous turbidity record from the Anacortes Water Treatment Plan from water year 1999-2013 was used as a surrogate for the concentration of fines. The turbidity record confirms that about one-half of the mean annual suspended-sediment load is composed of fines, and they conclude that their results support the hypothesis that turbidity is a useful surrogate for the concentration of suspended clay and silt that is held in the water column but less useful for suspended sands.

Information Relevant to Skagit River Relicensing: Regression models were developed to relate SSC to discharge, turbidity, and flow distribution the 15-km stretch of lower river, including the primary distributary channels of the Skagit Estuary, and these modeling tools and results are directly relevant to the Synthesis Study. The flow-range model had the closest fit between estimated and measured SSC. All the models have considerable variability and poor correlation during summer low-flow periods. The increase in SSC over time suggests changes in sediment supply, channel, hydraulics, and/or basin hydrology. These relationships can be used to estimate sediment delivery and relative particle-size distribution and inform proposed delta restoration design, as well as simulating how deltas and beaches will respond to climate change or sea level rise.

The authors also indicate that instream flows in the lower Skagit River are influenced by dams on the upper Skagit and Baker River, but the hydrograph is typical of large rivers in western Washington with… "*high flows typically occur from mid-October to March as a result of precipitation, and from April to mid-July as a result of snowmelt; the annual low-flow period generally is from mid-July to mid-October*." Mean daily discharges from 75 years of data from the Mount Vernon USGS gage are provided (1941-2015), with 5-95th percentiles and maximums. Suspended sediment concentrations (mg/L), percent fines (<0.0625 mm), and suspended sediment loads (Mg/d) are also reported for multiple water years (1974-2009) for the Mount Vernon USGS gage in plots and summary tables, as well as some information on particle size distributions. Numerous summaries of quantitative data could be extracted from the report based on measured or modeled data, but the modeling tools developed in this study are perhaps most relevant to the Synthesis Study given that they can be used to support integration of sediment supply and transport dynamics into other modeling efforts.

Davis (1981) (Unique Identifier: 257)

Reference	Davis, S. K. 1981. Determination of body composition, condition, and migration timing of juvenile chum and chinook salmon in the lower Skagit River, Washington. Master's thesis. University of Washington, Seattle.									
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: condition, periodicity; Habitat: instream flow. ***Water Quality and Productivity:*** temperature, turbidity.									
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration. ***Chum:*** outmigration, estuary rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary, R14 and R15 (between Mt. Vernon and the river mouth).									
Linkages to Hydroelectric Operations	NA									

Summary: This is a Master's thesis detailing outmigration timing, condition factor, and proximate analysis of lipid, protein, and ash content in juvenile Chum and Chinook collected in Freshwater Slough (Skagit Estuary). Fyke netting was conducted in Freshwater Slough from April 10 to June 14, 1979. Chum were the most abundant salmonid encountered; outmigration peaked in early-May with minor peaks observed in mid-April and mid-May. Chinook Salmon outmigration exhibited two peaks; the smaller peak occurred during late-April through early May while the larger peak occurred from mid-May into June. Catch per unit effort of both species was highest at night. Timing of migration was correlated with river discharge and the largest catches occurred during periods of rapid increase in river discharge. Condition factor in both species increased rapidly early in the study period and became more variable in the following weeks. Lipid levels declined sharply during early weeks of the study while protein levels increased coincidentally, likely reflecting tail-end of yolk sac absorption. A rapid decline in both lipid levels and condition factor later in the study period (May 14 – 18) may have resulted from reduced food availability following the first peak river discharge. This study provides insight into seasonal variability in body composition for wild Chum and Chinook Salmon outmigrating through a large estuarine system.

Information Relevant to Skagit River Relicensing: This thesis contains relevant information on juvenile Chum and Chinook condition and outmigration timing (periodicity) through the Skagit Estuary. Relationships between outmigrant movement, body condition, and flow are of particular relevance, and the data presented therein may be used to parameterize a model to predict changes in outmigration periodicity or body condition under different flow regimes in the estuary. Several tables with relevant quantitative data are contained in the appendices and relevant information is described in more detail below.

Fish and Habitat: Hourly catches of Chum (as a percent of total daily catch) are available in Appendix 4, and these data can be extracted to reconstruct outmigration rates. Nightly Chum catch per unit effort is available in Appendix 5, values ranged from 0 to 214.15 (fish/hr). Appendices 6 and 7 contain hourly and nightly catches for Chinook. Nightly Chinook CPUE ranged from 0.9 to 46 (fish/hr). Summary statistics for body condition data (condition factors, percent lipids, percent proteins, percent ash, and mean fork length) are presented in Appendices 8 and 11 for Chum and Chinook, respectively. Condition factor for Chum Salmon was highest between May 21-25. The average body condition values for Chum Salmon from mid-March to mid-June was 0.1424 (dry weight condition factor), 11.2 percent lipids, 70.7 percent protein, 8.1 percent ash, and 39.8 mm fork length. Condition factor for Chinook Salmon (all size ranges) peaked from June 4-8. Average body condition values from mid-March to mid-June for Chinook Salmon was 0.1898 (dry weight condition factor), 6.9 percent lipid, 73.2 percent protein, 9.66 percent ash, and 48.4 mm fork length.

Weekly mean body condition metrics are presented for two Chinook size classes (< 50mm and ≥ 50mm) in Appendices 12 and 13. Breaking Chinook Salmon into two size groups, condition factor for Chinook Salmon (< 50 mm) was highest from June 4 – 8. Average body condition values from mid-March to mid-June for Chinook Salmon (< 50 mm) was 0.1796 (dry weight condition factor), 6.9 percent lipid, 73.0 percent protein, and 9.54 percent ash. Condition factor for Chinook Salmon (≥ 50 mm) was highest from April 30 – May 4. Average body condition values from mid-March to mid-June for Chinook Salmon (≥ 50 mm) was 0.2175 (dry weight condition factor), 6.0 percent lipid, 74.5 percent protein, and 10.3 percent ash. Appendices 9 and 10 present weekly means, standard deviations, and sample size for fork-lengths of Chum and Chinook taken by in-channel fyke netting and beach seining, respectively. Fork lengths for outmigrating salmon caught in the fyke net ranged from 38 to 41 mm for Chum Salmon and 42 to 57 mm for Chinook Salmon. Fork lengths for outmigrating salmon caught in beach seines ranged from 37 to 42 mm for Chum Salmon and 40 to 59 mm for Chinook Salmon. Weekly mean dry weights and fork lengths Chinook are presented in Appendices 14 (for < 50mm) and 15 (for > 50mm). These data could be extracted and used as parameters in a life cycle model that incorporates body condition factors.

<u>Water Quality and Productivity</u>: Mean daily water temperatures and Secchi depths are available in Appendix 2 and Appendix 3. Water temperatures ranged from 7.0 ºC in early April to 12.5 ºC on June 12. Secchi depths were generally high > 1.5 – 2.0+ indicating clearing to clear waters in April and May but values were lower < 1.5 indicating cloudy water through most of May and June.

Engman et al. (1983) (Unique Identifier: 438)

Reference	Engman, G., S. C. Crumley, and Q. J. Stober. 1983. Chapter 2: Skagit River steelhead studies - 1983. Draft report for City of Seattle, Department of Lighting, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Yes
Topics and Keywords	**Fish and Habitat**: Fish: periodicity, distribution, abundance, size structure, harvest, hatchery. **Hydroelectric Operations**: stranding, downramping.									
Species and Life Stages	**steelhead**: migration, spawning, emergence, rearing.									
Reaches and Spatial extent	US of R7, R7-R12 (mainstem between Rockport and Newhalem), Sauk River, other lower Skagit tribs, other Sauk River tribs.									
Linkages to Hydroelectric Operations	**Hydroelectric Operations**: stranding, downramping.									

Summary: This is a study that was funded by Seattle City Light to define the period, exact timing, and general distribution of steelhead spawning activity for redd/depth flow analysis and expected mainstem fry distribution. The Washington Department of Game performed seven aerial redd surveys of the Skagit River mainstem at 13-to-20-day intervals from March through June 1983 followed by additional aerial and on-the ground surveys of Skagit tributaries and the upper Sauk River. Stranding studies were also conducted from August-October.

Information Relevant to Skagit River Relicensing: This report contains information about periodicity, abundance, and distribution of steelhead spawning activity in the Skagit River (R2 – R12), upper Sauk River, and Skagit River tributaries. It also contains information and data about stranding. The information presented in this report is relevant to the Synthesis Study in that it provides historical estimates of steelhead spawner abundance within the Skagit watershed and estimates of stranding mortality that can be used to help contextualize modern conditions.

Fish and Habitat: Peak instantaneous redd numbers in 1983 were observed in May, consistent with data extending back to 1975. Wild steelhead spawning typically starts in March and extends into June. Aerial redd counts from 1975 to 1983 are presented in Tables 2 and 3. Escapement estimates broken down by sub-basin were calculated based on aerial redd counts and presented in Table 4. Estimated escapement in mainstem reaches ranged from 474-1530 for the Skagit, 167-1203 in the Sauk River, 170-688 in Suiattle, and 102-412 in Cascade River from 1977-1983. In tributaries of these subbasins, escapement ranged from 2237-5358 for Skagit River tributaries, 214-441 for Sauk River tributaries, 98-265 for Suiattle tributaries, and 2-116 in Cascade tributaries during the same time periods. Roughly 80 percent of all steelhead spawning from 1977-78 to 1982-83 occurred in tributary streams (excluding Cascade and Sauk sub-basins), and it is believed that tributary spawning is a major contributor to juvenile abundances later observed in mainstem rearing areas. Tributary spawning relative to mainstem spawning may be influenced by run strength. In strong-run years, mainstem spawning increases while tributary spawning remains relatively stable, leading to a relative decrease in tributary spawning but no absolute change in tributary use. Total run size, harvest, and escapement estimates for spawning periods 1977-78 through 1982-83 are available in Table 5, which include estimates for hatchery and wild origin adults. steelhead fry stranding on gravel bars in 1983 is summarized in Table 6, however this study appears to have focused on R7 – R2. Maximum observed fry stranding occurred on August 17th, 1983. Based on observations that numbers of stranded fry declined throughout the study period, the researchers suggest that fry may be most susceptible to stranding early in the emergence period. Pothole stranding occurred at several sites throughout the study and peaked on August 24th followed by a gradual decline in the presence of potholes through to September 9th. The researchers suggest that smaller fry were more susceptible to stranding but length data were not collected in August during this study. Average length of stranded fry in September was 40.9 mm, and the data suggested that fry were less susceptible to stranding after reaching 40 mm. By early October, most fry had achieved sufficient growth and their distribution had shifted towards deeper waters within the channel, greatly reducing stranding risk.

ESA (2017) (Unique Identifier: 039)

Reference	Environmental Science Associates (ESA). 2017. Riparian assessment. Report prepared by ESA for Skagit Watershed Council, Mount Vernon, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related*** No
Topics and Keywords	***Fish and Habitat:*** Habitat: riparian, status and trends, invasive species. ***Geomorphology and Landforms:*** channel migration, large wood, log jam, side and off-channels, floodplain connectivity, aquatic habitats and landforms. ***Land Use and Cover:*** forestry, banks and shoreline, roads. ***Water Quality and Productivity***: bacteria, contaminants, dissolved oxygen, temperature, pH.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Watershed, including Sauk River, Day Creek, Finney Creek, Hansen Creek, Nookachamps Creek, and other Sauk River tribs.								
Linkages to Hydroelectric Operations	NA								

Summary: This report provides data and supporting information to help interested parties understand current riparian conditions throughout the entire Skagit River watershed. The assessment was designed with intention to help quantify the amount of riparian restoration that has been completed, existing conditions of priority riparian areas, status and trends of riparian habitat function by habitat and land ownership type, and to identify priority areas and strategies for future restoration. After classifying riparian cover, several riparian assessment metrics were calculated to address questions related to riparian function (cover type, area proximal to channel, canopy height), migration potential (hydromodification and off channel habitats), and impairment (floodplain connectivity). These metrics provide a baseline assessment of the riparian conditions in the Skagit Watershed and can be used to support restoration planning, develop hypotheses, direct monitoring efforts, and prioritize restoration actions.

Information Relevant to Skagit River Relicensing: This report provides extensive information on riparian conditions in the Skagit Watershed including the Study Area for the Synthesis Study mainstem, estuary, and tributary reaches. The information presented in this report can be used to identify and prioritize riparian restoration and protection efforts throughout the entire Skagit Watershed. This report includes an inventory of recent riparian habitat conditions, provides relevant quantitative data in tables, summarizes available spatial layers, and provides several conceptual frameworks for using riparian assessment data to inform riparian restoration and protection priorities. Habitat conditions characterized for this report include habitat type and edge types, water quality impairments (e.g., polluted waterbodies), presence of invasive species, and presence of log jams. Many of these attributes are available as shapefiles and may be obtained upon request to ESA or the SWC. These data could be used to inform a life cycle model, identify impaired habitats, or prioritize areas for restoration/monitoring. Data assembled and inventoried for this assessment include shapefiles, imagery, and modeled layers describing reach and riparian boundaries, canopy heights, floodplain impairments, vegetation classes, edge habitats, invasive species presence, depth and velocity layers, aerial imagery, logjams, riparian plantings, land cover/use classification layers, and protected area boundaries. Spatial data gathered/produced for this report and other data products are listed in Appendix A and maps are available in Appendix

B. These data may be available by request to ESA or the Skagit Watershed Council and could support efforts to characterize riparian conditions, inform a life cycle model, or conduct other spatial analyses within the Study Area for the Synthesis Study. Supplemental data overlays outlining protected lands, habitat types, and 303d water quality listings may have utility for the Synthesis Study as well. Quantitative data provided in the report are described in more detail below.

Fish and Habitat; Land Use and Cover: Riparian cover was classified for 62,683 acres of the Skagit River watershed, of which 65 percent was forested and roughly 26 percent was classified as an altered cover type (built, bare earth, agriculture). Table 10 shows percent forest cover, percent shrub, and percent altered land cover classes within 40 m of the active channel by reach and tributary. While upper Skagit reaches had 85 percent or greater forest cover within 40 m of the active channel, reaches near Mount Vernon – Sedro-Wooley (R14 – R12) had less than 45 percent forest cover within 40 m of the active channel. Similar patterns were seen with tributaries (less forested cover in the lower reaches and higher in the upper). Figures 15, 16, and 17 summarize percent forested, shrub, and altered land cover classes by each reach and tributary. It was noted that the percentage of shrub classes is noticeably higher in reaches downstream from Cockreham (R11). The Sauk-Suiattle mainstem and tributaries both had over 74 percent forest cover within 40 m of the active channel and shrub classes in this area were mainly natural successional stands following river erosion. Figures 18 through 20 further break down riparian forest cover by width bins (0-20m, 20-40m, and 40-91m from active channel). Forested cover in the Lower Skagit decreased laterally as distance from the channel increased while the Upper Skagit showed no decreasing pattern in forest cover with distance from the channel. The Sauk-Suiattle showed the opposite pattern, showing increasing forested cover as distance from the active channel increased. This finding is indicative of the relatively undisturbed state of the Sauk-Suiattle rivers where dynamic alluvial processes dominant the landscape. These data are important for identifying priority areas for restoration and protection. High forested areas (>90 percent) are generally considered priority areas for protection while areas with higher shrub cover can be considered for future riparian forest restoration.

Canopy heights for roughly 50 percent of the mainstem and Skagit tributary reaches, between Marblemount (R5) and Cockreham (R11), were represented by trees > 60 ft in height. Canopy heights in the Sauk-Suiattle were dominated by trees in smaller height categories due to natural alluvial erosion. However, no reaches in the mainstem Skagit had over 70 percent >60ft tree height canopy within 0-40m of the active channel, which may limit large wood recruitment given that large wood recruitment is partially driven by tree height (proxy for size) and proximity to the active channel. By contrast, the Sauk-Suiattle had higher percentages of tall trees >60ft within 0-40m of the active channel.

Status and trends of riparian cover was assessed for the entire study area between 2006 and 2013. Natural loss of forest cover was higher than loss caused by anthropogenic activities. Data from voluntary riparian plantings are included in this analysis in order to capture net increases or decreases in forest cover and functional riparian cover (0-40m extent). Reaches with the greatest forest cover loss were due to forestry activities beyond 91m (300ft) of the active channel, and so did not represent any immediate loss to salmonid habitat function. No reaches displayed cumulative loss within the functional riparian zones (0-40m extent) in the Upper Skagit and Skagit mainstem tributaries. Many reaches have gained functional riparian forest cover since 2006 as a result of voluntary and regulatory protections and riparian planting efforts. Table 18 summarizes forest cover status and trends and the primary driver of change for all reaches within the floodplain extent. The greatest gains were at the Ross Island reach (R11) (254.6 acres) while the greatest losses occurred in the lower Sauk (-32.2 acres).

Riparian restoration and plantings by reach are summarized in Figures 34 and 35. No plantings have occurred in the Upper Skagit mainstem and in 9 Sauk reaches and tributaries. The percent area at each reach under protected status is summarized in Figures 37 through 39. These data can be used to flag areas for priority protection or restoration consideration. Protected lands currently comprise 42 percent of the total land area within the watershed. Several conceptual frameworks and models are presented in Figures 41 and 42 which provide guidance for prioritizing and planning riparian restoration actions.

Geomorphology and Landforms; Land Use and Cover: Off-channel habitats and off-channel habitat to channel length ratios are indicators of channel migration potential. Table 11 compares ratios of off-channel habitats to channel lengths for reaches in the Sauk-Suiattle and Skagit mainstem reaches. In addition, Table 12 provides off-channel habitat areas under 2-year flood conditions and complementary off-channel to channel length ratios for reaches in several of the larger tributaries within the Skagit watershed. Channel and floodplain impairments, such as bank hydromodifications, percent of isolated or shadowed (by levee or roads) habitats, and percent of altered riparian cover are summarized in Tables 13 and 14. The reach with the highest percent of hydromodified bank was near Skiyou (R12) at 22 percent while several Upper Skagit tributaries and Sauk-Suiattle reaches had 0 percent hydromodified banks. Following a similar geographic pattern, floodplain impairment and altered riparian cover was highest at Lower Skagit reaches and lowest in Upper Skagit and Sauk-Suiattle reaches.

Water Quality and Productivity: Water body impairments (i.e., pollution) are listed in Table 20. Most reaches that are considered impaired waterbodies are due to low dissolved oxygen or extreme pH and temperatures.

FERC (1980) (Unique Identifier: 439)

Reference	Federal energy regulatory commission (FERC). 1980. Water resources appraisal for hydroelectric licensing. FERC-0057. Appraisal report prepared by FERC, Office of Electric Power Regulation San Francisco Regional Office.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Yes
Topics and Keywords	***Hydroelectric Operations:*** flood control, flow regulation, life stage flows. ***Geomorphology and Landforms:*** aquatic landforms, sediment supply and transport, history, floodplain, estuarine habitats and landforms. ***Land Use and Cover:*** forestry, agriculture, urban, banks and shoreline. ***Fish and Habitat:*** Habitat: instream flow, barriers; Fish: distribution. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity, bacteria, contaminants.								
Species and Life Stages	***All anadromous species:*** rearing, migration.								
Reaches and Spatial extent	Skagit Watershed, including Sauk River and Baker River.								
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flood control, flow regulation, life stage flows.								

Summary: This report was prepared by the staff of the Federal Power Commission as part of a program of Water Resources Appraisals for Hydroelectric Licensing. The report is intended to provide information which the Commission and staff may use or build upon when considering issues related to hydroelectric relicensing. Much of the material presented in the report is based on "*reconnaissance-type information*" and detailed quantitative data are limited. The report includes several chapters that include: (1) Description of the Basin, (2) Prior Reports and Current Investigations, (3) Economy of the Basin, (4) Existing Water and Related Land Resource Development, (5) Skagit River Project, (6) Economic and Human Needs for Further Development of Water and Related Land Resources, and (8) Possible Future Developments and Utilization of Water Resources. Detailed information on current power generating infrastructure and capabilities are provided for many projects current and potential future projects at the time of the report.

Information Relevant to Skagit River Relicensing: Much of the material presented in the report is based on "*reconnaissance-type information*" and detailed quantitative data are limited with a notable lack of citations for much of the quantitative or descriptive information presented. The scope of the report includes the entire Skagit River Watershed including the lower Skagit River, the Skagit Estuary, and several major target tributaries for the Synthesis Study (Baker River, Sauk River). Chapter 1 provides potentially useful "high-level" information on the Skagit River watershed with summaries of geography, physiography, geology and soils, climate and hydrology, and water quality but quantitative data are limited and descriptions are presented at coarse geographic scales with limited quantitative data that would be directly relevant to the Study Area for the Synthesis Study. Some general information on several topics of interest are provided for Fish and Habitat, Land Use and Cover, Hydroelectric Operations, and Water Quality and Productivity that are described in more detail below.

Geomorphology and Landforms*:* Geomorphology is generally described in Chapter 1. Sediment supply and transport is referenced in the water quality section, with a value of 10 million tons of sediment transported annually. The report indicates that this is due mostly to glacial inputs, but it is unclear to which spatial or temporal extent this estimate applies to. Sediment supply and transport concerns are also mentioned in Chapter 6, where unregulated tributaries are cited as a source of debris that can impact farming.

Fish and Habitat: This report notably contains little information on fish and fish habitat. A brief section (about 0.5 pages) in Chapter 4 indicates that the Skagit River is an excellent steelhead stream to support fisheries, and the river contains "*quality rearing habitat, especially for steelhead and for all five species of Pacific salmon*." Lack of anadromy above the Gorge Dam is noted, and fish collection structures associated with the Baker River projects are briefly described as well as other mitigation actions for losses of Sockeye spawning habitat. A preliminary regulations schedule prepared by the previously named Washington State Departments of Game and Fisheries is mentioned in Chapter 8, which prescribes minimum flows and fluctuation constraints for the discharge of Gorge Dam [presumably for fish], but this is caveated with the concern that "*losses in capacity and energy to Project No. 553 which could result from minimum flow regulation of the project have not been determined.*" Otherwise, not quantitative data on fish or specifically on fish habitats are provided in the report. Instream flows at USGS gages are summarized in Table 3, including gages at Concrete, Sedro Woolley, Mount Vernon, Sauk River, and Baker River. Flood risk from unregulated tributaries are mentioned in Chapter 6, and a recommendation for development of more flood control infrastructure is made but no quantitative data on the contribution of tributaries to flooding are provided.

Land Use and Cover*:* Chapter 3 provides an overview of land uses and cover in the Skagit Watershed, with an emphasis on land uses for forestry and agriculture as well as recreation, mining, and population growth related topics. Levee projects are identified as a means to reduce flood damage in the floodplains and Skagit Estuary where extensive agricultural land uses occur, and where the Samish and Skagit River deltas become connected during high flow events (Chapter 8). The extent of dikes/levees are described in Chapter 3, with 89.8 km of levees and 63 km of "*sea dikes*" reportedly protecting 18,200 ha of land from flooding. Maps of recreation facilities are provided in Figure 4.

Hydroelectric Operations*:* Power generating infrastructure and considerations are described, in great detail with supporting figures and tables (see Table 7), for both Baker River and upper Skagit River projects. Information on power generating capacities and many references to the operation of current infrastructure to support flood control as well as recommendations for future projects (e.g., in tributaries or improvements to existing projects) to improve flood control and reduce flood damage (see Chapters 4-8). Flood control and water supply are most extensively discussed in Chapter 4, 7, and 8. Maps of power generating infrastructure are provided (Figure 3), as well as current and future projects (Figure 6 and 22), and numerous photos of facilities. Chapter 5 provides a detailed history of the Skagit River project, but no references to downstream conditions linked to the projects or changes associated with the projects are mentioned for the Study Area for the Synthesis Study. Summaries in this chapter are mostly focused on the infrastructure itself and do not describe linkages to habitat or other factors.

Water Quality and Productivity: The report indicates that water quality is "*high*" or "*excellent*" with summaries of some concerns provided in Chapter 1. Maximum recorded stream temperatures at Mount Vernon are reported as 18°C with a mean high of 9.4°C but no date ranges are provided for these values. Dissolved oxygen concentrations are reported as near saturation, but it is not clear at what location or specific extent this refers to. Chemical water quality in "*all sections*" are cited as meeting US Public Health Service drinking water standards, and "*toxic and deleterious material*" concentrations are cited as "*low*." Bacteriological concentrations are cited as variable, with counts of coliform increasing downstream of Marblemount due to residential inputs. Salt water intrusion in groundwater is cited as a concern for floodplains in the Skagit River delta, but current concentrations are low (at the time of the report) suggesting minimal salt water intrusion in groundwater.

Gayeski et al. (2011) (Unique Identifier: 137)

Reference	Gayeski, N., B. McMillan, and P. Trotter. 2011. Historical abundance of Puget Sound steelhead, *Oncorhynchus mykiss*, estimated from catch record data. Canadian Journal of Fishery and Aquatic Sciences 68:498-510.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: abundance, harvest, hatchery, status and trends, survival; Habitat: ocean, status and trends, capacity.								
Species and Life Stages	***steelhead***: migration.								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: This study estimates historical abundance of harvestable winter run steelhead using commercial catch records from four major rivers (Nooksack, Skagit, Stillaguamish, and Snohomish) and the aggregate remainder of rivers in Puget Sound in 1895, the year of peak commercial steelhead harvest in Washington State. Bayesian data analysis was used to account for uncertainties in the estimation process and irregularities in catch reporting. Results from this analysis are compared to a 2005 NOAA Fisheries status review summarizing the previous 25 years of steelhead trends. The central 90 percent posterior distribution of abundance estimates ranged from 485,000 to 930,000 (mode = 622,000) winter run adult steelhead in Puget Sound, 1895. The 25-year average abundance estimates between 1980 and 2004 was 22,000 by comparison. The authors posit that loss of accessible stream lengths alone could not account for the dramatic difference in steelhead abundances observed between 1895 and 1980 – 2004. Rather, contemporaneous reductions in habitat quality have likely hamstrung steelhead production potential in Puget Sound. The importance of recovery efforts focused on improving existing habitat quality is underscored by the findings of this study.

Information Relevant to Skagit River Relicensing: Estimates of historical abundance, harvest rates, and accessible stream kilometers for Skagit River winter run steelhead are presented in this paper which may be of value as references for comparison against current or future conditions. However, these estimates are at a basin scale and do not provide detail specific to the Study Area for the Synthesis Study and would need to be used or interpreted appropriately. Detail of early European-American settlement of the Skagit River basin (and other major watersheds) are also discussed, which provides rich historical context when considering current anthropogenic impacts to anadromous fish in the region. The authors also found that steelhead early marine survival does not appear to strongly correlate with ocean productivity indices (e.g., Pacific Decadal Oscillation) as it does with other species like Coho. As this analysis is fully Bayesian, the posterior distributions for estimated parameters on steelhead abundance, harvest rates, and total catch could be used as inputs (i.e., prior distributions) in an expanded model which considers Project Impacts, for example.

Fish and Habitat: A 2005 NOAA fisheries status review for Puget Sound steelhead estimates a 25-year average run size for the Skagit River at 6,994 adults. Posterior parameter distributions for abundance (run size), total catch, and harvest rate for winter run steelhead in the Skagit River for 1895 are provided:

- Run size: Average = 105,600; SD = 24,700; Mode = 86,700; Central 90 percent interval = 70,000 – 149,000.
- Total catch: Average = 43,900; SD = 5,300; Mode = 43,300; Central 90 percent interval = 35,000 – 53,100.
- Harvest rate: Average = 0.43; SD = 0.09; Mode = 0.31; Central 90 percent interval = 0.31 – 0.58.

Estimates of historically and currently accessible stream lengths are also presented in this paper. For the Skagit River, an estimated 1,473 km of stream were accessible in 1895 which roughly translates to 59 fish-per-accessible-kilometer (FKM). Compared to contemporary estimates from a 2005 NOAA Fisheries status review of 982 km of accessible stream lengths (~7.12 FKM). Additional abundance, catch, harvest rate, and habitat loss estimates are reported for other rivers in Puget Sound. The authors include a section on relevance for recovery planning. Importantly, they provide several hypotheses for the dramatic declines in steelhead production in Puget Sound which they believe has outpaced stream habitat loss. Some of the hypotheses/avenues for further research they offer include interactions with hatchery conspecifics, reductions in run sizes, and simplification of life history components (i.e., reduced iteroparity), and/or changes in marine survival patterns. Depending on the causes of population declines, it may still be possible to see major recovery given the amount of suitable stream habitat that still exists in Puget Sound.

Gislason (1980) (Unique Identifier: 406)

<table>
<tr><td>Reference</td><td colspan="10">Gislason, J. C. 1980. Effects of flow fluctuations due to hydroelectric peaking on benthic insects and periphyton of the Skagit River, Washington. Doctoral dissertation. University of Washington, Seattle.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Thesis</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: distribution, diet; <u>Habitat</u>: instream flow. Geomorphology and Landforms: substrate and sediment, sediment supply and transport. Water Quality and Productivity: primary productivity, secondary productivity, pH, turbidity, dissolved oxygen, nutrients, salinity (conductivity), temperature. Hydroelectric Operations: flow regulation, downramping.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: rearing, spawning, migration. Coho: rearing, spawning, migration. Chum: rearing, spawning, migration. Pink: rearing, spawning, migration. steelhead (and resident Rainbow Trout): rearing, spawning, migration. Lamprey: rearing, spawning, migration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R7, US of R7, Sauk River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Hydroelectric Operations: flow regulation, downramping. Geomorphology and Landforms: sediment supply and transport. Fish and Habitat: <u>Habitat</u>: instream flow. Water Quality and Productivity: primary productivity, secondary productivity.</td></tr>
</table>

Summary: This doctoral thesis focused on the effects of hydroelectric peaking at the upper Skagit River dams on periphyton and benthic invertebrates in the Skagit River. Periodic exposure of stream edge habitats associated with diel changes in water levels from hydroelectric peaking and downramping cause desiccation of periphyton and benthic invertebrates, and this can reduce standing biomass and confine the distribution to a "permanent flow zone" that is not subject to daily water level fluctuations. The primary objective of this study was to *"determine if the benthic insect standing crop and community structure in the section of the Skagit River between Gorge Powerhouse and the confluence of the Sauk River had been altered by peaking flow fluctuation and to determine the probably causes of any changes."* The study initiated in 1976 and continued through 1977, and focused on the Skagit River but also included other Pacific Northwester coastal streams as references given that pre-project data could not be collected for comparison. The author also used artificial stream channels to study the effects of flow reduction on benthic invertebrates and their ability to avoid standing. In general, the study found a trend of increasing chlorophyll a with decreasing exposure to desiccation.

Information Relevant to Skagit River Relicensing: This study provides potentially relevant information for the Synthesis Study and describes linkages between Hydroelectric Operations and primary and secondary productivity, but the study was primarily focused on reaches the "*section of the Skagit River between Gorge Powerhouse and the confluence of the Sauk River."* Although the study area description extends to the Sauk River confluence, we noted that sampling sites were not located in Reach R7 and only the Sauk River sampling stations provide information for the Study Area for the Synthesis Study (see Figure 1 for map of sampling sites). We note that the author defines a lower and upper Skagit sampling location but these are both in the upper Skagit River reaches between reach R7 and the dams and should not be confused with lower Skagit reaches as defined in the Study Area for the Synthesis Study. However, the patterns identified that are associated with stable or fluctuating flows in the Skagit and Sauk River and the artificial stream studies could be informative to the development of conceptual models for the Synthesis Study.

Fish and Habitat: General descriptions of species distributions and uses are described for target species including anadromous salmonids and lamprey, but this information is provided for reference and context for potential impacts of the study findings and are not presented in a quantitative manner. A section on the implications for fish feeding is provided in the discussion section of the report, and potential linkages between primary and secondary productivity results and fish diets/growth are made throughout the report, but these are presented as context for the results, are based on references or cited studies, and are not directly quantified in this study.

Analyses of stream gage data are presented for the Sauk River, as well as the USGS gage on the Skagit River at Concrete. All other gages analyzed were located upstream of the Study Area for the Synthesis Study. A time series of river flow (mean daily discharge) for 1976-1977 are shown in Figures 3-4, which includes the Sauk River and Concrete gages. Figures 5-6 provide a comparison of monthly flows in the Skagit River that show reduction in streamflow during the spring runoff period (May – July) associated with flow regulation (1954-1975; and 1976-1977), and augmented (increased) streamflow in other periods, but these are based on the USGS gage at Newhalem upstream of the Study Area for the Synthesis Study. Diel changes in river flows are also shown in Figures 7-10, but these are also based on USGS gages upstream of the Study Area for the Synthesis Study. Daily flow fluctuations on the Sauk River are shown in Figures 11-12. Water velocities were monitored at each sample site and are summarized in Table 11, with the author noting that water velocities were higher at the Sauk River stations but within an optimal range for stream invertebrates.

Water Quality and Productivity: The artificial stream studies focused on three species of aquatic insects collected from and common to the Skagit River and Sauk River; *Ephemerella tibialis, Acroneuria pacifica*, and *Dicosmoecus* sp. The artificial stream study attempted to determine the ability of these species to avoid stranding associated with flow fluctuations, and their ability to survive desiccation. Water quality data from USGS, including pH, dissolved oxygen, nutrients (total nitrate, ammonia nitrogen, and total phosphorous), turbidity, and conductivity are generally described for the upper Skagit River and Sauk River. Mean annual summaries of water quality parameters are provided in Tables 7-9. Temperature data were also summarized and shown in Figures 18 for the Sauk River and mainstem Skagit River. An increasing trend in chlorophyll a with decreasing desiccation was detected and shown in Figure 21, and time series of chlorophyll a concentrations from periphyton are shown in Figures 22-23. Turbidity was noted as being 20x higher in the Sauk compared to the Skagit, and overall lower chlorophyll a concentrations in the Sauk were linked to the differences in turbidity. Peak flow events in the Sauk River were linked with reductions in periphyton due to scour in the months following the peak flow event.

Benthic macroinvertebrate communities are described for each section of the Skagit and Sauk River sampled in this study, and a list of all encountered species is provided in Appendix I. The distribution of macroinvertebrates were linked to seasonal changes in stream flows. Mean densities of macroinvertebrates are shown in Table 14, but Tables 15-16 provide mean densities broken out by year and sampling station that include the Sauk River. Survival estimates associated with desiccation by taxa are also provided from the artificial stream experiments (Table 22). Percent composition by month and station is shown in Figure 41 and 43, and diversity indices by month in Figure 42.

Geomorphology and Landforms: Substrate was characterized at sampling locations including the Sauk River sites, and substrate size composition is summarized in Table 10. No significant differences were detected between Skagit and Sauk River sites for most substrate size classes except 0.85, 0.425, and <0.106 mm size classes with the Sauk River sites having the highest percentage of 0.85 mm particles and Skagit sites having higher percentages of <0.106 mm size category. Reduced sediment supply and transport from reservoirs and increasing sediment supply and concentration from tributaries as distance from the dams increases is identified but quantitative data are not presented to describe these patterns.

Hydroelectric Operations: The author links standing biomass of periphyton and benthic invertebrates to Hydroelectric Operations. Extensive reference information is provided to demonstrate the effects of peaking on primary and secondary productivity in other systems, as well as to support the hypotheses that changes in primary and secondary productivity can influence the productivity of Pacific salmon and steelhead that rely on the Skagit River. The authors acknowledge that the effects of peaking in Pacific Northwester coastal streams may be less severe compared to other regions due to ecological and geomorphological adaptations to peak flow events associated with heavy rainfall or snowmelt events. Overall, the study concludes that several benefits of impoundment and flow regulation were noted in the results with increased standing crop of benthic invertebrates noted as a result of more stable flow conditions overall that ameliorated the negative effects of flow fluctuations during periods of peaking. Ultimately, the author concludes that "*comparisons of benthic insect standing crop under the fluctuating and stable flow regimes clearly indicates the beneficial effects of stablished flow in the Skagit River. Reduction in the degree of daily peaking fluctuations would greatly enhance insect production in the river. However, a relative natural seasonal flow regime should be maintained, including the release of large volumes of water at some time during the year, to flush accumulated sediment out of the interstices between substrate particles.*"

As noted above, Figures 5-10 shows changes in monthly and diel flow patterns associated with flow regulation, but these are based on USGS gage data upstream of the Study Area for the Synthesis Study. The impact of tributary inputs on changes in flow patterns, or dampening of fluctuations, was noted in that mean daily ranges in water level were less at the Marblemount gage than the Newhalem gage, although tributary inputs can also increase flow variation as a source of unregulated flow to the system. Temperature data were also summarized and shown in Figures 18, and the author notes that release of reservoir water is linked to higher temperatures in the Sauk River from October to December and lower temperatures in February to September as compared to the mainstem Skagit River. Impoundment of water at reservoirs is identified as a factor reducing the supply and transport of sediment downstream, but inputs from tributaries would increase the amount of sand and silt in sediments as distance downstream from the dams increases.

Changes in the width of periphyton were associated with peaking flows as shown in Figure 44, with peaking flows reducing the width of the periphyton zone. Densities of macroinvertebrates were linked to fluctuating flow patterns, with density increasing with increasing depth (presumably a signal of reduced exposure to diel changes in water levels). This pattern was reversed under stable flow conditions. Figure 26 shows patterns of macroinvertebrate densities with depth and month for the Skagit sampling sites, and reduced densities associated with increased hours of exposure are shown in Figure 30. Mean macroinvertebrate densities under periodic and 48-hour exposure to flow fluctuations are shown in comparison to controls and experimental treatments in Tables 17-20. Flow fluctuations in the experimental channel that were designed to mimic weekend flow variations in the upper Skagit River resulted in a 22 percent reduction in insects, which would significantly reduce potential food resources available to salmonids. However, it is unclear if these results would apply in the lower mainstem Skagit River given the attenuation of effects for flow regulation with increasing distance from the dams. Differences in benthic invertebrate densities in the regulated Skagit River and unregulated Sauk River are also shown (Figures 31-34), and differences in the unexposed zones are shown in Figures 36-40.

Graybill et al. (1979) (Unique Identifier: 259)

Reference	Graybill, J. P., R. L. Burgner, J. C. Gislason, P. E. Huffman, K. H. Wyman, R. G. Gibbons, K. W. Kurko, Q. J. Stober, T. W. Fagman, A. P. Stayman, and D. M. Eggers. 1979. Assessment of the reservoir-related effects of the Skagit Project on downstream fishery resources of the Skagit River, Washington. Final report for City of Seattle Department of Lighting by Fisheries Research Institute, University of Washington, Seattle.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	Yes
Topics and Keywords	***Fish and Habitat***: Habitat: instream flow; Fish: abundance, periodicity, hatchery, density dependence, harvest, survival, distribution, condition, rearing. ***Water Quality and Productivity***: temperature, primary productivity, secondary productivity, turbidity. ***Modeling Tools***: habitat. ***Hydroelectric Operations***: flow regulation, stranding.								
Species and Life Stages	***Chinook***: spawning, incubation, rearing. ***Coho***: spawning, incubation, rearing. ***Chum***: spawning, incubation, rearing. ***Pink***: spawning, incubation, rearing. ***steelhead***: spawning, incubation, rearing. ***Other species.***								
Reaches and Spatial extent	R8, R7, US of R7, Sauk River, Baker River, Other upper Skagit tribs.								
Linkages to Hydroelectric Operations	***Hydroelectric Operations***: flow regulation, stranding. ***Fish and Habitat***: Fish: survival, condition, rearing; Habitat: instream flow. ***Water Quality and Productivity:*** temperature.								

Summary: This extensive report describes the findings of studies designed to establish an ecological baseline for aquatic habitats of the Skagit River between Newhalem and Concrete (Reaches R1 – R8), including the Sauk and Baker Rivers and other upper Skagit tributaries. The rationale for focusing on these reaches was because it was determined that was where most of the impacts resulting from the Skagit Hydroelectric Project would occur. The report begins with a brief introduction of the Skagit Hydroelectric Project and a description of the physical characteristics (instream flow, temperature, and profile and gradient) of the study area. Subsequent studies were carried out to determine the effects of flow fluctuations on primary productivity (periphyton) secondary productivity (aquatic invertebrates) and compared to surveys conducted in the Sauk and Cascade Rivers for reference. Next, studies detailing project impacts on salmon and steelhead spawning, incubation, emergence, and fry rearing are presented. An additional chapter covering non-salmonid fishes is also presented. The studies in this report arrived at several conclusions summarized here:

- Reducing water level fluctuations by implementing a stable flow regime resulted in higher standing crop of periphyton and benthic insects.
- Flow reductions likely strand many aquatic insects, of which mayflies (Ephemeroptera) are especially susceptible.
- Zooplankton production in the reservoirs above the dams survive passage to the upper Skagit and were observed as far down river as R9 where they are presumably available to salmonid fry. However, feeding on zooplankton appears sporadic and opportunistic.
- No correlations could be identified between Chinook escapement/run size and patterns in flow during spawning, incubation, or rearing.
- Angler surveys revealed that fishing effort is low in the upper Skagit compared to the lower Skagit. Utilization was highest near Rockport steelhead Park in R7.

- Skagit River Chinook and Pink Salmon prefer deeper and faster water than conspecifics in smaller streams. Depth appears to be less important than velocity. Skagit River Chum appear to spawn in deeper waters than conspecifics in other streams, but similar velocities. Skagit River steelhead depth and velocity ranges were similar to other values reported in the literature.
- The periodicity of summer-fall Chinook was similar to other river systems, with peak spawning occurring in early September. Pink Salmon spawned from the end of September to the end of October, with peak spawning occurring in early October. Chum Salmon spawning period ranged from early November to late December and peaked in early-mid December. steelhead spawned from March to June but peak spawning was not well defined. Finally, Coho spawned from mid-October until mid-January.
- Fluctuating low flows drove adult Chinook off their redds, but residual water was always present beneath the redds.
- Peak spawnable discharge for areas above the Sauk River (R7 and up) was 3417 cfs for Chinook and 1824 cfs for Pink, Chum, and steelhead. However, it was noted that not all of the potential spawnable area was actually used by fish.
- The Skagit River temperature regime is warmer that it was before the dams were present. Skagit River Chinook fry emerge about one month earlier than Sauk and Cascade River fry. Early emergence of Chinook from the Skagit appears to coincide with less favorable environmental conditions for rearing.
- Residence time of Chinook fry in R1-R5 is 15 to 30 days on average. This would imply that at least half of emerging fry in early February would disappear by early March, but significant growth and seaward migration doesn’t peak until April and later. The most logical conclusion is that mortality among early emerging Chinook fry is probably extremely high.

Information Relevant to Skagit River Relicensing: This report provides the results of a collection of studies primarily focused on reaches upstream of the Synthesis Study, but includes information on Reaches R7-R8, Sauk River, and Baker River. Extensive baseline information on fish and habitat, water quality and productivity, modeling tools, and hydroelectric operations topics of interests and metrics are presented. The information here could be used to support the development of hypotheses, compare current conditions to a historical baseline, develop life history models, etc. While it was not always possible to determine which data were specific to the Study Area for the Synthesis Study, relevant data related the study area, and specific reach names, are called out where possible in the summary section below.

<u>Fish and Habitat</u>: Section 5.2 describes hatchery production in the Skagit for Chinook, Coho, Chum, and steelhead from 1952 – 1977. Table 5.1 contains hatchery production and numbers of fish planted each year by species from Boyd Creek (R10) to Newhalem (R1). Table 5.2 provides a summary of fish plants in the Skagit River from 1974 to 1977 between Concrete (R8-R9) and Ross Dam. Plant locations are given and can be mapped to specific tributaries and Study Area for the Synthesis Study reaches, including Baker River, Sauk River, and other upper and lower Skagit tributaries.

Table 5.3 presents natural spawning escapement estimates for Chinook, Pink, Chum, and Coho Salmon. Quantitative estimates of escapement to the Skagit Hatchery racks are displayed in Table 5.4. Data for tribal and sport harvest of steelhead and anger survey are presented in section 5.5 – 5.6 for the Sauk, Cascade, and the entire Skagit (Tables 5.6 – 5.8). These data could be useful for

quantifying historic harvests and effort for potential use in a fishery harvest model or for calculating common fishery statistics, such as maximum sustainable yield. Summary of angler efforts (# of excursions, anglers, and trucks or boats) for 1977 – 1978 for the upper Skagit, but also parts of R7, are presented in Table 5.9.

Spawn timing is for Chinook, Pink, Chum, Coho, and steelhead are summarized in section 6.4.2. Spawner count by date graphs displayed for each species. Periodicity of spawning is given for the areas of the mainstem Skagit included in the study area, but steelhead spawn timing is also summarized for the Sauk River. Spawner distribution is summarized in section 6.4.3. An estimated 78.2 percent of Chinook escapement spawned in the Skagit mainstem, 13.6 percent in the mainstem Sauk, 3.8 percent in the Cascade River, 1.7 percent in the Baker River, and the remaining 2.7 percent spawned in other tributaries. Within the mainstem, 66.4 percent of spawning occurred upstream of the Sauk confluence and 33.6 percent occurred downstream. Summaries of redd counts separated by study area locations are summarized in table 6.4 through 6.7.

Section 7.0 discusses incubation and emergence. They cite other studies that showed the completion of the Ross, Gorge, and Diablo dams raised water temperatures in the river relative to pre-dam conditions, especially in the fall and winter wen salmon eggs incubate. The logical conclusion is that embryonic development should accelerate through faster accumulation of temperature units (TU ºF; cumulative degree days above 32 ºF). A study was conducted to assess the effects of elevated river temperatures on the timing of fry emergence, largely focused on Chinook. Additional field studies for Pink, Chum, and Coho took place 1977 – 1978 as well. A literature review in Section 7.2 describes the thermal requirements for Chinook eggs to hatch and for fry to emerge under natural conditions, and they found that 974 TUs are required to reach 50 percent hatching of Skagit River Chinook.

The temperature/incubation study took place at four stations in R1 – R7 and in the Sauk and Cascade Rivers. Eggs were collected from migrating adults and fertilized. Egg diameter and weights were measured in 1976 and 1977. River incubation times were measured by burying 50-80 eggs in artificial redds within the Skagit, Sauk, and Cascade Rivers and monitoring until emergence. Additional eggs were transported to a UW hatchery and monitored for incubation. Egg and alevin mortality were monitored daily. Time to hatching and yolk absorption were measured. These experiments were repeated at different temperature regimes simulating the recorded temperature regimes from 1953-1977 and the mean, recent, and long-term temperature regimes for the Sauk and Cascade Rivers as well. Similar experiments were repeated for Pink, Chum, and steelhead. The results from these studies are summarized in section 7.5. Mean hatching (50 percent hatched) from eggs incubated in the Skagit in 1974 was estimated to occur in mid-November at 940 TUs accumulated. Date to mean yolk-absorption (50 percent of fry with yolk absorbed) was estimated to occur by February 28th, 1975 at 1913 TUs accumulated. The range of mean hatch dates (1976 to 1977) was from November 5 to December 16 and the range of TUs was 968 to 1000 and a mean of 981 (SD = 14). The average time from fertilization to hatching was 61 days. The range of dates to mean yolk absorption for 1976 to 1978 was February 6 to March 13 and the average TUs required was 1929 (SD = 153). Mean number of days from fertilization to yolk absorption was 151 (range: 139 to 165). Date to mean yolk absorption in 1977 and 1978 were March 15 and 19 with an average of 2055 TUs required. Table 7.2 to 7.4 summarize hatch date, temperature units, mean incubation temperatures, and yolk absorption dates for each monitoring station in the Skagit, Sauk, and Cascade Rivers.

Individual egg diameters and weights taken in 1975 are displayed in table 7.5. Egg diameter (range: 7.96 – 9.16 mm) and weight (range: 0.287 – 0.441 g) four Skagit River Chinook were correlated with TUs required to reach mean yolk absorption (r = 0.97 and 1.00, respectively). Egg diameters and weights were not well correlated with TUs to mean hatching (r = 0.28 and 0.43, respectively). Table 7.6 summarizes mean hatching and mean yolk absorption (Date, TUs, # of days, and mean temperature) for the Skagit, Cascade, Sauk Rivers, and the UW hatchery in 1976. Date to mean yolk absorption occurred 51 days later in the Sauk and 56 days later in the Cascade compared to the Skagit.

Timing of fry emergence was measured over artificial Chinook redds at each station. Date of emergence in 1975 was typically in late January (18 – 25). Table 7.22 summarizes data on juvenile Chinook emergence. Fry condition at emergence from incubation boxes were compared to fry caught from electrofishing in Table 7.23. Length weight and condition factor of emergent Chinook fry under hatchery conditions are given in Table 7.24.

Fry rearing is described in section 8.0. Juvenile Chinook, Coho, Pink, Chum, and steelhead were sampled by electrofishing at several stations Skagit Mainstem (R1 – R7) and in the Cascade and Sauk Rivers, as well as several other tributaries (Goodell, Bacon, Diobsud). Sampling from 1974 to 1977 generally took place biweekly from January to August. Table 8.1 through 8.5 summarizes Chinook fry catch and density at each sample date across sites. Timing of emergence and downstream migration periods are described. For example, Chinook fry from 1977 were first encountered in mid-December and juveniles were collected at the river mouth as early as March 23rd, 1977. Mean lengths, weights (wet and dry), and condition factors for the Sauk River are summarized 8.11 and 8.16. Chinook fry in the upper Skagit were smaller on average (41.6 mm; 0.153 g) than fry from the Sauk (43.8 mm; 0.1565 g). Skagit River fry also had a lower average condition factor. However, analyses suggest that Skagit fry condition factor was slightly higher or equal to those in the Sauk at the period of emergence (February to March) but deviated lower by mid-April. The authors note that some of the larger fry produced by the Sauk River near the end of the rearing period may have been spring run Chinook fry from the Suiattle River migrating through the study area. Higher turbidity in the Sauk River in 1977 may have reduced growth and condition factor compared to the Skagit.

Section 8.1.4.3 summarizes Chinook fry diets in 1975 from the Skagit (n = 250) and Sauk (n = 113). Diptera (chironomid larvae followed by adults) was the most common prey item in the Skagit and Sauk. Copepods were the second most abundant followed by Ephemeroptera nymphs, cladocerans, and Plecoptera nymphs. The frequency of Plecoptera nymphs compared to Ephemeroptera nymphs in stomach samples was greater in the Sauk. Tables 8.19 through 8.28 present stomach sample data. Percent of fry with yolk remaining by river and sample date was also quantified and summarized Tables 8.31 and 8.34 (Sauk River). Similar data for fry rearing is presented for Pink [Table 8.43 (R7), 8.44 (R9)], Chum [Table 8.47 (Sauk), 8.50 & 8.57 (R7)], Coho [8.65 & 8.77 (Sauk), 8.75 (R7)], and steelhead [Table 8.92 (R7), 8.94 (Sauk) and 8.99 (R9)].

Water Quality and Productivity: Long-term temperature (23-year average) regimes and semi-monthly temperature regimes are presented for the Skagit, Sauk, and Cascade rivers (Figure 2.27 – 2.31). Their analysis of temperature regimes in the basin led to the conclusion that the general effects of Skagit Hydroelectric Project has been to elevate fall and early winter temperatures and reduce late winter, early spring, and summer temperatures. Mean monthly turbidity data for the Sauk River for 1976 and 1977 are presented in Tables 3.8 and 3.9, as well as other locations outside the Study Area for the Synthesis Study. A study on plankton drift was also conducted with monitoring stations located along the river in reaches R1 – R8. Zooplankton feed into the Skagit River from Ross Reservoir but gradually become depauperate as the river progresses downstream. Table 4.1 – 4.9 contains zooplankton counts at monitoring stations from April through December 1977. Monitoring stations for zooplankton were outside of the Study Area for the Synthesis Study with the exception of one station at Concrete (R9).

Modeling Tools: Depth and velocity were measured at active Chinook, Pink, Chum, and steelhead redds and compared to values from smaller streams in the literature. Mean, standard deviation, range, and 80 percent data intervals are provided for each species in section 6.4.1. Skagit River Chinook and Pink Salmon spawned in deeper and faster waters than the same species in smaller rivers reported in the literature. Depth was the least important variable. The depth and velocity values provided could be used as inputs for an HSI model. Preferred spawning depth and velocity ranges were as follows: Chinook: 1.7 – 4.2 ft depth and 1.8 – 3.7 ft/s velocity, Pink: 0.9 – 2.5 ft depth and 1.2 – 3.2 ft/s velocity, Chum: 1.4 – 4.4 ft depth and 0.2 – 3.0 ft/s velocity, steelhead: 0.9 – 2.9 ft depth and 1.5 – 3.0 ft/s velocity. A steady state model to estimate residence time is presented in Section 8.3.3.3 and a simulation model is presented in Section 8.3.3.4. The estimated parameters could be used in a life cycle model. The authors criticize the accuracy of the fry population estimates produced by their models, therefore the predicted abundances from the models may be of limited use.

Hydroelectric Operations: Section 8.2 discusses fry stranding. Estimates of fry killed per linear foot were made by enumerating stranded fry on four exposed bars during flow fluctuation in March 1973. Stranding mortality data are presented in Table 8.103 and 8.104, which includes data at Rockport (R7). Analyses were also conducted to quantify the relationship between stranding mortality and ramping rate (rate of flow reduction) and is summarized in Section 8.2.3.3. However, fry stranding counts related to the ramping rate studies were outside of the Study Area for the Synthesis Study. Daily flow fluctuations resulting from Hydroelectric Operations reduce the periphyton habitable area within the stream channel at low flows and scour areas where periphyton grow during high flows. The net effect of daily flow fluctuations in regulated reaches is to reduce periphyton growth. Exposure at low flows also reduce periphyton growth through desiccation. The range of chlorophyll-a values in the Skagit, Sauk, and Cascade rivers were lower than similar North American rivers as indicated in Table 3.10. Relationships between percent of bed exposed and aquatic insect density and biomass are provided in figures 3.11 through 3.14. The authors conclude that diurnally fluctuating water levers during hydroelectric peaking has prevented productive benthic shoreline communities from establishing. As a result, during high flows salmonid fry would likely be forced into frequently exposed areas with low food abundance.

Artificial stream experiments indicated that periodic exposure resulting from fluctuating water levels over a period of at least one week can significantly reduce benthic insect density. Experiments testing stranding avoidance in benthic insects indicated that mayfly larvae are most likely to become stranded during dewatering compared to stonefly or caddisfly larvae.

Correlations between river flows at spawning, incubation, and rearing life history stages and returning run sizes were examined. No correlation could be determined for any life stage. The lack of correlation at the rearing life stage potentially indicates a compensatory mechanism masking the influence of fry losses due to stranding.

Greene et al. 2005 (Unique Identifier: 050)

<table>
<tr><td>Reference</td><td colspan="10">Greene, C. M., D. W. Jensen, G. R. Pess, E. A. Steel, and E. Beamer. 2005. Effects of environmental conditions during stream, estuary, and ocean residency on Chinook salmon return rates in the Skagit River, Washington. Transactions of the American Fisheries Society 134:1562-1581.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat</u>: limiting factors, freshwater, estuary, nearshore, ocean, instream flow; <u>Fish</u>: periodicity, harvest, hatchery, age structure, survival, sex structure, abundance, density dependence, competition, data gaps; <u>Monitoring:</u> abundance. Modeling Tools: adult returns.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: Full life cycle, incubation to outmigration, estuary rearing to emigration, nearshore rearing to emigration, ocean, migration, spawning.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit Estuary, and Reaches R1-R13.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: The authors used a 22-year time series of wild Chinook returns to the Skagit River to build predictive models based on environmental conditions experienced during freshwater, tidal delta, bay, and ocean life stages (1974-1995 brood years). They found that the best predictors of adult return rates were the magnitude of floods during incubation, as described by flood recurrence interval (FRI), and principal components of multiple indices of environmental conditions during bay residency and the third ocean year. The models they developed explained 90 percent of the variance in return rates with high forecasting precision, but ocean conditions only explained 5 percent of the variance, suggesting that conditions experienced during freshwater and delta life stages are more predictive of adult return rates than ocean conditions. They also found evidence of density dependence during incubation as indicated by the inclusion of an egg abundance parameter in the predictive model, but they found no evidence for competition effects from Pink salmon abundance.

Information Relevant to Skagit River Relicensing: This source provides quantitative data on fish and habitat, and models that can be used to inform the Synthesis Study. They developed a conceptual model for conditions experienced during different life stages and how they influence survival at different stages, including factors like FRI, sea surface temperatures (SST), sea level pressure (SLP), coastal upwelling index (UWI), and sea level (SL). Data used in this analysis are readily available and frequently updated/maintained and would support future analyses or expansion of analysis. The data and models provided in this source can be used to inform conceptual life cycle models and quantitative life cycle models as well as evaluate limiting factors and adult return forecasting. Quantitative information on the periodicity of Chinook in the Skagit System are provided as well as estimates of escapement to river, egg deposition, age-specific fecundity, age structure, sex structure, hatchery interactions, mixed stock harvest, terminal harvest, spawners per spawner and recruits per spawner for each brood year. The authors also discuss data limitations with respect to escapement estimates and harvest rates and how these impact the model results, including identification of important variables, and general monitoring of factors that inform management actions or monitoring needs for future research.

Fish and Habitat: Periodicity is generally described for Chinook based on the data they considered and cited studies. Adult Chinook spawn between July and October, peaking in low flow in September. Eggs incubate for about 5 months. Juveniles migrate downstream within a month of emergence and spend 1-2 months in the delta before migrating to marine habitats. Delta habitat use ranges from February to June, and Skagit Bay from June through October. Ocean residency ranges from 3-5 years. Data from 22 brood years (1974 – 1955) are presented and used to derive return rates as spawner per spawner and recruits per spawner, harvest rates, and egg production based on fecundity (see Table 2). Sex ratios ranged from 6.6 to 29.2 percent. On average, two-year old adults account for 0.9 percent of returns, three-year olds 13.7 percent, four-year olds 69.0 percent, five-year olds 16.5 percent, and six-year olds 0.2 percent of returns.

The authors derived flood recurrence intervals (FRI) from 1974-1995 for USGS station near Concrete, WA to describe peak flows. They also developed indicators for sea surface temperatures, sea level pressure, coastal upwelling, and sea level from readily available sources, which were used to describe marine conditions during key life stages, and as a proxy for conditions during delta and nearshore residency. These are presented as PCA factor loadings rather than actual values, but the original data can be obtained to support future analyses.

Greene et al. (2021) (Unique Identifier: 056)

Reference	Greene, C. M., E. Beamer, J. Chamberlin, G. Hood, M. Davis, K. Larsen, J. Anderson, R. Henderson, J. Hall, M. Pouley, T. Zackey, S. Hodgson, C. Ellings, and I. Woo. 2021. Landscape, density-dependent, and bioenergetic influences upon Chinook salmon in tidal delta habitats: comparison of four Puget Sound estuaries. Final Report prepared for Estuary Salmon and Restoration Program, ESRP Report 13-1508.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, side and off-channels, change. ***Fish and Habitat:*** Fish: abundance, density dependence, periodicity, growth, diet, hatchery, survival, life history; Habitat: estuary, restoration, capacity, wetlands. ***Modeling Tools:*** bioenergetics, habitat, connectivity.									
Species and Life Stages	***Chinook:*** rearing, estuary rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary.									
Linkages to Hydroelectric Operations	NA									

Summary: This report draws on a series of studies in four major Puget Sound estuaries (Nooksack, Skagit, Snohomish, and Nisqually) to help develop a set of general principles for characterizing rearing conditions in tidal river deltas within Puget Sound and beyond. There are three primary questions these studies attempt to address: 1) How do landscape-scale attributes and features affect juvenile Chinook distribution and abundance in tidal deltas? 2) How prevalent are habitat limitations (i.e., density dependence)? 3) Under what habitat conditions do juvenile Chinook experience variability in growth and/or food limitations in tidal deltas? The first study used long term beach seine and fyke net records to evaluate drivers of natural origin (NOr) and hatchery origin (HOr) juvenile Chinook abundance in estuaries with respect to landscape connectivity, wetland habitat type (forested riverine tidal [FRT], estuarine forest transition [EFT], and estuarine emergent marsh [EEM]), and channel type. It was determined that landscape connectivity is an important predictor of density of NOr Chinook, but not necessarily presence, and that blind channels disproportionately support rearing for NOr fish. The density dependence study combined data from all four estuaries into a stock-recruit analysis to determine seasonal and landscape patterns in habitat-specific capacity exceedance. The analysis showed that reduced tidal wetland habitats limits juvenile Chinook recruitment in Puget Sound by imposing a density dependent response, implying that tidal wetland restoration will ease early rearing population bottlenecks. Finally, the bioenergetics study found that diet energy density was variable through time and across wetland habitat types, implying that a “portfolio approach” to habitat management can improve juvenile Chinook growth conditions in Puget Sound estuaries. The implications of these studies for science-based restoration and recovery planning in Puget Sound estuaries are discussed, emphasizing the importance of diversity and connectivity of nearshore and estuarine habitat types.

Information Relevant to Skagit River Relicensing: This report combines data from the Nooksack, Skagit, Snohomish, and Nisqually River estuaries. While data and results specific to the Skagit is scattered throughout the report, all the major analyses, interpretations, and conclusions are general to Puget Sound tidal river deltas. Unless specified, the information presented below is not specific to the Skagit but is nonetheless relevant to the Synthesis Study. In addition, the information provided in this report can be used to inform development of conceptual life history models and identification of key factors influencing juvenile Chinook life stages.

Fish and Habitat: Natural origin small fry outmigrants in the Skagit rear extensively in blind channels and transition more slowly through wetland habitat. However, hatchery origin outmigrants had higher probability of being observed in the distributaries than blind channels. Variation in presence and density of NOr Chinook was independent of outmigration cohort size, refuting prior beliefs that large outmigration sizes "completely fill" estuary habitat. Peak co-occurrence of NOr and HOr fish for all estuaries occurred between weeks 17 and 36, overlapping with NOr residence (weeks 10-27). However, the duration of co-occurrence in the Skagit was shorter than the other estuaries. Median weekly subyearling migrations in the Skagit was over 60,000 but could be as high as 1.5 million in certain weeks/years.

Predicted capacity from a Beverton-Holt model for all four estuaries combined was 252.7 fish/ha but varied among on habitat types. Local juvenile Chinook densities regularly exceeded estimated capacity in the Skagit, with > 60 percent of observations exceeding 95 percent of the estimated capacity annually. Hatchery origin Chinook had a negligible effect on the exceedance frequency in the Skagit but had larger influence in other estuaries. Forested riverine tidal and estuarine forest transition habitat were more likely to exceed capacity than estuarine emergent marsh habitats, as were blind channels with respect to distributaries.

Table 2.1 summarizes wetland habitat characteristics and outmigrant numbers (total, fry, and hatchery releases) for the four estuarine river deltas. It was estimated that 74.1 percent of the habitat has been lost from the Skagit estuary. The range of total outmigrants (in 1000s) from the Skagit, based on data spanning from 1994 – 2015, was 1000.2 – 7712.3. Table 3.1 of summarizes tidal channel habitat areas estimates (ha). In the Skagit, there is an estimated 34.62 ha of distributary, 4.03 ha of primary distributary, 255.31 ha of tidal channel, and 293.69 ha of distributaries and tidal channel combined, and 38.12 ha of tidal complex area.

Table 4 of Appendix 2.2 summarizes landscape connectivity values at fourteen locations in the Skagit delta. Latitude and longitudes are given for each site as well as connectivity values for multiple years (2010 – 2016). Locations of smolt traps and estuarine habitat classification is shown in Figure 2.2. Sample sites and habitat attributes could be georeferenced and inventoried in a spatial database. Additionally, Table 2.2 contains corresponding landscape connectivity metrics and channel type attributes linked to study sites by a unique identifier. Figure 3.1 displays generalized relationships observed in natural-origin juvenile Chinook Salmon using the Skagit delta. These relationships may be used to support the development of hypotheses related to rearing and density dependence in estuary habitats. Figure 3.11 shows a decision diagram to help evaluate the optimal restoration strategy for a specific estuary system.

Table 3.2 contains Beverton-Holt parameters for predicting NOr density, modified to include a parameter for landscape connectivity. While not specific to the Skagit, the "All systems" model is parameterized using data from all four of the Puget Sound estuaries considered in this study (Nooksack, Skagit, Snohomish, and Nisqually). Instantaneous capacity estimates (Table 3.4) for the Skagit from the Beverton-Holt curve was estimated at 83,917, while the 90th and 95th density quantiles were 775,407 and 1,607,599 fish, respectively. The total channel area to support capacity (ha) was 332.08, which translates to 267.82 (fish/ha) for the Beverton-Holt estimate and between 2334 – 4841 (fish/ha) for the quantile estimates.

Modeling Tools: A bioenergetics model was used to evaluate individual growth among wetland habitat types. The analysis determined that growth pattern was dependent on arrival date and size. Mean growth potential was highest in FRT habitats early in the outmigration period and shifted to EFT habitats later. The main result of the bioenergetics study was that diet energy density was variable throughout the rearing period, as each habitat type displayed high growth conditions at some point in time. The general pattern was that freshwater wetland habitats (FRT) were more important early in the rearing period while marine-influenced habitats (EEM) offered more benefit later. Appendix 4.3 details a validation study of the bioenergetics model using otolith microstructure analysis. The overall average growth rate back calculated from otolith lengths at tidal delta entry was 1 g/day (range: 0.02 – 7.38 g/day). However, the distribution of growth rates were skewed, with ~70 percent of individuals experience growth below 1 g/day. Table 3 within Appendix 4.3 summarizes average growth (g/day) and average specific growth (g/g/day) at FRT (0.05 g/d; 0.03 g/g/d), EFT (0.10 g/day; 0.03 g/g/day), and EEM (0.16 g/day; 0.04 g/g/day) habitats. A length-weight relationship ($y = 2E\text{-}06x^{3.3822}$; $r^2 = 0.96$) was developed from fish sampled from the Skagit. The fitted parameter values can be re-used in a new analysis, either taken directly or used as priors in a Bayesian model.

Figures 4.5, 4.6, and 4.7 show trends in total energy consumption by estuary, week, and in relation to prey availability. These figures are useful for providing supporting information with respect to energy consumption in the Skagit estuary. The bioenergetics modeling results suggested that prey consumption in the Skagit was dominated by NOr fry between February and May before switching to NOr parr and HOr migrants through the remainder of the season. Energy consumption demand during the period of peak demand accounted for 50 percent of the total energy production.

Grossman et al. (2020) (Unique Identifier: 057)

Reference	Grossman, E. E., A. W. Stevens, P. Dartnell, D. George, and D. Finlayson. 2020. Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise, Skagit River Delta, Washington, USA. Marine Geology 430:106336.									
Source Information	*Type*	Journal	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Links
Topics and Keywords	*Geomorphology:* change, history, channel migration, channel incision, sinuosity, floodplain, side and off-channels, floodplain connectivity, substrate and sediment, sediment transport and supply, aquatic habitats and landforms, estuarine habitats and landforms, climate change. *Modeling Tools:* hydrology, climate change. *Land Use and Cover:* forestry.									
Species and Life Stages	None.									
Reaches and Spatial extent	Skagit Estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	*Geomorphology:* sediment transport and supply, estuarine habitat and landforms, change.									

Summary: The study authors used bathymetric change, sediment cores, and modeling to show how an estimated 142 ± 28 M m^3 of sediment, of which 68 percent was sand deposits, accumulated across the Skagit River delta between 1890 and 2014 related to land uses. The amount stored in reservoirs represents approximately 39 percent of the fluvial sand fraction over this time period. However, accumulation of 83 percent of the fluvial sand fraction found near the river mouth make retention in the delta foreset and tide flats effective metrics to evaluate land use impacts on sediment dynamics and ecosystems. A higher ratio of sand retention during the period 1890-1939, coinciding with extensive deforestation, channel dredging, and channelization activities, was found relative to the period 1940-2014, which was characterized by improved forest practices, and sediment management to protect endangered species.

Comparable offshore sand retention over time and higher nearshore retention before 1940 after normalizing for the assumed reduction in sediment runoff associated with improved forest practices, suggests the channelization has continued to influence sediment export at a magnitude equal to the effects of early logging. Adverse impacts of the bypassing sediment regime to natural hazards risk and ecosystem management concerns are discussed. Sediment budget and coastal change analyses provide a framework for evaluating opportunities to achiever great resilience in low-lying deltas worldwide.

Information Relevant to Skagit River Relicensing: The authors provide useful background information and narratives that describe the history of changes in sediment supply and transport that provide linkages between estuarine habitats and landforms and land uses (forestry, dredging, and diking) and dam operations (Baker River and Upper Skagit Dams). Their analysis provides quantitative and spatial data for a number of geomorphic metrics including estimates of changes in the amounts of sediment over time, and for which they describe linkages to sources of change that could inform the Synthesis Study as well as the Skagit River Relicensing GE-04 Geomorphology study. Changes in dam operations could result in changes in sediment supply and transport that are propagated downstream. Their results show that fluxes of sediment offshore are 5-10x higher under current conditions compared to Holocene rates, and this increased offshore transport bypasses emergent marshes and potentially impacts progradation rates in the Skagit River delta and potential resiliency to climate change. The sediment budget and historical change analyses provide a framework to assess coast responses to sediment delivery and routing to guide vulnerability assessments and resiliency planning. For example, they estimate that redirecting and retaining just 20 percent of the river sediment load within emergent marsh habitats could offset losses due to subsidence and levee construction, although it would take more than 22 years at this recovery rate to establish emergent marsh elevations that can be naturally maintained in the context of extreme tidal cycles.

Spatial data in the form of annotated aerial imagery maps show levee configurations; wetland types (estuarine emergent, estuarine scrub, palustrine, riverine tidal); channel configurations; locations of uplands, floodplains, and terraces; location of sediment reservoirs in the Skagit Estuary; digital elevation models of bathymetry including change from 1890 to 2014; and percent sediment composition and mean sediment size for sediment cores. Tabular summaries of sediment core samples provide estimates of accretion rates (mm/yr) and sediment budgets for different time periods that could be used to inform modeling tools.

Hartson and Shannahan (2015) (Unique Identifier: 415)

Reference	Hartson, R. and J.P. Shannahan. 2015. Inventory and Assessment of Hydromodified Bank Structures in the Skagit River Basin Chinook Bearing Streams. Final report submitted to Northwest Indian Fisheries Commission and Environmental Protection Agency. Prepared for The Upper Skagit Indian Tribe Natural Resources Division.									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Land Use and Cover:* banks and shoreline. *Fish and Habitat:* Fish: distribution; Habitat: status and trends.									
Species and Life Stages	*Chinook:* rearing.									
Reaches and Spatial extent	Reaches R1-13, including Sauk River, Finney Creek, East Fork Nookachamps, Day, Hansen, Jackman, and other tributaries (lower Skagit, upper Skagit, and Sauk River tributaries).									
Linkages to Hydroelectric Operations	NA									

Summary: This document reports on a 2015 field inventory of hydromodified banks in the Skagit basin. The inventory's extent encompasses all recorded Chinook Salmon bearing channels within the Skagit basin. This 2015 inventory was based on an initial inventory of hydromodified banks conducted in 1998 in the Skagit basin. The 2015 field inventory was conducted using Trimble GPS units and stored in a GIS database. In addition to capturing the spatial distribution of hydromodifications, the 2015 inventory also defined modification by "hydromodification type," "size class of material," "levee association," "length of structure," "location in channel," and more. Photos were also taken of each hydromodification. The results of this field inventory will be used to inform and prioritize restoration efforts in the Skagit basin.

Information Relevant to Skagit River Relicensing: This report provides data on hydromodified banks within the entire Skagit basin. This includes information in the main project area from the Gorge Dam to the Sauk River, and downstream to the highway 9 bridge crossing (Reaches R1-R13), including multiple tributaries of interest for the Synthesis Study. Tabular summaries of hydromodification length and feature counts by mainstem, secondary, and tributary channel lengths are provided for each reach and survey year. A reach map is provided that can be used to link tabular summaries to reach locations within the Study Area for the Synthesis Study, and maps of surveyed channels and Chinook distribution are provided. The proponents of the study indicate that they plan to solicit updates to the dataset on an annual basis, which would make the resulting habitat status and trends data set potentially useful for tracking changes in bank armoring and bank conditions in the Study Area for the Synthesis Study.

Hinton et al. (2008) (Unique Identifier: 174)

Reference	Hinton, S. R., W. G. Hood, N. E. Kammer, E. Mickelson, Z. Yang, T. Khangaonkar, E. E. Grossman, A. Stevens, and G. Gelfenbaum. 2008. McGlinn Island causeway and jetty habitat restoration feasibility phase 1: establishing the viability of hydraulic connectivity between Skagit and Padilla bays. Report prepared by Skagit River System Cooperative, Battelle Pacific Northwest National Laboratory, and U.S. Geological Survey, Puget Sound, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, nearshore habitats and landforms, change, history, sediment supply and transport. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat***: Habitat: restoration, estuary, nearshore, connectivity, barriers; Fish: abundance, distribution, density dependence. ***Modeling Tools***: hydrology, bathymetry, data gaps. ***Water Quality and Productivity***: salinity, temperature. ***Monitoring***: water quality, flow.								
Species and Life Stages	***Pink, Chum, Coho, Chinook:*** estuary rearing and emigration, nearshore rearing and emigration, adult migration.								
Reaches and Spatial extent	Skagit Estuary, Skagit Bay, Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: Swinomish Slough historically connected Skagit and Padilla Bays, and was a significant migratory corridor for juvenile Skagit River Chinook Salmon seeking rearing habitat in Padilla Bay. However, "*decades of engineering have changed this waterway from a highly complex, braided deltaic distributary wetland to a simplified, yet efficient, navigation channel*." The objective of this report is to evaluate the feasibility of "*restoring connectivity of natural processes between the North Fork of the Skagit River and this historic distributary*." Full connectivity comparable to historical conditions is recognized as an unreasonable goal for restoration, but the study explores "*the prospect of measured actions that seek to restore a level of hydraulic and geomorphic connections that work to the benefit of Pacific salmon*." To support this goal, surveys of existing conditions were conducted, analytical models were developed to explore hydraulic processes, and the historical chronology of alterations and the construction and maintenance of the waterway (Swinomish Channel) were considered. Specific objectives identified by the study include:

> ***Objective 1:*** *Determine likely location(s) for breaching the causeway or jetty to restore connectivity between the North Fork Skagit River and the Swinomish Channel. Likelihood refers to maximizing freshwater and salmonid passage while minimizing sediment transport from the North Fork Skagit River to the Swinomish Channel. It also includes a very general (1st-order) assessment of likely construction feasibility and costs, and a general estimate of the likely maintenance needs or risks*.
>
> ***Objective 2***: *Determine the amount of freshwater flow that could be restored from the North Fork Skagit River into the Swinomish Channel to create a salinity gradient along the channel suitable for outmigrating Chinook, and investigate alternatives for producing such a diversion.*
>
> ***Objective 3:*** *Predict likely changes in salinity for the Swinomish Channel and the lower North Fork of the Skagit River following restoration of connectivity.*

> ***Objective 4***: *Predict changes in juvenile salmon, especially Chinook, passage from the North Fork Skagit River to Padilla Bay following restoration of connectivity.*
>
> ***Objective 5***: *Determine the changes in sediment transport and deposition in Swinomish Channel resulting from reconnection to the North Fork Skagit River, and investigate alternatives for minimizing the introduction of sediment with the fresh water from the Skagit. Acceptable levels will be determined in consultation with the US Army Corps of Engineers (USACE), who have already declared that some increase in sediment deposition in the Swinomish Channel that may result from reconnecting the North Fork Skagit River to the Swinomish Channel can be accommodated by current and ongoing maintenance dredging for the channel.*

This report concludes that there was "…enough evidence to merit further investigation of two alternatives that seek to establish connectivity through the "causeway" to McGlinn Island and/or lower the overall height of the jetty from McGlinn Island to the "fish hole" (Figure 2)." The authors also developed a set of conceptual designs to support development and investigation of these restoration concepts.

Information Relevant to Skagit River Relicensing: This report provides information specific to the Study Area for the Synthesis Study and a major constructed feature that influences the estuarine hydrology and connectivity between the Skagit River, Skagit Bay, and Padilla Bay through the Swinomish Channel. Between 1892 and 1937, a series of Army Corps of Engineers developed the Swinomish Channel into what is its current form. The resulting modifications have contributed in some part to two critical changes in the environment for Pacific Salmon species; which include changes in the distribution and migration pathways as well as hydrology and tidal/freshwater mixing patterns. There are significant challenges associated with restoring connectivity in the Swinomish Channel including maintaining and navigable waterway and understanding sediment supply and transport processes and mixing of salt and freshwater; "The causeway and jetty were constructed to prevent river-borne sediment from filling the Swinomish navigation channel." Therefore, "…breaching the causeway or jetty to allow salmon passage must account for sediment transport and its effect on current maintenance dredging schedules." In addition, the authors indicate that simply allowing salmon access to the Swinomish Channel is not sufficient; they must also have "physiological access, i.e., sufficient freshwater must enter the Swinomish Channel to allow Chinook Salmon to take advantage of a salinity gradient along the channel to reach additional rearing habitat in the northern half of the channel and in Padilla Bay." Therefore, models for sediment transport, tidal and riverine currents, and saltwater mixing are critical to evaluate restoration scenarios for the Jetty.

<u>Geomorphology and Landforms</u>: Figure 1 shows a map of historical marsh habitat extents by marsh type for the historic geomorphic delta for the Skagit River, which includes the Samish River delta footprint. Pre- and Post-dredge maps of channel and marsh habitat associated with the Swinomish Channel and Skagit Bay and Padilla Bay are shown in Figure 4, which show the extent of habitat changes associated with dredging and the Jetty construction. A map of the year 1892 shoreline with a comparison to the year 2000 shoreline is shown in Figure 5. The history of ACOE projects are described in detail in this report, with additional supporting figures and diagrams (Figures 6-9) that describe the structure and chronology of modifications. Table 1 provides a summary of amplitude and phase metrics for major harmonic tidal constituents at the north and

south sites. Comparisons of velocity, speed, and direction between north and south sites are shown in Figures 12-14.

Fish and Habitat: Previous surveys indicate juvenile salmon use or enter Swinomish Channel, but abundances are low compared to other areas in the North Fork Skagit marsh habitats. Catches of juvenile Chinook show steady declines with increasing distance northward within and from the Swinomish Channel. The authors cite evidence of density dependence in the Skagit Estuary from previous studies, and that juvenile salmon are split between the North and South Forks where three times the marsh habitat is available in the South Fork. Therefore, they postulate that density dependent effects are likely three times greater in the North Fork and support the possible need for restoration in the North Fork despite overall Skagit Estuary habitat extent being high. In addition, "reconnecting the North Fork Skagit River with the Swinomish Channel will allow access to significant current habitat within the channel and in Padilla Bay, and to significant future restoration sites in the Swinomish Channel which are in progress or proposed." Access to historical eelgrass beds and rearing habitat in Padilla Bay through Swinomish Channel is cited as a significant factor influencing estuary rearing for juvenile salmon (Pink, Chum, Coho, and Chinook), and the Swinomish Channel was an important adult migration pathway as they returned to their natal rivers. The authors indicate that several completed and planned restoration projects in the north end of the Swinomish Channel are limited in their effectiveness due to the connectivity issues associated with the Jetty in its current form.

This report includes a summary of a companion USGS report titled "Nearshore Circulation and Water Column Properties in the Skagit River Delta, Northern Puget Sound, Washington PART I: Juvenile Chinook Salmon habitat availability in the Swinomish Channel." Water velocities, salinity, temperature, and water depths were measured with ADCPs and CTDs. Comparisons of water levels and tidal patterns between north and south sites are shown in Figure 11. River flows are described in the hydrodynamic model section, with a time series of river flows at USGS gage station in Mount Vernon (RM 15.7).

Water Quality and Productivity: The Jetty influences mixing of freshwater and saltwater, and historical salinity gradients within the Swinomish Channel (that supported transition of juvenile salmonids) are not currently present. The Swinomish Channel is predominately polyhaline (>18 ppt), while the channels on the west side of the Jetty are predominately freshwater. Time series of salinities are provided in Figure 15, with cross-sections shown in Figure 17. Salinities and responses to restoration alternatives from the hydrodynamic model described below are provided throughout the report given that salinity was used as an evaluation criteria for the evaluation. Availability of low salinity waters (5-10 ppt) were considered an important evaluation criteria for scenarios given the reliance on these habitats for juvenile Chinook to adapt and transition to marine life stages.

Modeling Tools: This report also includes a section that summarizes a companion report entitled "Hydrodynamic Modeling Analysis for McGlinn Island Causeway Feasibility Study." A Finite Volume Coastal Ocean Model (FVCOM) was developed to model 3-D momentum, continuity, temperature, salinity, and density equations in an integral form for an unstructured grid. The model grid is shown in Figures 18-19, which show the modeling extent as well as the input bathymetry. Comparisons of modeled and observed tidal elevations, velocities, and salinities, are shown in Figures 20-22. A map of modeled salinities at ebb and flood tides are shown in Figure 23. The leakage of flow and scour around the Jetty near the south end of the Swinomish Channel are shown in Figure 26, and this was an attribute that was included in the simulation model. Additional modeling diagnostic plots are shown in Figures 27-33. The section concludes that “Overall, the updated hydrodynamic model reproduced water surface elevations and velocities well in the bay and Swinomish Channel. The model was able to simulate the general salinity distributions, particularly the sharp salinity drops caused by the leaking jetty. Thus, the model can be used to evaluate relative effects of project alternatives on Swinomish Channel salinity resulting from restoring Skagit River freshwater inflows. Model behavior could likely be improved by extending boundary conditions northward into Padilla Bay with concomitant water salinity and velocity data collection.”

A final section describes restoration alternatives analyses that were completed as part of this study, which were evaluated using the FVCOM model. Availability of low salinity waters (5-10 ppt) were considered an important evaluation criteria for scenarios given the reliance on these habitats for juvenile Chinook to adapt and transition to marine life stages. Two restoration alternatives were considered:

(1) Lower the jetty to allow additional freshwater flow to the Swinomish Channel from the North Fork Skagit River.

(2) Extend an existing channel from Dunlap Bay to the Swinomish Channel through a breach in the McGlinn Causeway.

The model grid for the FVCOM model was modified to support the alternatives analyses. The results of modeled responses to restoration alternatives are shown in Figures 36-39. Ultimately the modeling results indicate that there were little differences between the two scenarios, and conceptual designs based on the modeling results are shown in Appendix A (note these are conceptual designs and are not intended for engineering). Drawings include profiles, cross-sections, and plan view drawings showing the different conceptual designs.

Hinton et al. (2018) (Unique Identifier: 167)

Reference	Hinton, S., K. Ramsden, E. Mickelson, and B. Clifton. 2018. Skagit River basin habitat status and trends for freshwater rearing targets. Report by Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** slope, floodplain, floodplain connectivity, aquatic habitats and landforms. ***Land Use and Cover:*** land cover, floodplain, banks and shoreline, urban, roads, data gaps. ***Fish and Habitat:*** Habitat: riparian, freshwater, connectivity, status and trends, data gaps; Monitoring: habitat, data gaps. ***Modeling Tools:*** habitat.									
Species and Life Stages	***Chinook:*** spawning. ***steelhead:*** rearing.									
Reaches and Spatial extent	R1-6, R7-15, Sauk River, Other Sauk River tribs, Other lower Skagit tribs, Other upper Skagit tribs.									
Linkages to Hydroelectric Operations	NA									

Summary: This report is a collection of nine studies that compares the Skagit Chinook Recovery Plan (2005), NOAA Status and Trends Monitoring Program and Puget Sound Partnership Common Indicators with updated data from 2006 and 2015 to *"assess the status of Skagit basin habitat throughout the anadromous fish zone."* The goal of this report was to assess habitat quantity over time and provide support for the Skagit Monitoring and Adaptative Management Strategy implementation, the updated 2005 Chinook Recovery Plan, and the 2017 Skagit steelhead Recovery Plan. They found different habitat trends through time where data were available, and the report provides recommendations for future studies.

Information Relevant to Skagit River Relicensing: This report compared nine different studies that were part of the Skagit Chinook Recovery Plan 2005 that reviewed the floodplain extent, floodplain structure and connectivity, tributary connectivity and structure, and riparian extent and continuity. This report provides maps and quantitative data for the Study Area for the Synthesis Study, target species, and topics of interest. This report provides recommendations for potential monitoring to confirm habitat trends and results reported in this study. The primary results of each study are summarized below. Results are presented in tables with reaches delineated in Figure 1, with their reaches SK100 - SK060 representing Study Area for the Synthesis Study Reaches R7-R12, and SA070-SA010 and SU060-SU010 representing Study Area for the Synthesis Study Reaches Sauk River and other Sauk River tributaries (Suiattle River).

Fish and Habitat: The first study used road and hydromodification data from the 1998 Skagit Chinook Recovery Plan geomorphic floodplain layer and compared it with 2015 National Agriculture Imagery Program data. They found 10,510 ha of total floodplain area was exposed to hydrologic processes in 1998 with 31 percent of the floodplain impaired or isolated from roads or hydromodifications. Total floodplain area was higher by 352 ha in 2015, with 28 percent of the floodplain impaired or isolated. Another study reviewed hydromodifications from a 1998 field inventory to create an updated inventory with field data, and they found that hydromodified length in 1998 was 49,418 m, whereas in 2006 and 2015, it was 41,375 km and 39,886 km, respectively. Table 6 provides the hydromodified length for 1998, 2006, and 2015 for each of the rearing floodplain reaches.

Large mainstem channels from 1998, 2006, and 2015 aerial imagery were evaluated, and they found that mainstem edge length was 589.4 km in 1998, 234 km in 2006, and 235 km in 2015. The 1998 mapping effort *"included more braided channels as mainstem habitat than the 2006 and 2015 efforts"* and explains the different large mainstem edge totals. The authors did note that while the 2006 and 2015 mainstem edge totals are more comparable, the 2006 aerial photographs were taken during a higher level of flow, causing some aquatic features to not be visible during analysis. This report provides tables that show each rearing range for Chinook, where they are in the floodplain reach, and mainstem channel lengths and total edge habitat lengths. Table 4 provides estimates of mainstem channel length and total edge habitat length by rearing range (stock) for Chinook Salmon that includes the non-tidal delta to Sauk River confluence on the mainstem, and the Sauk River.

Backwater habitats were mapped from aerial photographs in 1998, 2006, and 2015 and they report backwater habitat perimeter totals of 63,239 m, 23,678 m, and 20,064 m, respectively. Table 7 provides 2006 and 2015 backwater perimeters for each floodplain reach. Data from another study (Beamer et al. 2010, ID202) found that the total area of floodplain channel types was 560 ha and mainstem habitat area was 1,855 ha in 2006 compared to 644 ha for total floodplain channel area and 1,784 ha for total mainstem area in 2015. The slight difference between years was due to braids being assigned to the mainstem category for the 2006 data.

Another one of the studies reviewed in this report found that the Skagit Chinook Recovery Plan was the only study that analyzed floodplain channel lengths (at least since the publication of this report); with 371.1 km of reported floodplain channel length. The authors recommend that future studies include floodplain channel lengths measurements, which could potentially be easier than determining the area of a floodplain because of heavy vegetation. Another study that hasn't been replicated was the Skagit Chinook Recovery Plan's review of the available habitat for juvenile Chinook Salmon, which identified twenty mainstem reaches as priority areas for restoration. They recommend future studies to measure the spacing of all rearing habitat opportunities within mainstem habitats.

Another study classified habitat segments (length) into interval spaced gradient classes (e.g., 0-1 percent gradient was pool-riffle/plane bed) that were further divided by accessibility (i.e., accessible, isolated, and inaccessible) (Table 11). They also categorized habitat segments based on the location within the watershed by alluvial plain, alluvial fan, or upland and accessibility as well. The authors recommend verifying the presence and location of artificial/ natural barriers through field work, but provide maps showing accessible, isolated, and inaccessible habitats). They also recommend incorporating channel width estimates into the hydrography layer that they used which is a required parameter in the NOAA Fisheries Intrinsic Potential Model that estimates habitat area.

The final study in this report *"focused on the spatial extent and continuity of riparian habitat in the tributary's floodplains"* that are spawning grounds of five Skagit Chinook populations. They classified areas by functional vegetation (i.e., woody species present), dysfunctional vegetation (i.e., lawns, invasive species present, and or agriculture lands), and by infrastructure (i.e., roads, parking lots, or structures present). This study found that percent functional vegetation increased from 70 to 72.4 percent from 2006 to 2015, increasing in Finney Creek but decreased in Illabot Creek, Diobsud Creek and Lower Sauk tributaries. Infrastructure remained steady at 3.9 percent from 2006 to 2015, increasing in Illabot Creek and Lower Sauk tributaries but decreased in Diobsud Creek. Finney Creek remained steady. Dysfunctional vegetation decreased from 26.1 to

23.6 percent from 2006 to 2015, decreasing in Finney Creek but increased in Illabot Creek, Diobsud Creek, and Lower Sauk tributaries. The authors do provide some comparison of this study to the Skagit Chinook Recovery Plan, however the Skagit Chinook Recovery Plan study area encompassed the entire anadromous zone, whereas this study focused on specific habitats. The study provides tables that compare, when appropriate, to the Skagit County data from 2010.

Hood et al. (2016) (Unique Identifier: 142)

Reference	Hood, W. G., E. E. Grossman, and C. Veldhuisen. 2016. Assessing tidal marsh vulnerability to sea-level rise in the Skagit Delta. Northwest Science 90(1):79-93.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: status and trends, estuary, climate change, data gaps; Monitoring: climate change, habitat, sediment. ***Geomorphology and landforms:*** change, substrate and sediment, sediment transport and supply, estuarine habitats and landforms, climate change, shallow and deep surface processes. ***Land use and Cover:*** land cover. ***Modeling tools:*** bathymetry, habitat.									
Species and Life Stages	***Chinook:*** rearing.									
Reaches and Spatial extent	Skagit Bay, Skagit Estuary.									
Linkages to Hydroelectric Operations	***Geomorphology and landforms:*** sediment transport and supply.									

Summary: This study assessed the vulnerability of Skagit Bay's tidal marshes that are being impacted by sea-level rise (SLR) and changes of sediment delivery. To analyze marsh progradation throughout the years at low tide, GIS analysis of different types of photographs were used: true color photos from 2000 and 2011, infrared photos from 2004, gray-scale photos from 1937, 1956, 1972 and 1991 were rectified in GIS relative to 2000 true color photos. Shorelines were defined in the photographs by the abrupt transition from vegetated marsh to unvegetated tidal flat. A linear regression model was used to evaluate trends in marsh progradation/erosion rates. SLR data was available from tide gages at Port Townsend (since 1972) and Seattle (since 1898). Land movement has been measured with GPS at Chimacum (since 2004), Seattle (since 1996), and Sedro Woolley and Mount Vernon (both since 2007). The SLR and land movement data helped provide vicinity rates for Skagit Bay. Sediment delivery rates from 1937 on were determined by using a sediment loading flow-duration curve ([Curran et al. (2016)] [Unique Identifier: 373]) for the USGS Stream Gauge 12200500 (located at head of tide at Mount Vernon, river km 25). Landslide rates were calculated from landslide scars from aerial photos that were taken roughly every decade since 1960s. All together, these different sources of data helped with the assessment of Skagit Bay's tidal marshes vulnerability. Their analysis indicates show that Skagit Delta marshes have prograded into Skagit Bay for most of the record (1937 to present), but that progradation rates have been declining with marsh erosion being detected in recent decades despite large suspended sediment loads from the Skagit River. They implicate SLR and wave-generate erosion as potential factors that can overwhelm sediment supply, as well as obstruction of historical distributaries and levee construction along distributaries that can result in increased transport of suspended sediments through the delta that would have typically increased marsh resilience to SLR. Therefore, they recommend that restoration of historical distributaries and constrictive levees should be considered in restoration strategies for SLR resilience to increase sediment delivery to marsh habitats.

Information Relevant to Skagit River Relicensing: This study provides information about Skagit Bay's current and historical tidal marshes extent, as well as the factors impacting marsh extent such as the change in sediment delivery and SLR. This information can be used to inform linkages between resource conditions and processes in the Skagit Estuary for the Synthesis Study. They found a net increase or progradation of Skagit River estuary marsh habitats since 1937, but significant erosion has occurred in recent years and progradation rates have declined in recent decades. They indicate that the current Skagit River Chinook Recovery Plan targets do not account for declining potential future tidal marsh losses due to climate change or SLR, and therefore targets are likely an underestimate of what are needed for salmon recovery. Maps are provided that show spatial data for changes in marsh boundaries over time, and spatial data for all time periods could be requested. Data and time series for sediment loading and supply are provided, as well as estimated SLR rates to support their recommendation that Skagit River estuary marshes are vulnerable to SLR and that restoration strategies need to increase sediment retention to offset declining progradation rates and increase marsh resilience to SLR. The authors also state how the estuary and marshes of the Skagit Bay are eroding despite the high sediment delivery because of the sediment delivery being bimodal and that the delivery of sediment is not synchronous with marsh vegetation growth. Additionally, at least half of the annual sediment load delivered is during winter storms which is when marsh vegetation is minimal, and vegetation is unable to store sediment. With climate change, winter precipitation is going to take on the form of rain versus snow which will increase winter river discharge and decrease summer river discharge. This can have cascading effects on ESA listed Chinook Salmon that used the estuary and delta habitats during rearing.

<u>Fish and Habitat:</u> Maps and marsh progradation history are presented for the Skagit Estuary, for both North and South Forks, with 1937-2011 extents of marsh habitat shown. However, the authors note additional time steps were developed in this analysis. Progradation rates from the time series are provided as linear regression models for the North Fork, South Fork, and bay-fringe regions of the Skagit Estuary, along with temporal patterns (1920-2011) of timber harvest, sediment delivery, and land slide rates are provided (see Figure 4). These data can be used to inform linkages between processes and resource conditions in the Skagit Estuary.

Data gaps were identified in this paper such as the assessment of snow geese grazing and their impact as a potential biotic stressor on the Skagit delta marshes. The authors suggest goose exclosures or changing hunting management rules to "direct hunters to the most affected areas to discourage grazing." Similarly, there is a data gap on the fraction of sediment that is delivered to the delta and its resulting fate out of the system. This would help determine the degree of how building levees and or blocking historical distributaries through anthropogenic means is responsible for the net sediment export. The authors conclude if the net export of sediment was known, "remedial actions such as distributary restoration or levee set-back can significantly reduce the jet momentum of the river to reduce sediment export and thereby improve marsh resilience." They also state that monitoring climate change is important for vegetation composition and composition. It is predicted that through climate change, there will be more SLR which will increase salinity and will thus have an impact on vegetation, particularly salt-sensitive woody shrubs in the tidal freshwater marsh.

> *"Better quantification of sediment fate is required to determine to what degree anthropogenic occlusion of historical distributaries and construction of constrictive levees are responsible for net sediment export from the system, and whether remedial actions such as distributary restoration or levee set-back can significantly reduce the jet momentum of the river to reduce sediment export and thereby improve marsh resilience."*
>
> *"Also unclear is the importance of some potential biotic system stressors. While snow goose grazing is significant in the nearby Fraser Delta, their impact on Skagit Delta*

> *marshes has not been assessed. If goose grazing were shown to similarly impact the Skagit marshes, changes in hunting management might direct hunters to the most affected areas to discourage grazing. Alternatively, grazing might be managed with goose exclosures. Similarly, if algal wrack were shown to be a significant impact, this would argue for reductions in N-pollution from Skagit watershed sources to reduce algal blooms."*

Geomorphology and Landforms: Sediment loads reaching the Skagit Bay increased 3 percent from 1940s to early 1990s but have decreased 11 percent since the peak in 1990s to the present. The authors assumed that the dams built prior to 1930, have had a constant effect on suspended sediment trapping since 1937. A 5 cm relative increase sea level was determined from the 2002 LiDAR images. An allometric model (simply a power equation) was used to infer wave erosion on the bay-fringe marsh (located between the two North and South Fork distributary outlets). This allometric model used with a log transformation to determine the elevations the morphology of a known erosional landform and compared that to a test landform that was suspected of erosional landform. They found that the smallest outcrops were 1.5 m higher than the marsh in their lee. Craft Island and an adjacent island were 24 and 4 m higher than the downwind marsh. They did find that the scaling components of both systems were the same, meaning that both were experiencing similar wave erosion processes.

Hood (2007) (Unique Identifier: 061)

Reference	Hood, W. G. 2007. Large woody debris influences vegetation zonation in an oligohaline tidal marsh. Estuaries and Coasts, 30(3):441-450.									
Source Information	*Type*	Journal	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology:* large wood, estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply. *Water Quality and Productivity:* nutrients. *Land Use and Land Cover:* agriculture. *Fish and Habitat:* Habitat: estuary, beaver, riparian.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: This study shows that large woody debris (LWD) plays a role in the establishment of shrubs, particularly nitrogen-fixing *Myrica gale* L. (*M. gale;* sweetgale) in the Skagit Delta tidal marshes. LWD, sweetgale, and other shrubs were surveyed along line transects in an oligohaline tidal marsh and in abandoned agricultural land whose dikes failed over 50 years ago and has reverted to marsh. The results show a strong association between LWD and *M. gale*. Sweetgale was very rare on LWD < 30 cm (12 in), more common for LWD between 30-75 cm (12-30 in), and always present on LWD ≥ 75 cm (30 in). The marsh surface was generally 45 cm below mean higher high water (MHHW), suggesting LWD provides a growth platform at an elevation near MHHW and reduces flood stress. The largest and most abundant tree in the marsh averaged only 35.8 cm (14 in), which suggests LWD recruitment from upstream sources is necessary to sustain sweetgale populations in the geomorphologically dynamic Skagit marsh.

Information Relevant to Skagit River Relicensing: This study provides relevant information on LWD in estuary habitats of the Skagit River, and links important marsh formation processes and vegetation characteristics to LWD supply, size, and distribution. *M. gale* dependence on estuarine LWD suggests upstream riparian management can affect LWD subsidies to estuaries with potentially cascading effects on estuarine ecology, particularly community structure and nitrogen dynamics and secondary marsh production. The authors also indicate that beaver activity in tidal channels is strongly related to the distribution of *M. gale* in the Skagit River delta. Long-term estuarine habitat management should include upstream riparian zone management to allow LWD recruitment to the estuary to sustain LWD-dependent estuarine ecosystem structures and processes, and the authors suggests that dike breaching actions alone may not be enough to restore marsh vegetation communicates given the reduce recruitment of LWD to marshes.

Spatial data are provided showing distribution of *M. gale* in the South Fork tidal marsh as well as emergent marsh, other shrubs, floodplain forest, farmed agricultural lands, and restored former agricultural lands. Maps of tidal shrub habitat circa 1860 and 2004 are also shown for the entire Skagit Estuary. Mean LWD diameters of trees colonized by various shrub and tree species in the delta are shown, as well as modeled probability of encountering *M. gale* based on LWD diameters.

Hood (2007) (Unique Identifier: 271)

Reference	Hood, W. G. 2007b. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process. Water Resources Research 43:W03409.								
Source Information	*Type*	Study	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* estuarine habitats and landforms. *Modeling Tools:* Connectivity, habitat. *Fish and Habitat:* Habitat: estuary.								
Species and Life Stages	*Chinook:* estuary rearing and emigration.								
Reaches and Spatial extent	Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: This study proposes an alternative approach to examining tidal channel geometry and evolution to inform marsh restoration. This approach relies on scaling relationships between marsh island surface area and various metrics of the set of tidal channels draining each marsh island. This study was conducted in the Skagit River delta. Tide channel margins were digitized from aerial photos and used to measure marsh island and tide channel geometries. These geometries were then scaled with each other as a function of marsh island area for 7 tide channel metrics which include total channel length, total channel surface area, tributary count, and more. These scaled relationships were then analyzed for statistical significance. This process was done separately for five different marsh island groups in the Skagit delta, one of which was cut off from sediment inputs by anthropogenic processes in the 1950s.

Results from this analysis showed statistically significant scaling for 6 of 7 metrics. When comparing these scaling relationships between marsh island groups it was observed that slopes remained uniform, but the intercepts varied. The difference in scaling intercept between the marsh island group cut off from sediment inputs and the other marsh island groups was most pronounced. This new approach to examining tidal marsh systems shows promise as seen in the difference in scaling relationships of a sediment starved marsh island group and a sediment connected marsh island group. Such differences can be used to identify marsh restoration opportunities.

Information Relevant to Skagit River Relicensing: This study examines an alternative process for examining tide channel geometries and evolution. This study was conducted in and reports on empirical data collected in the Skagit River delta. This data could be used to inform current status of tide channels in the Skagit delta, as well as inform evaluation and development of restoration designs based on the expected number, area, or complexity of tidal channels for a given marsh area. Numerous regression models and statistics are reported that can be used to support estimates of tidal channel metrics based on marsh island areas. Using their models, they report that minimum marsh areas that sustain tidal channels are 0.21-0.45 ha. In addition, they found that given the disproportionate scaling pattern, restoration of a 100-ha marsh would be preferable to restoration of 10 separate 10-ha sites based on predicted channel metrics. This has implications for salmon recovery if restoration is intended to provide tidal marsh and channel habitats for juvenile salmonids, of which the author specifically mentions Chinook Salmon that rely on tidal channel rearing habitats. Several conceptual models for tidal channel evolution from early to late stages are presented.

Hood (2010) (Unique Identifier: 272)

Reference	Hood, W. G. 2010. Tidal channel meander formation by depositional rather than erosional processes: examples from the prograding Skagit River delta (Washington, USA). Earth Surface Processes and Landforms 25(3):319-330.									
Source Information	*Type*	Journal	*Status*	Final	*Quantitative Data*	No	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply, channel migration. *Modeling Tools:* habitat.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: The author used geographic information system (GIS) analysis of historical aerial photographs of the Skagit Delta marshes. These provide examples of an alternative channel meander forming process in a rapidly prograding river delta. Parallel sequences of marsh ridges and swales indicate locations of historical distributary shoreline levees adjacent to filled former island/mainland gaps. The location of marsh islands within delta distributaries is not random. Islands are disproportionately associated with blind tical channel/distributary confluences. Additionally, blind tidal channel outlet width is positively correlated with the size of the marsh island that forms at the outlet and the time until island fusion occurs within mainland marsh. These observations suggest confluence hydrodynamics favor sandbar/marsh island development. The transition from confluence sandbar to tidal channel meander can take less than 10 years, but usually occurs over several decades. This channel meander formation process is part of a larger scale depositional process of delta progradation that includes distributary elongation, gradient reduction, flow-switching, shallowing, and narrowing

Information Relevant to Skagit River Relicensing: This study focused on the South Fork Skagit River delta and provides useful information on habitat changes and processes in tidal delta systems. The Skagit River provides 34-50 percent of Puget Sound's freshwater and sediment inputs, depending on the season, and the author provides a narrative of historical changes in estuary habitat for the Skagit River. Distinguishing systems in which depositional version erosional channel-forming processes predominate may provide useful guidance for further refinement of morphodynamic models and for land-use management affecting sediment supply or river discharge to deltaic systems. Numerous regression model results and plots are provided that can be used to inform morphodynamic models. Rates of formation, or process rates, are provided for marsh island formation from sand bars (average 14.6 years, range 4-27 years, SD = 8.3 years), and marsh islands persisted an average of 18 years (range 6-47 years, SD = 13.9 years) before junction with historical marsh mainlands and the formation of a meander bend. This study also provides information that informs remote sensing methodologies, with the authors indicating that minimum channel widths that can be mapped from aerial imagery varied with imagery resolution over time. Newer imagery with 30-cm pixels could be used to identify and map channels as small as 60 cm wide, while channels bigger than 1-2 m wide could be distinguished in older imagery with 60-cm pixels.

Hood (2015) (Unique Identifier: 063)

Reference	Hood, W. G. 2015. Geographic variation in Puget Sound tidal channel planform geometry. Geomorphology 230:98-108.									
Source Information	*Type*	Journal	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Yes
Topics and Keywords	*Geomorphology and Landforms:* large wood, estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply, channel migration, aquatic habitat and landforms, climate change. *Fish and Habitat:* Habitat: estuary, climate change. *Modeling Tools*: habitat.									
Species and Life Stages	NA.									
Reaches and Spatial extent	Skagit Estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	*Geomorphology and Landforms:* estuarine habitats and landforms, sediment transport and supply.									

Summary: The author performed allometric models to predict the number and size of tidal channels that could develop following salt marsh restoration and channels were digitized. Channel size and complexity were positively related to tidal range and negatively related to wave height in tidal channels throughout Puget Sound. The apparent accretion deficit suggested by larger tidal channel in the South Fork (SF) Skagit delta compared to North Fork (NF) delta is consistent with greater declines in historical salt marsh progradation rates in the SF compared to the NF delta. The results of this study suggest that sediment-challenged salt marshes in Puget Sound are already showing impacts from 20th century sea level rise.

Information Relevant to Skagit River Relicensing: The geographic scope of this analysis includes many systems in the Puget Sound, but specifically provides information and data for the Skagit River estuary and delta. The allometric models and concepts developed can be used to support restoration designs, planning, and evaluation and regression models for predicting channel count, total channel area, total channel length, magnitude, area of largest channel, length of largest channel, magnitude of largest channel, tributary count for the largest channel, and largest outlet width (slopes with upper and lower confidence intervals). However, these regression models are presented using data from multiple systems in the Puget Sound. Sensitivity tests for aerial imagery resolution results are presented for the South Fork Skagit Delta which show relationships between marsh area and total channel magnitude, total channel area, total channel length, and channel count that could be extracted. Scatter plots of marsh island area and relationships with magnitude of largest channel, area of largest channel, length of largest channel, and number of tributaries are presented for all systems considered, with symbology by system that could be used to extract information specific to the Skagit River delta. Supplemental data for this report were available that provides log linear regression statistics for each delta included in the analysis, including the NF and SF Skagit Delta for all parameters listed above. These data were appended to the digital archive for this report, and regression statistics could be extracted to support the Synthesis Study.

The results of this study suggest restoration of system-scale natural processes through relaxation of anthropogenic constraints on sediment supply could likely change patterns within the affected deltas. The author's conclusions claim that *"…river systems with known anthropogenic reductions in river sediment delivery, through dam construction and flow diversion, also tended to have larger channel networks*" in describing the roll of sediment supply and transport on tidal marsh channel geometry. This provides a potential linkage between Hydroelectric Operations and tidal marsh and tidal channel habitat formation and maintenance processes through sediment supply and transport. Wave environments also appear to affect channel geometry, with wave-sheltered areas experiencing relative sediment deficits, such that some salt marshes in Puget Sound, such as the SF Skagit delta, are suffering sea-level rise impacts. The author recommends measurement of suspended sediment concentrations and salt marsh accretion rates in both wave-exposed and wave-sheltered marshes to improve our understanding of how wave exposure and sediment supply are related in the Skagit River delta.

Hood (*No Date*) (Unique Identifier: 065)

Reference	Hood, W. G. No date. Distribution of large woody debris in river delta tidal marshes: Preliminary Results. Skagit River System Cooperative.								
Source Information	*Type*	Future Study	*Status*	Draft	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* large wood, data gaps, estuarine habitats and landforms.								
Species and Life Stages	NA.								
Reaches and Spatial extent	Skagit Estuary.								
Linkages to Hydroelectric Operations	NA								

Summary: Many studies have evaluated the effectiveness of large wood debris (LWD) placements in stream habitat restoration, but few have evaluated LWD in tidal wetland habitats. This future study will attempt to address this data gap by evaluating large wood dynamics and patterns in large river deltas of Puget Sound. In doing this, this study will provide guidance for restoration design and evaluation by describing LWD distribution patterns in reference marsh systems. Some of the factors that affect LWD include topography, fetch, elevation, proximity to distributaries and dikes. The preliminary analyses presented indicate that marsh island size strongly correlates ($r^2 = 0.90$) with total LWD length and count in the SF Skagit, and tidal channel size affects wood density and size. There is more total wood on the marsh surface than in channels, but channel density is higher. The wood appears to get trapped in tidal channels, especially smaller channels.

Information Relevant to Skagit River Relicensing: This analysis will include data from the Skagit River delta and estuary, along with data from other reference marshes in other Puget Sound delta systems. Preliminary results presented in the draft indicate that LWD in the Skagit is affected by topography, fetch, elevation, proximity to distributaries, and dikes. Scaling relationships between tidal channel and marsh island size with large wood density and size can be used to inform restoration design and evaluation, which is a significant data gap, and provide guidance for evaluating large wood abundance in tidal marsh habitats to evaluate habitat conditions relative to reference conditions. Preliminary figures show average LWD density (with Standard error) for marsh and tidal channels among delta systems, and relationships between: blind tidal channel surface area and maximum LWD lengths and density; and marsh island area and LWD counts, total length, and maximum length. Preliminary maps show mapped LWD with elevation models, suggesting that spatial data showing LWD distributions and locations will be developed as part of this analysis.

Jaeger et al. (2017) (Unique Identifier: 374)

Reference	Jaeger, K. L., C. A. Curran, S. W. Anderson, S. T. Morris, P.W. Moran, and K. A. Reams. 2017. Suspended sediment, turbidity, and stream water temperature in the Sauk River Basin, Washington, water years 2012–16. U.S. Geological Survey Scientific Investigations Report 2017–5113. Available at https://doi.org/10.3133/sir20175113.									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* change, history, substrate and sediment, sediment transport and supply. *Water Quality and Productivity:* temperature, turbidity, data gaps. *Fish and Habitat:* Fish: survival. *Modeling Tools:* sediment.									
Species and Life Stages	*Chinook:* spawning, rearing, incubation, outmigration.									
Reaches and Spatial extent	Sauk River, Other Sauk River tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: Suspended sediment, turbidity, and water temperature data was collected at two USGS streamgages in the upper and middle reaches of the Sauk River over a 4-year period, October 2011 to September 2015, and at a downstream location in the lower Sauk River for a 5-year period from October 2011 to September 2016. Over the 5-year period, mean annual suspended sediment loads (SSL) at the upper, middle, and lower Sauk River streamgages were 94,200 metric tons (t) (240 t/km^2), 203,000 t (270 t/km^2), and 940,000 t (510 t/km^2), respectively. The median daily SSL for the streamgages was 27 t at Upper Sauk, 34 t at Middle Sauk, and 242 t at Lower Sauk. At the upper, middle, and lower Sauk River streamgages the fine sediment (smaller than 0.0625 mm) was approximately 53 percent, 42 percent, and 34 percent, respectively, of the total SSL.

SSL in the Sauk River Basin exhibited seasonal trends and substantial inter-annual variability. Fall (September to December) SSL, on average, accounted for more than half of the total annual suspended sediment load at the three streamgages (55 percent in upper, 67 percent in middle, and 62 percent in lower. Summer suspended sediment load was the smallest at the upper and middle streamgages (6 and 7 percent, respectively) and was 16 percent at the lower streamgage. The higher suspended sediment load at the lower gage was attributed to a relatively high load associated with late summer glacial melt in the tributary river, the Suiattle River, which joins the Sauk River downstream of the middle streamgage. Sediment availability typically remained high during the first fall storms, which glacial sediment accumulated over the summer was flushed out of the watershed. During five fall floods in fall 2015, 1.5 million metric tons more sediment was transported than would have been expected based on typical relations between sediment load and discharge.

A mass-balance analysis indicates that the Suiattle River accounts for about 80 percent of the total suspended-sediment load in the lower Sauk streamgage. The remaining load was split evenly between the inputs from the Upper Sauk River and White Chuck River Basins (10 percent each). About 60 percent of the SSL from the Suiattle River is estimated to be from the eastern flank of Glacier Peak. Sediment from the eastern flank of Glacier Peak may contribute approximately 50 percent of the sediment load for the entire Sauk River Basin in any given year.

Less than 1 percent of the study period included elevated water temperature and turbidity values that could impair Chinook Salmon at various life stages at the Sauk River streamgages. During the study, potential temperature stress to fish in the Sauk River usually occurred during late summer and early fall, compared to periods of concern of turbidity. The study provides an opportunity to effectively determine what the background level might be for this or other regional rivers with regards to Washington state water quality standards.

Information Relevant to Skagit River Relicensing: The study provides information on sediment load of the Sauk River, which enters the Skagit at the downstream end of the main project area (Reach R7). The Sauk River supplies a large amount of sediment to the Skagit River each year, and the sediment supply and transport metrics and dynamics described in the summary section above are directly relevant to the lower Synthesis Study. The authors measured SSL from 2011 to 2016 in the Sauk River and provide a budget that can be used to better understand the SSL contribution from the Sauk River to the lower Skagit River inter-annually and seasonally, which will support development of modeling tools for the Study Area for the Synthesis Study. Many time series plots of discharge, turbidity, and temperature are provided that could be used to extract other summary metrics of interest.

They also included an analysis of how turbidity and stream temperatures could affect Chinook Salmon life cycles, and they found that elevated water temperatures and turbidity during periods of concern for life stages were rare and represented less than 1 percent of the study period. Temperature thresholds for months and life stages are provided, and thresholds for turbidity are also developed and described, although the authors indicate that seasonal background levels need to be defined for particular species and settings of interest given natural variability and the “pulse’ or “press” behavior of this stressor.

An appendix points to a data file for particle size distribution for suspended sediment samples collected as part of this study. These data were downloaded and archived for the Synthesis Study.

Jackman (2020) (Unique Identifier: 109)

Reference	Jackman, K. 2020. Annual Report: 2019 water year (October 2018- September 2019). Report prepared by Skagit County Monitoring Program, Mount Vernon, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, nutrients, dissolved oxygen, pH, bacteria, turbidity, salinity. ***Fish and Habitat:*** Monitoring: water quality. ***Land Use and Cover:*** agriculture.								
Species and Life Stages	NA								
Reaches and Spatial extent	R10 – R15, Skagit Estuary, including Nookachamps Creek and Hansen Creek, Other lower Skagit Tribs.								
Linkages to Hydroelectric Operations	NA								

Summary: This report summarizes the water quality monitoring program for the 2019 water year (October 2018 – September 2019) directed by Skagit County Public Works, and the results of trends analysis from previous water years (2003 – 2019). This program monitors forty stations inside agricultural areas and at reference locations outside of agricultural zones within the Skagit River watershed. The intent of this program, established in 2003, was to determine whether county ordinances sufficiently protect water quality in agricultural areas. Data collected for the 2019 water year indicate that none of the forty stations monitored met all water quality standards set for the project. As such, most streams inside agricultural zones of the Skagit River watershed likely reflect subpar water quality conditions for salmonid populations, recreation, and downstream shellfish resources. Within streams, conditions varied from occasional failures to meet standards to a continual pattern of poor performance between monitoring years. However, many sites are showing promising trends towards improved water quality conditions.

Information Relevant to Skagit River Relicensing: This report provides potentially useful water quality data for sites within the Study Area for the Synthesis Study and identifies areas of concern with respect to water quality conditions in agricultural land use areas. Monitoring sites include locations within reach R10 downstream to the estuary, including North and South Fork distributaries and the Swinomish Channel as well as monitoring sites within the Nookachamps and Hansen Creek tributary basins. While this report focuses on impacts of agricultural land use, the data available are a valuable for general habitat quality evaluations and should be considered important for a watershed-scale synthesis study (especially with limited water quality data reported/monitored in other studies). Appendix A of the report is a Microsoft Excel file containing all data for the entire history of the monitoring program going back to water year 2003. It is not included in the report but is available upon request. Appendix B contains summary statistics tables for all metrics at all sites. Summary statistics reported are sample size, mean, standard deviation, min, and max values. Appendix C contains Seasonal Kendall's trend test results for 2019. Site locations (latitudes and longitudes) are also given in Table 1, giving potential for subsequent spatial analyses of these data. Additional water quality monitoring reports and data are available at: https://www.skagitcounty.net/Departments/publicworkssurfacewater management/wq.htm.

Water Quality and Productivity: Water quality data presented in this report include dissolved oxygen, temperature, pH, turbidity, conductivity, salinity, and fecal coliforms. In addition, plant nutrients including total nitrogen, ammonia, nitrate, nitrite, total phosphorus, and orthophosphate were quantified for this report. This report also provides several numerical standards for various water quality metrics set by various state and local government institutions, which should be convenient benchmarks to compare future analyses/model outputs against.

Current temperature standards set by the Washington State Department of Ecology are measured by the 7-day average daily maximum, which is currently 16 ºC. Additionally, recent revisions to state standards have imposed a 13 ºC standard from February 15 to June 15 in portions of the Samish River, Friday Creek, Hansen Creek, Lake Creek, and East Fork Nookachamps Creek and from September 1 to May 15 in the Skagit River upstream of Sedro-Wooley. These temperature thresholds are intended to protect spawning and egg incubation for multiple salmon species. Trend analyses indicate that at least ten sites have increased in temperature compared to 2003, most notably in Nookachamps Creek. However, the most recent 5-year trend shows a decrease in temperature at 24 sites, corresponding to local climate conditions. These trend reversals underscore the need to consider temporal scale when interpreting trends. Tables 4 and 5 in the report contain quantitative data for maximum temperature recorded and 7-day average of the daily maximum. Only four monitoring sites (at Thomas Creek, Mannser Creek, Colony Creek, and Fisher Creek) passed the state standard in 2019.

State water quality standards for dissolved oxygen ranges from 6.0 mg/L to 9.5 mg/L for a single-day minimum measurement depending on the watercourse type (lowland, marine, other). Site specific standards are detailed in the report. Tables 6 and 7 in the report contain dissolved oxygen data. Eight sites met the dissolved oxygen standard in 2019 (no change from 2018). Dissolved oxygen readings are influenced by the time of day (lower at night due to algal oxygen consumption), therefore the values reported here do not account for nocturnal dissolved oxygen fluctuations since measurements are only collected during the day. Trend analysis indicated that 11 sites have improved dissolved oxygen conditions compared to 2003 and 18 have improved in the most recent 5-year period.

Standards for waterborne fecal coliforms are interpreted using the “most probable number” method (MPN) of bacterial colony counts. State standards set fecal coliform limits based on the geometric mean of the samples taken and the percent of samples that exceed a given threshold. In general, the geometric mean of fecal coliforms cannot exceed 100 MPN and no more than 10 percent of samples can exceed 200 MPN. Upriver sites may not exceed a geometric mean of 50 MPN and no more than 10 percent of samples may exceed 100 MPN. Marine sites cannot exceed a geometric mean of 14 MPN with no more than 10 percent exceeding 41 MPN to protect shellfish beds. Sixteen sites met the state standard for fecal coliforms during the 2019 water year. Eleven sites show declining trends in fecal coliform compared to 2003. Tables 8 and 9 contain summaries of fecal coliform measurements for the forty sites.

Monitoring nutrient levels is important for determining potential algal growth. Increased algal growth can lead to major variations in dissolved oxygen throughout the day. Nutrient samples for this study are taken only once quarterly, thus the temporal resolution is much lower compared to the other metrics presented in this report. Nonetheless, the measurements can still be useful for indicating general trends. Mean nutrient values are presented in Table 10 of the report, with more detailed data, summary statistics, and trend analyses located in Appendices A-C. There are currently no state standards for nutrient levels as contributors to algal blooms. Most plant nutrients had moderate levels in natural streams and elevated levels in drainage infrastructure. Phosphorus was the only nutrient showing an increasing trend across the valley, which is notable because phosphorus is an important limiting nutrient for algal growth.

Additional data on pH, conductivity, and salinity are available in Appendix A and B. All sites have generally met state standards for pH since monitoring began. This report also provides a water quality index (WQI) for each site. The WQI is a unitless measurement of overall water quality developed by WA Ecology. The inputs to WQI include dissolved oxygen, temperature, pH, turbidity, suspended solids, fecal coliform, and nutrients. Ecology divides ratings on WQI into three general categories: lowest concern (WQI > 80), moderate concern (49 < WQI < 79), and highest concern (WQI < 40). Tables 13 and 14 summarize WQI for all sites. Several sites scored in the highest concern category, though those sites were agricultural ditches and not considered salmon habitat.

Kammer et al. (2020) (Unique Identifier: 280)

Reference	Kammer, N., M. Olis, C. Velduisen, S. Morris. 2020. Forested tributary stream temperature monitoring in the Skagit watershed: 2008-2018 results and interpretation. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity****:* temperature, data gaps. ***Fish and Habitat***: Habitat: riparian, climate change; Monitoring: water quality. ***Land Use and Cover***: land cover, forestry. ***Geomorphology and Landforms:*** sediment supply and transport, large wood.									
Species and Life Stages	All anadromous species.									
Reaches and Spatial extent	Day Creek, Finney Creek, Jackman Creek, Wiseman Creek, other lower Skagit tribs, other Sauk River tribs.									
Linkages to Hydroelectric Operations	NA									

Summary: Stream temperature is an important determinant of stream health because it can affect distribution and abundance of aquatic life. During mid-summer low flow periods, extreme stream temperatures may limit in-channel habitat availability for salmonids. Prolonged exposure to elevated stream temperatures can result in myriad behavioral and physiological responses in salmon up to and including death. Thermal maxima and diurnal fluctuations in streams are predicted to increase over time with changes in hydrologic extremes, air temperatures, precipitation, snow cover, and glacier cover. As such, stream temperature monitoring is necessary to determine the extent of harmful summer temperatures in Skagit River. This report summarizes continued long-term summer stream temperature monitoring efforts conducted by the Skagit River System Cooperative (SRSC) and contains and expands all temperature data from Mostovetsky et al. 2015 (ID 291). Data gaps were identified in previous stream temperature monitoring reports, which did not collect long-term monitoring data with broad spatial coverage within the watershed. The goal of this report was to improve upon previous stream temperature monitoring by collecting long-term data suitable for temporal analysis. Through repeated long-term monitoring, it was possible to identify tributaries that may serve as thermal refugia during periods of extreme heat.

Information Relevant to Skagit River Relicensing: Relevant data on stream temperatures for several Skagit River tributaries within, or that drain into, the Study Area for the Synthesis Study are reported. Comparisons to Washington State temperature standards are made, which can be useful for assessing stream health relative to physiological requirements for salmon during summer low flow periods. The information in this study can be used to inform salmon management strategies in the Skagit River watershed and guide restoration priorities at highly impacted streams. The findings in this report highlight the role of riparian vegetation and forest canopy in regulating stream temperatures. Spatial data are limited to maps of site locations monitored in this study.

This report compiles stream temperature data collected over an 11-year period (2008-2018) at 38 monitoring sites throughout timber-managed forested lands in the lower Skagit and Sauk basins (WRIAs 3, 4). Seasonal Maximum Hourly Temperature (SMHT) and 7-Day Average Daily Maximum (7-DADM) temperature metrics were measured and compared to differences in site-specific parameters (bankfull width, canopy cover, gradient) and inter-annual weather differences (air temperature, precipitation, snowpack) throughout the Skagit basin. Appendix A includes a summary of site locations and available data years. SMHT (Appendix B) and 7-DADM (Appendix C) were measured using submersible Onset HOBO data loggers following the Timber Fish and Wildlife Stream Temperature Survey Manual and Washington Department of Ecology (DOE) standards. Table 2 highlights twenty-two of the 38 monitoring sites that maintained a sufficient record of 9+ years included in the inter-annual analysis. Figure 2 shows basic spatial outline of sites as well as grouped average temperature metrics. Metrics indicating inter-annual weather differences include Air Temperature Index (ATI), Drought Index (DI), and snow water equivalence (SWE).

Water Quality and Productivity: Table 1 provides temperature ranges and modes of thermally induced mortality that can be used to support development of factors affecting life stage survival. Between 2008-2018, the sites with highest recorded stream temperatures (above 20ºC) were in lower Day Creek and Finney Creek, and below the outlet of Grandy Lakes. Quartz Creek and Dan Creek occasionally showed temperatures above the sub-lethal threshold. These sites all had wide channels with little forest canopy and slow water velocities. Sites exhibiting high seasonal temperature maxima also were more sensitive to short (diurnal) and long (inter-annual) timescales, suggesting that streams with higher average temperatures were prone to the greatest increases during warm periods (Figure 3, 12). Many sites consistently exceeded Washington State water quality standards at least one day in every year (between 15 percent and 85 percent) (Appendix D). Ten of the 38 monitoring sites exceeded 16ºC (DOE "Core Summer Salmonid Habitat" standard) at least once during each year of monitoring (Figure 4), and 32 sites recorded temperatures exceeding 16ºC in one or more years of monitoring. Of the sites added since the previous progress report (Mostovetsky et al. 2015, ID 291), 5 sites exceeded the core standard temperature every year of monitoring while 3 sites did not exceed the core standard temperature. Approximately 53 percent of sites exhibited an average diurnal range greater than 2ºC, with 'Finney Mid' exhibiting the largest diurnal temperature fluctuations of 3.6ºC in 2013 and 6.6ºC in 2018.

Figures 7 and 8 show the inter-annual differences in 7-DADM and SMHT, respectively. Inter-annual variability was strongly correlated with ATI but not with DI or SWE, emphasizing the impact of direct solar radiation on summer instream temperatures (Figure 13, Table 5). However, no significant trend was found in the inter-annual temperature data during 2008-2018 (Appendix E). More monitoring is needed to develop baseline temperature conditions in the basin, to assess specific temperature drivers and effects, and to identify and enhance thermal refuge areas within temperature impaired streams to maximize fish use.

Fish and Habitat: It is noted that riparian forest canopy today is composed mostly of hardwood broadleaf species which do not reach the same heights as native conifers, and consequently provide less instream shading. Vast majority of SMHT were recorded between mid-July and late-August, with an average peak temperature date of August 1st. Figure 9 shows the distribution of dates exhibiting SMHT throughout 2008-2018. Table 3 lists times of year at a given site when instream temperatures support supplemental spawning and incubation protection criteria, or 13ºC. Restoring riparian buffers with native conifers such as western red cedars and western hemlocks could provide long-term thermal regulation in affected streams. Site-level habitat data are presented in Table 2 which includes gradient, canopy closure, bankfull width, elevation, basin drainage area, and upstream land cover type.

Land Use and Cover: Landslides exacerbated by logging can lead to sedimentation, channel widening, and destruction of riparian vegetation and exacerbate stream warming. Mitigation steps such as buffering and upgrading forest roads could help to address this problem. More analyses of spatial and temporal relationships between harvest units and stream temperatures may lead to more effective forest buffer practices.

Khangaonkar et al. 2016 (Unique Identifier: 334)

<table>
<tr><td>Reference</td><td colspan="10">Khangaonkar, T., W. Long, B. Sackmann, T. Mohamedali, and A. Hamlet. 2016. Sensitivity of circulation in the Skagit River estuary to sea level rise and future flows. Northwest Science 90(1):94–118.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> climate change, nearshore, estuary, instream flow, freshwater, status and trends. Water Quality and Productivity: salinity, temperature, climate change, data gaps. Modeling tools: hydrology, bathymetry, climate change.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Estuary, Skagit Bay, Padilla Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This paper presents a 3-D hydrodynamic analysis of circulation and transport in the Skagit River estuary including the interaction between the interconnected basins of Skagit Bay, Padilla Bay, and Saratoga Passage. The goal was to quantify the future hydrodynamic response of the Skagit River estuary to climate change given accompanying sea level rise and site-specific complexities with multiple interconnected basins. The model was set up with localized high-resolution grids in Skagit and Padilla Bay sub-basins within the Finite Volume Community Ocean Model (FVCOM) of the Salish Sea and future changes to salinity and annual transport through the basin were examined. This study used an embedded high-resolution grid model within the existing grid of the Salish Sea Model (SSM) for the Skagit-Padilla Bay domain. The SSM uses the FVCOM framework and has been used in several previous studies. The model is forced by tides, freshwater inflows, wind, and heat flux at the water surface. The model was validated by applying the existing SSM to data from 2008 and comparing the results with monthly monitoring data collected by the Department of Ecology over the larger Puget Sound scale. Changes in estuarine salinity distribution and circulation were predicted as a result of 2070 sea level rise and flows using the upper bound of the A1B sea level rise estimate of 48 cm and altered hydrology (13 percent higher total flow with about 80 percent higher winter and spring flows and lower summer flows).

Information Relevant to Skagit River Relicensing: The study provides modeling tools and predicted changes in estuarine salinity distribution and circulation for the Skagit estuary under the Intergovernmental Panel on Climate Change emission scenario A1B. Because the availability of freshwater supply and nearshore environmental conditions have been shown to influence the survival of Chinook Salmon, the baseline characterization of estuarine hydrodynamics and future predictions could support the design and development of habitat restoration projects. The model results also indicate that "*a little over half (53 percent) of Skagit River freshwater is transported out to Puget Sound via Deception Pass while a comparable and significant fraction, nearly 43 percent, of Skagit River water is transported south to Saratoga Passage based on existing Year 2008 simulations. Only 4 percent, a small fraction of total freshwater delivered to the Skagit Basin makes it to Padilla Bay through the Swinomish Channel*." This has potential implications for expected fish use given flow paths influence landscape connectivity and routing of fish paths during emigration from estuary habitats to nearshore habitats.

Water Quality and Productivity: The results show that expected sea level rise and lower summer flows in the future will increase salinity in the nearshore environment of the Skagit River estuary and result in possible upstream salinity intrusion, but the magnitude of change is predicted to be relatively small. An increase in salinity of ~1 psu in the nearshore environment and a salinity intrusion of approximately 3 km further upstream is predicted in the Skagit River (2008 compared to 2070). The authors caution that results should be treated as preliminary estimates because a conservative sea level rise was used along with the moderate emissions scenario A1B, and a more extensive analyses is needed.

Modeling Tools: The paper describes details about the Finite Volume Community Ocean Model (FVCOM), which has been used in previous studies in the Puget Sound region. This study includes a new synoptic data set of currents, tides, and salinities from 2008 from the Skagit and Padilla bays. The analysis was conducted using an existing model of the Salish Sea, improved with a high-resolution grid implemented for the Padilla Bay, Skagit Bay, and Saratoga Passage. The model could potentially be used for future studies to evaluate restoration projects, impacts on various fish life stages, other climate change scenarios, or inform or integrate with other hydrodynamic modeling in the Study Area for the Synthesis Study. Simulated total and freshwater flows through selected transects in Skagit River estuary for the years 2008 and 2070 are provided in Table 5, and distribution of Skagit River freshwater flow for the years 2008 and 2070 through selected reaches of the estuary are provided in Table 6.

Kinsel et al. 2013 (Unique Identifier: 147)

Reference	Kinsel, C. W., S. E. Vincent, M. S. Zimmerman, and J. H. Anderson. 2013. Abundance and age structure of Skagit River steelhead smolts: 2012 annual report. Report prepared by Washington Department of Fish and Wildlife Fish Program for Upper Skagit Indian Tribe, Sedro-Woolley, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, size structure, age structure, status and trends, hatchery; Habitat: instream flow; Monitoring: abundance, scale or otoliths, flow, biotelemetry. ***Modeling Tools:*** juvenile production.									
Species and Life Stages	***steelhead:*** outmigration, rearing. ***Chinook:*** outmigration. ***Bull Trout:*** outmigration. ***Coho:*** outmigration. ***Chum:*** outmigration. ***Pink:*** outmigration. ***Sockeye:*** outmigration. ***Other species:*** (Cutthroat Trout): outmigration.									
Reaches and Spatial extent	R14, Finney Creek, other upper Skagit tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: This report provides the results of the 2012 juvenile salmonid monitoring efforts conducted by WDFW. The project started in 1990 to estimate natural Coho Salmon smolt abundance and was later expanded to estimate abundance of wild juvenile Chinook Salmon and to enumerate other salmonid migrants. They added three upstream traps in the 2012 season to target juvenile steelhead. The goals of this study were to 1) estimate abundance of steelhead smolts from three Skagit River tributaries (Bacon Creek, Illabot Creek, and Finney Creek), 2) estimate abundance of steelhead smolts in the entire Skagit River Basin, and 3) provide life history information for Skagit River steelhead. They also sought to enumerate catch by species and age class for each trap site and sub-sample other species for fork length. The two mainstem traps were placed in the lower Skagit River at river km 27.4 in R14. A total of 1,096 steelhead smolts were PIT-tagged in the three upstream tributaries, 431 steelhead were captured at the mainstem trap, but only one was a recapture of a smolt tagged in the three upstream tributaries. Due to an insufficient number of recaptures, they were unable to estimate total Skagit basin steelhead smolt abundance, but they did estimate abundance in the three tributaries. To estimate steelhead smolt abundance from each tributary trapping location they used DARR 2.0 (Darroch Analysis with Rank Reduction) to estimate abundance and the associated variance.

Information Relevant to Skagit River Relicensing: This report provides important information and quantitative data on the abundance, size structure, age structure, and periodicity of emigrating steelhead juveniles in the Skagit River and three tributaries, as well as some other target species. The report specifically provides quantitative data on steelhead smolt catch numbers and catch timing in three tributaries and the lower Skagit for 2012 (Table 4); steelhead smolt catches from 1993 – 2012 on the lower Skagit (Figure 4); trout parr catches; migration timing of wild and hatchery steelhead smolts (Figure 7); length, age, and size data as well as age distributions of steelhead (Table 5-7); 2012 steelhead smolt catch and production estimates (Table 9); FL metrics for Bull Trout in the lower Skagit (Table 10), and 2012 catch totals of Chinook, Cutthroat Trout, Bull Trout, Coho Salmon, Chum Salmon, Pink Salmon, and Sockeye Salmon in the mainstem and tributaries (Table 11).

Fish and Habitat: Detailed catch data are provided in appendices for each screw trap. Median migration (catch) dates of steelhead smolts were much earlier for Bacon and Illabot creeks (April 21st and 25th, respectively) compared to Finney Creek and the mainstem trap (May 13th and 15th, respectively). Trapping locations further upstream or at higher elevation (Bacon and Illabot creeks) had earlier median catch dates than the lower tributary (Finney Creek). steelhead smolt population age structure was different in each sampled tributary. The higher elevation and colder water tributaries of Illabot and Bacon creeks had more age-4 and age-3 smolts than Finney Creek and the mainstem trap. Finney Creek steelhead smolts were the smallest among the trapping locations. They sampled 164 fish for fork lengths and the average size was 155.7 mm. Age structure of Finney steelhead were dominated by age-2 smolts (74.1 percent) followed by age-3 (18.5 percent) and age-1 (7.4 percent). steelhead smolts captured in the mainstem traps averaged 174 mm fork length, the largest among the trapping locations. Scale age composition of smolts captured in the mainstem were: 77.1 percent age-2 and 22.9 percent age-3 migrants. No age-1 or age-4 smolts were seen in the mainstem traps. Size of the age- 2 smolts captured in the mainstem were significantly larger than those captured at tributary locations. This suggests that age-2 smolts that reared in the mainstem Skagit River or other unsampled tributaries are growing faster than those that were captured in the higher elevation tributary traps. steelhead smolt production estimates were completed from each tributary trapping location. Bacon Creek had a much higher smolt estimate (8,253) than Finney or Illabot creeks (2,464 and 2,705, respectively) which were similar to each other. They were unable to estimate steelhead smolt production for the entire Skagit basin because only one PIT-tagged steelhead smolt was recaptured at the mainstem site, and they recommend increased sample sizes in future years as well as monitoring using acoustic tags. They also captured other species of salmonids in at the trap sites and catch totals are displayed in Table 11. Bull Trout fork lengths from the mainstem and Illabot Creek are shown in Table 10.

The low catch total of steelhead smolts at the mainstem suggests that the spring of 2012 may have been a low steelhead smolt abundance year for the Skagit River basin. Adult escapements for smolts emigrating in 2012 were also estimated to be among the lowest escapements observed, with 2010 escapement estimated at 3,981 and the 2009 escapement estimated at 2,502. steelhead smolt catch totals from the mainstem trap and adult escapement numbers are on a downward trend through time (Figure 9).

Lawrence (2008) (Unique Identifier: 071)

Reference	Lawrence, S. 2008. Lower Skagit River tributaries temperature total maximum daily load: water quality improvement report. Report prepared by Washington Department of Ecology, Water Quality Program, Publication No. 08-10-020, Bellevue, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, nutrients, dissolved oxygen, pH, bacteria, contaminants, turbidity. ***Modeling Tools:*** hydrology, habitat. ***Land Use and Cover:*** land cover, forestry, agriculture, urban, banks and shoreline. ***Fish and Habitat:*** Habitat: instream flow, riparian, wetlands, freshwater, status and trends, restoration, climate change, data gaps; Fish: condition, survival, climate change, rearing. ***Geomorphology and Landforms:*** sediment supply and transport.									
Species and Life Stages	***All Anadromous Species:*** migration, spawning, incubation, rearing, emergence, overwintering.									
Reaches and Spatial extent	Hansen Creek, Nookachamps Creek, Day Creek, Wiseman Creek, Other lower Skagit tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: This water quality improvement report contains a strategy for reducing late summer maximum temperatures in nine creeks that are tributaries to the lower Skagit River. In the summer of 2001, it was determined that Fisher, Carpenter, Hansen, Red, Nookachamps, East Fork Nookachamps, Otter pond, Lake, and Turn Creeks did not meet Washington state water quality standards in regard to temperature. Private land owners were encouraged to increase the amount of riparian shading along these creeks. The authors believe that temperature goals for these creeks could be met by 2080 through increased riparian shading on private lands. The creeks in this study provide core summer salmonid habitat for one or more life stages. The temperature goal for all creeks in the Lower Skagit basin was 18°C, but several streams had goals set at lower temperatures depending on the species and life stages they supported. The Lower Skagit Temperature Study prescribed several methods to improve the temperature regime of the nine creeks including, management of riparian zones, management of erosion and sedimentation, encouragement of residents to reduce water use during low-flow conditions, and promotion of restoration activities that increase groundwater discharge to streams.

This report also describes potential strategies for increasing landowner involvement. Local organizations, government agencies, and Indian Tribes were expected to undertake or facilitate the implementation actions identified in this report. The roles and authority of each organization and agency are described in this report as well. Overviews of plans for measuring progress toward restoration goals, adaptive management, and public involvement and provided and the authors identify potential funding sources for the restoration and enhancement work. Required implementation actions for each organization are organized into a table by the authors.

This report contains numerous appendices that go in depth on some of the previously mentioned topics. Appendix A is the Total Maximum Daily Load (TMDL) Study that contains information on fish mortality temperatures, maximum temperatures reached by each tributary, estimated riparian vegetation and shade, loading capacity and allocations, and recommendations for management and monitoring. Other appendices contain remote analysis of riparian vegetation from historic and modern imagery, revisions to the Water Quality Standards for Temperature, and

findings of the analysis to evaluate the impacts of a 2 percent reduction of flows on the maximum temperatures. The final appendix of this report addresses comments on the TMDL process completed on the Skagit River tributaries.

Information Relevant to Skagit River Relicensing: Overall, this report provides detailed quantitative and spatial data on water temperatures and riparian health for lower Skagit River tributaries included in the Study Area for the Synthesis Study (including Hansen Creek, Nookachamps Creek, Day Creek, Wiseman Creek, Other lower Skagit tributaries). The authors identify riparian shade as a crucial factor in the reduction of instream temperatures, so there is a large focus on this topic throughout the report. In addition, information on thermal tolerances by life stages for target species are provided that can inform development conceptual life history models and identification of factors affecting life stages in the Study Area for the Synthesis Study.

Fish and Habitat: Table 4 provides a summary of tolerable and preferred temperature ranges for adult migrations, spawning, and incubation of native salmonids. Most adult salmonids migrate at temperatures less than 14°C. Salmonids have been observed to spawn at temperatures ranging from 1-20°C, but most spawning occurs at temperatures between 4 and 14°C. Table 5 contains information on upper and lower lethal temperatures and preferred temperatures of salmonid. Table 6 contains descriptions of thermally induced fish mortality along with the time to death for reach range.

Actual water withdrawals at any given time from streams in the lower Skagit River are not known, but estimations can be made. Table 7 summarizes consumptive water rights in several Skagit River tributaries. Appendix F contains a summary of the findings of the analysis to evaluate the impacts of a 2 percent reduction of 7-day average flows with a 10-year recurrence interval (7Q10) on the maximum temperature of Nookachamps Creek. A 2 percent reduction of 7Q10 flow on Nookachamps Creek resulted in a 0.05-cfs reduction and can be seen in Table 1 of Appendix F. Table 2 of Appendix F details the impact of a 2 percent reduction of flows on maximum stream temperature for current and potential vegetation scenarios. Impacts on stream temperature were found to be negligible under existing vegetation conditions.

Figures 21- 23 show effective shade from estimated and predicted riparian vegetation in Carpenter, Fisher, Hansen, Lake, East Fork Nookachamps, and Nookachamps Creek. Appendix D contains remote analysis of riparian vegetation at a 50ft and 150ft buffer. This appendix provides a description of the three main watersheds and side-by-side examples of the riparian assessment of Nookachamps, East Fork Nookachamps, Lake, Hanson, Carpenter, and Fisher Creek. The assessment was completed using imagery from 1990 and 2006. Each assessment classified the riparian zone as either barren pasture, grasses, sparse trees, dense trees, no vegetation, sparse shrubs, dense shrubs, or tall trees.

Modeling Tools: Hydraulic geometry results can be found in Figure 20 as the relationship between bankfull width and drainage area, in Table 12 as estimated Manning's roughness coefficients, and in Table 13 as Rosgen classification for the lower Skagit River. Attachment B to Appendix A contains Riparian codes used in Shade model vegetation classification in Table B-1, riparian codes used for 100-year-old riparian vegetation in Table B-2, low flow model inputs for discharge, width, depth, and velocity in Table B-3, summary of flow measurements in the lower Skagit River in Table B-4, and methodology and calculations for estimating future riparian vegetation species, heights, and widths in Table B-5.

Land Use and Cover: Small farms and rural residential development dominate the lowland portion of the Skagit River basin. Cropland and pasture dominate the western portion of the basin. The eastern uplands are predominantly forest with some scattered residential development. Many of the degraded water bodies have been diked, dredged, or channelized leading to little or no riparian vegetation. Figure 9 contains information on generalized land use in 1997 within the report's study area. Land use in this figure was identified as a mixture of agriculture, urban, suburban, and forestland.

Water Quality and Productivity: Fisher, Carpenter, Lake, Otter Pond, Turner, Hansen, Red, Nookachamps, and Lake creeks were assigned a 7-DADM temperature of 16°C. Most of the East Fork Nookachamps Creek was assigned a 7-DADM temperature of 16°C, however the upper reaches and smaller tributaries to the East Fork were assigned a 7-DADM temperature of 12°C. Also, for the period between February 15 and June 15, Upper Lake, Lower Hansen, and a middle reach of East Fork Nookachamps Creek were assigned a 7-DADM temperature of 13°C. Stream types of each tributary are identified in Table 3. Figures 30-32 contain model results that predict full riparian shade would enable Carpenter, Fisher, and Hansen creeks to meet the 16°C standard. Figure 33 contains model results that predict Lake Creek could meet stricter standards at its downstream end, but not its upstream end due to the lake effect. Figures 34 and 35 contain model results that predict that the East Fork Nookachamps and Nookachamps creeks could meet the 16°C standard through full riparian vegetation and deepening and narrowing of channels. Figures 30-35 contain predicted daily maximum temperatures for several estimated and potential restoration stages of Skagit River tributaries under critical conditions for the TMDL. Tables 17-22 detail the daily load allocations for effective shade in Skagit River tributaries. Attachment A to Appendix A contains instream water temperature standard exceedances and station disposition for all temperature stations.

The authors set a goal to have 100 percent of all stream miles of these nine creeks protected by riparian shade or enrolled as part of a larger creek restoration project by 2020 and if successful, water quality standards would be met by 2080. Table 3 provides a timeline and list of objectives for the phases of the TMDL implementation strategy. Table 9 contains the highest daily maximum temperatures in the lower Skagit River tributaries during 2001. Each stream listed in this table contain temperatures that exceed the water quality standard. Figure 13 represents tributaries temperature stations highest daily maximum temperature on the hottest day of the year in 2000. Figure 14 represents temperature stations maximum 7-day average of the daily maximum temperature in 2000. Water and air temperature were continuously monitored in the spring, summer, and fall of 2001 and 2002 in Nookachamps, East Fork Nookachamps, Lake, and Hanson Creeks. Figure 15 displays the location of these temperature stations. Figures 16-18 graphically show daily maximum water temperatures in many Skagit River tributaries for the months of June through September in 2001. Table 10 contains estimated seven-day average flow for several Skagit River tributaries. Table 15 contains comparisons of the study's temperature stations and the temperatures obtained at the Mt. Vernon National Centers for Environmental Information (NCDC) station.

Appendix E contains revisions to the Water Quality Standards for Temperature including the following changes. To protect Char spawning and rearing, 7-day average of daily maximum temperatures (7-DADMax) must not exceed 12°C more than once every ten years. To protect core summer salmonid habitat, 7-DADMax temperature must not exceed 16°C more than once every ten years. To protect salmonid spawning, rearing, and migration, 7-DADMax temperature must not exceed 17.5°C more than once every ten years.

Lee et al. (2016) (Unique Identifier: 417)

Reference	Lee, S-Y, A. F. Hamlet, and E. E. Grossman. 2016. Impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin. Northwest Science 90(1):23-43.										
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Yes	
Topics and Keywords	*Geomorphology and Landforms:* change, sediment transport and supply, climate change. *Water Quality and Productivity:* temperature, turbidity, climate change. *Modeling Tools:* hydrology, climate change. *Land Use and Cover:* banks and shoreline, floodplain. *Fish and Habitat:* Habitat: instream flow, estuary, freshwater; Fish: climate change. *Hydroelectric Operations:* flow regulation, flood control, life stage flows.										
Species and Life Stages	Nonspecific, but implications linked to regulation of stream temperatures for fish.										
Reaches and Spatial extent	Skagit Watershed including Reaches R1 – R14, Sauk River, and Baker River.										
Linkages to Hydroelectric Operations	*Modeling Tools:* hydrology, climate change. *Fish and Habitat:* Habitat: instream flow. *Hydroelectric Operations:* flow regulation, flood control, life stage flows. *Geomorphology and Landforms:* sediment transport and supply.										

Summary: To assess the hydrologic response of the Skagit River due to climate change an integrated daily-time-step reservoir operations model, SkagitSim, was created to simulate reservoir operation policies for historical flow conditions and projected flow conditions in the 2040s (2030–2059) and 2080s (2070–2099). Results show that climate change will cause substantial seasonal changes in both natural and regulated projected flow conditions. The Skagit River Basin will transition from a mixed rain and snow watershed with dual peaks in the winter and spring to a rain dominated watershed with a single peak in the winter for both natural and regulated flow conditions.

Projected flow conditions were calculated using five different global climate models forced by the A1B greenhouse gas emissions scenario. The Variable Infiltration Capacity (VIC) hydrologic model was implemented at 1/16 latitude and longitude resolution over the Pacific Northwest. The VIC model was used to generate a streamflow time series for this study.

The projected shift in seasonal timing of flow affects the magnitude and timing of hydropower production. Hydropower production will increase in the winter and decrease in the summer. This will be a benefit to the region in the winter but will present challenges in the summer with additional increases in energy demand due to an increase in population and an increase in cooling demand. Additionally, increasing pressure to use reservoir releases of cold water to sustain temperature sensitive fish downstream may present additional challenges.

There will be large changes in the magnitude and timing of sediment load at the Skagit River near Mount Vernon. The peak sediment load in December will increase from a historic average of 0.40 teragrams/month to a projected average of 1.74 teragrams/ month (+ 335 percent) by the 2080s. The December to February total sediment discharge is projected to increase by 376 percent for the 2080s. This will benefit the Skagit delta by potentially mitigating the projected loss of marsh and shallow water habitat due to rising sea levels. Although an increase in suspended sediment load may also negatively impact many aquatic species.

The 100-year flood is projected to increase relative to historic baselines for both a natural and regulated scenario in both the 2040s and 2080s. Additionally annual peak flows are projected to increase in magnitude and occur more frequently in the winter season. Alternative flood control operations that increase flood control storage were shown to be not effective in mitigating higher flood risks in future climate change scenarios.

Extreme low flows under regulated conditions are projected to decrease due to an increase in evapotranspiration and a decrease in summer precipitation. Although projected low flows under regulated conditions will still be higher than historic low flows under natural conditions. This suggests that ecosystem impacts from a changing low flow regime may be modest.

Information Relevant to Skagit River Relicensing: The report provides insight on projected changes in seasonal hydropower generation, flood mitigation, and sediment loading in the Skagit River Basin with climate change and describes a modeling tool (SkagitSim) that was developed to support the analysis. In addition to the tabular and graphical summaries presented in this report, the modeling tools themselves could be used to develop quantitative data summaries or support integration of climate change and operations models with other modeling tools being developed to inform resource conditions in the lower study area for the Synthesis Study. Summaries of changes in streamflows in the mainstem Skagit River near Mount Vernon are described throughout the report, which are useful for characterizing the combined effects of inputs from reaches with regulated flows (upper Skagit and Baker River) as well as unregulated tributaries (Sauk River), which are generally described in the summary section above.

Annual hydropower generation will not change significantly based on projected hydrologic conditions but seasonal changes in hydropower production will be significant. By the 2080s hydropower generation in the Skagit basin is projected to increase by 19 percent in the winter and spring and decrease by 29 percent in the summer. Annual peak flows as well as 100-year interval flows are projected to increase in magnitude causing an increase in flood risks downstream. An alternative reservoir operation policy that allows for an increase in flood control storage was shown to be ineffective in mitigating flood risks. There is projected to be a dramatic increase in sediment load with the total sediment discharge from December to February at the Skagit River near Mount Vernon increasing by 376 percent, and this could be linked with hypotheses that sediment supply and transport are related to estuary habitat and landform processes in the Skagit River delta to determine how this change could impact future habitat conditions and resiliency to climate change. In addition, the authors indicate that this increased suspended sediment loading may reduce flood conveyance and increase water elevations during flooding and may also interfere with tide gate operations.

Lee and Hamlet 2011 (Unique Identifier: 196)

Reference	Lee, Se-Yeun, A.F. Hamlet. 2011. Skagit River basin climate science report. Report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	Yes
Topics and Keywords	***Fish and Habitat***: Habitat: climate change, instream flow, estuary, connectivity, freshwater, ocean; Fish: climate change; Monitoring: climate change. ***Geomorphology and Landforms***: change, history, sediment supply and transport, estuarine habitats and landforms, glaciers and snowpack, shallow and deep surface processes, scour. ***Water Quality and Productivity***: climate change, temperature, dissolved oxygen, turbidity, nutrients, primary productivity, contaminants. ***Land Use and Cover***: banks and shoreline, forestry, agriculture, urban, commercial. ***Modeling Tools***: hydrology, climate change. ***Hydroelectric Operations***: flow regulation, flood control, life stage flows.									
Species and Life Stages	***Chinook***: not specified. ***Sockeye*** **(*including kokanee*)**: not specified. ***Coho***: not specified. ***Pink***: not specified. ***Bull Trout***: not specified. ***Other species*** **(Cutthroat):** not specified.									
Reaches and Spatial extent	Skagit Watershed, Sauk River, Skagit Bay, Nookachamps Creek, Baker River, other lower Skagit tribs.									
Linkages to Hydroelectric Operations	***Fish and Habitat***: Habitat: climate change. ***Hydroelectric Operations***: flood control, flow regulation, life stage flows.									

Summary: This report is a summary of climate science research for the Skagit River basin. The report is divided into eight separate chapters. Each chapter focuses on different consequences of climate change projected for the Skagit River basin. The summary that follows proceeds in order by chapter and captures the main ideas presented in each section.

Chapter 1 – An overview of the Skagit Basin: The Skagit River basin has experienced extensive human development since the process of colonial settlement began in the 1850s. Throughout the 19th century, extractive industries (e.g., logging and mining) in the headwaters and agricultural and urban development in the floodplain has forced dramatic changes to the hydrology, geomorphology, and ecosystem functions in the basin. Construction of levees and dikes have constrained sediment supply to the delta, resulting in loss of tidal wetland areas. Cities located within the floodplain are vulnerable to river flooding exacerbated by climate change and agricultural lands on reclaimed tidal flats are at risk of inundation. Finally, habitat loss within the basin threatens a wide range of species, including economically and culturally important species.

Chapter 2 – Climate variability: Two large-scale cyclic climate patterns influence hydrology in the Pacific Northwest, the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The impact to regional hydrology has implications for streamflow, snowpack, and frequency and magnitude of drought and floods. Warm PDO and ENSO years are generally associated with drier and warmer winter and spring weather and vice versa. PDO/ENSO effects tend to be amplified in synchronous phase years. Snowpack and instream flows in the Skagit River are more sensitive to PDO/ENSO driven climate variability than other Pacific Northwest rivers.

Chapter 3 – Climate Change Scenarios: Physics-based simulations of future climate scenarios are essential for informing long-term community planning and policy making. Outputs from global and regional climate models were used as inputs to finer resolution hydrologic models for the Skagit River to simulate future temperature and precipitation scenarios. Projected temperatures for the Skagit River are expected to increase, in concert with the rest of the PNW, but increases are expected to be somewhat below the regional average. Precipitation is also expected to increase, although the trend was not statistically significant due to greater variance in simulated precipitation values. Sea-level rise is expected to have dramatic impacts in Puget Sound without aggressive reductions in greenhouse gas emissions.

Chapter 4 – Glaciers: Glaciers play a crucial role in the Skagit Basin's hydrology. There are 394 glaciers in the Skagit River basin, which contribute between 12 and 18 percent of the May to September summer flow. Glacial retreat since 1900 has resulted in a 50 percent reduction in total glacial area, the rate of which has been more rapid on the wetter western side of the Skagit River basin than on the drier eastern side.

Chapter 5 – Hydrology: Climate modeling scenarios predict warmer temperatures will result in more precipitation falling as rain in the cool season, resulting in reduced snowpack and a shift in runoff timing. Reduced snowpack will carry over into more extreme low flows in the summer. Compared to the Pacific Northwest as a whole, the Skagit River is expected to experience a less severe reduction in April 1 snow water equivalent (SWE). By the end of the 21st century, the Skagit River basin will resemble a rain-dominant watershed. Floods are expected to increase in frequency and magnitude due to greater winter precipitation and higher freezing elevations. Changes in summer low flows will be more pronounced in basins with significant glacial influence.

Chapter 6 – Geomorphology: Diking, levee building, channelization, and large wood removal has fundamentally altered the spatial arrangement, function, and connectivity of distributaries, while at the same time has increased the sediment load transported to the Skagit delta. Marsh habitat in the South Fork is actively eroding since the dominant flow path was forced to the North Fork. Today, most of the sediment reaching the delta bypasses the shoreline and tidal flats and is deposited onto the delta face in deeper areas. Climate change is expected to further increase sediment loads as glaciers and snowpack retreat, exposing more bare earth. Sea level rise may increase coastal erosion as well, but little is known about whether sea level rise will lead to marsh accretion or net loss in tidal marsh habitat. Initial modeling exercises predict net losses of tidal marsh with sea level rise. Removal of existing dikes may increase marsh habitat and mitigate potential impacts of sea level rise.

Chapter 7 – Ecosystems: Climate change is expected to have profound consequences for Skagit basin ecosystems. Changes in hydrologic extremes (i.e., floods and drought) will impact many fish and wildlife species. The composition of tree and vegetation communities will likely be impacted by drier and warmer summers, especially impacting drought-susceptible species such as western red cedar. Forecasted future conditions will likely favor forest pest species, diseases, and wildfire. Prolonged summer low flows, increased flooding, and warmer air temperatures are expected to impose additional stress on cold-water fish species, such as salmon and trout. Loss of estuarine and marsh habitats due to sea level rise may increase delivery of pollutants and excess nutrient runoff into Skagit Bay, resulting in increased frequency of harmful algal blooms and hypoxia events.

Chapter 8 – Human Systems: Climate change impacts are expected to affect human systems of water management, agriculture, power generation, flood control, and recreation. Shifts in instream flow timing will change the seasonal power generation at the Skagit hydroelectric project. Peak hydropower generation will likely shift from July to January, potentially resulting in a mismatch between power generation and power demand as energy use increases with hotter summers.

Changes in flood storage capacity in the headwaters and timing of peak flows in the Skagit River increases flood risks in low lying areas. Exaggerated summer low flows are also expected to reduce recreational opportunities, such as fishing, kayaking, and rafting. Increased probability of wildfire may result in more frequent closures on forested lands. Increased disease, invasive species establishment, and pests due to warmer temperatures may impact agricultural production. Warmer temperatures may also impact the quality of some crops. Impacts to agriculture would result in significant financial losses in Skagit County due to the prominence of the agricultural sector to the local economy. Current resource management strategies will need to be reassessed for a warmer climate, because current strategies may introduce conflicts with other goals for the system (i.e., changes in seasonal flood storage capacity must be balanced with instream flow objectives for anadromous fish).

Information Relevant to Skagit River Relicensing: This report provides relevant information and context for the state of the climate in the Skagit River watershed, as well as simulated projections for the impact of climate change on key hydrologic features, such as stream temperatures, precipitation, and glaciers. While the information presented is general, the consequences of climate change will affect many aspects of the Skagit River's hydrologic regime and have impacts on Hydroelectric Operations, ecosystem function, and socio-economic stability in the region. These impacts are applicable to the Skagit Watershed as a whole, as well as within the Study Area for the Synthesis Study. Furthermore, the report provides information that supports the development of conceptual life history models and identification of linkages between climate change and other factors and resource conditions. Information on topics of interests are described in more detail below.

Geomorphology and Landforms: Maps of historic (1860) and 2002 land use types in the Skagit delta are displayed in Figure 6.1 and can provide spatial and historical context for developing habitat and/or landform restoration targets. Glaciers in the North Cascades that feed the Skagit River have been in retreat, in accordance with global patterns. Table 4.1 provides statistics on cumulative mass balance and changes in area since 1958 for 10 North Cascade glaciers. Disappearance of glaciers in the Skagit River basin is expected to exacerbate summer low flows, which will impact hydroelectric operations (e.g., hydroelectric power generation), agriculture, and instream flow.

Water Quality and Productivity: Climate variability driven by ENSO and PDO in the Skagit River basin follows the same general pattern seen throughout the Pacific Northwest, where warm (cool) ENSO and PDO phases tend to produce warmer and drier (cooler and wetter) conditions. Long-term average temperatures in the Skagit River basin between October and March are typically 1.4 to 1.7 ºF higher during warm PDO and ENSO years, respectively, and average warming increases to 2.8 ºF when PDO and ENSO are in phase.

Fish and Habitat: April 1 snow water equivalent (SWE), the amount of liquid water locked in snowpack, is 25/58 percent lower during cool PDO/ENSO years. April 1 SWE in the Skagit River is negatively correlated with cool season temperatures and positively correlated with warm season precipitation. Warm PDO/ENSO phases are also associated with lower instream flows with the most pronounced effects typically observed in June. Synchronous ENSO/PDO phases tends to amplify climate variability and hydrologic anomalies, increasing risk for flood and drought, and increases thermal stress for cold water fish species. The hydrologic regime of the Skagit River correlates better with cool season temperatures compared to other Pacific Northwest rivers (e.g., Columbia River). The result is that PDO and ENSO have more pronounced influence on snowpack and instream flow in the Skagit compared to other large rivers in the PNW. Warming and loss of snowpack is expected to transform the Skagit River watershed from snowmelt-dominant to transient snow-dominant (upper Skagit River) and transient snow-dominant (lower Skagit River) to rain-dominant watersheds. As a result, the peak flows are expected to occur earlier in spring and summer low flows are expected to become more extreme.

Modeling Tools: Climate modeling for the Skagit River basin suggests that average annual water temperatures are expected to increase between 4.0 and 5.8 ºF by the end of the 21st century, somewhat less than Pacific Northwest average. Compared to temperature, there is more uncertainty in the trends describing average annual precipitation for the Skagit River. Modeled precipitation in the Skagit River basin are expected to change by +9.8 percent in winter, +8.0 percent in spring, +19.2 percent in fall, and -27.6 percent in summer. Tables 3.3 and 3.4 contain summaries of 20th and 21st century average annual and seasonal mean temperature and precipitation values for historic and modeled climate scenarios for the entire Skagit River upstream from Mt. Vernon (R15 +). Sea-level rise in Puget Sound under the highest emission scenarios is expected to be between 128 – 219 cm and only 16 cm under the low emissions scenario.

Hydroelectric Operations: Changes in hydropower demand are expected as global temperatures rise. Annual power generation for the Skagit hydroelectric project is expected to increase (relative to 2011 when this report was written) by 3 percent by the 2020s, 5 percent by the 2040s, and 9 percent by the 2080s. Increased power generation is partly attributable to greater annual inflow from Ross Lake resulting from increased cool season precipitation. By 2080, peak hydropower generation will have shifted from July to January due to changes in the hydrologic regime of the basin and timing of peak flows. Summer power generation is projected to decline by 30 percent, which may impose challenges for the region in which air conditioning use is expected to increase. Figure 8.4 shows cumulative distribution functions for unregulated (natural) daily peak flows for the Skagit River under alternative climate change scenarios in the 2040s and 2080s. These curves can be used to inform instream flow scenarios to predict flooding and/or impacts to anadromous fish. Flood control policies may need to consider altering the timing of refill to ensure that reservoirs have enough storage during the summer to meet in-stream flow requirements for fish species and recreation. Increased river flooding combined with sea level rise will likely prevent current flood control structures (i.e., dikes and levees) in the lower Skagit from operating properly, resulting in flooding. Additionally, sea level rise may prevent tide gates from draining areas as intended.

Lowery and Beauchamp (2015) (Unique Identifier: 074)

Reference	Lowery, E. D., and D. A. Beauchamp. 2015. Trophic ontogeny of fluvial bull trout and seasonal predation on Pacific salmon in a riverine food web. Transactions of the American Fisheries Society 144:724-741.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Modeling tools:*** bioenergetics, data gaps. ***Fish and Habitat:*** Fish: diet, distribution, predation, age structure, size structure, growth, status and trends, hatchery, data gaps.								
Species and Life Stages	***Bull Trout***: full life cycle. ***Chinook***: rearing. ***steelhead***: rearing. ***Pink***: rearing. ***Chum***: rearing. ***Coho:*** rearing.								
Reaches and Spatial extent	R7, US of R7, Other upper Skagit tribs (Bacon Creek, Illabot Creek).								
Linkages to Hydroelectric Operations	NA								

Summary: This study analyzed fluvial Bull Trout's ontogenetic trophic ecology within the Skagit River system and their role as predators and consumers in the riverine food web including listed salmonid species. Specifically, Bull Trout's ontogenetic energy budgets and the importance of invertebrates, prey fishes, salmon eggs, and salmon carcasses in their diet. Diet analysis, relative isotope values of Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), and bioenergetics modeling were used to answer this first part of the study. Ontogenetic energy budgets for Bull Trout were quantified at the individual and population levels by estimating year-round consumptive rates. The data from sampling the contents of 525 nonempty Bull Trout stomachs were used with a Wisconsin bioenergetics modeling to estimate the annual and lifetime budgets of Skagit Bull Trout and to evaluate their potential impact on prey populations (including ESA listed salmonids). Additionally, field sampling of age-specific growth, size-specific data, spatial distribution, thermal experience, abundance, Bull Trout key prey types and energy densities of Bull Trout provided data inputs for the bioenergetics model. For the second part of the study, Bull Trout size- and stage-specific predation on anadromous salmons and resident fishes were determined. From winter to fall of 2007, and winter to spring of 2008, diet analysis data from stomach contents were sampled within a 40 km reach of the Skagit River mainstem from Gorge Dam powerhouse to the Sauk River confluence as well as Bacon and Illabot creeks.

Information Relevant to Skagit River Relicensing: This source provides relevant information on Bull Trout and other target species, including Chinook, Chum, Pink, and steelhead, but is primarily focused on reaches upstream of the Sauk River confluence. However, the study includes Reach R7 and it is likely that the patterns identified and modeling tools developed in this study could be applicable to reaches within the Study Area for the Synthesis Study. Quantitative data for a number of fish metrics, including a large amount of data on seasonal and age specific summaries of diet composition and predation, are provided. In addition, the modeling tools and data presented in this study could be used to evaluate how Bull Trout diets, abundance, and life histories influence recovery of other target species given their diet. Potentially relevant data and modeling tools are summarized below.

Fish and Habitat: Bull Trout were grouped by their relevant size classes habitat use patterns and were categorized as follows: age 0-2 were 30-95mm, occupying natal tributaries; age 3 were 96-

300 mm and were assumed to be subadults transitioning from tributaries to mainstem; age 4-5 were 301-450mm in the mainstem; and age 6 and older were greater than 450 mm were also in the mainstem. They found that the $\delta^{15}N$ and $\delta^{13}C$ values generally became more enriched as Bull Trout FL increased, suggesting an ontogenetic shift in diet and habitat at roughly 300 mm FL. The broad range of $\delta^{15}N$ and $\delta^{13}C$ exhibited by juvenile Bull Trout in the tributaries suggests a wider range of invertebrates and higher-trophic-level prey, whereas Bull Trout larger than 300 mm FL occupied the uppermost trophic level in the main stem, primarily feeding on marine-derived food sources and prey fishes. Diets varied by Bull Trout size-class, season, and year depending on available prey in the tributaries and mainstem habitats. For example, in 2007, the 30-95 mm size class in tributaries were eating mostly aquatic insects for all seasons. At 100 mm, Bull Trout began to be more piscivore while in tributaries. The 96-300 mm size-class in the tributaries had stomach contents that primarily contained age-0 steelhead/Rainbow Trout and some aquatic insects during the fall and Coho Salmon and aquatic insects during the other seasons. The mainstem diets, the 301-450 mm size-class predominantly had salmon eggs during the fall, salmon carcass flesh and salmon fry during the winter; salmon and Steel/Rainbow Trout fry in the spring, and almost exclusively sculpins during summer. The greater than 450 mm size-class, consumed salmon eggs during the fall; salmon carcass flesh, salmon eggs, sculpins, smaller Bull Trout, juvenile salmon, and steelhead/Rainbow Trout during the winter; salmon fry, steelhead/Rainbow Trout and resident fishes (Mountain whitefish, sculpins, and daces) during the spring; resident fishes (dace and sculpins), invertebrates, juvenile Coho and steelhead/Rainbow Trout and salmon eggs were the primary diet during the summer. In comparison, diets during the 2008 seasons, the 30-95 mm size class contained mostly aquatic insects during the spring. The 96-300 mm size class in tributaries had mostly salmon eggs during the winter, and juvenile Coho and aquatic insects during the spring. Detailed tabular summaries of proportion diet composition by size classes and season are provided that could be extracted (see Table 4).

Length to body weight conversion relationships are also provided from captured Bull Trout, with Weight (g) equal to 0.0000135 x (FL in mm)$^{2.96}$ from 853 fish ranging from 34 – 687 mm FL. Plots of mean length at ages 1-9 are provided with standard deviations showing increasing mean sizes at ages. Detailed tabular summaries of mass, spawning loss, growth, total consumption, and growth efficiency by age class as also provided, which can use used to inform modeling or food web analyses (see Table 1). In addition, tabular summaries mean FLs with standard deviations of prey found in Bull Trout stomachs by season and prey types, including target species and other non-target species.

Modeling Tools: The Wisconsin bioenergetics model framework was coded into R and used species specific parameters for Bull Trout. The estimated biomass of each prey consumed during each season and life stage in the model simulations was multiplied by the corresponding energy density of prey to calculate the total energy contributed by each prey type during the different seasons and life stages for Bull Trout. Modeling consumption simulation found that 30-95 mm juvenile Bull Trout in the tributary were feeding 31-60 percent of their theoretical maximum consumption (C_{max}) and growth efficiency (GE) at 18-25 percent. Bull Trout greater than 300 mm in the mainstem fed at 14-20 percent C_{max}. A data gap was found for the 96-300 mm size class due to low captured rates within the tributaries and mainstem habitats. For the modeling of consumption analysis, this source suggests additional accurate growth and diet data are needed to increase the precision of consumption estimates for the 96-300 mm size class.

The energy densities for Bull Trout and prey were either directly measured or values were obtained from literature and were used as energy density inputs for the bioenergetic model. They found energy budgets for Bull Trout were different at each life stage and between the two habitat types, tributary and mainstem. Aquatic invertebrates made up 92-96 percent of the estimated energy budget for the 30-95 mm size class in tributaries whereas 96-300 mm size class estimated energy budget was from Coho Salmon at 73 percent. Bull Trout greater than 300 mm got most of their energy budget from salmon eggs (41-44 percent). The model simulations also indicated that the majority of energy intake was during the fall and summer. Detailed stacked bar plots are provided that show the energy budgets by size class and season, as well as tabular summaries of seasonal energy densities by prey type.

During the size structured predation analysis, a unit population of 1,000 Bull Trout greater than 300 mm consumed 308 kg of resident fishes (dace and sculpins primarily), 170 kg of fish eggs (mostly salmonid), 142 kg of steelhead/Rainbow Trout, 84 kg of immature aquatic insects, and 62 kg of terrestrial and adult aquatic insects. The total estimated predation of a unit population of Bull Trout on age 1+ Chinook Salmon was 2,447 fish in 2007. In 2008, no predation was detected during winter-spring 2008. The total predation of a unit population of Bull Trout on target salmonids in the Skagit River varied throughout the seasons but most of the predation occurred during winter (i.e., the fry emergence period) and spring (i.e., the smolt out-migration period). Detailed tabular summaries of estimated seasonal numbers of fish consumed by Bull Trout by prey types are provided.

Lowery et al. (2020) (Unique Identifier: 075)

Reference	Lowery, E. D., J. N. Thompson, E. Connor, D. Pflug, B. Donahue, and J. Shannahan. 2020. Seasonal distribution and habitat associations of salmonids with extended juvenile freshwater rearing in different precipitation zones of the Skagit River, WA, January, 2020. Report prepared for Seattle City Light, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: rearing, age structure, size structure, periodicity, status and trends, data gaps, movement, predation, survival, competition, life history, distribution; Habitat: freshwater, capacity, limiting factors, riparian; Monitoring: abundance, scale or otoliths. ***Modeling Tools:*** habitat. ***Water Quality and Productivity:*** temperature. ***Geomorphology and Landforms:*** large wood, log jam, substrate and sediment, aquatic habitats and landforms.									
Species and Life Stages	***Chinook:*** rearing-outmigration, overwintering. ***Coho:*** rearing. ***steelhead:*** rearing. ***Bull Trout:*** rearing.									
Reaches and Spatial extent	US of R7, R8-R13, Sauk River, Suiattle River, Cascade River, Diobsud Creek, Illabot Creek, Hansen Creek, Finney Creek, Day Creek, Nookachamps Creek.									
Linkages to Hydroelectric Operations	NA									

Summary: Migratory salmonids utilize a variety of habitats throughout multiple life stages where growth efficiency is closely linked to survival in both freshwater and estuarine ecosystems. As climate change progresses, dramatic shifts in hydrology are expected to alter the spatial-temporal distribution of habitats that favor growth during critical life stages for anadromous salmonids. The Skagit River Chinook Salmon Recovery Plan (Beamer et al. 2005, ID175) points to the availability of suitable freshwater habitat as a limiting factor for juvenile Chinook with extended freshwater life histories (referred to as 'stream-type Chinook'), and identifies seasonal habitat use and distribution life histories of anadromous salmonids as an important data gap in Puget Sound salmon recovery plans. The goals of this research effort are to describe the spatial distribution of stream-type juvenile Chinook, Coho, steelhead, and Bull Trout on a seasonal basis in the Skagit River Basin, and differentiate between physiographical variables, aquatic habitat variables, and channel types associated with juvenile fish use. Throughout 2011-2012, field sampling within known Chinook reaches of sub-basin and precipitation regions (hydro-regions) of the Skagit River Basin and the resulting length frequencies, mean densities, primary component analyses (PCA), seasonal occupancy (Ψ) modeling, and classification tree modeling suggest interactions between hydro-region, channel type, and seasons for anadromous salmonid spatial-temporal distribution. Stage-specific life history summaries were generated for all target species highlighting rearing and migratory behaviors with inter-specific and intra-cohort interactions, but more investigation is needed to determine the specific physical habitat attributes/mechanisms that drive migratory behavior and carrying capacity for Chinook parr migrants.

Information Relevant to Skagit River Relicensing: This source contains relevant information on the rearing and migratory patterns of anadromous salmonids throughout the Skagit River. Dominant seasonal gradients of habitat use by juvenile stream-type Chinook, Coho, steelhead, and Bull Trout are described by hydro-regions (Snow, Rain, Mixed) throughout freshwater reaches within the Study Area for the Synthesis Study. Field sampling for seasonal species composition, relative density, age/length structure included nighttime snorkeling and supplemental electrofishing surveys (Table 5) among channel margins of 28 sites following Generalized

Randomized Tessellated Stratified (GRTS) algorithms stratified spatially by hydro-regions (Table 1) and temporally by significant life stages and seasonal benchmarks (Table 2). Snorkeling and electrofishing surveys were conducted throughout freshwater systems in the Skagit River Basin between spring 2011 and spring 2012, covering 36.4km of freshwater channel types throughout mainstem Skagit River (upstream of reach R7, reaches R8-R13), upper Skagit tributaries (Cascade River, Diobsud Creek, Illabot Creek), Sauk River (lower Sauk, upper Sauk, Suiattle River) and lower Skagit tributaries (Finney Creek, Day Creek, Hansen Creek, Nookachamps Creek) (Figure 1). All habitat data (and subsequent fish data) were analyzed by channel types, including tributary, mainstem, side channel, floodplain, and logjam channel. Quantitative data of vegetation cover, large woody debris, substrate composition, wetted/bankfull widths, and unit length, depth, and velocity were compiled to evaluate physiographic and aquatic habitat parameters (Tables 1, 3-4) within channel units. Length frequency histograms (Figures 3-9) and mean density histograms (Figures 10-14) were utilized to determine trends in size structure and abundance of each target species population by hydro-region and by season. Scale samples were extracted to determine age structure of observed Chinook Salmon and juvenile steelhead ('*O. mykiss*') and estimate seasonal size-at-age by hydro-region (Tables 6-7).

Previous studies incorporated in the Synthesis Study discuss seasonal distributions, relative densities, and edge habitat use of juvenile salmonids (Beechie et al. 2005, ID014) as well as channel type hierarchy and nonmetric multidimensional scaling analysis (NMDS) in the Skagit Basin (Beamer et al. 2010, ID202). The scope of this source builds on previous research by including precipitation zones (hydro-regions), additional target species (steelhead, Bull Trout), additional physiographic and aquatic habitat parameters, and additional modeling techniques (occupancy probabilities, classification modeling) in the assessment of life history strategies of juvenile salmonids.

<u>Fish and Habitat:</u> Throughout the 2011-2012 surveys, several trends in species presences and size structures were observed throughout hydro-regions, seasons, and channel type, with specific interactions ranging between highly specific to broadly general. *O. mykiss* were observed in every hydro-region, season, and channel type. Coho Salmon were found in every hydro-region and season except for Snow hydro-region in winter. Both fry and stream-type Chinook Salmon were found in every hydro-region and season, but varied in distribution, relative density, and use of channel type; and were observed at lower rates in winter compared to other species. Bull Trout were found in similar habitats as Chinook but were not detected in the Rain hydro-region in winter. Mean modal lengths of a given species were compared between hydro-regions, seasons, and survey methods, showing significant differences in detectable size structures between snorkeling and electrofishing for Chinook. Age structure through electrofishing indicates presence of larger, age-2 stream-type Chinook detected in late summer and early winter seasons. Stream-type Chinook were observed at lower densities in Snow hydro-regions compared to Mixed and Rain hydro-regions, and were more commonly found in mainstem, large logjams, and floodplain channels adjacent to larger stream systems. Chinook densities were greatest in large logjam channels in Rain hydro-region in spring and summer, and in floodplain channels in all hydro-regions in winter (with limited detection). Densities of Chinook fry were greatest in mainstem channels in all hydro-regions in spring, while stream-type Chinook densities were greatest in floodplain channels in Snow hydro-regions in spring and in mainstems in Snow hydro-region in summer. Ultimately, habitat use during end of spring outmigration was less distinct in spring seasons than in summer and winter season, as stream-type life-history migrants move into new rearing habitats in higher flows. Some habitat overlaps between stream-type Chinook and other migratory species were

frequently observed in summer and spring. *O. mykiss* 20-300mm were commonly detected with stream-type Chinook but did not display strong associations with similar habitat variables or channel types. While strongly associated with the Snow hydro-region, Bull Trout sub-adults were consistently found in mainstem channel types favored by migratory Chinook, highlighting a potential predation risk to stream-type Chinook and *O. mykiss*. With lower densities observed in every channel type throughout the study area, stream-type Chinook displayed generalist behavior to occupy habitats with moderate depth, cover, and wood/bank structure may allow individuals to hit critical growth and anti-predation benchmarks amid other overlapping anadromous migrants.

Principal component analysis was used to highlight habitat gradients of physiographic habitat variables (Figure 15) and aquatic habitat variables (Figure A1) with respect to sampling site locations within a given hydro-region (Appendix A); as well as fish assemblages stratified by hydro-region through seasonal nonmetric multidimensional scaling analysis (NMDS) (Figures 16a-c). Results of the physiographic variable PCA highlight a strong primary gradient by hydro-region along the first axis (40.03 percent of variance) characterized as basin area positively associated with Rain hydro-region and negatively associated with elevation, distance to confluence, and distance to Skagit Delta. The secondary gradient (23.55 percent of variance) was characterized by a positive association between channel confinement and maximum temperature and negative associations of both variables with solar radiation. These secondary gradient associations suggest that geomorphological processes increased instream temperatures to extremes beyond the effects of total annual solar radiation. As shown by the relative clusters of hydro-regions, the Rain hydro-region was more distinct compared to Mixed and Snow hydro-regions along the first axis. All NMDS analyses by season display a strong gradient in fish species composition and hydro-region along the first axis, with greater explained variance in Snow hydro-region than in Rain and Mixed hydro-regions.

<u>Modeling Tools:</u> Spatiotemporal distribution of target species with low detection rates (primarily Bull Trout and Chinook Salmon) by season were characterized using occupancy modeling (Table 8), with Bull Trout pooled as a single taxon (30-300mm) and Chinook as two distinct taxa (20-80mm, 80+mm) to differentiate ocean- and stream-type size classes. Bull Trout seasonal probability of occupancy (Ψ[SE]) was high in Snow hydro-region in every season and in Rain hydro-region in spring (Ψ= 1[0.0]) but varied in Mixed hydro-region in every season (summer: Ψ= 0.73 [0.33]; winter: Ψ= 0.44 [0.14]) and in Rain hydro-region in summer (Ψ= 0.61[0.43]). No Bull Trout were detected in Rain hydro-region in winter. Chinook occupancy in all hydro-regions trended towards larger body size from spring to summer, with 80+mm individuals detected in all hydro-regions in all seasons and with 20-80mm individuals detected in all hydro-region only in spring and summer.

Factors associated with ocean- and stream-type Chinook Salmon and sub-adult Bull Trout were also examined through classification and regression tree (CART) modeling using seasonality, hydro-region, physiographic and aquatic habitat variables as explanatory variables to predict presence and absence thresholds by species (Figures 17-19). Bull Trout sub-adult presence/absence was classified using 5 explanatory variables (distance from Skagit Delta, hydro-region, basin area, season, depth). The 5-node CART (Figure 17) indicates Bull Trout were likely to be present further upstream in the Skagit River Basin (>114 river km), in Snow/Mixed hydro-regions, in smaller sub-basins (<585km^2) within Mixed hydro-regions, and in higher velocity (>0.49m/s) in larger sub-basins (>585km^2) within Mixed hydro-regions. Smaller sub-basins include the upper Skagit River, lower Cascade River, Diobsud Creek, and Illabot Creek. No Bull

Trout were likely to be present downstream of 114 river km (boundary to Reach 7) or in smaller sub-basins or Mixed hydro-basins in winter. Chinook fry (20-80mm) presence/absence model was estimated using 2 explanatory variables (season, depth) in a 3-node CART (Figure 18). Chinook fry were only likely to be present in spring and were more likely to be present at high depths (>0.24m) in spring. Stream-type Chinook (80+mm) presence/absence was classified using 5 explanatory variables (season, distance upstream from confluence, wetted width, wood cover, vegetation cover) in a 5-node CART. Stream-type Chinook were likely to be present in spring and summer, more commonly in wider wetted channels (wetted width >7.3m) with less vegetation (vegetation cover <58 percent) and in narrow wetted channels (wetted width <7.3m) with more wood cover (wood cover >17 percent). Additionally, stream-type Chinook were not likely to be present in winter unless they were further upstream from a given stream confluence (>21 river km). Both occupancy and classification modeling techniques were not utilized for Coho Salmon and *O. mykiss* due to generalist habitat use and widespread distribution of both species in the Skagit River Basin.

McMillan (2012) (Unique Identifier: 434)

Reference	McMillan, B. 2012. Skagit River winter steelhead historic-to-present trends and compared to those of the greater Northwest Region.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: hatchery, status and trends, harvest, abundance, age structure, life history, distribution; Habitat: ocean, barriers; Monitoring: abundance, scale or otoliths. ***Hydroelectric Operations:*** downramping.								
Species and Life Stages	***steelhead:*** migration, ocean, outmigration. ***Pink:*** spawning.								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: The goal of winter steelhead hatchery stocking operations throughout the Skagit River watershed has been to provide harvest of retuning hatchery fish prior to wild steelhead returns. However, total steelhead harvest consistently declined throughout 1951-2011 in lieu of increased hatchery smolt releases throughout the Skagit Basin. This report outlines the history of hatchery steelhead releases and run-sizes in the Skagit River and compares overall steelhead return patterns in stream systems throughout the Pacific Northwest with notable hatchery management practices. Findings indicate significant negative correlations between winter-run steelhead run-size estimates and winter-run steelhead smolt releases in the Skagit River and show similar negative trends in most other hatchery-managed systems. Although a direct cause of declining steelhead returns remains unclear, the author suggests that Chambers Creek hatchery smolt plantings may have a negative impact on wild steelhead populations in the Skagit River (Appendix F).

Information Relevant to Skagit River Relicensing: This source provides relevant information on steelhead run-size and harvest rates in the Skagit River. Wild and hatchery steelhead data were compiled to provide a time series of juvenile hatchery releases, adult escapements (hatchery/wild), adult harvests (hatchery/wild), and adult run-sizes (hatchery/wild) in the Skagit River. Primary data sources considered included run-size estimates, hatchery plantings, scale sample age structures, and Indian Tribe / sport harvest reports from Washington Dept. of Game (WDG), Washington Department of Fish and Wildlife (WDFW), Upper Skagit Indian Tribe, and NOAA/Puget Sound steelhead Technical Review Team (TRT) (Appendices A-C). The author utilized two-tailed significance tests and Pearson's correlation coefficient (r) to illustrate linear relationships between hatchery smolt releases (adjusted to 2-year, 3-year releases) and total harvest (1948-2011), total run-size estimates (1978-2011), and wild steelhead returns (1978-2011). Significance tests used to distinguish statistical differences between steelhead returns and hatchery smolt plantings are not specified throughout the report. As part of a broader comparison, 35 additional streams with 20-40 years of steelhead data were used to represent multiple regions throughout the Pacific Northwest, including the Puget Sound/Strait of Juan de Fuca, the Washington coast, the Columbia River, the Oregon coast, and the Southern British Columbia. The author cites previous studies considered in the Synthesis Study to demonstrate how hydroelectric and reservoir facilities in the Skagit basin have impacted anadromous fish distributions (Upper Skagit and Baker River facilities) and potential negative impacts of rapid downramping on rearing and spawning in the lower Skagit River from the Baker River (e.g., Smith 2003 ID376). In addition, the history of trapping and transport operations of steelhead in the Baker River are also described in detail.

Fish and Habitat: All relationships between hatchery smolt plantings and Skagit steelhead returns were negative, highlighting long declining trends in total harvest, total run-size, wild escapement, and wild run-size (Figures 4-22) despite increasing hatchery smolt plantings in the Skagit Basin between 1978-2011. These negative trends were evident in the 1960s as Skagit steelhead sport harvest leveled off with increased hatchery stocking in the Skagit and additional Puget Sound systems (Table 1). Hatchery survival rates also declined throughout 1978-2011, as hatchery adults dropped from 45 percent of total return run-size to less than 10 percent (Figure 20, Appendix C: Table 1). The author accounts for the dominant 2-salt adult life history (returning adults that mature for two years in the ocean) in hatchery steelhead and variations in 2-salt/3-salt adult life histories in wild steelhead by adjusting hatchery smolt plants by two/three years for each comparison (Figures 4-5, 7-8, 10a-15). While all comparisons demonstrated negative correlations, the negative relationships between run-size (total, wild) and hatchery planting were stronger in 2-salt return components than in 3-salt returns. Annual 2-salt and 3-salt wild steelhead run-sizes dominated alternating years, corresponding with nutrient benefits of odd-year Pink Salmon spawning prior to juvenile steelhead outmigrations in the Skagit (Figures 13, 14). This potential synchrony between adult Pink escapement and subsequent wild steelhead juvenile productivity is relevant to development of conceptual life history models. The author notes that patterns in alternating ocean conditions (Oceanic Niño Index, Figure 22; Pacific Decadal Oscillation, Figure 23) do not correspond with the decline in steelhead harvest in the Skagit and surrounding systems (Figure 21). Appendix F expands on the potential negative impacts of hatchery fish on wild steelhead populations, such as spawning interactions/hybridization, hatchery adult straying by location and run timing, diminished fitness and life histories, and competition.

Tables 2-5 list the hatchery histories and comparisons between total steelhead harvest and hatchery plantings for the additional 35 streams and show most regional systems resemble trends found in the Skagit. This information is potentially useful to compare patterns in the Skagit with regional patterns.

McMillan (2015) (Unique Identifier: 436)

Reference	McMillan, B. 2015. The reproductive ecology of *Oncorhynchus mykiss* in tributary streams of the mid Skagit river Basin.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: periodicity, distribution, abundance, life history, rearing, hatchery, data gaps; Habitat: instream flow, climate change, status and trends; Monitoring: climate change, abundance, habitat. ***Water Quality and Productivity:*** temperature.									
Species and Life Stages	***steelhead:*** spawning, emergence, rearing. ***Chinook:*** spawning. ***Chum:*** spawning. ***Coho:*** spawning. ***Pink:*** spawning. ***Bull Trout:*** spawning.									
Reaches and Spatial extent	Finney Creek, other lower Skagit tribs.									
Linkages to Hydroelectric Operations	NA									

Summary: Multiple groups and government agencies have documented wild winter steelhead spawning between the months of January and June-July throughout western Washington and coastal US stream systems. Throughout the 20th century, however, Skagit River steelhead management by Washington Department of Fish & Wildlife revolved around the assumption that winter steelhead spawning (pre/post March 15th) and periodicity are dependent on genetic origin. Due to the lack of historical spawning surveys, run timing trends between hatchery and wild steelhead in middle Skagit River tributaries remain largely unknown. The primary objectives of this report are to determine variations in spawning behavior and to outline potential overlaps in spawning between wild and hatchery winter steelhead throughout Finney Creek and surround tributaries in the middle Skagit Valley (Reach R10). Independent steelhead redd surveys were conducted by the author within perennial (O'Toole Creek) and intermittent streams (Savage Creek, Mill Creek, Dry Creek, Finney Creek) throughout the winter/spring months of 2010-2014. The report outlines total steelhead spawning redds by tributary, hatchery and wild steelhead determinations during active spawning, proportion of steelhead spawning prior to March 15th, egg-to-fry emergence rates, and relationships between periodicity and environmental conditions by tributary observed between 2010 and 2014.

Information Relevant to Skagit River Relicensing: This report provides quantitative information on fish and habitat that are relevant to the Synthesis Study. The author outlines biological responses in periodicity, entry timing, and origin determinations of observed steelhead between 5 mid-Skagit tributaries throughout 2010 and 2014. The author notes the limitations of conducting single-person, independent surveys and thus narrowed the study area to streams near his residence on the mainstem Skagit River (~RM47). The report focuses on steelhead spawning redd counts and estimated spawn times collected through weekly spawning ground surveys between 2010-2014 (Figures 32-33; Tables 3, 6, 7, 18; Appendix C). Estimated spawn times were adjusted based on the date of redd observation, condition of redd (coloration, surrounding sediment, pit depth), overall spawning activity in each tributary, and favorable streamflow/weather conditions proximate to observation. The author draws correlations between estimated steelhead spawning activity and various habitat factors including streamflow (Figures 26-31, 39-40; Table 24; Appendices D, G: Table 3), precipitation (Figures 21-25, 37(2)-38; Table 22; Appendices A, G: Table 2), air temperatures (Figures 12-20, 36-38(2), 41; Table 11, 23; Appendix G: Table 1), and instream temperatures (Table 9, 10). Streamflow data for the North Fork Stillaguamish River (USGS 1928-2014) was used as a surrogate for historical flows in Finney Creek since the Finney Creek gauge was only active between 1943 and 1948. Long-term daily records of precipitation and air temperatures taken at lower Baker River in Concrete, Washington (available throughout 1906-1915, 1931-present) were used as a proxy for historical instream temperature patterns throughout the middle Skagit River basin due to the strong correlation between air temperature and instream temperatures.

Water Quality and Productivity: Changes in weather patterns and environmental conditions were highlighted through comparisons in historical monthly physical habitat parameters (Figures 37-39; Tables 22-24). The author notes shifts in average streamflow, air temperature, and precipitation in the middle Skagit Basin throughout the full cycle of winter steelhead spawning activity (January-June). The report describes trends in higher streamflows in January, March, and April with peak spring streamflow shifting two months from May to March, warmer air temperatures in January and cooler temperatures in March, April, and May, and higher precipitation in every month but February. Between the three metrics, average conditions in February throughout historical datasets remains relatively consistent and may be a timeframe of relative stability for steelhead spawning activity.

Fish and Habitat: 104 steelhead redds were observed throughout five Skagit tributaries between 2010-2014, with 53 percent of redds (adjusted to estimated spawn time) occurring before March 15th and with 42 percent of redds observed in 2014. Of the 17 live steelhead sightings throughout 2010-2014, both hatchery and wild steelhead were observed spawning prior to March 15th (Tables 8, 15-17), with hatchery fish consisting of 67 percent of early season spawning and 30-40 percent of total spawning activity. The majority of the steelhead spawning in primarily intermittent systems (Savage Creek, Dry Creek, and Mill Creek) occurred prior to March 15th. Figure 33 provides trends of relative estimated spawning dates through observed steelhead redds pre/post March 15th in systems ordered by degree of intermittency. While intermittent conditions in late spring may be viewed as limitations to spawning success, steelhead fry emergence observed in Dry Creek in mid-May (Table 13) indicates accelerated egg-to-fry emergence rates amidst high instream temperatures. (Table 14). Considering the overlap in hatchery and wild steelhead spawn timing and changing environmental conditions, the author suggests that further genetic studies must consider early periods of fry emergence to examine the breadth of hatchery signals and hybridization.

Instream temperatures and streamflow are considered by many to be important factors in salmonid reproductive ecology. No statistically significant correlations were established between mean monthly habitat metrics (air temperature, precipitation, streamflow) and mean monthly adjusted steelhead redds between 2010-2014, as lack of exact spawning dates and use of surrogate habitat data may confound discrepancies between spawning activity and weather conditions. Nevertheless, the author notes a potential trend between monthly air temperatures and monthly steelhead redds (Figures 15-19) with the exclusion of June spawning activity and temperature outliers. Continued spawner surveys are necessary to develop associations between spawning variations and environmental conditions as well as to monitor hatchery and wild steelhead escapements throughout the full steelhead spawning cycle (January-June) and to develop a comprehensive recovery/management plan.

Appendix C lists the estimated adjusted redd counts and live/carcass counts per week for steelhead, Chinook, Coho, Chum, Bull Trout, and Cutthroat Trout by tributary between 2010-2014. Appendix

B details the Skagit River steelhead Egg Take Operation between 1914-1920. Appendix E shows the wild/hatchery winter steelhead harvest in the Skagit River in the 1960s and mid-1970s. Appendix F compares the number of adjusted steelhead redd by day by tributary and weather conditions in Concrete between the year 2011 and 2014.

McMillan 2015 (Unique Identifier: 437)

Reference	McMillan, B. 2015. steelhead reproductive ecology: spawning time, water temperature, emergence time, intermittency, and climate change – a race for survival in mid Skagit River tributaries.							
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No
							Project Related	No
Topics and Keywords	***Fish and Habitat:*** Fish: periodicity, distribution, abundance, life history, rearing, hatchery, data gaps; Habitat: instream flow, climate change, status and trends; Monitoring: climate change, abundance, habitat. ***Water Quality and Productivity:*** temperature.							
Species and Life Stages	***steelhead:*** spawning, emergence, rearing. ***Chinook:*** spawning. ***Chum:*** spawning. ***Coho:*** spawning.							
Reaches and Spatial extent	Finney Creek, other lower Skagit tribs.							
Linkages to Hydroelectric Operations	NA							

Summary: This report provides a summary of continued independent monitoring of steelhead periodicity trends and instream temperatures in Finney Creek and other intermittent tributaries along the middle Skagit Valley (Reach R10). steelhead redd surveys were conducted within perennial (O’Toole Creek) and intermittent streams (Savage Creek, Mill Creek, Dry Creek, Finney Creek) throughout Winter/Spring 2015 to evaluate spawning trends in shifting seasonal water temperatures. Instream temperatures and ambient air temperatures were measured from mid October 2014 to May 2015 and were compared to variations in steelhead spawning times (pre/post March 15th) throughout 2010-2014 surveys. The author highlights observations of early emergence in lower Finney Creek due to severely dry and warm conditions in April/May 2015 and draws correlations between high instream temperatures and accelerated egg-to-fry emergence rates. He also suggests wild steelhead may be able to resist late-season temperatures in intermittent tributaries due to the prolific spawning observed after March 15th. Ultimately, increasing instream temperatures and intermittency due to warming conditions, coupled with reduction of hatchery steelhead, may promote natural selection toward earlier entry and spawning for wild steelhead in the mid Skagit basin over time.

Information Relevant to Skagit River Relicensing: This source provides quantitative information on fish and habitat that may be used to inform the Synthesis Study. The author outlines biological responses in periodicity, entry timing, and embryotic development of steelhead due to increasing mean water temperatures and earlier seasonal intermittence in mid-Skagit River basin tributaries. The report focuses on steelhead spawning redd counts collected through weekly spawning ground surveys and weekly instream and air temperature readings in 2014-2015. The report does not include quantitative flow measurements for the five streams within in the study or temperature measurements taken for the five streams between 2010-2014, as the author relies on the 2014-2015 instream temperatures to *“…explain some of the variations in steelhead spawning time associated with intermittent streams.”*

Water Quality and Productivity: April/May rainfall within the mid-Skagit valley was notably low (6.885” in 2015 compared to the 10.456” 2002-2015 average) and coincided with little winter snow accumulation despite average winter precipitation. High and low air temperatures throughout the Puget Sound in fall 2014 and winter 2015 were observed to be “well above normal,” leading to abnormally dry and warm instream conditions in intermittent streams in 2015. Instream and ambient air temperatures at the time of survey throughout 2014-2015 are presented in the Appendix. Finney Creek maintains a wide, exposed stream channel with little canopy cover due to past logging operations. Table 2 shows the historically rapid increase in water temperatures observed in Finney Creek in May 2015. The author notes Dry Creek and several productive side channels of Finney Creek were dry in late May, though *"the streamflow height remained sufficient for steelhead entry from the Skagit River."*

Fish and Habitat: Figure 1 provides trends of relative estimated spawning dates through observed steelhead redds pre/post March 15th in systems ordered by degree of intermittency. Most of the steelhead spawning in Savage Creek, Dry Creek, and Mill Creek between 2010-2014 occurred prior to March 15th. Intermittent streams maintained higher mean water temperatures and earlier relative spawning activity compared to more perennial streams within the 2014-2015 surveys, as shown in Figure 2. steelhead escapement in Finney Creek was notably high in 2015 (101 redds) compared to other years (past high of 22 redds in 2014) with 87 percent of new steelhead redds observed after March 15th, as shown in Figure 4. Fry were observed in several late-season, nearly dry redds within 21-42 days after spawning events, suggesting accelerated egg-to-fry emergence rate amidst high instream temperatures. In addition, 50-67 percent of spawners in Finney Creek before March 15th were of hatchery origin, indicating that wild steelhead in intermittent tributaries may be able to resist late-season lethal embryo temperatures observed in Finney Creek in May 2015. However, estimates for embryo survival to instream temperature relationships for steelhead remain unknown, and variability in hydrological conditions and spawn timing (and possibly genetics) show that lethal water temperature thresholds may vary between tributaries and within tributaries of the Skagit River.

Appendix data include observations of adult salmon throughout the weekly 2014-2015 spawning surveys within the study area. Active Chinook spawning was observed in mid-October in O'Toole Creek. Active Coho Salmon spawning was observed between early-November and mid-February in Mill Creek, Savage Creek, and Dry Creek. Active Chum Salmon spawning was observed between late-October and mid-December in O'Toole Creek, Mill Creek, Savage Creek, and Finney Creek.

McMillian 2018 (Unique Identifier: 400)

Reference	McMillan, B. 2018. A review of historic and current information for winter and summer steelhead of Finney Creek of the Skagit River basin: habitat, distribution, life histories, population sizes, and spawner capacities. Concrete, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: life history, abundance, data gaps, distribution, status and trends, hatchery; Habitat: freshwater, limiting factors, capacity, barriers, restoration; Monitoring: genetics, abundance. ***Geomorphology and Landforms:*** substrate and sediment, aquatic habitat and landforms, large wood, log jam. ***Land Use and Cover:*** forestry. ***Water Quality and Productivity*:** temperature.								
Species and Life Stages	***steelhead:*** spawning, migration, rearing.								
Reaches and Spatial extent	Finney Creek.								
Linkages to Hydroelectric Operations	NA								

Summary: This report provides a review of historic and current information on winter- and summer-run steelhead, land use, and habitat in Finney Creek, a moderate sized steelhead spawning tributary of the Skagit River. Finney Creek has a history of native populations of summer- and winter-runs of steelhead and resident *O. mykiss* above and below the anadromous zone, separated by an impassable waterfall 12.9 miles above the mouth. The resident *O. mykiss* in the anadromous zone were historically numerous and large. Both summer- and winter-run steelhead populations are currently depressed and are present in small numbers in lower Finney Creek and dominated by males. The summer population was particularly low with no adult summer steelhead sighted in the 2009 snorkel survey, and with only 11 steelhead redds found in the probable summer steelhead habitat reach during surveys made from early February through late May of 2013. Summer steelhead are at remnant levels with recent run-sizes likely no more than 30 returning individuals, in even the best years. Habitat degradation and illegal fishing activity are identified as limiting factors for steelhead in Finney Creek. Genetic analyses found most summer steelhead differed from Finney Creek and Skagit River winter steelhead. Genetic analyses have yet to identify all the diversity that occurs in the Skagit basin and Finney Creek, as suggested by the breath of life history diversity.

Freshwater habitat in Finney Creek has been on a continuous trajectory of degradation dating back to timber harvest activities stating in 1920. Habitat recovery activities started in the 1990s. Major floods in 2003 and 2006 led to further channel widening and sedimentation. However, by 2009, and continuing into early 2015, subsequent channel stabilization has occurred with reformation of pools and increasing exposure of gravel, cobble, and boulder substrate. Some of these improvements have likely been furthered by construction of numerous large woody debris placements that occurred in Finney Creek from 1999 to 2010. Spawning escapement of winter-run steelhead appears to be improving, but still far below historic levels. Using Google Earth images, it was estimated that 10 percent of the channel bottom substate was usable for steelhead spawning, indicating that the spawning area of Finney Creek has the capacity for 1,154 - 3,998 winter steelhead redds and the capacity for 675 - 2,341 summer steelhead redds. Present spawning redd counts of both winter and summer steelhead in Finney Creek were far below their actual spawner

capacities. Although all historical *O. mykiss* life histories may still potentially be represented within the Finney Creek population(s), some are now reduced to remnant levels (such as early-return winter steelhead, summer steelhead, and lower Finney residents). The available Finney Creek spawning habitat for both the winter and summer steelhead populations suggests that significant recovery remains possible.

Information Relevant to Skagit River Relicensing: This report provides relevant historical and current information on steelhead and their habitat use in Finney Creek, a tributary of interest in the Synthesis Study. Quantitative data and descriptions of steelhead life history diversity, abundance, periodicity, and capacity are provided along with information describing habitat changes, restoration, land uses, and water quality issues in the Finney Creek watershed. Anecdotal historical information is provided on *O. mykiss* fishing, winter- and summer-run steelhead run timing, size and age of summer-run steelhead, and habitat alterations over time (going back to the early 1900s), including changes as a result of timber harvest and historic floods in 2003 and 2006. Results of juvenile and resident sampling and snorkel surveys from 2009, and documentation of spawning and large resident males in 2010 are presented. Spawning survey data from 1979, 2010, 2014, and 2015 are included. Spawning capacity was calculated for winter- and summer-run steelhead using 2013 Google Earth images of Finney Creek. Skagit and Finney Creek steelhead genetic findings over time are summarized. Data gaps and recovery considerations are also discussed.

Fish and Habitat: Available information for Finney Creek suggests complex *O. mykiss* life history diversity that was sufficient to effectively fill the available habitat niches. These include a resident upper Finney *O. mykiss* population above RM 12 based on collections made in 2009 and 2010. DNA analysis has yet to be completed to determine whether there is a close relationship to the lower Finney *O. mykiss* population(s) below RM 12.9 that also includes a resident life history form as well as two anadromous races. Finney Creek *O. mykiss* diversity includes a resident population above the falls at RM 12.9 (an anadromous barrier) and both resident and anadromous life histories below the falls. However, large mature members of the resident group below the falls have been largely confined to about RM 8 to RM 12.9, as found in 2009 snorkel surveys (except during late winter and early spring for spawning as found in 2009 and 2010 sampling). The anadromous population is currently depleted numerically, and the historical summer-run component is at a remnant level. Observations suggest that the resident *O. mykiss* group spawns with the winter-run anadromous group. "Half-pounders" were observed in Finney Creek in 2010, suggesting some fish might be expressing this life history strategy.

Winter-run steelhead redd densities in lower Finney Creek: 1979 = 11.94/km, 2010 = 1.90/km, 2014 = 5.71/km, 2015 = 13.95/km. Seven spawning surveys from February 11th to May 23rd of 2013 found 11 redds in upper Finney Creek in the flatter gradient section from RM 8 (1975 measures) above the second cascades to the falls at RM 11.5 with an estimated spawning escapement of 22 summer steelhead (WDFW 2013). In early November of 2012, a two-day sampling effort captured 25 steelhead thought to be potential summer-runs. In 2015, the actual winter steelhead spawner use was 4 - 18 percent of the computed spawner capacity. In 2013, the actual summer steelhead spawner use was 0.5 - 2 percent of the computed spawner capacity. In 1925, winter-run steelhead had entry timing from January through April. Currently, summer-run steelhead returning to Finney Creek are uncommon to rare. When summer-run steelhead were once numerous, they may have spawned primarily from late January to early March with a head start on emergence from that of later spawning winter-run steelhead. Winter-run spawning may have dominated from early March through May, as is presently the case, although significant January-February overlaps occur and may have been more prevalent historically.

Finney Creek habitat has been greatly altered from historic conditions due to logging operations that started around the 1920s. Based on photos, the old growth forest was gone from many places by 1947 by timber harvest or possibly fires. Extensive clear-cutting took place between prior to 1947- 48. Logging operations and road construction activities along the creek caused serious silting and erosion problems, with large numbers of landslides documented in the report that impacted substrate composition in Finney Creek. In addition, logging within the riparian zone reduced the amount of wood in the stream channel and stream temperatures elevated. Although individual cuts are smaller today and more staggered in time, the overall rotation sequence of cuts continues to limit the ability of the slopes and forests to retain water with subsequent streamflow conditions much as they were in earlier times. From 2009 to 2015 channel stabilization has occurred with reformation of pools and increasing exposure of gravel, cobble, and boulder substrate. Construction of numerous large woody debris placements occurred in Finney Creek from 1999 to 2010. Under current conditions, Finney Creek has the capacity for 1,154 - 3,998 winter steelhead redds and the capacity for 675 - 2,341 summer steelhead redds (computed using 2013 Google Earth imagery, so these are very rough estimates). There are tables in the appendix that provide wetted widths, lineal lengths, and wetted channel areas from Google Earth Measures of images from July 14, 2013 that were used to calculate capacity.

Water Quality and Productivity: It is apparent that water temperatures have dramatically warmed from what they were 94 years ago. Today only late fall, winter, and early spring are likely to yield a water temperature of 44 degrees F or less in lower Finney Creek. The report provides some quantitative data for spot measurements of water temperatures, but spatially and temporally extensive monitoring data are not presented. Nevertheless, more thorough water temperature recordings are necessary to determine how water temperatures have been altered in Finney Creek. This may not be entirely due to extensive timber harvest that has occurred but may also reflect progression of climate change.

Mickelson et al. (2020) (Unique Identifier: 289)

Reference	Mickelson, E., D. Smith, and S. Hinton. 2020. Skagit basin barrier culvert analysis: public and private stream crossings. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** <u>Habitat:</u> barriers, data gaps; <u>Fish</u>: distribution. ***Geomorphology and Landforms:*** slope, substrate and sediment, scour, data gaps.									
Species and Life Stages	***Chinook***: NA. steelhead***:*** NA.									
Reaches and Spatial extent	R1- R14, Sauk River, other Sauk River tribs, other upper Skagit tribs, other lower Skagit tribs, Day Creek, Nookachamps Creek, Tributaries, Baker River.									
Linkages to Hydroelectric Operations	NA									

Summary: This report's objective was to combine previous culvert inventories and update the data with more information (such as ownership and habitat estimates), into a consistent format to be used across different agencies. This report is still ongoing which will expand the current inventory beyond the Skagit River basin, outside of Whatcom and Samish counties. The current inventory covers the Skagit basin, excluding the estuary, Fidalgo Island, all the way to Gorge Dam at Newhalem. Quantitative and qualitative data about barriers and their characteristics such as percent passability, culvert locations and the type of property (i.e., state, private, county, and or city owned land), and the reason for being a barrier (i.e., due to slope, velocity, drop, tide gate, depth, etc.). The goal was to "*improve the spatial accuracy of previous data sets and increase compatibility of existing data formed*" and use methods and formats similar to the Washington Department of Fish and Wildlife Fish passage and surface water diversion screening assessment and prioritization manual. Additionally, they used GIS habitat estimates from a previous study to evaluate potential habitat area upstream of the barrier as well as field surveys for some sites.

Information Relevant to Skagit River Relicensing: This report provides water crossing and culvert data within the Study Area for the Synthesis Study and represents one of the most up to date inventories of culverts in the Skagit River basin. They report the barrier status for water crossings and culverts if they are known or unknown, which can help inform future surveys to address data gaps in the inventory. Knowing if culverts are causing barriers to fish passage can also support restoration planning and prioritization to support salmon recovery. This report focused mostly on county and privately owned culverts in Skagit basin, and more data are needed for culverts that are under other public ownership types. The appendices in the report as provide additional tables that could assist with fish passage improvement projects that could be eligible for Salmon Recovery Funding Board.

<u>Fish and Habitat:</u> Within the Skagit Watershed, barrier and habitat assessment results are available for 369 culverts. Among these, 122 are on county, 204 on private, and 117 are on public lands. Of the county owned culverts, 15 have unknown barrier status, 37 unknown barrier statuses for private, and 39 unknown status barriers for other public culverts, which by knowing what barriers have unknown statuses, can determine where future surveys need to be done. They report that six culverts on county property and eight on private property or other public ownership had greater than 10,000 square meters of upstream drainage (see Table 7). This information is useful to inform

restoration prioritization based on potential habitat area affected by fish passage barriers. Field surveys for habitat assessments were completed for 36 sites, and when combined with previously done surveys from other studies, 152 culverts had physical habitat survey data available. The authors then created habitat Priority Index values as well as calculated spawning and rearing area, and lineal gain (Appendix A, Table 8). Table 8 provides the stream name, the ownership, the culvert's barrier status, the percent passability, the barrier reason (e.g. velocity, depth, slope, etc.), the spawning area, rearing area, lineal gain as well as the calculated Priority Index. To assess barriers based on their position in the system, and if there were up or downstream barriers, they classified culverts by orders and found that "*79 of the 443 culverts in the Skagit basin have a barrier order or '0', meaning that no other barrier crossings are present on the stream system.*" Most of the barriers (208) were between 2 and 5 orders, meaning that barriers of various potential habitat area above site had between two to five barriers up or downstream of the barrier (see Table 3).

Appendix B provides a list of culverts to address the Skagit Watershed Council's (SWC) three tiered categorization system for determining if a project would provide greater Chinook Salmon (and steelhead) habitat. There are also maps that highlight the targets areas of SWC's tier 1 and 2 priority habitats for both Chinook and steelhead. They found that 66 barriers and 41 unknown status of barriers that are within the portion of the Skagit Basin for SWC's Strategic Approach are classified as Tier 1. For tier 2, there are only six barriers and three unknown status culverts. Appendix B, Table 1 provides the culvert ownership, percent passability and the upstream habitat estimate. For steelhead, there are 205 barriers and 38 unknown status barriers on streams known or modeled to be used by steelhead. Appendix B, Table 2 provides the barrier status, percent passability, barrier reason, SWC Tier, and weighted habitat area. Similarly, in Appendix C they provide the same information about culverts except that is specific to the Baker River watershed and middle Skagit River tributaries.

Nichols and Ketcheson (2013) (Unique Identifier: 412)

Reference	Nichols, R. A., and G. L. Ketcheson. 2013. A two-decade watershed approach to stream restoration log jam design and stream recovery monitoring: Finney Creek, Washington. Journal of the American Water Resources Association 49(6):1367-1384.								
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landforms:* change, history, large wood, substrate and sediment, sediment transport and supply, log jam, data gaps, aquatic habitats and landforms. *Fish and Habitat:* Fish: survival; Habitat: barriers, freshwater, riparian, restoration; Monitoring: restoration, habitat, water quality. *Water Quality and Productivity:* temperature. *Land Use and Cover:* forestry, roads.								
Species and Life Stages	*Chinook:* rearing.								
Reaches and Spatial extent	Reach R9-10.								
Linkages to Hydroelectric Operations	NA								

Summary: This report synthesizes 12 years (1999-2010) of stream restoration log jam design and stream recovery monitoring on Finney Creek, tributary to the Skagit River downstream of the Sauk River. The goals of the restoration were to construct log jams to: (1) trap other large wood being recruited in the system, (2) modify channel form and cross section and contribute to stream habitat complexity, and (3) provide more stable sites for the regeneration of riparian vegetation. A total of 1,881 pieces of large wood were placed in 181 log jams, including 60 floating log ballasted jams, were constructed along 12.2 km (7.6 miles) of the Finney Creek channel. The goal was to alter hydraulic processes that affect aquatic habitat formation along 39 km (24.4 miles) with emphases on 18.5 km (11.5 miles) of lower Finney Creek. Aquatic habitat surveys over a five-year period show an increase in the area of large pools and an increase in residual and maximum pool depth in the lower reach of Finney Creek. Channel cross-sections show a deeper channel at most log jams, better channel definition in the gravel deposits at the head of the log jams, and improved riffle and thalweg development below the log jams. Stream temperature in the upper creek decrease by 1.0 degrees F in the first three years, and 1.1 degrees F in the lowest treated reach over nine years. Photo points over the restoration time period show that riparian vegetation is recolonizing gravel bars. The observations and lessons learned from this study are also used to describe recommendations for placement and configuration of LWD structures to support restoration goals.

Information Relevant to Skagit River Relicensing: Log jams alter local hydraulics and sediment transport and storage processes that contribute to creation and maintenance of high-quality habitat features. A total of 1,881 logs were imported and placed in 181 log jams covering 7.6 miles (12.2 km) of stream. The log jam number density went from 4.2 per mile to 39.3 per mile. In August 2021, the main project area from Gorge Dam to the Sauk River had a density of 2.7 log jams per mile. Based on aquatic habitat surveys, the number of pools decreased by 13 percent over time but the percent pool area increased by 27 percent, and pool depths showed a slight increase with a 4 percent increase in residual pool depths and 2 percent increase in maximum depths. However, they note that the increased in pool depth metrics were not statistically significant, but they conclude that their study demonstrates positive changes in freshwater habitat associated with the log jam restoration actions. These positive changes include increased large pool area and accompanied increases in residual and maximum pool depths, and reduced temperatures as described in the summary section above. A narrative of land use history in Finney Creek in the context of the larger Skagit River watershed is provided, which provides context for the restoration goals and objectives to address watershed scale impacts from forestry, landslides, and road construction. Spatial data are provided in the form of maps showing areas treated with LWD placements by year, and location of an anadromous barrier in Finney Creek. The authors indicate that continued monitoring would support long-term evaluation of restoration effectiveness, including integration of remote sensing approaches to characterize habitat changes more efficiently over a longer spatial extent, and measurement of riparian encroachment associated with LWD responses.

NHC (2013) (Unique Identifier: 428)

<table>
<tr><td>Reference</td><td colspan="8">Northwest Hydraulic Consultants (NHC). 2013. Skagit River basin general investigation flood risk reduction - hydraulic analysis final report. Appendix B of Skagit River flood risk management general investigation draft feasibility report and environmental impact statement. Report prepared by NHC for U.S. Army Corps of Engineers.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td></tr>
<tr><td></td><td colspan="6"></td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="8">Modeling tools: hydrology. Hydroelectric Operations: flow regulation, flood control. Geomorphology and Landforms: large wood. Land Use and Cover: banks and shoreline.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="8">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="8">R15, R14, R12, R9, Baker River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="8">Hydroelectric Operations: flow regulation, flood control.</td></tr>
</table>

Summary: The Burlington Northern Santa Fe (BNSF) Railway bridge east of Interstate 5 in Mount Vernon is the most significant hydraulic structure in the lower Skagit River. It has a low deck elevation and entraps debris at high flows. Debris jams can form, causing flooding as was seen during a 25-year (141,000 cfs) event in November of 1995. A series of hydraulic analyses were performed to characterize hydrology under existing conditions and alternative flood control scenarios. Among flood control scenarios considered were a potential increase in early season flood regulation storage at Upper Baker Dam on regulated peak flows at Concrete (R9), consideration of authorizing flood control storage at Lower Baker Dam improved levees upstream from Mt. Vernon, addition of three new setback levees downstream of Mt. Vernon, and addition of two flood bypass channels. Hydraulic model results inform economic flood damage analyses. The primary focus of these studies is the lower Skagit River downstream from Sedro-Wooley. Hydraulic modeling of flooding impacts from the BNSF railroad bridge suggested that debris accumulation is highly variable between and within flood events. Debris accumulation can happen relatively rapidly following or during a flood event (evidenced from photo analysis of the 1995 25-year event which showed no debris accumulation at the time of peak flow suggesting rapid formation). Long term trends will likely result in greater total volume and size of logs becoming entrained during floods, especially as riparian restoration projects along the upstream banks mature and recruit more wood into the river. As such, debris accumulation at the BNSF bridge is a serious risk in need of greater attention.

Existing flood control regulations do not consider seasonal variation in flood control storage at Upper Baker Dam. Consideration of seasonal variation in flood control storage at Upper Baker increases estimated regulated peak flow quantiles for the Skagit River by as much as 5 percent for a 50-year event. Therefore, to improve flood mitigation strategies and risk analysis, it is important to consider seasonal variation in flood control storage. Lower Baker dam currently has no authorized flood control storage. Authorization of 20,000 acre-ft of flood control storage at Lower Baker Dam can restrict flow contributions from Baker River into the mainstem Skagit to just 1,200 cfs for up to a 50-year event if full flood control storage is available at Upper Baker and Ross Dams. This would result in a 4 percent (8,000 cfs) to 9 percent (13,000 cfs) reduction in peak flows in the Skagit mainstem. Effectiveness of Lower Baker Dam for flood control storage diminishes if flood events increase past a 50-year event or if full flood storage capacity at Upper Baker and Ross is not available.

Three flood risk reduction alternatives: a series of setback levees between Mt. Vernon to the North and South Forks and on the left and right banks of Fir Island, a flood bypass upstream of Burlington (Joe Leary Slough Flood Bypass), and a flood bypass downstream from Burlington (Swinomish Flood Bypass) were considered for economic flood damage analysis. The setback levee alternative did not have an appreciable impact on flooding along urban levee segments upstream of the BNSF bridge. The Joe Leary Slough alternative (draining to Padilla Bay or Samish Bay) would reduce a 100-year event by about 3 feet upstream and by about 1.5 ft downstream of the BNSF bridge. The Swinomish Bypass alternative would reduce a 100-year event by about 4 ft below the BNSF bridge. In all alternative scenarios, adding debris jams at the BNSF bridge impacts the performance of flood risk reduction structures.

Information Relevant to Skagit River Relicensing: This report provides hydraulic modeling outputs for various alternative flood regulation scenarios for the lower Skagit River, which include effects related to Hydroelectric Operations at both the upper Skagit River and Baker River facilities. These modeled outputs may be used to inform future hydraulic analyses, as well as informing conceptual life history models and factors affecting life stages and instream flow conditions in the Study Area for the Synthesis Study. Information on Hydroelectric Operations is described in more detail below. Additional supporting information on sediment budget and geomorphology is included as an appendix (USACE 2008, ID 355), but was already included with the GE-04 sources.

Hydroelectric Operations: Tables 3-1 and 3-2 contain existing and optional flood control storage requirements at Upper Baker and Ross Dams at various dates throughout the year. These may be used as references for considering alternative flood storage scenarios. Similarly, Table 3-3 contains existing condition regulated peak discharges for the Skagit River near Concrete, providing useful reference information for considering alternative flood control scenarios. Tables 4-3 through 4-5 contain similar information for the Lower Baker Dam. Potential reductions in regulated peak discharge resulting from flood control at Lower Baker dam is presented in Table 4-8 and 4-9. Flood quantiles under alternative modeling scenarios at various recurrence intervals and river miles are presented in Tables 5-2, 5-5, and 5-7. These data may be extracted and turned into flood recurrence curves suitable for further analysis or other uses. Table 5-13 contains a range of Manning's *n* values and associated uncertainties for the reach of primary interest downstream from Sedro-Woolley, which can be used as inputs into a new hydraulic model. Flood quantiles for the Joe Leary Slough Flood Bypass and Swinomish Bypass are presented in Tables 6-5 and 6-10. Figure 3-9 shows cumulative seasonal distribution of winter floods before a specific date, which may be translated into probabilities of exceeding a certain size event. Maps of maximum flood depth under a 100-year flood scenario are given in Figure 5-3, potentially useful for directing effort at vulnerable locations. Exceedance probably and discharge plots (no figure labels) are given in Appendix 5-1 (Existing conditions), Appendix 5-2 (Additional early season flood regulation storage), Appendix 5-3 (Improved levee), Appendix 6-1 (Joe Leary Slough Bypass), Appendix 6-2 (Swinomish Bypass). These may be used in further analyses or used to simulate stochasticity in river discharge on other processes (e.g., salmon redd scour).

NRCS (2006) (Unique Identifier: 500)

Reference	Natural Resources Conservation Service (NRCS). 2006. Lower Skagit Watershed, HUC: 17110007, rapid watershed assessment. Report prepared by United States Department of Agriculture, Natural Resources Conservation Service, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** land cover, agriculture, forestry, commercial. ***Geomorphology and Landforms:*** substrate and sediment. ***Modeling tools:*** bathymetry. ***Fish and Habitat:*** Habitat: barriers, riparian, restoration, invasive species. ***Water Quality and Productivity:*** contaminants, pH, temperature, bacteria, nutrients.									
Species and Life Stages	***Other species:*** not specified.									
Reaches and Spatial extent	Finney Creek, Hansen Creek, Nookachamps Creek, Skagit Bay, other lower Skagit tribs, Skagit Watershed (below Concrete).									
Linkages to Hydroelectric Operations	NA									

Summary: This rapid assessment used GIS technology and various invested groups to provide an overview of the Lower Skagit (WIRA 03) watershed and watershed profile that included general land use coverage and ownership, types of soil coverage throughout the basin, fish passage barriers, and 303d impacted areas. It provides quantitative and qualitative information *"to develop a watershed profile, sufficient analysis of that information to make qualitative statements as to resource concerns and conditions, and the generation of information with which to make decisions about conservation needs and recommendations."*

Information Relevant to Skagit River Relicensing: The rapid assessment provides relevant information specific to the Skagit River mainstem from the bay to Concrete as well as tributaries including Finney, Hansen, Nookachamps creeks, and other creeks not listed. Multiple maps are provided including soil types, elevation, average annual precipitation, land use and land cover, ownership, and types of farmland. Additionally, a fish passage barrier map including the different types of barriers known within the Lower Skagit Watershed is provided along with a list of known invasive and native fish species present. Another map details reaches and waterbodies that are listed as known 303d areas. A table is provided with 303d listed streams that are impaired by pollutants.

NSD (2017) (Unique Identifier: 086)

Reference	Natural Systems Design (NSD). 2017. Skagit River large woody debris assessment: connecting LWD to the 2005 Skagit Chinook recovery plan. Report prepared for Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	No	*Spatial Data*	No	*Project Related*	Yes
Topics and Keywords	*Geomorphology and Landform:* change, history, large wood, substrate and sediment. *Fish and Habitat:* Fish: survival; Habitat: limiting factors, riparian. *Modeling Tools:* habitat.									
Species and Life Stages	*Chinook:* rearing, overwintering.									
Reaches and Spatial extent	Reach R1-13, and tributaries to the Skagit River.									
Linkages to Hydroelectric Operations	*Geomorphology and Landform:* large wood.									

Summary: This report presents a method for developing a set of descriptive conceptual models that explain how large wood in the Skagit River Basin functions to achieve the goals of the 2005 Skagit Chinook Recovery Plan, as well as a method for a comprehensive assessment of large wood resources across Chinook habitat in the Skagit Basin. The seven limiting factors that influence the presence of large woody debris (LWD) include seeding levels, degraded riparian zones, dam operations, sediment and mass wasting, flooding, high water temperatures, and hydromodification. Throughout the Skagit River Basin, LWD forms key riverine habitat features that have a significant impact on hydraulic processes, geomorphology, and salmonid habitat quality. The depletion of LWD has led to extensive degradation of fish habitats throughout the Skagit Basin and region.

NSD presents a conceptual model for four distinct geomorphic sections of the Skagit River:

(1) In narrow, high-gradient, headwater Skagit River reaches individual LWD can span the channel and dominate stream bedform and hydraulics.

(2) Wider, intermediate-gradient reaches in the middle of the Skagit River system, LWD no longer spans the channel and is often is lodged on the bank, on bars, or in the channel bed.

(3) In low-gradient tributaries, single pieces of wood usually do not span channel, but can form snags in the channel that can cause large LWD jams and obstruct large portions of the channel.

(4) In wide, low-gradient Skagit River reaches surrounded by historic floodplain, single pieces of wood can lead to the formation of massive LWD jams that can change the course of the river, block river channels, and induce massive floods. In lower reaches of the Skagit River system, LWD jams and jam-related river features have the highest densities of juvenile Chinook across multiple seasons.

NSD presents a metrics matrix for the seven limiting factors that include processes affected and characteristics to measure to better understand the interaction between limiting factors and LWD. Additionally, the report identifies methods for wood inventory and assessment on large and small rivers. This includes using high resolution LiDAR, Green LIDAR, imagery, field verification, and modeling. The report provides recommended metrics for LWD assessment in the Skagit Basin.

This included number of jams, number of key members, number of nodes, river complexity index, volume of wood, and number of pools greater than 1 meter depth by reach.

Information Relevant to Skagit River Relicensing: The report provides guidelines for a comprehensive assessment of large wood in the Skagit Basin. Many of the recommended metrics were measured by the Skagit River Relicensing GE-04 Geomorphology Study Team in August 2021. Additionally, available LiDAR, green LiDAR, and aerial photography was used to identify historic location of jams and individual pieces, when the imagery had high resolution. The conceptual model for four distinct geomorphic sections provides some patterns and trends that were verified as part of the Skagit River Relicensing GE-04 Geomorphology study. The model can be refined based on the additional data collected. The authors also provide a narrative that connects LWD to limiting factors for Skagit Chinook recovery, which can support development of life stage factors and hypotheses for linkages between resource conditions and factors. These include seeding levels, degraded riparian zones, dam operations, sediment and mass wasting, flooding, high water temperatures, and hydromodification. These linkages are important given that previous work has identified that freshwater habitat is limiting Chinook production in the Skagit, and therefore restoration of freshwater habitat is important to salmon recovery in the Skagit. In the narratives of these linkages, the report provides information on potential linkages between Hydroelectric Operations and resource conditions, indicating that the hydroelectric dams that create reservoirs for significant portions of the Skagit River drainage area, including the upper Skagit and Baker River, have significantly altered the hydrosystem and LWD recruitment and transport in the system. Some wood trapped by the Gorge Dam and Diablo Dam is moved downstream, but they indicate that all large wood trapped by Ross Dam is isolated from the lower river, however significant unregulated inputs remain from mainstem reaches downstream of dams and from unregulated tributaries like the Sauk River.

NWFSC (2003) (Unique Identifier: 087)

<table>
<tr><td>Reference</td><td colspan="10">Northwest Fisheries Science Center (NWFSC). 2003. Summaries for the salmon habitat in recovery planning (SHRP) document, the Chinook salmon life cycle model, and the salmonid watershed analysis (SWAM). Northwest Fisheries Science Center, Watershed Program, Seattle, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat</u>: restoration; <u>Fish</u>: survival, density dependence, distribution. Modeling Tools: life cycle. Land Use and Cover: land cover, data gaps.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: full life cycle. steelhead: spawning. Coho: spawning.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">NA</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This document is a summary of three research projects from the Northwest Fisheries Science Center's Watershed Program that focused on habitat recovery planning; (1) Salmon Habitat in Recovery Planning (SHRP), (2) Chinook Salmon Life Cycle Model (LCM), and (3) Salmonid Watershed Analysis Model (SWAM). The SHRP provides guidance for incorporating habitat in recovery planning. The LCM (Greene and Beechie 2004, ID 047) is a watershed-scale Leslie matrix model for estimating sources of mortality for Chinook Salmon in the Skagit River, and supports evaluating the relative importance of different habitat types. SWAM is a series of landscape-scale assessments that relate salmon abundance to various landscape processes and coarse-scale habitat metrics.

Information Relevant to Skagit River Relicensing: The Chinook Salmon LCM is the only research project among the ones featured in this report that focuses specifically on the Skagit Watershed. However, the SHRP document presents a general-purpose set of guidelines for habitat components of recovery planning that could inform the Synthesis Study. The SHRP document provides a conceptual framework for understanding landscape-scale influences on watersheds and salmon populations and gives advice for how to identify and prioritize ecosystem recovery needs. Relevant information on fish and habitat and modeling tools from this source are described in more detail below.

<u>Fish and Habitat</u>: The SHRP document can be used to support the development of recovery plans for the Skagit River. Additionally, it can be used to identify research priorities. A sensitivity analysis of the Chinook LCM developed for the Skagit River revealed that small changes in juvenile mortality in nearshore habitats contributed the greatest to changes in escapement. Therefore, the model implies that practitioners should focus on strategies to improve nearshore habitat quantity and quality for juvenile Chinook and/or ways to increase survival within these habitats.

<u>Modeling Tools</u>: A table of the model parameters, estimates, and references for each estimate used in the Chinook LCM is given. Estimated parameters describe important life-history aspects such as survival, residency, fecundity, stream capacity, and productivity. These estimates could be used to construct or inform the development of an updated life cycle model for Skagit River Chinook.

While the materials related to the SWAM models and analyses are not directly based on data collected in the Skagit River, the methods and results from these analyses are potentially useful for developing hypotheses or for repeating these analyses for the Study Area for the Synthesis Study. A list of landscape variables used as predictors in a suite of spatial analyses to describe relationships with redd densities are given in a table for Chinook Salmon and steelhead in five Pacific Northwest watersheds (Yakima, Wenatchee, Salmon, John Day, and Willamette). This table (Table 1; SWAM model) can be used to guide similar spatial analyses for the Study Area for the Synthesis Study.

Several paper abstracts related to the SWAM modeling work identify potentially important landscape variables used to explain variation in salmonid abundance within different watersheds. Broadly speaking, important landscape variables included various aspects of climate, geology, wetland presence, terrain, and land-use types. Additionally, a consistent theme between analyses performed under the SWAM research indicates that spatial scale of the analysis is an important consideration. A potential data gap identified from this research is in understanding the appropriate spatial scales at which questions can be reliably answered given the type of data used during the analysis.

Paulson (1997) (Unique Identifier: 354)

<table>
<tr><td>Reference</td><td colspan="10">Paulson, K. 1997. Estimating changes in sediment supply due to forest practices: a sediment budget approach applied to the Skagit River basin in northwestern Washington. Master's thesis. University of Washington, Seattle.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Thesis</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: sediment supply and transport, large wood, substrate and sediment, history, data gaps. Land Use and Cover: forestry, roads. Fish and Habitat: <u>Habitat</u>: restoration. Modeling Tools: sediment. Water Quality and Productivity: turbidity.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Coho: rearing (only references to other studies).</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Watershed, including Hansen Creek, Finney Creek, Jackman Creek, other lower Skagit tributaries, other upper Skagit tributaries, and other Sauk River tributaries.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This Master's thesis investigates the influence of geology, landforms, and land use on the delivery of sediment to streams through mass wasting. The study focused on ten subbasins in the Skagit River, and partial sediment budgets were developed for these basins. Three processes that deliver sediment to streams were considered that included mass wasting, surface erosion from the construction and use of logging roads, and soil creep. Surface erosion rates were estimated using a calibrated model and soil creep rates were estimated based on literature values. A mass wasting inventory was developed with data on failure mechanism, geologic association, geomorphic association, and land-use association. Three broad geologic groupings were identified for the ten subbasins that included: (1) low-grade metamorphic and sedimentary rocks; (2) high-grade metamorphic rocks, and (3) deep glacial deposits. Landforms were classified as (1) upland hillslopes < 30°, (2) upland hillslopes > 30°, inner gorges adjacent to streams with gradient < 20°, and inner gorges adjacent to streams with gradient > 20°. Land-use categories considered include mature forest (stands >20 years old), immature forests (stands < 20 years old), and roads. The study found that *"…geologic association strongly influenced rates of sediment delivery to streams by mass wasting*." The primary conclusions are summarized as:

- Portions of sub-basins formed in Darington Phyllite had higher rates of delivery for shallow-rapid failures (70 $m^3/km^2/yr$) than portions of sub-basins in high-grade metamorphic rocks (19 $m^3/km^2/yr$), or deep glacial deposits (23 $m^3/km^2/yr$).
- Rates for debris flows were high in both Darington Phyllite portions of the sub-basins (67 $m^3/km^2/yr$) and high-grade portions (75 $m^3/km^2/yr$), relative to portions in deep glacial deposits (28 $m^3/km^2/yr$).
- Earth-slump rates of delivery were much higher in portions of sub-basins formed in deep glacial deposits (2,282 $m^3/km^2/yr$) (dominated by one failure that contributed over 700,000 m^3 sediment) than in either of the other groups (20 $m^3/km^2/yr$ for low-grade metamorphic; 8 $m^3/km^2/yr$ for high-grade metamorphics).
- Although inner gorge areas occupy only 2-24 percent of the sub-basins, a majority of all sediment delivered by mass wasting (75-96 percent) comes from these geomorphic units. This finding suggests that a management technique that reduced sediment inputs from these units

would be an effective method to reduce the overall sediment supply to a sub-basin. An estimate of the potential reduction ranged from 24 to 97 percent and averaged 47 percent.

Several Appendices are provided that provide detailed information and data for various topics of interest including Appendix 5-1 (mass wasting inventory data for each subbasin), Appendix 5-2 (regression equations developed to estimate volumes from measurements of failure scar areas and average erosion rates used to estimate debris flow volumes), Appendix 5-3 (mass wasting delivery rates by land-use association for each sub-basin), Appendix 5-4 (calculations made to estimate surface erosion rates in each sub-basin).

Information Relevant to Skagit River Relicensing: This study provides extensive information on ten subbasins of the Skagit Watershed, including tributaries identified in the Study Area for the Synthesis Study (including Hansen Creek, Finney Creek, Jackman Creek, and other Sauk River tributaries). Therefore, this study provides data that are spatially relevant to the Study Area for the Synthesis Study. The potential negative impacts of sediment supply and transport, mainly from forestry practices, on salmonids are described as context for this study's primary goal, which was to develop a better understanding of the influence of geology, landforms, and land use on the delivery of sediment to streams through mass wasting. An overall goal of the project as stated by the author is to "*describe mechanisms of sediment delivery and changes in woody debris supply, estimate impacts to salmonid habitat conditions, and estimate recovery time with and without rehabilitation*." Therefore, the information in this study can be used to inform the development of conceptual life history models and identification of factors affecting life stages of target species for the Synthesis Study. Coho Salmon habitat use and population estimates from a previous study that was included in the Synthesis Study is referenced in this report (Beechie et al. 1994, ID337), but this information was used for context and the results of the study were not applied to evaluate or quantify impacts to Coho or other target species. Modeling Tools and data to support modeling of sediment supply and transport are presented that can be used to inform the Synthesis Study. The author also describes suggestions for future research which include (1) improvement of the sediment budget approach; (2) analysis of mature forested areas only; (3) investigation of the relationship between structural aspects of the landscape and mass wasting. Some of these recommendations are tied to use of GIS mapping and other data that may now be available given the time that this study was completed.

<u>Geomorphology and Landforms</u>; <u>Land Use and Cover</u>: Chapter 3 describes the study area and provides detailed descriptions of geology, soils, vegetation, hydrologic characteristics, ownership, and management history for the Skagit River Watershed. Figure 3-2 provides a simplified geologic map of the Skagit Basin, with deep glacial deposits, low-grade metamorphic, high-grade metamorphic, and volcanic geologies shown. Subbasin characteristics are described in Table 3-2 for Synthesis Study tributaries Finney Creek, Hansen Creek, and Jackman Creek as well as other tributaries, including basin area, dominant geology, average annual precipitation, and relative land use intensity.

Area of total mass wasting failures are shown in Table 5-1 for each subbasin, including the number of failures, years or record, and failure rate. Average delivery percentages for shallow-rapid failures, debris flows, and earth slump failures are provided in Table 5-2 for each subbasin. Table 5-3 summarizes the average delivery percentage by geomorphic unit types for each subbasin. These summaries (Tables 5-1 through 5-3) report means, standard deviations, and medians from all subbasins. Overall failure rates by underlying geology are described in Table 5-4, and Figures

5-1 and 5-2 show average failure rates and sediment delivery rates with standard deviations by geology type. Relative failure rates for different land use categories are shown in Figure 5-3, with average road-related failure rates in several subbasins being more than 30x the rate for mature forest cover. Detailed data for failure rates by subbasin and cover type are provided in Table 5-5, and relative and total rates of sediment delivery from mass wasting associated with different land uses are shown in Figure 5-4 and 5-5, respectively. Soil creep rates and sediment delivery from soil creep are provided for each subbasin in Table 5-9.

In general, sediment delivery from roads tended to be much lower than sediment delivery to streams from mass wasting events. Figure 5-8 provides a summary of rates of sediment delivery by source (mass wasting, surface erosion, and soil creep) among the subbasins with detailed numbers provided in Table 5-10. Among the Study Area for the Synthesis Study tributaries of interest, Hansen Creek was classified as having a moderate overall sediment supply rating (100-200 $m^3/km^2/yr$) and has been heavily logged, while Finney Creek and Jackman Creek were classified as having a high supply (>200 $m^3/km^2/yr$). 50 percent of the supply from Jackman Creek was from a large failure event that occurred in deep glacial sediments that had been recently harvested, and Finney Creek has been intensively logged with high road building intensity.

The degree of alteration of sediment budgets are described in Chapter 6, with sediment supply estimates developed that represent natural rates in the absence of forestry, which the author proposes can be used as a target for restoration. In addition, the sediment budgets are also used to examine the potential effects of different management scenarios/strategies to address sediment supply and transport. Table 6-2 lists the estimate of the natural rate of sediment supply and the predicted rate under two different management scenarios for each subbasin. Management Scenario 1 (MS 1) assumes a 60-year rotation (a harvest rate of 2.5 percent/yr) and a time span of 240 years (4 rotations). Management Scenario 2 (MS 2) assumes a 120-year rotation (a harvest rate of 1.25 percent/yr) over a time period of 240 years (2 rotations). The author concludes that *"…although inner gorge areas (GU 4 and GU 5) occupy only 2-24 percent of the sub-basins (Figure 5-5), a majority of all sediment delivered by mass wasting (75-96 percent) comes from these two units (Figure 5-6)."* Predictions for reduced sediment production from leaving trees along inner gorge units are then provided for each subbasin in Table 6-3 to highlight the importance of these units in sediment supply and transport.

<u>Modeling Tools</u>: A modeling tool that predicts the amount of sediment produced from a road system was used and calibrated in this study. "*The volume of sediment mobilized and delivered by surface erosion from roads was estimated using a simplified version of the method outlined in the Surface Erosion Module in Washington state's Standard methodology for conducting watershed analysis under Chapter 222-22 WAC (version 3.0)*." Surface erosion rates were measured in one basin to support calibration of the model, and this included installation of sediment traps in Hansen Creek. The average rate of sediment trapped from four sites with similar site characteristics was 310 m^3/km^2 road prism/yr, but this was increased by 20 percent to account for sediment from fill slope erosion. Estimated average rates of sediment delivery to streams from surface erosion of roads from the model are reported for each subbasin in Table 5-8, with detailed methods and inputs described in Appendix 5-4.

Pflug et al. (2013) (Unique Identifier: 154)

Reference	Pflug, D., E. Connor, B. Hayman, T. Kassler, K. Warheit, B. McMillan, and E. Beamer. 2013. Ecological, genetic and productivity consequences of interactions between hatchery and natural-origin steelhead of the Skagit watershed. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: life history, abundance, hatchery, competition, predation, sex structure, harvest, movement, survival, distribution, periodicity, density dependence, data gaps, age structure, status and trends; Habitat: instream flow, capacity, limiting factors, ocean; Monitoring: biotelemetry, genetics, scale or otoliths. ***Modeling Tools:*** adult returns.								
Species and Life Stages	***steelhead***: migration, spawning, adult outmigration, rearing, outmigration, overwintering, estuary rearing and emigration, nearshore rearing and emigration, ocean. ***Lamprey, Chinook, Chum, Coho, Pink:*** rearing to outmigration (documented as prey items).								
Reaches and Spatial extent	Skagit Watershed including Sauk River, Baker River, Finney Creek, and tributaries, Skagit Bay, Skagit Estuary, and Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: Declines in Puget Sound steelhead populations have been linked to habitat degradation and loss, increasing hydrological variability, shifting ocean conditions, harvest, predation, and hatchery programs. This study focuses on the potential effects of hatchery releases on natural-origin steelhead survival and abundance from ecological and genetic perspectives in the Skagit Watershed. The authors suggests that the findings of their research will support the development of a Skagit-specific recovery plan that will address the full range of potential factors contributing to declining steelhead populations in the Skagit Watershed. Looking at the potential effects of hatchery steelhead that could contribute to ecological risk for natural origin steelhead production, the authors identify several pathways including large releases of hatchery fish and increased density-dependent mortality (habitat competition), residual hatchery fish and physical advantages of hatchery origin juveniles (habitat competition and predation), and genetic interactions or disease transmission. The primary goal of this study is *"…to develop science-based management actions that will allow commercial and sport fishers to access harvestable fish while not impeding the recovery of wild steelhead stocks within the Skagit River Basin."* The study has three main elements; (1) collection of genetic and biotelemetry data to evaluate interactions between hatchery and natural-origin steelhead, (2) genetically-based evaluation of hatchery-natural-origin introgressive hybridization, and (3) evaluation of smolt release population status and trends data from the Skagit Watershed and comparisons to other Puget Sound population status and trends and smolt release patterns.

Information Relevant to Skagit River Relicensing: This study provides quantitative data on target species (steelhead) and topics of interests for the Synthesis Study, as well as providing information that can inform development of conceptual life history models and hypotheses and factors that linked to resource conditions. Mainly, this study provides information that helps describe potential interactions between hatchery and natural-origin steelhead in the Skagit Watershed during each life stage. Figure 1 provides a meta-analysis diagram of hatchery and natural-origin steelhead interactions during juvenile and adult life stages that can be used to inform conceptual life history models and life stage factors affecting steelhead. In addition, their statistical analyses of population status and trends provides information on potential sources of variability (e.g., ocean conditions, hydrological variability) and controls for these other sources to evaluate the potential impacts of hatchery-origin fish on natural-origin population status and trends. The report is organized into sections that provide information on a number of topics of interest and life stages including:

- **Section 3:** Natural-Origin and Hatchery Smolt Freshwater Outmigration Timing Characteristics
- **Section 4:** Natural-Origin and Hatchery Smolt Freshwater Outmigration and Early Marine Residency Duration, Pathways and Survival
- **Section 5:** Hatchery steelhead Smolt Predation on Natural-Origin steelhead Juveniles and Competition for Similar Diet Items
- **Section 6:** Adult Natural-Origin Spawn Lifestage Timing and Behavior Patterns in Riverine, Estuarine and Marine Habitats
- **Section 7:** Evidence of Hatchery Straying and Natural Spawning Within the Skagit Watershed from Adult Capture Data Sources
- **Section 8:** Population Structure Within the Skagit Based on Genetics
- **Section 9:** Hybrid Density in Juvenile and Adult steelhead on a Spatial Level
- **Section 10:** Introgressive Hybridization
- **Section 11:** Effects of Hatchery Smolt Release Practices and Environmental Factors on Native Skagit steelhead Populations

A final section (Section 12) provides a synthesis of the previous sections, and appendices provide information on steelhead escapement goals, hatchery smolt predation, and ancestry of adult and juvenile steelhead from different sampling locations. In this chapter, Table 44 describes the effect of ecological and genetic interaction factors on Skagit steelhead viability based on Viable Salmon Population (VSP) criteria, and this information can be used to support development of conceptual life history models and identification of key life stage factors for steelhead. They conclude that spatial structure is the only VSP criteria not effected by hatchery interactions in the Skagit. The potential effects of four different hatchery management scenarios are also described in Table 45, and a list of recommended actions are described in this section.

The following provides a summary of information provided in each of the sections listed above. These are organized based on the chapter subjects rather than topics of interest to facilitate finding information in the report.

Natural-Origin and Hatchery Smolt Freshwater Outmigration Timing Characteristics: Hatchery releases of steelhead smolts in the Skagit River are propagated at the Marblemount hatchery on the Cascade River upstream of the Study Area for the Synthesis Study. Locations of juvenile trap monitoring sites and hatchery releases sites are provided in Figure 3. Average releases have changed over time, with 413,900 smolts for 1995-2005 brood years and 286,337 smolts for 1985-1995 brood years. Hatchery releases are 100 percent marked with adipose fin clips and are released at a size of 6 fish/pound in May to mimic the outmigration timing of natural origin steelhead smolts. Outmigration observed at smolt traps in Mount Vernon show similar timing patterns for wild and hatchery origin steelhead outmigrants, with peaks for both origins occurring in May although the duration of outmigration was shorter for hatchery origin smolts (Figure 4-5). The authors indicate that this synchrony in timing is consistent with current WDFW management objectives, but the report indicates that this creates opportunity for direct competition habitat and food among outmigrating smolts as well as from residualized hatchery fish (juveniles that do not migrate and remain in freshwater). In addition, direct mortality is possible if hatchery releases are sized large enough to introduce predation of wild origin juveniles as well as large pulses of releases that can attract other predators (e.g., Bull Trout) and increase predation risk of wild origin smolts. However, they note the effects of competitive interactions between wild and hatchery origin smolts are not well known and require additional research to support improved hatchery management strategies. The report recommends reducing the size of hatchery releases and alter the timing of releases to reduce potential negative competitive interactions between hatchery and wild steelhead juveniles.

Natural-Origin and Hatchery Smolt Freshwater Outmigration and Early Marine Residency Duration, Pathways and Survival: Hatchery and natural origin smolts were captured and tagged with acoustic tags in 2008 and 2009 from upper and lower Skagit River trap sites to study riverine, estuarine and marine migratory behavior and smolt survival. However, natural origin smolts were only captured in 2009 at upper Skagit River trap sites and this limited their comparative analysis. Average lengths, length range, average weight, and weight ranges for tagged natural origin smolts are provided in Table 3, and the location of acoustic receiver arrays are shown in Figures 6-7. Regardless of release location and time of release, smolts spent 11-30 days in river before entering Skagit Bay (19.4-22 days average). Freshwater residency times are summarized in Table 5. Hatchery origin smolts had shorter marine residency times than natural origin smolts, with natural origin smolts reaching Deception Pass and the San Juan Island arrays in 18.3 days on average compared to 5.3-13.5 days for hatchery origin smolts. Marine residency times are summarized in Table 6. An equal number of hatchery smolts were detected using the north and south forks of the Skagit River as they emigrate from freshwater to the estuary, and once they left the estuary a vast majority migrated northward through Deception Pass (93 percent) as opposed to a southern route around Whidbey Island. Migration route tendencies are described in Table 7. Marine survival was estimated based on the number of fish detected at check points and these should be viewed as minimum survival rates as detection efficiencies and other factors bias survival estimates low. Freshwater survival rates were estimated at 40-60 percent for hatchery smolts with 24-40 percent marine survival. The calculated survival rates for natural origin smolts was considerably lower (e.g., 4 percent marine survival), but they authors indicate low sample sizes and detection efficiencies limit their analyses. Calculated survival rates are provided in Table 8. The authors conclude that the results of this study component indicate that hatchery and natural origin smolts occupy the same habitats in space and time, and this provides a potential opportunity for ecological interactions that could result in hatchery influences on natural origin steelhead growth and survival.

Hatchery steelhead Smolt Predation on Natural-Origin steelhead Juveniles and Competition for Similar Diet Items: This study component attempts to address concerns about hatchery released steelhead preying upon natural origin steelhead and juvenile salmonids in general. From two years of sampling (2009-2010), they found that hatchery steelhead smolts stomachs contained juvenile salmonids (including Chinook, Coho, Pink, and Chum Salmon), Lamprey, and various invertebrates. However, they note a notable absence of juvenile steelhead in the hatchery smolt diet analysis. Pink Salmon dominated the diet in years with Pink Salmon outmigrations where as other juvenile salmonids dominated the diet in non-Pink Salmon outmigration years. Figures 7-8 provide information on hatchery smolt diet composition. Overall, their findings suggests that hatchery origin steelhead smolts are opportunistic feeders and potentially impact survival of other juvenile salmonids but do not appear to significantly impact natural origin steelhead juveniles during freshwater rearing and outmigration life stages.

Adult Natural-Origin Spawn Lifestage Timing and Behavior Patterns in Riverine, Estuarine and Marine Habitats: This study component used acoustic tag biotelemetry from 2008-2010 return years to evaluate the spatial distribution of spawners by basin or sub-reach, temporal effects on spawner distribution, pre-spawn migration patterns and behavior, spawning sub-period behavior patterns, post-spawning movement and timing. The authors note that DNA tissue and scale samples were collected along with data on length and gender during tagging and the biotelemetry data were used to characterize spawn location, entry timing (tagging date) vs. spawn location, arrival month at spawn location, travel time to spawn location, time spent at spawn location, pre- and post spawn wandering, time spent in freshwater, post spawn outmigration timing, marine entry timing of kelts, Puget Sound residency time of kelts (outmigrating post-spawn steelhead), and freshwater/estuarine/marine pathways. Fish gender and size were not identified as factors affecting time to reach spawning location, but earlier tagged adults had longer migration times to reach spawning locations and later arriving adults tended to spawn in the upstream most reaches of the watershed (Figure 10). The average time was reported as 25.4 days for adults to travel upstream from the middle Skagit River to upstream spawning locations. Average days to spawning location for natural origin steelhead are shown in Figure 9 by capture month and spawning location, and Tables 12-13 provides data on average days to reach spawning reaches by gender and length class. Average days at spawning locations decreased with later arriving adults (Figure 12), and some wandering was detected (9.2 percent) with higher wandering rates observed for females than males. Adult outmigration was also characterized, with outmigrations averaging 14.5 days and ranging from 1-255 days (Figure 13) with 63-71 days in freshwater before kelts (outmigrating adults) entered Skagit Bay (Figures 14-15) and males remaining in freshwater longer than females (85 days on average). Kelts entered marine waters from March to December with most marine entries occurring in May and June (Figure 16). Kelt residency in marine waters of Whidbey Basin ranged from 1-70 days with most spending 2 days before passing the San Juan Island receiver array (Figure 17). Collectively, the results of this study component indicate that there is opportunity for spatial and temporal overlap in natural and hatchery origin adult spawners especially in the months of March and April and early spawning populations (e.g., like Finney Creek).

Evidence of Hatchery Straying and Natural Spawning Within the Skagit Watershed from Adult Capture Data Sources: A key Marblemount hatchery operating goal is for all hatchery steelhead to either return to the hatchery or be harvested through fisheries. This chapter of their report describes potential impacts of hatchery origin spawning with natural origin spawners, and they used data from 2008-2012 to describe natural spawning timing and abundance of hatchery origin adults. Stray hatchery spawners have been detected in the mainstem Skagit, Sauk, and Cascade rivers as well as mid Skagit tributaries including Savage, Finney, and Mill Creeks. Figure 18 shows the number of natural hatchery spawners by year. WDFW scale analyses also provide evidence of repeat spawning for hatchery origin adults from 1985-2011 (Figure 19). The authors acknowledge that it is unclear as to the extent to which hatchery fish residualize and become residents in the Skagit based on the data they analyzed, and this is another possible source of hatchery and natural origin steelhead interaction.

Population Structure Within the Skagit Based on Genetics: Genetic samples were collected from 2008-2010 from mainstem reaches and tributaries, and Sauk River samples from the 1980s. Collections and samples included juveniles and adults as well as resident life histories and steelhead (Tables 15-16). Detailed genetic testing results are provided in Tables 17-26. Significant genotypic differences were detected between hatchery origin and natural origin steelhead, and resident Rainbow Trout from above migration barriers were significantly different from all steelhead of either origin. However, Baker River residents were not significantly different than anadromous steelhead in the Skagit. Long term sampling in the Sauk River indicates the genetic profile of steelhead has not changed over the 30-year sampling period. The homogeneous genetic makeup of natural origin steelhead described in this study is interpreted as evidence for mixing through reduced spawning location fidelity. However, they were not able to determine from their results if similarities in genetic information between natural and hatchery origin steelhead was the result of introgression or shared ancestry.

Hybrid Density in Juvenile and Adult steelhead on a Spatial Level: Recent studies have shown that hatchery-natural hybrids have reduced reproductive success, and this chapter describes the presence and relative densities oh hybrids from a spatial standpoint. Hybrid juveniles were detected in all sampled locations (Figure 21 and Table 27). Hybrid densities ranged from 6 percent in the Sauk to 32.7 percent in Finney Creek with middle Skagit River tributaries having the highest hybrid detection rates. Hybridization was also detected in adults with densities ranging from 15.4 percent to 35.8 percent, with densities again being highest in middle Skagit tributaries (Figure 22). In contrast, only 0.6 percent of hatchery origin adults collected at the Marblemount hatchery had more than 20 percent natural-origin ancestry (Table 28). Collectively, the amount of hatchery ancestry detected ranged from 20-90 percent in nearly all collection areas, and distance from the hatchery did not seem to be a factor. Therefore, they speculate that hatchery adults spawn throughout the watershed and significant mixing has occurred with the natural spawning population. The authors indicate that hatchery managers do not have effective tools to prevent hatchery origin adults from spawning outside the hatchery, and the temporal segregation strategy (segregated spawn timing) does not appear to be effective at preventing temporal and spatial overlap in natural spawners in the system or undesired genetic and ecological interactions.

Introgressive Hybridization: This chapter provides a narrative description of hatchery management strategies in the basin and potential effects of hybridization of hatchery and natural origin steelhead. Through an analysis of adult and juvenile samples collected from lower mainstem to upper mainstem and Sauk River sites (Figure 23), it was determined that introgressive hybridization can be detected in the Skagit basin but there is low confidence in quantifying introgressive rate between Marblemount hatchery and natural origin steelhead in the Skagit aside from some mid Skagit tributaries with early spawn timing (e.g., Finney Creek).

Effects of Hatchery Smolt Release Practices and Environmental Factors on Native Skagit steelhead Populations: The abundance of wild steelhead in the Skagit has declined significantly since the 1980s and fell below escapement goals of 6,000 in the 2000s. Historical estimates of escapement (1895) range between 70,000-149,000 steelhead with a mean of 105,600 adults. The nearly 10x decline in abundance was not explained by 33 percent losses in available stream length or ocean indices of productivity. Capacity was estimated using Intrinsic Potential methods at 54,000 adults for the mainstem Skagit, 4,300 for Baker River, and 18,000 for Sauk River for a total of 78,068 adults (a value exceeding the 6,000 adult escapement goal). Annual returns of wild steelhead and harvest are shown in Figure 38 (1978-2010), and average annual declines of 3.6

percent were detected in escapement from 1998-2010. Releases of hatchery smolts have varied from 200,000 to 550,000 winter run fish per year, with most releases between 200,000 and 300,000 winter run fish. Some releases of summer run fish occurred during a 10-year period (20,000-100,000 fish per year). Total winter and summer run release by year are shown in Figure 39. Increased releases of hatchery fish from 1994-2007 to compensate for declining escapement resulted in an inverse relationship between cumulative hatchery releases and wild steelhead returns (Figure 40). Shifts in ocean conditions and peak flow events have been identified as major factors affecting abundance of steelhead returns, and annual PDO index and peak flows are shown in Figures 41 and 42. Freshwater survival rates, reported as egg-to-smolt) ranged between 0.5 and 5.3 percent from 1993-2007 (Figure 43) and hatchery releases outpaced wild outmigrant production in all but one year (Figure 44). steelhead are especially sensitive to marine conditions given the potential for extended ocean residency (up to four years or more). Smolt to adult return rates (SAR) ranged from 1.5 – 3.5 percent from 1970s to early 1980s, peaked around 6 percent in 1985, and declined to about 0.3 percent from 1994-2007. SAR were higher for wild steelhead than hatchery steelhead with hatchery steelhead having SARs ranging from 0.2-0.8 percent (Figure 46).

Strong negative relationships were detected between cumulative hatchery smolt releases and wild spawner escapement (Figure 47), and a significant positive relationship between SST PDO index and steelhead escapement was detected (Figure 48). A correlation between Skagit River returns and Keogh River, BC returns was used to demonstrate synchrony in abundance patterns that support an ocean productivity hypothesis (Figure 49). A multiple regression model was developed that included PDO, peak flow, and hatchery smolt releases that had an $R^2 = 0.69$ and was statistically significant (Table 39). This model can be used to predict adult steelhead returns based on ocean, river, and hatchery release conditions.

A regional analysis of hatchery smolt effects on steelhead productivity is also presented in this chapter, which can provide additional context for potential effects of hatchery management strategies. Through this analysis, they found that population growth rates significantly decline as the number of hatchery smolts per spawner increased (Figure 54). In addition, Table 40 provides a detailed table of potential mechanisms with citations for potential hatchery impacts on steelhead populations that can be used to support development of conceptual life history models and identification of key factors affecting life stages of steelhead.

PSI and WDFW (2017) (Unique Identifier: 085)

Reference	Puget Sound Indian (PSI) Tribes, and Washington Department of Fish and Wildlife (WDFW). 2017. Comprehensive management plan for Puget Sound Chinook: harvest management component. Washington Department of Fish and Wildlife, Olympia, WA.
Source Information	***Type*** Report | ***Status*** Final | ***Quantitative Data*** Yes | ***Spatial Data*** Yes | ***Project Related*** Links
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply. ***Land Use and Cover:*** land cover. ***Fish and Habitat:*** <u>Fish:</u> abundance, hatchery, harvest, life history, climate change, age structure; <u>Habitat:</u> floodplain, connectivity, capacity, barriers, restoration, freshwater, estuary; <u>Monitoring</u>: abundance, data gaps. ***Hydroelectric Operations:*** flood control. ***Modeling tools:*** adult returns, juvenile production.
Species and Life Stages	***Chinook:*** rearing – outmigration, estuary rearing and emigration, spawning.
Reaches and Spatial extent	Skagit Watershed including Sauk River, other upper Skagit tribs, other lower Skagit tribs.
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flood control.

Summary: This report focuses on Summer/fall Chinook Salmon and Spring Chinook Salmon management units (MU) in the Skagit River basin and describes what reaches these MU's use and the changes to their habitats that have caused decreasing numbers or limited habitat capacity. It provides a brief overview of general landcover, geography and habitats, and the reaches that are within the distribution range of the two MU's. It also provides information about the stocks' age structure, hatchery programs to help supplement, brood status, exploitation rates, and harvest distribution. They developed a spawner-recruit and RER (maximum allowable exploitation rate) model for their analysis to help guide management decisions for these stocks.

Information Relevant to Skagit River Relicensing: This report provides quantitative information about two Chinook stocks in the Skagit River watershed, providing descriptions of the geography and habitats that these two MU's reside in and a general overview of the Skagit's landcover. Additionally, this report lists the five life histories strategies exhibited by both MU's and causes for their limiting numbers such as habitat loss due to loss of connectivity or barriers or being limited by capacity of the habitat. Annually, the Skagit River system produces 1.3 million juvenile Chinook, *"regardless of escapement levels, providing evidence of limited habitat capacity and reductions to population productivity."* This report also discusses linkages to Hydroelectric Operations in regard to flood control and consequently its effects on stream flow and changes to peak discharges due to habitat modifications that decrease complexity and straighten channels.

<u>Fish and Habitat:</u> The Summer/fall Chinook Salmon management unit is composed of the Lower Sauk River (summer), Upper Skagit River mainstem and tributaries (summer), and the Lower Skagit River mainstem and tributaries (fall) stocks. Some of these stocks spawn within the Study Area for the Synthesis Study such as the Lower Sauk River stock, while the other two stocks spawn outside. The Upper Skagit Chinook spawn in the mainstem of the Skagit and some tributaries above the Sauk confluence to Newhalem, as well as in the lower portions of the Cascade River and Diobsud, Falls, Goodell, Illabot, and Bacon creeks. The Lower Sauk River Chinook spawn mostly from the Sauk mouth to RM 27. The Lower Skagit River Chinook stock spawn downstream of the Sauk confluence and in larger tributaries such as Hansen, Alder, Grandy, Pressentin,

Jackman, Jones, Nookachamps, O'Toole, Day, and Finney creeks. These stocks reach sexual maturity between three and five years, the majority of spawners being four year old adults (see Figures 3 and 4 which show the age composition and proportion of brood years).

The spring Chinook MU includes the upper Sauk River, the Suiattle River, and upper Cascade River, falling slightly outside the scope of the Study Area for the Synthesis Study. The Upper Sauk River stock spawns in the North and South forks of the Sauk, White Chuck River and other creeks. The Suiattle River spring Chinook Salmon stock pawn in tributaries outside the Study Area for the Synthesis Study such as Buck, Downey, Sulphur, Tenas, Lime, Circle, Straight, Milk and Big creeks. The final stock, Cascade River, spawn above RM 8.1 to both the North and South forks, and some additional tributaries as well. Spring Chinook MU also reach sexual maturity between three to five years of age, with most spawning four to five years (see Figures 1 and 2).

The report also discusses the Marblemount's hatchery program that releases 200,000 subyearlings annually that are coded-wire tagged. These hatcheries raised subyearlings are supplements to the Skagit River Summer/Fall Chinook MU. Another hatchery program at Marblemount takes broodstock from the Suiattle River to raise juveniles to supplement the Skagit River Spring Chinook MU. Their subyearling annual goal of released Spring Chinook MU is 587,500 subyearlings.

The status of the management units are also described, with Appendix A describing the methodology used to determine harvest and abundance reference points. With those reference points, they used a fishery regulation and assessment model (FRAM) for validation runs of 2014 and 2017 *"to conduct a cohort reconstruction and spawner recruit analysis for brood years 1986-2012 for Skagit Spring Chinook, and 1983-2012 for Skagit Summer/Fall Chinook."* For Spring Chinook MU, there is a "*increasing trend in productivity*" although within the last five years, the stock has experienced a decline for brood years 2012-2018. Using NOAA's population specific rebuilding thresholds (RET), they found that the Suiattle Spring Chinook stock *"have exceeded NOAA's RET of 223 spawners in nine out of the last ten years,"* Upper Sauk Chinook stock have exceeded the "*RET of 470 spawners eight out of the last ten years*," and the Upper Cascade stock has exceeded the "*RET of 148 spawners in nine out of the last ten years*" (see figure 5).

For Summer/Fall Chinook MU, there is also "an increasing trend in productivity with generally above replacement productivity" and that each stock "exhibited an increasing trend in productivity from brood year 2006-2012." Within the last ten years, the Lower Skagit fall Chinook have *"exceeded NOAA's RET of 371 spawners in three"* years, the Lower Sauk summer Chinook have *"exceeded "RET of 371 spawners in four"* years, the Upper Skagit Summer Chinook have exceeded the *"RET of 5,470 spawners in eight"* years (see figure 6).

The report also discusses how exploitation rates have changed in the FRAM analysis, giving some brief history of fishing regulation changes, as well as the exploitation rates per fishing region (e.g., Alaska, Canada, and southern US fisheries). Figure 7 provides the proportion of exploitation rates per MU and each fishery. The report then provides their updated spawner- recruit and RER analysis (methodologies described in Appendix A) *"to guide proposed updates to the abundance and harvest rate objectives for wild Skagit River summer/fall Chinook MU and Skagit River spring Chinook MU."* Table 1 provides the harvest management thresholds for both MU's and objectives including the point of instability, the low abundance threshold, the critical exploitation rate ceiling, exploitation rate ceiling, and upper management threshold.

This report also lists out some data gaps that need to be prioritized to understand the current Skagit River MUs population dynamics and to further refine the harvest management objectives. Some suggestions include adding genetic stock identifications to juvenile monitoring programs, estimating natural dispersal to understand connectivity between populations, and to continue assessing life stage survivals between habitats.

Redman et al. (2005) (Unique Identifier: 100)

Reference	Redman, S., D. Myers, and D. Averill (editors). 2005. Regional nearshore and marine aspects of salmon recovery in Puget Sound. Report prepared for Shared Strategy for Puget Sound, Seattle, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, large wood. ***Land Use and Cover:*** banks and shoreline, data gaps. ***Fish and Habitat:*** Habitat: riparian, estuary, pocket estuary, nearshore, ocean, invasive species, restoration, climate change; Fish: periodicity, life history, movement, aquaculture, data gaps, climate change; Monitoring: habitat. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity, nutrients, primary production, data gaps. ***Hydroelectric Operations:*** flow regulation.								
Species and Life Stages	***Chinook:*** nearshore rearing and emigration, migration. ***Chum:*** nearshore rearing and emigration. ***Sockeye:*** nearshore rearing and emigration. ***Bull Trout:*** NA.								
Reaches and Spatial extent	Skagit Bay, Skagit Estuary, Padilla Bay, Sauk River.								
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flow regulation. ***Water Quality and Productivity:*** salinity. ***Fish and Habitat:*** Habitat: instream flow.								

Summary: Nearshore and marine aspects of salmonid and Bull Trout life histories are not well understood, nor have they been a major consideration in most salmonid recovery efforts. Puget Sound Chinook Salmon, Hood Canal Chum, and Coastal and Puget Sound Bull Trout populations are all listed as threatened under the Endangered Species Act. Nearshore and marine environments in Puget Sound support listed salmon and Bull Trout populations by providing habitat for multiple stages of their life cycles, rearing most notably. The nearshore and marine habitats of Puget Sound have been altered substantially from historic conditions and is thought to be a factor in the decline of salmon and Bull Trout populations in Puget Sound. Therefore, nearshore and marine aspects of salmon and Bull Trout must be considered in ongoing and future recovery efforts. This report offers a broad overview of the nearshore and marine habitat uses of Chinook, Chum, and Bull Trout throughout Puget Sound and provides general rationale for incorporating nearshore and marine aspects into recovery planning efforts. The report gives detailed evaluations of the status of natal Chinook, Chum, and Bull Trout populations at delineated subbasins within Puget Sound. Finally, recovery goals, objectives, and strategies are defined for improving nearshore and marine conditions in Puget Sound. Primary recovery strategies in this document include protecting existing high quality nearshore and marine habitats, improving functions of degraded nearshore and marine habitats through restoration actions, and increased monitoring and research to help support refinement of management and recovery strategies.

Information Relevant to Skagit River Relicensing: This report presents a broad overview of nearshore and marine influences on Chinook, Chum, and Bull Trout in Puget Sound. Emphasis is placed on landscape scale processes and habitat attributes in this report and recovery plan recommendations are made for each of eleven subbasins that were the focus of the report, including for the outlet of the Skagit River into Whidbey Basin. While this report contains little information specific to the Study Area for the Synthesis Study, it provides information general enough (primarily sourced from studies conducted in other Puget Sound estuaries) to be applicable to all populations interacting with the nearshore marine zones within Puget Sound, including in Whidbey Basin into which the Skagit River drains. The information contained in this report can support the development of hypotheses and conceptual life history models of the nearshore and marine habitat uses of juvenile salmon and Bull Trout.

Fish and Habitat: Small blind side channels and off-channel habitats in the estuary are critically important to delta rearing fry. Optimal habitat conditions appear to include low gradient and shallow waters containing fine sediments. In addition, low salinity, presence of wetland vegetation species, and low wave energy are conducive to Chinook fry rearing.

Invasive plants, such as *Spartina spp.*, *Sargassum muticum*, and *Zostera japonica*, have altered the vegetation assemblages and sedimentation patterns in Puget Sound. *Zostera japonica* is established in northern Puget Sound and is known to negatively affect native eel grass beds, which are considered essential habitats for juvenile salmon rearing in estuaries. Declining diatom abundances within estuaries shaded out by invasive *Spartina spp*. is another concern, especially for planktivorous salmon such as Sockeye.

Section 6.1 provides the individual subbasin evaluation for the South Georgia Straits and San Juan Islands. It is noted that larger juvenile Chinook Salmon form the Skagit River, although non-natal to this subbasin, use the South Georgia Straits and San Juan Islands for feeding, growth, refuge, physiological transition, and as a migratory corridor.

Section 6.2 provides the individual subbasin assessment for Padilla/Samish Bay. Padilla and Samish Bays are used by independent populations spawning in the Skagit, Stillaguamish, and Snohomish Rivers. Padilla, Samish, and Fidalgo bays were historically part of the Skagit River natal estuary but alterations to the delta have fragmented the historic connection and are no longer directly accessible to outmigrating Skagit Chinook. Despite having no natal estuary, the Padilla/Samish Bay subbasin contains large eelgrass beds (most prominently in Padilla Bay), which are important for juvenile salmon in Puget Sound, including Skagit River populations. Because of the severance of the historical connection with the Skagit River delta, there is a loss of opportunity and capacity from the Skagit Chinook populations. Table 6-4 summarizes recommended protection actions for Padilla and Samish Bays, including protection of existing eelgrass beds, protection of unarmored shorelines, protection of herring stock, and prevention of further *Spartina* infestations.

Section 6.6 provides the individual subbasin assessment for Whidbey Basin, which covers 10 of the 22 independent populations of Puget Sound Chinook Salmon, including the Skagit and Sauk Rivers. Certain parts of Whidbey Basin are susceptible to low levels of dissolved oxygen in some areas due to high nutrient inputs and low circulation. Roughly 49 percent of the subbasin area (77,440 acres) is nearshore, while the other 51 percent (80,128 acres) is deep-water. Sixty-one percent (47,520 acres) of the total nearshore area are the natal estuaries of the Skagit, Stillaguamish, and Snohomish Rivers. The nearshore are in the Whidbey Basin represents 19 percent of all nearshore area in Puget Sound. Fifty-six linear miles of the shoreline is marine riparian and 46 percent of the shoreline (162 linear miles) harbor at least one species of eel grass (*Zostera marina* and *Z. japonica*). There are 17 pocket estuaries in Whidbey Basin, of which only two were determined to be properly functioning. Historical records suggest that subaerial wetland area in the Skagit Estuary decreased from 6.18 square miles to 4.63 square miles by 1980. Intertidal wetland area measured 21.24 square miles in 1980. Upstream of the estuary, the report cites early impacts to habitat with the removal of large wood (30,000 snags) from the Skagit River Between 1898 and 1908. The sites of the three Skagit Project dams in the upper Skagit River are thought to be in areas above the historic migration extent of any species of anadromous salmon species.

However, alteration in the downstream flow regime has impacted large woody debris recruitment into the lower river and estuary. Habitat has been simplified as a result. At the time of this report, shoreline armoring covers nearly 44 percent of the subbasin and there were 5,046 overwater structures. A series of goals for salmon and Bull Trout natal to the subbasin area, which includes Skagit Bay, listed in this section:

- *"Provide early marine support for all four life history types (fry migrants, delta fry, parr migrants, yearlings) for the 10 independent populations of Chinook Salmon emanating from this sub-basin."*
- *"Provide support for sub-adult and adult Chinook Salmon populations who utilize habitats within this sub-basin as a migratory corridor and grazing area."*
- *"Provide marine support for sub-adult and adult anadromous Bull Trout populations (approximately 33) within the four core areas in this sub-basin (Snohomish/Skykomish, Stillaguamish, Upper Skagit, Lower Skagit). The Lower Skagit core area is absolutely essential to sustaining the distribution of the anadromous Bull Trout life history trait within Puget Sound."*
- *"Provide for connectivity of habitats; also, adequate prey resources, marine foraging areas, and migratory corridors for juvenile, sub-adult and adult Chinook, and Bull Trout."*
- *"Provide early marine support for independent spawning aggregations occurring in this*
- *sub-basin."*

Tables 6-12 and 6-13 summarize recommended protection and improvement actions for the Whidbey subbasin. Recommendations include protection of pocket estuaries and shorelines, monitoring/prevention of eutrophication, ensuring adequate flow of freshwater, restoration of delta habitats, and reconnecting flow between Padilla and Skagit Bays. Several tables provide summaries of qualitative information regarding various stressors and associated impacts to nearshore and marine ecosystem processes in Puget Sound which can inform development of life stage factors and hypotheses for linkages between resource conditions and factors affecting life stage transitions. Table 4-1 qualitatively summarizes various human impacts to estuaries and wetlands in Puget Sound. Impacts include industrial and residential development, agricultural impacts (diking, filling, and tide gates), channelization, and shoreline construction. Effects of each class of impact on nearshore and marine ecosystem processes are summarized as well as hypothesized effects on salmon and Bull Trout. Table 4-2 qualitatively summarizes various human impacts on alterations in flow into estuarine habitats, effects on nearshore and marine ecosystem processes, and effects on salmon and bull trout. Those impacts include dams, diversions, channelization, re-plumbing of stream networks, forestry practices, and land development. Table 4-3 qualitatively summarizes various effects of shoreline modifications on ecosystem processes and salmon and Bull Trout. These include shoreline armoring, overwater structures, and riparian vegetation/large woody debris removal.

Life history diversity and periodicity are described at a regional level. Natal estuary habitat use in Chinook can be divided into life-history strategies corresponding to whether emerging fry migrate directly to the estuary, rear in freshwater and migrate as parr, or rear in freshwater and migrate as yearlings. For fry migrating straight to the estuary, they can arrive as early as mid-December and continue until April. As fry enter the estuary, they may continue into Puget Sound waters or remain in the natal estuary and rear for an extended period. Unlike migrant fry, delta fry rear in the natal estuary and their distribution is controlled by combined tidal and fluvial processes and the underlying geomorphology of the estuary. Residence time estimates of delta fry ranges from 25 to 90 days based on studies from other estuaries. Parr migrant Chinook typically arrive at estuaries in late May. Catch data throughout Puget Sound suggests that peak parr migrant abundance in estuaries occurs from May through mid-July. Habitat use, growth, diet, and so on in parr migrants are probably indistinguishable from that of fry migrants. Limited studies on Chum Salmon in Hood Canal suggests that Chum fry typically pass through their natal estuaries straight on to shoreline habitats. Limited rearing in estuaries may occur or non-natal fish may enter estuaries from Puget Sound, based on size data. Residence time for Chum fry rearing in estuaries is thought to last for less than two weeks. Larger Chum (> 60mm) make extensive use of nearshore surface waters. Bull Trout in the lower Skagit have been affected by wetland habitat loss and simplification (i.e., channelization) through curtailed residence times of juvenile salmon seeking cover in deeper waters. Lower densities of delta rearing fry presents a loss in potential foraging opportunity for Bull Trout.

It is noted that a net pen aquaculture facility is active in Skagit Bay. While it is not clear which species this facility produces, the authors mention that 99 percent of aquaculture in Washington is Atlantic Salmon, with Coho, Chinook, and steelhead accounting for the remainder. Starting on page 4-32, a considerable section is devoted to discussing impacts of hatcheries on salmon and Bull Trout in nearshore and marine environments. Competition between hatchery and wild origin fish is cited as an example of a negative impact. Hatchery Chinook juveniles tend to be larger and, according to one study, dominate in nearshore beach seining samples (54-75 percent of all Chinook caught). Coincident hatchery releases can also affect survival in wild outmigrating Chinook by increasing competition and/or predation (e.g., by hatchery origin Coho). Table 4-5 qualitatively summarizes the effects of different biological impacts on nearshore and marine ecosystems, salmon, and Bull Trout. Biological impacts considered include hatchery releases/introductions, harvest, aquaculture, and shellfish farming. Table 8.2 is an example 10-year action plan for regional restoration in Puget Sound and includes a recommendation to restore the Skagit River delta.

Spatial data of pocket estuaries and likely Chinook functions associated with each (feeding, osmoregulation, and refuge) for Whidbey subbasin are given in Appendix E-6.4. In addition, it is noted whether pocket estuaries are affected by shoreline development, urbanization, diking and filling, spills and discharges, aquaculture, and/or sea level rise and a final evaluation score is given (Properly functioning, not properly functioning, or at risk). Methods for identifying, mapping, and analyzing pocket estuaries are described in Appendix B. A potentially useful dataset is identified, the Washington Dept. of Ecology Digital Coastal Atlas, which can be used to update locations and status of pocket estuaries. In addition, Figure E-5.3 in the Appendices shows the spatial extent of shoreline armoring and sewage outlets in Whidbey basin, which may be useful for evaluating coarse-scale stressors on nearshore and marine habitats.

Appendix G presents details on climate variability within Puget Sound. The level of detail provided may support the development of hypotheses related to climatic or oceanographic processes.

<u>Water Quality and Productivity</u>: Water temperature affects growth rates; warmer temperatures can lead to earlier arrivals to the natal delta. The Skagit River, combined with the Snohomish, is responsible for about 50 percent of the annual total nutrient loadings into Puget Sound. High water temperatures combined with low levels of dissolved oxygen have been cited as concerns affecting adult Chinook Salmon within estuaries, sometimes leading to increased spawner mortality and

delays in upstream migration. Low dissolved oxygen from sewage discharges and poor circulation is a concern for Bull Trout and salmon using Whidbey Basin. Table 4-4 qualitatively summarized the effects of different contamination types on salmon and Bull Trout. Contamination types include municipal and industrial wastewater, cruise ship discharges, stormwater discharges, on-site sewage effluent, oil spills, and other hazardous chemical spills. Tables 7.1 through 7.3 outline recommended protection, improvement, and monitoring strategies for nearshore and marine habitats in Puget Sound. These tables are valuable for supporting the development of new hypotheses and/or informing management strategies.

Geomorphology and Landforms: The Skagit River transports the greatest amount of sediment to Puget Sound. However, removal of agricultural levees and navigation structures that impede natural sediment transport and deposition processes are identified as a recovery action for Whidbey Basin. Loss and simplification of estuarine, delta, and wetland habitats is a major stressor on anadromous fishes in Puget Sound. Greater than 73 percent of historic river delta wetland area in Puget Sound has been lost since the beginning of the 20th century. Diking is the primary cause of subaerial wetland loss, while dredging is the primary cause of intertidal wetland loss.

Hydroelectric Operations: The size and shape of the delta face are influenced by prevention of downstream sediment transport by dams. Reduced flow and sediment transport changes the rates of erosion and aggradation in estuaries. Erosion and incision of blind side channels within estuaries can occur resulting from dam construction. In some cases, eel grass beds can be negatively affected by changes in the sediment regime, which impacts foraging opportunities for Bull Trout. Loss of gradual salinity gradients in estuaries resulting from reduced freshwater input can affect residence times of juvenile salmon rearing within delta habitats. Curtailed residence times in estuaries can impair physiological transitions from freshwater to saltwater. Dams on the upper Skagit have affected habitat complexity in the lower Skagit by preventing transfers of large woody debris.

Riedel and Larrabee (2016) (Unique Identifier: 155)

Reference	Riedel, J. L., and M. A. Larrabee. 2016. Impact of recent glacial recession on summer streamflow in the Skagit River. Northwest Science 90(1):5-22.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and landforms:*** substrate and sediment; history, glaciers and snowpack, change. ***Land use and Cover:*** land cover. ***Fish and Habitat:*** Habitat: instream flow, climate change, data gaps. ***Modeling Tools:*** hydrology, climate change.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Watershed, including Sauk River and Baker River.								
Linkages to Hydroelectric Operations	NA								

Summary: This source provides a general overview of the bedrock composition and the history of glaciation that led to the current Skagit basin geomorphology. The Skagit River basin is composed of metamorphic and igneous rocks with the upper part of the basin being composed mostly of gneiss and granite; west of the Cascade River is mostly schist and phyllite and from Mount Baker to Glacier Peak is volcanic rock. This study also analyzed glacial coverage, extent, runoff, and volume from 1959 to 2009 throughout the entire Skagit basin watershed. This study provides a brief history of the ice ages during the Pleistocene period that shaped the current drainage pattern and topography of the Skagit watershed. The authors used data from three USGS gauge stations to analyze basin runoff patterns, which included stations near the Baker River confluence, on the Skagit River after the Baker confluence, and on the Sauk River. Additionally, for 1959 data, they produced a 10m DEM created from 1959 ortho-photographs, and a USGS 1:24,000 scale topographic map from 1982 to create past glacier outlines. For 2009 data, they used 2009 NAIP ortho-photograph imagery, and 1:12,000 scale stereo-photographs for glacier outlines. Combining these data sources allowed them to do a comparison of glacial extent and contributions from 1959 to 2009.

Information Relevant to Skagit River Relicensing: Given that glaciers impact overall hydrography patterns and sediment supply and transport, the changes in glacial area and volume described in this paper provide useful context for understanding sources of variation in hydrography in the study area. They report changes in surface area for subbasins, including the Sauk River and Baker River which can influence hydrography in the study area as well as basins upstream of the Project in the Upper Skagit (see Table 1). Percent glaciated estimates by hydrological unit code (HUC 6) are provided as spatial data in a map of the entire Skagit River basin for 2009 conditions. They also provide estimates of glacial surface melt contribution to total summer (May – September) streamflow for major basins (see Table 2). They found glaciers greater than 0.1 km^2 decreased from 396 in 1959 to 377 in 2009 and glacial extent has decreased by 32.02 ± 14.42 km^2 (roughly 19 percent). From DEM analysis and additional surveys, there was 14.72 km^2 of glaciers in 1959 below 1700m, while in 2009 there was 8.84 km^2 of glaciers. Averaged across the 30 years, glacial volume lost was 0.1 km^3 per year, or equivalently 3.01 ±0.69 km^3 water equivalent (w.e.). This loss of glacial coverage has impacted summer base flow on the Skagit

River. The average cumulative annual mass balance for five Skagit watershed glaciers was -20.35 ± 3.63 m w.e., and they indicate that the losses of ice in the watershed are roughly equivalent to 100 years of freshwater consumption at current rates in the basin. Collectively, these data can be used to inform how changes in glacial coverage and resulting surface melt runoff contribute to summer flows in the Skagit River (a time when cold glacial waters can ameliorate low flows and temperatures in the summer), including subbasins that contribute to the lower Skagit River study area. This information can be used to inform hydrological models or scenarios to evaluate how climate change or different sources of hydrological variation can influence flows and water quality in the lower Skagit River, which could provide valuable information for evaluating sources of flow variation and Hydroelectric Operations.

Riedel et al. 2020 (Unique Identifier: 001)

Reference	Riedel, J., S. Sarrantonio, K. Ladig, and M. Larrabee, 2020. DRAFT Skagit River geomorphology inventory report: part I – Gorge Dam to Sauk River. Report prepared by the National Park Service for Seattle City Light, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Geomorphology and Landforms:*** change, history, channel migration, channel incision, sinuosity, floodplain, secondary channels, floodplain connectivity, substrate and sediment, sediment transport and supply, aquatic habitats and landforms, estuarine habitats and landforms. ***Fish and Habitat:*** Habitat: instream flow.									
Species and Life Stages	NA									
Reaches and Spatial extent	R7-R13, R1-R6.									
Linkages to Hydroelectric operations	***Fish and Habitat:*** Habitat: instream flow. ***Geomorphology:*** sinuosity, sediment transport and supply, aquatic habitats and landforms.									

Summary: This is a draft study report that was prepared for City Light to address one of eight identified data gaps related to the physical state of aquatic and riparian habitats in the Skagit Valley—mapping of surficial geology. The authors anticipate that the information developed in this study will inform management of cultural resources, habitat restoration, and future studies. A total of 13 geomorphic reaches were delineated and described in this study, with information on dominant habitat forming processes and history, as well as current landforms and processes, from Skagit Gorge to the Skagit Delta/Estuary. As part of this study, over 800 distinct landforms were identified and digitized in a Geographic Information System (GIS) for the upper Skagit Valley, but detailed descriptions of reaches were only provided for the upper reaches (R1-R6 upstream of the Sauk River confluence) in this draft. The authors indicate that more detailed mapping of the lower reaches (R7-R13) will be developed in the next phase of the study.

Information Relevant to Skagit River Relicensing: This report defines the geomorphic reaches that will be used in the Synthesis Study and the dominate processes that formed and control geomorphic features and processes in these reaches. Reaches relevant to the Study Area for the Synthesis Study are defined as Reach R7 (Sauk River Alluvial Fan – "Wide alluvial fan that forces Skagit to north side of valley. Influenced by Glacier Peak sediment, some from lahars." RM 68-65), Reach R8 (Sauk Alluvial Fan to Baker Mouth – "Steep, narrowed channel because river is incised into 30-50m thick, over-consolidated glacial deposits (till, silt, sand, and gravel)." RM 65-56.5), Reach R9 (Baker to Finney Cr. – "Channel incised into glacial and lahar terraces, Baker Hydro influence on sediment, large wood, and channel pattern." RM 56.5-49), Reach R10 (Finney Cr. To Hamilton Moraine – "Sinuosity higher strong right bank ground water influence, extensive lahar terrace." RM 49-36.5), Reach R11 (HM to Sedro-Wooley – "High sinuosity in wide outwash valley wide meander loops. Extensive lahar terrace on right bank."), Reach R12 (SW to Burlington Hill – "River leaves valley and enters Puget Lowland. Start of river levees transition to sand bed."), and Reach R13 (Delta (BH to Skagit Bay) – "Puget Lowland river constrained by levees on delta, split into two distributary channels, very limited sediment and LWD."). However, the reaches have been refined since this report was developed and will be updated in the Synthesis Study to reflect these changes. In addition, detailed mapping of landforms in the reaches relevant to the Synthesis

Study were not developed in this phase of the study, but future efforts will develop spatial data for landforms (e.g., terraces, alluvial fans, mass-wasting deposits, gravel bars, islands, and active and relict side channels) as well as edge maps, relative elevation models, geologic cross sections, contours, and shading; and quantitative data were collected or developed describing valley and channel characteristics (e.g., valley width, sinuosity, and depth to groundwater) that will support Synthesis Study objectives. The authors also briefly discuss potential Project linkages with flow regulation and reservoirs with downstream habitats and habitat forming processes through reduced peak flow events and a 70 percent reduction in sediment supply. However, these are not described with detailed quantitative data in this report although it is possible that more information will be developed in Part 2 of the study focused on the lower reaches (Reaches R7-R13).

Geomorphology and Landforms: Reach maps with aquatic and geomorphic landforms are available, with example maps shown in the report. Some limited data for the lower Skagit River are provided in this report, but most spatial data and quantitative data are for Reaches R1-R6. Tables 1 and 2 provide the descriptions of reaches, and summaries of geomorphic metrics (reach lengths, sinuosity (1915 and 2019), slope, active side channel counts and relict side channel counts) are provided for each reach (with some data to be developed or updated in the next phase of the project) that are relevant to the Study Area for the Synthesis Study.

Rothleutner (2017) (Unique Identifier: 375)

Reference	Rothleutner, A. D. 2017. Sediment budget of the middle Skagit River, Washington 1937-2015 reveals decadal variations in sediment export and storage. Master's thesis. Western Washington University, Bellingham.								
Source Information	*Type*	Thesis	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Yes
Topics and Keywords	*Geomorphology and Landform:* change, channel migration, history, sinuosity, substrate and sediment, sediment transport and supply, floodplain, climate change. *Fish and Habitat:* Habitat: climate change, instream flow. *Modeling Tools:* sediment, habitat.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Estuary, Reach R7-12, Sauk River, Baker River.								
Linkages to Hydroelectric Operations	*Geomorphology and Landform:* sediment transport and supply. *Fish and Habitat:* Habitat: instream flow.								

Summary: The thesis includes an evaluation of historical channel meandering since 1937 of the middle reach Skagit River between Rockport and Sedro-Wooley, Washington (Geomorphic Reach 7-12). The active floodplain has periodically been a significant source of sediment to the lower Skagit River and delta. She examined the geomorphic change and potential sediment production of the middle reach to test whether it is a significant source to the lower river. ArcGIS was used to calculate sediment volume produced by bank erosion versus stored in bars, island, and side channels through time. The results show changes in net sediment production through time, between 2006 through 2015, recruitment of floodplain sediment from the middle reach to the active channel produced approximately 27 percent of the annual sediment mean load measured in Mount Vernon. The sediment source was dominated by lateral incision at rates of 3-8 m/yr in several areas of high-relief (3-15 m) banks characterized by unconsolidated deposits. The results help quantify recent channel dynamics, rates of change, and sources of sediment that influence sediment transport and aggradation patterns, that are important to flood risk and salmon habitat.

Channel width consistently decrease through time along the entire mainstem middle Skagit reach. The overall width decreased from an average of 221.2 m in 1937 to 178.8 m in 2015. Channel widths were generally wider in the confined reach. There is an increase in the amount of erosion in comparison to aggradation in the more recent time periods of 2003-2006 and from 2006-2015. There will likely be a much more seasonal pattern of aggradation and erosion in the future. Erosion will likely be much higher during the winter months with periods of higher flow and more precipitation falling as rain.

Between 2006-2015 the mean annual sediment load from the middle reaches was 630,000 Mg. This accounts for approximately 25 percent of the estimated 2,500,000 Mg annual sediment load calculated from sediment rating curves. However, this value is probably an underestimate because most of the changes identified by the 2D Model for Aggradation and Erosion are large scale. Smaller changes are less likely to be captured. The estimated sediment contributions from the Sauk River are 950,000 Mg.

Information Relevant to Skagit River Relicensing: Between 1937 and 2015, the overall channel width has decreased by approximately 42 m (138 feet) in the middle Skagit. There has been an increase in the amount of erosion in recent years. The mean annual sediment load for the middle reaches between 2006-2015 was approximately 63,000 Mg. This account for approximately 25 percent of the estimated 2,500,000 Mg annual sediment load calculated from sediment rating curves. The author describes the effects of dams on sediment supply and transport in the Skagit Watershed, but the impacts are only qualitatively described. Climate change and dam operations can potentially change the amount of sediment being discharged. Therefore, this study provides important information that can be used to understand how the sediment load could change in the future and how sediment supply and transport are related to factors in the Skagit Watershed and the Study Area for the Synthesis Study.

Numerous quantitative summaries and figures of metrics related to geomorphology and landforms are provided in this report including channel migration rates, sinuosity, and channel widths by geomorphic reaches and river miles for mainstem and side channels; estimates of volume change by geomorphic reach and river mile; and discharge at the Mount Vernon USGS gage with plots that include exceedances percentiles and other discharge metrics. Spatial data delineating buffer zones, transects, active floodplains, bedrock, channel centerlines, erosion and aggradation rates, and mean erodible bank heights among other metrics are presented in numerous maps and could be extracted to support analyses. Ultimately, the results of this study can be used to inform sediment modeling in the lower Skagit River, and the ArcGIS modeling tools used in this study can be used to calculate sediment volume produced from bank erosion verses stored in bars, islands, and side channels from aerial-imagery based lateral meander migration analyses and digital elevation models, which could be applied to future conditions or other reaches.

Roni et al. (2006) (Unique Identifier: 104)

<table>
<tr><td>Reference</td><td colspan="10">Roni, P., S. A. Morley, P. Garcia, C. Detrick, D. King, and E. Beamer. 2006. Coho salmon smolt production from constructed and natural floodplain habitats. Transactions of the American Fisheries Society 135(5):1398-1408.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: abundance, size structure, density dependence, data gaps; <u>Habitat</u>: restoration, freshwater; <u>Monitoring</u>: restoration.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Coho: rearing, migration – spawning.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R7–R13, US of R7, Baker River, Sauk River, Finney Creek.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This study examines smolt trapping data at 30 western Washington floodplain habitats collected between 1987 and 2000 at natural, enhanced, and constructed sites. The sites were dispersed across four watersheds, including the Skagit, Stillaguamish, Quillayute, and Hoh basins. The aim of this study was to determine whether Coho Salmon smolt numbers, density, and length differed across project types (natural, enhanced, constructed) and area. The researchers found no significant differences in smolt numbers or density among project types. Smolt length did differ by project type. Excavated ponds produced larger smolts than natural or constructed groundwater channels. Smolt numbers were positively correlated to wetted area and length was negatively correlated with density and distance to saltwater. A multiple regression analysis of other habitat variables found that shoreline irregularity (calculated as the perimeter of the project length divided by the perimeter of a circle with the same length) explained 70 percent of the variance in smolt length.

Information Relevant to Skagit River Relicensing: Information relevant to the Synthesis Study presented in this paper largely relate to physical and habitat factors that influence Coho density and smolt length. This study contains tables with summary data for physical characteristics and fish abundance and size structure metrics (smolt numbers [mean ± SE], density [fish/m^2], fork length [mean ± SE], and adult escapement [mean ± SE]) for natural, enhanced, and constructed floodplain habitat types (channels and ponds) and project types (natural floodplain channels, reconnected natural habitat, impoundment, gravel pits or mill pond, excavated groundwater channels) in the Study Area for the Synthesis Study as well as other sites within the Skagit River watershed. Their finding that constructed floodplain habitats produced smolts of similar sized and density compared to natural floodplain habitats, and the abundance metrics for density and production could be used to inform restoration planning or evaluation. In addition, they recommend that floodplain restoration consider project size, shoreline irregularity, and complexity in designs to address recovery goals. Shoreline irregularity was positively correlated with smolt density but negatively correlated with smolt length. The positive correlation was expected due to demonstrated relationships between habitat complexity, large wood, and smolt numbers. The negative relationship with smolt length may be reflect project-scale differences or may be a result of density-dependent processes. Distance from saltwater was also an important factor for explaining variance in smolt lengths. Smolt length was negatively correlated with distance to saltwater, which the researchers interpret as an indication of habitat productivity (i.e., lower primary production further upstream). They identify a research need to better understand how use of floodplain habitats for refuge from high flow events in addition to rearing contribute to smolt production at basin or site scales.

Fish and Habitat: For all sites, average smolt production (number) across all sites surveyed was 2,492 smolts, average density was 0.37 (fish/m^2), and average fork length was 98.9 mm. Data relevant to the Skagit River basin are presented in Table 1, from which summaries can be calculated. Percent cover, littoral area, mean depths, perimeter, and shoreline irregularity metrics are also provided for a subset of sites sampled in this study, that include sites within the Study Area for the Synthesis Study, as well as wetted areas and year of construction and river km for all sites considered in the analysis.

Rubenstein et al. (2018) (Unique Identifier: 411)

Reference	Rubenstein, M. A., R. Christophersen, and J. I. Ransom. 2018. Trophic implications of a phenological paradigm shift: bald eagles and salmon in a changing climate. Journal of Applied Ecology 56:769-778.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Yes
Topics and Keywords	***Hydroelectric Operations***: flow regulation, life stage flows. ***Fish and Habitat:*** Habitat: instream flow, climate change; Fish: abundance, status and trends, climate change, data gaps; Monitoring: abundance, flow.								
Species and Life Stages	***Chum:*** spawning. ***Coho:*** spawning.								
Reaches and Spatial extent	US of R7, R7-R11.								
Linkages to Hydroelectric Operations	***Hydroelectric operations:*** flow regulation, life stage flows. ***Fish and Habitat:*** Habitat: instream low.								

Summary: This study explores phenological (cyclical or seasonal relationships) relationships between bald eagles, Coho, and Chum Salmon and Skagit River flood events. Specifically, they analyzed local bald eagle abundance from various sources that go back to 1982 and fall Chum and Coho escapement data that was available starting in 1983 to 2015. The Skagit River mainstem was divided into two sections: upstream section (river mile 24-67.2) that is *"dominated by flow regulation from the Ross, Diablo, and Gorge hydroelectric dams,"* and the downstream section (river mile 24-67.2) that includes the Sauk River confluence. They used stream flow data from two USGS gauge stations in each section and identified the daily maximum flow rate and calculated the number of flooding events per season. The authors found that over the study period, the average weekly eagle counts declined, and that the week of peak eagle count advanced 0.45 days per year. Chum and Coho Salmon escape estimates were declining both by less than 5 percent. The Chum peak date was earlier each year by roughly 0.43 days per year (nearly the same as eagles) and the Coho peak date was 0.8 days earlier per year. Overall, the authors found *"a strong positive relationship between Chum escapement and eagle counts, a strong negative relationship between flood events and eagle counts, and a non-significant relationship between Coho escapement and eagle counts."*

Information Relevant to Skagit River Relicensing: This study provides quantitative information on the phenological relationships between two target species of salmon (Chum and Coho), eagles, and the timing of flooding events in the Skagit River in two reaches. Coho Salmon were considered but due to eagle preference of Chum over Coho as well as Chum being more prevalent, the study focused on Chum in their analyses. The spatial extent includes reaches upstream of the Study Area for the Synthesis Study (upstream of Reach R7) and Reaches R7-R11 in the Study Area for the Synthesis Study. They examine the dynamics of phenology among eagles and salmon in both the context of climate change and hydroelectric dam management by comparing sections of the river with primarily controlled (upstream reaches) versus uncontrolled (downstream reaches) flows in reaches with inputs from uncontrolled tributaries (Sauk River). When the downstream and upstream reaches were considered as a whole, changing flow patterns linked to climate change are used to demonstrate that there is a phenological impact on salmon and eagles that is shifting. The authors also provide a discussion of how their results can be used to inform flow regulation and life stage flow management strategies. They indicate that current flow management practices *"…aim to promote, among other things, salmon spawning and redd protection, with increased flow resuming immediately following salmon spawning,"* and their study provides a link between salmon phenology, eagle phenology, and flood patterns that supports an adaptive management opportunity to consider other trophic levels in flow management plans.

Fish and habitat: This study provides some abundance data for Chum and Coho. Chum were more abundant than Coho, especially in even years when Chum escapement was "*three times higher than odd-year escapement,*" ranging from 3,193 to 209,478 (average 61,810 fish), while Coho ranges from 5,476 to 136,054 (average 52,972 fish). Figure 4 provides annual salmon escapement in the Skagit River from 1968 to 2015 with regression lines (see Table S5 for regression values). Chum escapement had an estimated annual decline of -3.8 percent and -0.95 percent for even and all years, respectively. Coho had an estimated annual decline of -1.9 percent.

Upstream reaches had on average 1.1 flood events per season (range 0-5), and downstream had 3.7 floods per season (range 0-7). The dates of the first floods were slightly later each year (but not statistically significant) and the *"variability in day of first flood… increased markedly over time."* When the authors modeled all three variables together, there was a *"strong correlation between Chum escapement and eagle detections across the entire river"* and that floods were a significant predictor of eagle counts (i.e., per a flood event, there were 121 less eagles). The number of days between the first flood event in the season and the peak Chum escapement has been increasing by roughly 0.91 days per year (P-value = 0.03). This means that in the earlier periods of the data record, Chum were alive in the stream when the first flood occurred, whereas currently, Chum have spawned and died off before the first flood.

Seixas and Veldhuisen (2019) (Unique Identifier: 301)

<table>
<tr><td>Reference</td><td colspan="10">Seixas, G. B., and C. N. Veldhuisen. 2019. Forest practices and regulatory channel migration zones in the Skagit River basin since the forests and fish report. Report prepared for Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>No</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landform: channel migration, sediment transport and supply, channel incision, side and off-channels, floodplain connectivity, large wood, log jam. Land Use and Cover: forestry. Fish and Habitat: <u>Habitat</u>: riparian.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Reach R9-11, Sauk River, Finney Creek, and Other Sauk River tributaries.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: In Washington State, riparian corridors along fish bearing streams are protected from forest practices. Rivers that show potential for channel migration face additional protections. Channel migration zones (CMZs) are recognized areas adjacent to streams and rivers that are deemed susceptible to channel migration within the next 140 years. Land managers are required to begin their riparian buffers at the outer edge of the CMZ. This protects critical riparian processes for future migrating channels such as large wood recruitment and streamside shading. These protections were put into practice in 2001 under the updated Forest Practice Rules document.

This report assesses the implementation of recognized CMZ zones within the Skagit River basin since the 2001 update. Additionally, CMZs within the basin that were missed are included in this assessment. "Missed" CMZs are sites where channel migration occurred since 2001 or occurred prior to 2001 in aerial photographs that were not analyzed in the original forest practice application. This assessment was done through an analysis of a compiled dataset of aerial photographs, LiDAR derived digital elevation models, and data from forest practice applications.

The results of this assessment found that of the 25 sites that were assessed, 11 sites were recognized as a CMZ and migration occurred, 3 sites were not recognized as a CMZ and migration occurred, 7 sites were not recognized as a CMZ and migration did not occur, and 4 sites were not recognized as a CMZ and migration did not occur. Additionally of the 14 sites that experienced migration only one avulsed and the other 13 migrated due to bank erosion. The authors of this paper propose four possible reasons as to why bank erosion is a more common process than avulsion among study sites. Reason one is that landowners may preferentially avoid avulsion-prone reaches due to easily identifiable risks. Reason two is that the historical removal of large wood may have increased channel incision and disconnected side channels and low-lying floodplains. Reason three, a reduction in sediment supply increased relative incision which again would disconnect side channels and low-lying floodplains. Reason four, it's possible the authors methods of identifying avulsion prone reaches may have overestimated the number of avulsion-prone reaches.

Several conclusions could be drawn from this estimate. Channel migration occurs most commonly at the outer edges of meander bends and along unconfined channels. Additionally, bank erosion was the most common migration process affecting the sites in the dataset.

Information Relevant to Skagit River Relicensing: This study focused primarily on the lower mainstem Skagit, Sauk River, and smaller tributaries including Finney Creek, Grandy Creek, and other Sauk River tributaries. They evaluated bank erosion and avulsion rates at sites related to implementation of CMZ and forest practice management practices. Bank erosion appears to be the most common channel migration processes that occurs at recognized CMZ sites within the Skagit River Basin, avulsion is much less common. There are several geomorphic factors that may have led to this observed condition. (1) riparian logging practices that historically removed old growth trees along channel banks decreased the overall rooting depth of floodplain vegetation and increased the likelihood for undercutting of banks. (2) historic removal of log jams disabled their ability to increase the upstream water surface elevation during floods and thus disconnected side channels and low-lying floodplains. Lastly, a decrease in sediment supply could have increase relative incision of the bed and further disconnected side channels and low-lying floodplains. This is relevant to Skagit River Relicensing GE-04 Geomorphology and Synthesis Study as the lack of CMZs that experienced avulsion provides evidence that the Skagit River system is being impacted by the historic removal of log jams, harvest of trees from the riparian zone, and a decrease in sediment supply. However, limited quantitative data are provided outside of categorical classification data and analyses related to avulsion or erosion detection.

Seixas et al. (2020) (Unique Identifier: 303)

Reference	Seixas, G. B., C. N. Veldhuisen, and M. Olis. 2020. Wood controls on pool spacing, step characteristics and sediment storage in headwater streams of the northwestern Cascade Mountains. Geomorphology 348:106898.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landform:*** large wood, aquatic habitat and landforms, side and off-channels. ***Fish and Habitat:*** Habitat: freshwater.								
Species and Life Stages	NA								
Reaches and Spatial extent	Finney Creek, Sauk River, other lower Skagit tributaries, other Sauk River tributaries.								
Linkages to Hydroelectric Operations	NA								

Summary: This report investigates the relationships between wood, pools, steps, and sediment storage characteristics in northwest Cascade headwater streams. The authors of this paper aim specifically to test three hypotheses.

(1) Larger diameter classes of large wood are critical step-keying materials in headwater channels despite narrow channel widths.

(2) Wood-keyed steps trap more sediment than clast- and root-keyed steps.

(3) The negative relationship between LW frequency and the distance between pools observed elsewhere in large streams extends to headwater streams.

These hypotheses were investigated through a field analysis of 32 sites. These sites spanned a range of channel widths less than 4 meters, covered a range of gradients, were in unlogged and logged forests, and contained either sandstone or phyllite bedrock. Each site was studied across a reach length 30 to 50 times the active channel width. At each site a channel survey was completed which includes a longitudinal profile along with the width of the active channel every 10 meters. Additionally, a wood inventory was completed at every site and all pools exceeding 10 centimeters in height were documented.

The authors classified wood into categories of 2-5, 5-10, 10-20, 20-40, and 40-100 centimeters in diameter. The results of this study showed wood within the 40-100 centimeter (16-39 inches) diameter class has the greatest potential to form key pieces relative to the total piece count associated with step formation in that diameter class. Additionally, the authors note that wood smaller than 10 centimeters (4 inches) diameter plays a significant role in key-step formation within channels that are less than 2 meters (6.6 feet) wide but drops off sharply on wider channels. These findings show that wood in larger size classes are particularly effective at anchoring steps and are critical for step formation in small headwater channels. The observation that smaller wood in channels less than 2 meters wide play a more significant role in key-step formation than in wider channels shows that potential wood function depends on channel size even within a small range of 1- to 4-meter (3.3- to 13.1-feet) width channels.

This report found that wood-keyed steps are significantly more likely to trap sediment than clast- and root-keyed steps. The authors of this report suspect this effect is due to the geometry of most wood pieces having a much larger length compared to their diameter. This increases the likelihood of jamming in between channel banks which thus creates stable structures that accumulates sediment.

This report found that there is a significant correlation between large wood frequency and distance between pools, similar to what has been observed in larger streams. As the frequency of large wood increase the average distance between pools decreases. This emphasizes the importance of large wood in headwater streams to form pools.

Information Relevant to Skagit River Relicensing: This report gives information on the importance of wood in forming pools, steps, and trapping sediment in small headwater stream in the Cascade region that focused on Skagit River and Samish River basins. The study sites include headwaters of tributaries that drain into the lower Skagit River and Sauk River, and therefore is directly relevant to the Study Area for the Synthesis Study and provides insight on wood in small width side channels and tributaries in the study area. One particularly important finding from this report is that wood smaller than 10 centimeters (4 inches) in diameter plays a significant role in step-pool formation within channels that are less than 2 meters (6.6 ft) wide. This highlights that wood that may not be geomorphically important in the mainstem of the Skagit, but could be geomorphically important in side channels and tributaries. An appendix is included that provides drainage area, active channel width, reach lengths, mean step height, mean pool depth, number of pools, number of steps, sediment volume, LWD frequency, and fine wood (FW, 2-10 cm diameter) frequency for each site considered in the study. Additional supplemental data were available that were downloaded and archived for this source.

Smith and Anderson (1921) (Unique Identifier: 347)

Reference	Smith, E. V., and M. G. Anderson. 1921. A preliminary survey of the Skagit and Stillaguamish Rivers. University of Washington, Seattle.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow, barriers, freshwater, estuary, status and trends, capacity; Fish: abundance, distribution, condition, diet, sex structure, hatchery, harvest, status and trends, fecundity. ***Land use and Cover:*** land cover, agriculture, urban. ***Geomorphology and Landforms:*** substrate and sediment, estuarine habitats and landforms, aquatic habitats and landforms. ***Water quality and productivity:*** temperature, primary productivity, turbidity.								
Species and Life Stages	***Chinook*:** migration. ***Coho*:** migration. ***Sockeye*:** migration. ***Pink*:** migration. ***Chum*:** migration. ***steelhead*:** migration. ***Other species:*** Dolly Varden: NA.								
Reaches and Spatial extent	Skagit Watershed including R1-R15, Skagit Estuary, Day Creek, Finney Creek, Sauk River, Baker River, Jackman Creek, Nookachamps Creek, other upper Skagit tribs, other lower Skagit tribs.								
Linkages to Hydroelectric Operations	NA								

Summary: This report is a broad survey of the Skagit River, its tributaries, and conditions for migrating salmon in the early 20th century prior to the construction of the Skagit Hydroelectric Project (referred to in the report as the City of Seattle Project). Descriptions of the geomorphology, water quality, temperature, benthic vegetation, and water velocity are given for nearly every section of the river and tributary. In addition, accounts of where species migrated for spawning are given and whether obstacles existed that might block passage.

Information Relevant to Skagit River Relicensing: This report is valuable because it describes conditions in the Skagit River prior to the start of construction of the Skagit Hydroelectric Project (construction on Gorge Dam began in 1921). Much of the relevant information is descriptive and qualitative but some quantitative data are also reported or are made available in tables, and include information on fish and habitat, geomorphology and landforms, land use and cover, and water quality and productivity topics of interest as well as multiple species and life stages of interest. The information presented in this report provides a valuable reference to compare to present conditions, which could be used to support development of hypotheses and linkages to Hydroelectric Operations given that this report provides pre-Project conditions throughout the Study Area for the Synthesis Study. However, no Project related linkages are discussed because this survey was conducted pre-project. Descriptions of the data and information are described in the following narrative.

The first section of the river extends between the City of Seattle Project campsite (about 14 miles downstream of the Ruby Creek confluence) and the Canadian border. The authors stated that no salmon had ever been reported more than one mile above the City of Seattle Project campsite. Apparently, much of the river in this area in 1921 was composed of fast riffles and cascades which prevented anadromous migration. The next section they describe is downstream of the City of Seattle camp and extends to Rockport (~ 25 mi – roughly corresponding to R1-R7). In this portion of the river, no salmon migration barriers are noted. Chinook, Coho, Pink, and Chum Salmon were observed in this section of the river. They also noted that steelhead pass through in the spring on their way up various tributaries to spawn. The next section of the river delineated by the authors extends between Rockport and Lyman (R7 – R11). The authors describe this section of the river as still mountainous but gradually becomes a widening valley. The river widens considerably due to inflow from the Sauk. The water itself is muddy and turbid. Water temperatures remain cold throughout the year (no quantitative information given). The river bottom is still largely devoid of vegetation and mostly composed of coarse gravel. Land use was mixed forest and agricultural by this section of the river. The final section constituting R12 – R15 was described as flat settled country widening considerably and several sloughs were present, all eventually draining into Puget Sound through several channels. They note Nookachamps Creek as the only significant tributary in this section.

Much of the rest of the report is devoted to descriptions of individual tributaries, lakes, and adjacent waterbodies, including the Stillaguamish River. At minimum, physical characteristics of each waterbody are given including dominant geomorphology, temperatures, and sediment types. Most include indications of whether salmon migrate to each tributary, including which species, and if barriers to migration existed at the time. In some cases, quantitative data are available in the form of tables. Data on egg production, fish lengths, diets, are found in this report though not always for the tributaries included in the study area of interest for the Synthesis Study. Specific descriptions of the following tributaries relevant to the Synthesis Study include the Sauk River (North and South Forks), Jackman Creek, Day Creek, Baker River (including Baker Lake), Finney Creek, and Nookachamps Creek.

A description of the Skagit River mouth and estuary is given. They describe a muddy flat area in which the river breaks into several sloughs through largely agricultural land and state that it is tidally influenced up to Mount Vernon, WA. They mention considerable fishing harvest pressure is exerted on migrating salmon from gill netters in the estuary. They voice concern over the sex structure noting a sex imbalance that gill netting may be causing by capturing only large females and letting small males escape. They go on to describe depleted run sizes on several major tributaries in recent years that they attribute to harvest from gill netting.

Finally, they summarize their survey findings by species. Sockeye Salmon were only found migrating up Baker River and Lake, but conditions in the South Fork of the Sauk and Lake Monte Cristo were noted as the only other tributary with potential to support Sockeye. All other species of salmon were found to run in almost all other tributaries except those upstream of the City of Seattle Camp at Newhalem. By this time, the run sizes in almost all tributaries had been much diminished. A table summarizing eggs sampled from hatchery returns in Illabot Creek, Baker River, Day Creek, and Grandy Creek combined in two time periods (1912-1915 and 1916-1919) shows a nearly 50 percent decline. They blame the cause of such serious declines on harvest with extreme fishing pressure in the Skagit River, particularly from gill netting in the estuary, and go as far as to recommend a complete moratorium on fishing in the Skagit River. Last, they make recommendations for where hatcheries might be successful if constructed within the watershed.

Smith (2003) (Unique Identifier: 376)

Reference	Smith, C. J. 2003. Salmon and steelhead habitat limiting factors water resource inventory areas 3 & 4, the Skagit and Samish basins. Report prepared by Washington State Conservation Commission, Lacey, Washington.
Source Information	***Type*** Report; ***Status*** Final; ***Quantitative Data*** Yes; ***Spatial Data*** Yes; ***Project Related*** Links
Topics and Keywords	***Fish and Habitat:*** Habitat: limiting factors, barriers, instream flow, riparian, nearshore, estuary, freshwater, pocket estuary, data gaps; Fish: periodicity, distribution, life history, growth, diet, predation, age structure, status and trends, abundance, data gaps. ***Geomorphology and Landforms:*** sediment supply and transport, substrate and sediment, slope, channel migration, floodplain, data gaps. ***Water Quality and Productivity:*** nutrients, contaminants, temperature, dissolved oxygen, turbidity, data gaps. ***Land Use and Cover:*** roads, agriculture, forestry, urban. ***Hydroelectric Operations:*** downramping, flow regulation, life stage flows.
Species and Life Stages	***Chinook:*** full life cycle. ***steelhead:*** full life cycle. ***Pink:*** full life cycle. ***Chum:*** full life cycle. ***Sockeye:*** full life cycle. ***Bull Trout:*** full life cycle. ***Coho:*** full life cycle.
Reaches and Spatial extent	Skagit Watershed including Skagit Bay, Padilla Bay; tributaries including Nookachamps Creek, Finney Creek, Day Creek, Jackman Creek, Sauk, Baker, Hansen Creek, Wiseman Creek, other lower Skagit tributaries, other Sauk River tributaries, and other Upper Skagit tributaries.
Linkages to Hydroelectric Operations	Linkages primarily described for Baker River facilities and habitat in the Skagit River at the Baker River confluence.

Summary: This report is the Habitat Limiting Factors report for Water Resource Inventory Areas (WRIA) 3 and 4. Summaries of existing habitat information are consolidated and used to describe the status of fish habitat access, floodplain, sediment, streambed, riparian, water quality, flow, estuarine and nearshore conditions that are related to limiting factors for salmon populations. Conditions are rated as poor, fair, good, or data gap for each of these habitat categories. The report covers all anadromous salmonid-bearing streams and nearshore areas of WRIAs 3 and 4 and consolidates and rates salmonid habitat conditions from the freshwater to nearshore environment with a list of recommended actions and data needs. The information presented in this report is intended to support the development and prioritization of restoration and protection projects, and recovery strategies for WRIA 3 and 4. The report indicates that the most degraded areas are found in the lower Skagit River, and the sloughs that drain into the Skagit and Padilla Bays, and the Samish Basin. Extensive impacts to estuarine, floodplain, riparian, sediment, water quality, and land cover conditions are identified in these areas. The loss of forested riparian vegetation and increased sedimentation are common in tributaries to the lower Skagit River and Samish Basin. Salmonid habitats in the upper Skagit, Sauk, and Baker River tributaries are generally good, with a few exceptions identified in the report. The Baker River dams are identified as one of the greatest problems for salmonid habitat in the Baker River basin and nearby segments of the lower Skagit River.

Information Relevant to Skagit River Relicensing: This report provides extensive information on habitat conditions and limiting factors, as well as supporting information on the linkages between factors and resource conditions in the Skagit Watershed. Limiting factors are defined as "*…conditions that limit the ability of habitat to fully sustain populations of salmon*" and the assessment includes nearshore, estuary, mainstem and tributary habitats within the Study Area for the Synthesis Study as well as the upper Skagit River. The last section of the report provides an overview of the limiting factors evaluated in their analysis and includes a description of parameters for each habitat factor considered as well as the rating criteria (e.g., poor, fair, good) and the source of information in Table 14. Table 15 provides a rating framework for estuary habitat conditions. The results are summarized in Tables 16-17 for reaches within the Study Area for the Synthesis Study.

The data presented in this report and the assessment framework can be used to support future assessments to evaluate habitat status and trends as well as progress towards recovery targets/goals. Linkages between factors and salmonid demographics and life stages are described in detail within the introduction of the report, but most of the demographics (e.g., periodicity, life history diversity) and linkages are described based on reference information and not necessarily derived from observations within the Study Area for the Synthesis Study. However, this information can be used to inform the development of conceptual life history models and factors linked to life stage transitions that, when combined with the findings of the limiting factors assessment presented in this report, can be used to identify key factors for the Synthesis Study. Many data gaps and monitoring needs are identified in the report, which are summarized in the last section detailing recommendations from the limiting factors analysis. The data gaps identified in this report can be used to support identification of key uncertainties and monitoring needs for the Study Area for the Synthesis Study.

Fish and Habitat: Many demographic attributes are described for target species and life stages in the introduction of this report, including information on periodicity, life history diversity, habitat preferences, growth, behavior, population status and trends; and these are linked to factors or conditions that influence or limit populations. This information can be used to inform the development of conceptual life history models and identification of key factors, although much of the information presented is based on reference information and may not be specific to the Study Area for the Synthesis Study. In general, all salmon species are susceptible to peak flows during incubation periods, and low flows during summer months constrain salmon production for species with extended freshwater rearing periods. Estuary habitats are identified as most important to juvenile Chinook and Chum Salmon, and to a lesser extent Pink Salmon, while floodplain habitats are identified as being most important for juvenile Coho Salmon. Chum and Pink Salmon are least sensitive to stream conditions because they spend little time rearing in freshwater habitats. Bull Trout, steelhead, and Sockeye are most dependent on freshwater habitats due to their extended rearing life histories. Population escapement status and trends are shown for Skagit populations of Chinook, Chum, Coho, Pink, Sockeye, and steelhead in Figures 1-6.

Watershed descriptions and conditions are described in detail for WRIA 3 and 4, and summaries of habitat conditions are provided in the executive summary. Maps of salmonid distribution, floodplain, and nearshore habitat conditions are available in supplemental data and include gradient and channel confinement designations for each geographic basin. The watershed description and conditions section also provides descriptions of salmon distribution and habitat use in lower Skagit River tributaries including Finney Creek, Day Creek, Hansen Creek, and Nookachamps Creek as well as other lower Skagit River tributaries. Distribution and habitat use are also described for Sauk River and its tributaries as well as Baker River. A GIS based assessment of salmonid habitat upstream of fish passage barriers is also provided, with the goal of support evaluation of restoration opportunities based on potential accessible habitat. A framework for habitat classifications based on the needs of multiple life stages was used that could inform development of conceptual life history models and factors affecting life stages (Table 1). A list of GIS data layers used in their analysis are provided in Table 2.

The condition of floodplain and stream habitats are described in detail, with Figure 13 showing a map of diked or hardened stream banks within the lower Skagit River and Sauk River. Table 7 also provides lengths and percentages of modified stream bank in current anadromous distribution for reaches within the Study Area for the Synthesis Study, including the Sauk River and its tributaries and the lower Skagit River. Detailed maps of wetland habitat and hydric soils are provided in Figures 14-23. Sediment supply and streambed conditions are described, with Figure 27 showing estimated sediment supply rates and multiple figures showing the relationship between road densities and land ownership (Figures 28-32). Riparian conditions are described in detail in another section, with plots showing the composition of riparian habitat for tributaries of the lower Skagit River (Figures 35-36, and Baker River tributaries (Figure 39). Stream reaches are rated with respect to LWD recruitment potential based on the riparian conditions (Table 8). Water quantity issues are described in a separate section, which include graphs of surface water withdrawal uses in the lower Skagit River (Figure 46) and estimates of withdrawals for the Sauk and Baker River subbasins and lower Skagit River are also provided to describe potential impacts on instream flow and fish habitat associated with water uses. Water quantity issues related to Hydroelectric Operations of the Baker River dams are described as well as improvements in Hydroelectric Operations for the Upper Skagit facilities to support salmon life stages.

The following provides an overview of habitat conditions summarized in the executive summary and other sections for areas relevant to the Study Area for the Synthesis Study:

Nearshore: Shoreline modifications (e.g., dikes, riprap) are identified as one of the greatest nearshore habitats impacts in WRIA 3, with shorelines rated as poor in east Skagit Bay, Swinomish Channel, Padilla Bay, and north Fidalgo Island. Shoreline modifications disrupt sediment and nutrient supply and transport. However, the report indicates that areas important to sediment and nutrient supply and transport processes are not known for WRIA 3. Impaired riparian vegetation linked with shoreline modifications are also identified as an issue, and shoreline shading is identified as an important factor for forage fish spawning habitat. Most other habitat parameters considered in their rating system were rated as “good” or “fair” for nearshore habitats in WRIA 3 with the exception of contaminated sediments in Padilla Bay, Fidalgo Bay, and Guemes Channel, and overwater structures were identified as a concern in Swinomish Channel and north Fidalgo Island. However, the authors indicate that less is known about how alterations to nearshore habitats impact salmonids and therefore there is more uncertainty regarding the benefits or restoration actions. Nearshore aquatic vegetation composition is shown in Figure 47, and location of known tide gates and shoreline modifications are shown in supplemental maps. The composition of shoreline (or shoreforms) are shown in Figure 53 for Skagit Bay, with maps of known eelgrass beds and overhanging vegetation in supplemental maps. Sites with known sediment quality issues are shown in Figure 54, and supplemental maps show the location of overwater structures. Known spawning habitat for non-target species are shown in Figure 55 (herring, smelt, sand lance).

Estuary: Loss of 72 percent of intertidal habitat is reported for the Skagit delta, and this is identified as a particular concern for juvenile Chinook Salmon. Figures 48-51 show changes in estuary habitat. Dikes and fish-blocking tide gates are identified as the primary causes of disconnected estuary habitats. Ditching, channelization, filling, riparian loss, and loss of habitat complexity are also identified as issues for isolated habitats in the delta. Loss and degradation of Skagit Estuary habitat is also identified as one of the most important habitat issues for salmonids at a regional scale given that the Skagit basin "*produces most of the salmonids and salmonid stocks in Puget Sound*," and the report suggests that restoration/conservation of Skagit estuary habitats and nearby non-natal pocket estuaries should be a regional priority for Puget Sound salmon recovery. Figure 52 shows riparian conditions for sloughs entering Skagit and Padilla Bay.

Lower Skagit River: The lower Skagit River is defined in this report as "…*all streams downstream of the Sauk River confluence except the Baker River*." The report identifies this area as containing the "…*most highly degraded freshwater salmon habitat in the Skagit Basin with considerable impacts in every habitat category*." The lower Skagit River has the most extensive floodplain habitats in the basin (108 square miles), but degradation from dikes and riprap are extensive with an estimated 62 percent of the mainstem river length from Sedro Woolley to the mouth has been hydromodified and only 10 percent of its length has split channels or forested island habitats. Hydromodifications are cited as disconnecting floodplain habitats, increasing water and sediment transport, and disrupting other natural processes like LWD recruitment, riparian vegetation growth, hydrological connectivity, and side- and off-channel development.

Extensive losses of wetland habitats are also likely, and road densities in the lower Skagit River floodplains are "*excessive at 3.3 mi/mi^2*." Table 6 provides a summary of road densities and length in floodplains for each geographic area. Water quality is also degraded in the lower Skagit River mainstem by various types of development, with elevated nutrient levels and chronic levels of lead and copper, which are linked in the report to urban and highway runoff, wastewater treatment, failing septic systems, and agricultural/livestock impacts. Water quality in lower Skagit River tributaries is identified as "…*worse than the mainstem Skagit River and all other Skagit sub-basins*." Most tributaries to the lower Skagit River are identified as having elevated summer temperatures (including Nookachamps, Hansen, Wiseman, Day, Finney, and Jackman Creeks), and elevated nutrients, low dissolved oxygen, increased turbidity, and potential contaminants (five potentially toxic organic compounds, lead, copper, and zinc) of concern in Nookachamps Creek. Many of the same watersheds with summer temperature problems were also identified as having impaired riparian and sediment conditions, and these are identified as likely contributing factors to part of the water quality issues in lower Skagit River tributaries. "Poor" riparian conditions were identified in Nookachamps, Hansen, Jackman, Gilligan, Finney, Day, and Loretta Creeks. Excess sedimentation was identified in Nookachamps, Hansen, Finney, Loretta, and Gilligan Creeks. However, very few drainages have been assessed to identify the sources of sedimentation. Where assessments have occurred, landslides associated with roads and clearcuts are identified as major sources of sediment. Lack of large wood and pool habitat has also been identified as a potential concern but a general lack of instream tributary habitat data are noted in the report. Many tributaries and drainages were also identified as having impaired or moderately impaired flow conditions for peak flows based on land cover data including the lower Skagit River, Nookachamps, Hansen, Gilligan, Day, and Finney Creeks with likely impairments noted in Loretta and Jackman Creeks. However, no information was found regarding low flow conditions or impacts of low flows and the report identifies this as a significant data gap in the lower Skagit Rivera and its tributaries. Lastly, fish access was also assessed, and many high priority and medium priority blockages were identified in the Nookachamps and Hansen Creek watersheds.

Sauk Sub-Basin: The report indicates that most of the known impacts to salmonid habitat in the Sauk River basin are in areas that are primarily private or state owned. High road densities, poor riparian conditions, excess sedimentation, peak flows, and reduced pool habitat and LWD are noted for tributaries to the Sauk River. However, risk from human water consumption is identified as a low threat to fish habitat (via water quantity) in the Sauk River basin due to low water consumption in the basin. Instream habitat and water quality data are noted as data gaps for Sauk River tributaries, and water quality monitoring is recommended for this drainage.

Baker Sub-Basin: The hydroelectric dams and operations are identified as having the greatest impact on salmonid habitat in the Baker River basin. The report indicates downramp agreements have not been met, and inadequate life stage flows have been noted downstream of facilities. An estimated 117 acres of wetlands and ponds, 5 miles of side channel habitat, and 52 miles of tributary habitat have been lost due to reservoir creation, and sedimentation and riparian vegetation impacts are linked to the Baker River dams and operations in the report. The Baker River dams are identified as one of the greatest problems for salmonid habitat in the Baker River basin and nearby segments of the lower Skagit River. Baker River tributary habitat is generally good, but a few drainages are identified as having sediment supply and transport impairments due to landslides and high road densities. Riparian conditions are "good" or "fair" for most subbasins, and temperatures are mostly "good" except for one subbasin.

Land Use and Cover: Watershed descriptions and conditions are described in detail for WRIA 3 and 4, and summaries of habitat conditions are provided in the executive summary. Detailed summaries include descriptions of land cover and land use, including history of land use and descriptions of major impacts. Major habitat impacts are linked to land cover in general, with major impacts occurring where land use is predominately agricultural, urban, or private/state forestry. Road densities increase with increasing percentage of state or private land contained within a watershed, and road density is identified as a major indicator of sedimentation and fish passage impacts as well as hydrological changes. Links between road densities and land ownership are shown in Figure 28-32, and road related sediment impacts are described for sub-basins of the Skagit River. Percent land cover for Skagit County is shown in Figure 11, but detailed descriptions of land cover are described in text for geographic areas with maps provided in supplemental materials.

Water Quality and Productivity: A section describes the condition of freshwater habitat with respect to water quality, and descriptions of water quality with respect to temperature, dissolved oxygen, pH, nutrients, contaminants, and turbidity are provided based on available data in this section. A map of areas rated as "poor" for water quality (Figure 43) is provided, as well as water quality exceedances for the lower Skagit River (Table 9), daily maximum temperature patterns for Finney Creek (Figures 44-45), and temperature ratings for Sauk River (Table 10). However, temperature data, as well as other water quality data, presented in the report are not comprehensive and are limited to subsets of areas within the Study Area for the Synthesis Study and based on relatively few years of monitoring (e.g., point samples or 1-2 years of monitoring).

Hydroelectric Operations: The report indicates that changes in Hydroelectric Operations at the Upper Skagit River facilities have improved, and stranding impacts have been reduced as flows are managed for salmon habitat and life stage flows. In contrast, the report indicates that monitoring of the Skagit River at Concrete has found that negative impacts of downramping and flow regulation from the Baker Project are persistent in the Skagit River near the Baker River confluence.

Smith (2005) (Unique Identifier: 177)

Reference	Smith, D. 2005. Off-channel habitat inventory and assessment for the Upper Skagit River basin. Report prepared by Skagit River System Cooperative for Non-Flow Coordinating Committee.
Source Information	***Type*** Report; ***Status*** Final; ***Quantitative Data*** Yes; ***Spatial Data*** Yes; ***Project Related*** Yes
Topics and Keywords	***Hydroelectric Operations:*** flow regulation. ***Fish and Habitat:*** Habitat: freshwater, beaver, data gaps, restoration. ***Geomorphology and Landforms***: side- and off-channels, aquatic habitats and landforms, floodplain. ***Modeling Tools:*** habitat.
Species and Life Stages	NA (but mentions how salmon are impacted by these flow regulations).
Reaches and Spatial extent	R7, US of R7, Sauk River, other Sauk River tribs, other upper Skagit tribs.
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flow regulation.

Summary: This report provides off channel habitat data on the upper reaches of the Skagit River, which are impacted by the altered flow regime from the Skagit Hydroelectric Project. Using habitat data from the 1980s, conducted by various Washington Department Fish and Wildlife studies and field work from when this report was published, they documented the location and characteristics of off-channel habitats as well as compared natural and constructed habitat in the upper reaches (which are not impacted by flow regulation). Additionally, they collected data on site information (i.e., ownership, county, local name, river basin, river mile, tributary, etc.), source the data came from, habitat type (i.e., surface water tributary, groundwater tributary, slough or pond, overflow channel, constructed pond and or channel), channel width, channel winter wetted width, channel length, channel area, flow type (i.e., intermittent or year-round flow), spawning habitat area, dominant water source (i.e., hillslope groundwater, hillslope surface water, or river groundwater), and if there was any beaver activity. Data was imported into GIS as well as aerial photographs, field maps, and mapping grade Trimble Global Positioning System unit. They found that there was a positive relationship between average effective floodplain width of the river reach and off-channel habitat density. They provide some recommendations based on their analyses including; 1) habitat construction activities may no longer be needed in the upper reach of the Skagit River, 2) habitat in the floodplain of Barnaby reach should be protected, 3) future restoration activities should emphasize increasing effective floodplain area by removing or relocating infrastructure.

Information Relevant to Skagit River Relicensing: This report provides a good synopsis of average characteristics for both natural and constructed off-channel habitats in the upper reaches of Skagit River, but the report only includes information on the upper portion of Reach R7 at the confluence of the Sauk River as well as the Sauk River and other Sauk River tributaries. This report also provides limitations to their study, one being that it only analyzed off channel habitat in the upper reaches of the Skagit River and not the lower or middle portions. Another limitation was that some of the previous off-channel and side channel habitat inventories available were not fully complete due to these habitats often changing on a yearly basis.

Geomorphology and Landforms: Table 3 provides numerous geomorphic metrics for geographic areas that includes the Sauk River as well as Suiattle River with mainstem channel length, contributing drainage area, floodplain area, effective floodplain area, percent effective floodplain area, average floodplain width, average effective floodplain width, average channel width, and average channel gradient. However, Reach R7 is lumped with larger geographic extents for the mainstem Skagit and would require original data to extract. These data are also broken down by constructed and natural habitats with winter habitat extents provided in Table 5. Wetted surface areas for the various sites sampled within each of the reaches are provided with classifications by dominant water source (Figure 3). Similarly, they show the wetted surface area, wetted area per effective floodplain area, channel length, and channel length per mainstem channel length for constructed and natural off-channel habitat types (Figure 4). Table 2 provides channel lengths, wetted areas, and pre-project areas (for a subset of sites) for constructed channels in the Sauk River, but all mainstem Skagit River sites are outside of the Study Area for the Synthesis Study. The appendices provide reach maps that show the floodplain area that is impaired or isolated, effective floodplain, the main channel, the current floodplain reach and whether the off-channel habitat was natural or constructed. Even though this report was published in 2005, these maps can provide context for restoration effectiveness if identified sites were restored, or support habitat status and trends monitoring if additional surveys have been completed at these sites.

Hydroelectric Operations: Through a simple regression analysis, they compared flow regulation of the affected reaches to unregulated river reaches to evaluate the effectiveness and progress of constructed channels mitigating the loss of off-channel habitat due to flow regulation. There was a positive relationship found between the average effective floodplain width of the river reach and the off-channel habitat density that had an r^2 of 0.75 but was not statistically significant at a 95 percent confidence interval (*P*-value = 0.058) (see screenshot of figure 5). They indicate that this regression can be used to predict the density of off-channel habitats that would be expected within a range of effective floodplain widths under unregulated flow conditions, or in the absence of flow regulation. Departures from the regression model in the upper Skagit River reaches are hypothesized to be the result of flow regulation reducing habitat creation and maintenance processes for off-channel habitats. However, the regression model is based on habitat extents with flows at a 2-yr recurrence interval or less and may therefore underestimate off-channel habitat under higher flows.

Smith (2010) (Unique Identifier: 352)

Reference	Smith, M. 2010. Final report, population structure and genetic assignment of bull trout (*Salvelinus confluentus*) in the Skagit River basin. School of Aquatic and Fishery Sciences, University of Washington, Seattle.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	Yes
Topics and Keywords	**Fish and Habitat**: Fish: genetics; Habitat: barriers; Monitoring: genetics.									
Species and Life Stages	**Bull Trout:** fluvial.									
Reaches and Spatial extent	R7, US of R7, Sauk River, other Upper Skagit tribs, other Sauk River tribs.									
Linkages to Hydroelectric Operations	**Fish and Habitat**: Habitat: barriers.									

Summary: Bull Trout were listed as threatened under the Endangered Species Act in 1999. Genetic isolation caused by the Skagit Hydroelectric Project breaking connectivity between meta-populations was identified as a high priority research need by the U.S. Fish and Wildlife Service. This study summarized the genetic diversity both within and among fluvial sub-adult and adult Bull Trout in Skagit River subbasins above and below the dams collected from 2001 to 2009. Their goals were to:

- *"Identify all samples collected as Bull Trout, Dolly Varden, Brook Trout, or hybrids using a suite of diagnostic genetic markers."*
- *"Describe the genetic diversity within all baseline collections and quantify the level of genetic differentiation among collections."*
- *"Develop a genetic baseline for individual genetic assignment tests by pooling individual collections into appropriate reporting groups based on subbasin of collection and genetic characteristics of collections."*
- *"Evaluate the distinctness of reporting groups and determine whether the genetic baseline was suitable for individual assignment of adult and sub-adult Bull Trout from the Skagit River through individual population assignment tests."*
- *"Use individual population assignment tests to determine the composition of adult and sub-adult Bull Trout that utilize habitat in the Skagit River immediately downstream of Seattle City Light's Hydroelectric Project."*

The genetics of populations above the dams were less diverse on measures of heterozygosity and allelic richness than populations below the dams. Pairwise F_{st} values between above dam populations were lower than below dam populations, indicating that geneflow among populations above the dams occurs with greater frequency than those below the dams. However, above and below dam populations were highly differentiated indicating total reproductive isolation, which is both a result of the dams blocking migration and historical natural gradient barriers at present day Diablo dam which probably existed prior to the construction of the dams. Principal coordinate analysis and a neighbor joining dendrogram supported differentiation of Bull Trout into distinct

reporting groups based on subbasin. Genetic assignment tests on fish of unknown origin collected immediately downstream of the dams were mostly believed to originate from Goodell, Cascade, Illabot, Downey, Bacon, and Sauk River. First generation migrants detected in Bacon Creek and the Cascade River following landslide that occurred in Goodell Creek in 2003, inhibiting migration, highlights the importance of nearby subbasins as refuges following major disturbances. No fish collected below the dams were originated from populations above the dams.

Information Relevant to Skagit River Relicensing: Although the focus of this study was largely beyond the scope of the Study Area for the Synthesis Study, part of the study sampled Bull Trout from within R7 and in the Sauk River. Important findings on the population genetics structure of fluvial sub-adult and adult Bull Trout are presented with the finding that some degree of reproductive isolation between and among geographically grouped metapopulations has occurred. This study represents a genetic baseline for Bull Trout in the Upper Skagit River, and the findings presented herein have implications for managing species exhibiting metapopulation structures that are influenced by migration barriers like the hydroelectric dams in the Upper Skagit River. Summary tables provide information specific to collection locations, with data reported specifically for the South Fork Sauk River and a number of tributaries outside of the Study Area for the Synthesis Study, but most summaries and narratives are described based on position relative to the dams (upstream vs downstream). Therefore, the quantitative data and conclusions are more generally applicable to the population of Bull Trout rather than specific geographic areas within the Study Area for the Synthesis Study. Potentially relevant information presented in the report are described in more detail below.

Fish and Habitat: Heterozygosity and allelic richness in baseline collections above the dams were less diverse than those below the dams. Unbiased expected heterozygosity values ranged from 0.373 to 0.445 above the dam and from 0.620 to 0.696 below the dams (0 to 1 scale; higher values = higher heterozygosity). Allelic richness (mean number of alleles per locus) ranged from 2.72 to 3.93 above the dams and 4.64 to 6.14 below the dams. Table 4 contains summaries of genetic statistics including sample size, observed heterozygosity, expected heterozygosity, and allelic richness for each collection and reporting group. Assignments into reporting groups by month of capture are given in Table 9, which could have implications for mixing, distribution, and periodicity.

Average F_{st} values between below-dam populations was higher than average F_{st} values between above dam populations. High F_{st} values indicate a greater degree of differentiation among populations. This suggests that below-dam populations are more genetically distinct and interbreed less than above-dam populations. Principal coordinate analysis corroborated this finding. Therefore, it may be inappropriate to manage Bull Trout below the dams as a single population. Consideration of metapopulation dynamics occurring within the Study Area for the Synthesis Study for Bull Trout and other species with non-anadromous life history expressions may be warranted.

Smith et al. (2011) (Unique Identifier: 111)

Reference	Smith, D., K. Ramsden, and S. Hinton. 2011. Reach level analysis for the middle Skagit River assessment. Report prepared by Skagit River System Cooperative for Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landform:* change, history, floodplain, side and off-channel, floodplain connectivity, aquatic habitats and landforms, sinuosity, slope, floodplain connectivity, data gaps. *Land Use and Cover:* land cover, roads, banks and shoreline. *Fish and Habitat:* Habitat: freshwater, capacity, instream flow, riparian. *Modeling Tools:* hydrology.									
Species and Life Stages	*Chinook:* rearing, spawning.									
Reaches and Spatial extent	Reaches R7-12.									
Linkages to Hydroelectric Operations	NA									

Summary: This report identifies priority reaches within the Middle Skagit River, from Sedro-Wooley upstream to the confluence of the Sauk River. A conceptual model for rating reaches included geomorphic potential, existing habitat function, and floodplain impairment. Skagit Watershed Council contracted with Pacific Northwest National Laboratory (PNNL) to develop a three-dimensional hydrodynamic model covering all of the Middle Skagit study area except the Rockport reach. The model was developed with the Finite Volume Coastal Ocean Model (FV-COM) software to estimate water depth, velocity, and shear stress across the channel and floodplain for the 2-year, 5-year, and 25-year flow.

In order to estimate juvenile Chinook capacity for each reach, the surface area for banks and bars was estimated by measuring lengths from aerial photography. The measured length was multiplied by an average width which was based on field measurements. The area of remaining habitat types was measured in GIS. Then assumed fish capacity was calculated for each habitat type. The highest density of juvenile Chinook was found in natural backwater, natural bank, hydromodified backwater, and natural bars. The most fish were found in Skiyou, Ross Island, Savage, and Cockreham reaches (NPS R10-11, Smith Reach 1-4).

The geomorphic potential refers to potential of the channel within the reach to migrate across its floodplain and create or maintain abundant side-channel, off-channel, and complex mainstem edge habitats. The reaches with the least confinement, largest floodplain areas, and widest floodplain widths occur in the downstream end of the study area and include Skiyou, Ross Island, and Cockreham (NPS R11, Smith Reach 1-3). Baker and Aldon (NPS Reach 6 and 8) reaches had the least floodplain inundation and Rockport reach was not measured.

The Cockreham reach has the highest floodplain impairment based on forest conditions, followed by Skiyou, Cape Horn, Ross Island, and Savage. Aldon and Rockport rated the lowest.

The top three reaches for geomorphic potential, Skiyou, Ross Island, and Cockreham were rated high for both restoration and protection actions. Skiyou was rated "Med/High" for protection because current habitat function was rated as medium, and Ross Island was rated "Med/High" for restoration because floodplain impairment was rated as medium. Savage was also rated "Med/High" for protection because even though it was rated medium for geomorphic function it was rated high for current habitat function.

The report recommends additional modeling, vegetation, habitat, and floodplain impairment data be collected, as well as some field validation of the habitat features and connectivity mapped with remote sensing in this study. For specific sites additional data may be useful for understanding project feasibility, field check for existing habitat features, hydrodynamic modeling for individual hydromodifications, photo survey to identify historic channels and migration, and fish modeling of potential new habitat. They also recommend updating bathymetry data to improve the FV-COM model, especially as restoration projects are identified to evaluate potential responses to restoration actions.

Information Relevant to Skagit River Relicensing: This report provides a lot of relevant data on current habitat condition and juvenile Chinook capacities for the middle Skagit River and Study Area for the Synthesis Study reaches, and rating of reaches based on geomorphic potential and protection/restoration ratings. In addition, the spatial data and hydrodynamic model outputs and tools developed for this evaluation are directly relevant to the Synthesis Study and can be used to support evaluation of habitat status and trends or integration with other modeling tools. The reaches in this study (Smith) roughly match the NPS reaches as follows: NPS R8 (Smith Reach 7,8, and 9), NPS R9 (Smith Reach 5&6), NPS R10 (Smith Reach 3&4), NPS R11 (Smith Reach 1, 2, and 3). The reaches covered by this study include geomorphic reaches R7 with Smith Reach 9 spanning the Sauk River confluence, downstream to reach R12 near Sedro Wooley at Smith Reach 1. The report provides a conceptual model for geomorphic potential, existing habitat function, and floodplain impairment. This can be used to characterize the reaches from Rockport to Sedro Wooley.

Tabular summaries are provided for many fish habitat and geomorphic metrics, including maps showing spatial data for habitat within the floodplain of the middle Skagit River (note the appendices provide detail maps as well as GIS methods and inventories of spatial data layers that were produced as part of this study). Tabular summaries of mainstem channel length, average channel width, gradient, floodplain length, floodplain arc, average floodplain width, floodplain gradient, confinement, sinuosity, and ratio of floodplain area to channel length are provided for each reach. Inundated area estimates are also provided for each reach for 2-yr, 5-yr, and 25-yr flood events from the hydrodynamic model, as well inundation area and percent change in inundation area with simulations that remove certain hydromodifications and lowered levee elevations to increase floodplain connectivity. Channel pattern classifications and percent and area coverage for unmodified and modified cover types are provided for each reach which include area of roads and developed land uses. Observed channel pattern, land cover data, and reference data were used to develop estimates of the age composition of floodplains for each reach including the percent floodplain <5 years old and >75 years old. The GIS and modeling data were later used in the report to quantify areas of the floodplain that are isolated or shadowed within each reach, providing yet another useful metric for floodplain connectivity among reaches. Lastly, floodplains were also evaluated for protected land coverage and area of water to provide additional information to support reach evaluations.

Habitat unit areas for mainstem, backwater, off-channel, and tributary habitats were developed for each reach, along with estimates of edge lengths for each habitat unit type and the percentage and lengths of edge types (hydromodified, bar, bank). Average widths for edge types (8.5 ft for bank edge, and 51.2 ft for bar edge) and areas measured from remote sensing of aerial imagery for mainstem, backwater, and off-channel habitats were used to estimate capacities using published densities of juvenile Chinook by edge type. Total estimated capacities for juvenile Chinook are reported for each reach and by habitat unit types, but it appears these were not adjusted for residency time and should be used appropriately.

Sobocinski (2004) (Unique Identifier: 176)

Reference	Sobocinski, K. 2004. A comparison of tidally influenced salt marshes using a bioenergetics model for Chinook salmon. Skagit System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: diet, rearing, growth, data gaps; Habitat: restoration, estuary; Monitoring: habitat. ***Modeling Tools:*** bioenergetics.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary.									
Linkages to Hydroelectric Operations	NA									

Summary: This study presents results of an energetic comparison of sites with Deepwater Slough Restoration area in the Skagit River delta. In 2000, The Deepwater Slough Restoration Project removed an upstream agricultural dike and allowed flow to resume to 250 acres of pastureland in the Skagit delta with the goal of returning it to a tidally influenced emergent marsh. Beach seine and fyke net sampling showed that fish were using the restored areas for rearing. Fish stomachs were collected for diet analysis and showed an abundance of chironomid larvae and adults and mysid shrimp (*Neomysis mercedis*). The diet data was used in this study as the basis for comparison among the study sites using the Wisconsin fish bioenergetics model. Data was collected at four sites (two references and two treatment [restoration] sites). Fish were collected on four sampling dates throughout the spring, coinciding with outmigration of juvenile Chinook Salmon from the Skagit River. Fish were identified, counted, and weighed, their lengths recorded, and their stomach contents were preserved for analysis. Bioenergetics simulations were run using a cohort model; the cohort was defined as the duration of sampling, or March 1, 2001 (Day 1) to June 8, 2001 (Day 100), which coincided with the period of outmigration and rapid growth in juvenile Chinook. The output given was the growth of an individual over the specified time interval. In general, while fish growth remained positive in the simulations, the specific growth rate decreased as the simulation progressed, coinciding with the increase in temperature and thus, the higher metabolic demands throughout the spring season. This simulation showed that fish surveyed at the treatment site had to consume 27 percent more food to attain the same weight as fish at the reference site (treatment 16.8 g vs. reference 13.2 g), suggesting that the quality of prey found at the reference sites was more energy rich than the treatment sites. When comparing all four sites, the two reference sites showed similar values, however the two treatment sites differed greatly, with one treatment site more closely aligning with the reference condition and one treatment site not providing energy-rich prey to fish using the site.

Information Relevant to Skagit River Relicensing: This report contains information on fish diets at two restoration sites and two treatment sites at the Deepwater Slough Monitoring area, including a bioenergetics model for fish growth that are relevant to the Synthesis Study. The report provides simulation outputs for average fish growth over time at the sites based on diets consumed and temperature using a bioenergetics model, which could be used to support evaluations of restoration effectiveness in the Skagit River delta and estuary as well as support prioritization or design of restoration projects. Quantitative data on diets, prey items, and energy content as well as simulated growth with temperatures among restored and references sites are provided and described below.

Fish and Habitat: At the four sites within the Deepwater Slough Monitoring area, *N. mercedis* was the dominant prey item in Chinook diets (40 percent of total biomass, across all sites). Dipterans, specifically chironomids in several life stages, were also important prey items for Chinook Salmon. Chinook diets were similar at three of the four sites (Reference East, Reference West and Treatment East) and differed at the fourth site (Treatment West), where *N. mercedis* was not as prevalent in stomachs. Both diet analysis and bioenergetics analysis in this paper suggested that the absence of an energy rich prey item such as *N. mercedis* in Chinook diets may diminish growth. Figure 2 provides Chinook prey composition averaged across all fish caught at each site on each sampling day. The author indicated that increased sampling of otoliths in juvenile salmon would help refine growth estimates during estuary rearing and emigration life stages.

This report showed that *N. mercedis* is a preferred prey item, and also nutritionally valuable to rearing and emigrating Chinook Salmon. The availability of this prey species in habitats might be a limiting factor for Chinook growth at the Deepwater Slough Monitoring sites. The one site that did not have this prey species in abundance in the fish diets, which was a restoration site, showed diminished Chinook growth compared to the three sites where *N. mercedis* was prevalent in the diet. The author suggested that larger environmental variables were driving occurrence and abundance of prey items and it was unclear whether or not fish selected sites based upon specific prey availability. However, the author suggested that perhaps efforts should be aimed at restoring areas where *N. mercedis* is likely to persist.

Modeling Tools: The Wisconsin fish bioenergetics model was used in this paper:

$$C = G + M + W$$

where, G = growth (both somatic and gonadal), M = metabolism (including activity costs and specific dynamic action), W = waste (scaled from consumption), and C = the consumption necessary to satisfy the observed growth plus the other costs. Growth can be solved for if there is a known consumption rate. Because metabolism, and thus consumption, is highly dependent upon thermal experience, water temperatures are used to determine costs and growth, with growth only being attainable once costs have been met. Energy densities of prey items used in the model simulations are provided in Table 1, Table 2 provides diet proportion of each prey group per sampling day/site, and temperatures used in the model are provided in Figure 3. Plots of simulated specific growth rates, weight, and temperature are provided for days 28-100 of the simulation are provided in Figure 4. In addition, comparisons of consumption, specific growth rate, weight, and temperature among sites are provided in Figures 5-8.

Souder et al. (2018) (Unique Identifier: 115)

Reference	Souder, J. A., L. M. Tomaro, G. R. Giannico and J. R. Behan. 2018. Ecological effects of tide gate upgrade or removal: a literature review and knowledge synthesis. Report prepared by Institute for Natural Resources for Oregon Watershed Enhancement Board, Salem, Oregon.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: barriers, estuary, restoration; Fish: life history, rearing, diet. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity, primary productivity, secondary productivity. ***Land Use and Cover:*** banks and shoreline.									
Species and Life Stages	***Coho, Chinook, Chum, steelhead, Pink, Sockeye, Bull Trout:*** estuary rearing and emigration, adult outmigration. ***Lamprey***: estuary rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary including Swinomish Channel, Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: This extensive report presents the findings of a literature review on the effectiveness of tide date removals or upgrades in improving conditions for Oregon's native migratory fish species, with an emphasis on salmonids that utilize estuarine ecosystems. Restoration benefits can vary greatly, and this report seeks to improve our understanding of the ecological effects of existing tide gates and how replacement, upgrade, or removal strategies benefit fish. The authors *"…used a multi-faceted approach to knowledge synthesis, including review of relevant scientific literature, OWEB and non-OWEB agency reports on tide gate projects, and inquiries to state and federal agency staff working on estuary restoration in the Pacific Northwest region*." The report includes seven chapters; (1) an introduction that provides an overview of tide gates and tide gate hydraulics to help understand their effects; (2) a methods section that describes the literature search; (3) a section on the ecological context of tide gates in streams and estuaries that examines the effects of tide gates, salmon life history diversity, and the importance of coastal marsh habitats for juvenile salmonids; (4) a section on the effects of tide gate upgrades and removal on aquatic organisms and estuarine environments that provides a summary of the literature review; (5) summaries of regional projects, (6) a synthesis of chapters 3-5 into a framework that can be used for restoration program development, and (7) a final chapter that summarizes the findings and recommendations of the report. The primary findings of this study with respect to the physical and ecological effects of tide gates were: (1) limited or nonexistent connectivity significantly affects fish community composition and water quality; (2) life-history diversity of juvenile Coho Salmon is greater than previously realized; (3) estuary rearing provides increased growth opportunities for juvenile Coho Salmon. Additional findings related to project scoping, prioritization, and planning for Oregon are presented along with project implementation, effectiveness, monitoring, and future opportunities. Appendix A includes annotated bibliographies of literature considered in their analysis, Appendix B provides summaries of tide gate related projects in the Oregon coastal region, and Appendix C provides summaries of tide gate projects in Oregon, Washington, and California.

Information Relevant to Skagit River Relicensing: This study is not specifically focused on the Skagit River or Study Area for the Synthesis Study, but the extensive literature review considered studies of tide gate removals and upgrades from the Skagit River. This report provides relevant information that can be used to inform the development of conceptual life history models and identification of factors affecting salmonid life stages, especially in Chapters 3-4 where the ecological context and effects of restoration of tide gates are discussed with an emphasis on juvenile salmonids that rely on estuarine habitats. All salmonid species are considered, but an emphasis is placed on Coho and to a lesser extent Chinook Salmon with specific sections describing the life history diversity and importance of estuarine habitats for these species. In addition, information on Lamprey are presented for studies including projects in the Study Area for the Synthesis Study as well as summaries of water quality topics of interest that were monitored for projects. Collectively, this report provides a good reference for the effects of tide gates for a wide range of target species and topics of interest from a broad geographic range.

Specific to the Study Area for the Synthesis Study, summaries of projects in the Study Area are included in Chapter 3 with the authors noting "*significant monitoring effort has been devoted to several projects, primarily Fisher Slough and Crescent Harbor Salt Marsh, both in the delta of the river*" as well as tide gates in Swinomish Channel that were monitored as part of another study. The summary of regional projects chapter (Chapter 5) includes additional summaries of studies in the Northeastern Puget Sound, which is focused on the mouth of the Skagit River. In addition, detailed annotated bibliographies of reports and publications are provided in Appendix A that include these projects in the Study Area for the Synthesis Study. These include included Beamer et al. (2014, ID188), Beamer et al. (2015, ID011), Beamer et al. (2016, ID211), Greene et al. (2012, ID051), Lyons and Ramsey (2013, ID339), Beamer and Henderson (2015, ID125), Beamer et al. (2012, ID204) included in our Tier 2 Sources that will be summarized in the Tier 2 Synthesis Study annotated bibliographies. In addition, Beamer et al. (2013, ID209), Beamer et al. (2016, ID513) Greene et al. (2016, ID053), Henderson et al. (2016, ID240), Beamer and Henderson (2013, ID124), Beamer et al. (2010, ID134), Beamer et al. (2011, ID133), Greene and Beamer (2012, ID123), Greene et al. (2015, ID341) are summarized and these sources are included in our archive of previous reports. Beamer et al. (2009, ID340) is also summarized in Appendix A and is a source for which we only have a citation and no copy of the report, therefore the annotated bibliography presented in this report can be used to summarize the findings of this report. Appendix C also provides information on projects in the Skagit Estuary and Skagit Bay including; Crescent Harbor Salt Marsh Restoration Project, Fisher Slough Restoration Project, Wiley Slough Restoration Project, Swinomish Channel/Fornsby Creek/Smokehouse Floodplain Project, Fir Island Farms Estuary Restoration Project, Deepwater Slough Restoration, and McElroy Slough Estuary Restoration Project that are relevant to the Study Area for the Synthesis Study. Each of these summaries includes aerial project maps and detailed information restoration metrics, monitoring focus, study design, species monitored, project findings, system effects, and lessons learned.

<u>Fish and Habitat</u>: Table 3-1 provides a summary of maximum velocities through culverts for fish passage for salmonids by species, life stage, and culvert lengths that includes adult Chinook, Coho, Sockeye, steelhead, Chum, and Pink as well as juvenile salmonids of all species classified as fry (>60mm) and fingerlings (<60mm). Table 6-1 provides information on tide gate removal effects, upgrade effects, and evaluation metrics that can inform conceptual life history models, with Table 6-2 providing information on the geographical context of the effects based on the location of tide gates in the landscape (river/stream mouth, tributary creek, or drainages).

SRSC and WDFW (2005) (Unique Identifier: 304)

<table>
<tr><td>Reference</td><td colspan="10">Skagit River System Cooperative (SRSC) and Washington Department of Fish and Wildlife (WDFW). 2005. Appendix A: trends in spawning escapement in Skagit Chinook recovery plan. Report prepared by Skagit River System Cooperative and Washington Department Fish and Wildlife.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: abundance, status and trends.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: migration, spawning, overwintering, rearing.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Watershed, including Sauk River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This is an appendix to the Skagit Chinook Recovery Plan (Beamer et al. 2005, ID175) and provides information on the trends in in spawning escapement for Chinook in the Skagit River watershed. Escapement estimates have been made since 1952, and spawning escapement of Skagit summer and fall Chinook have been relatively stable since monitoring began. Escapements were low in the mid-1950s and early 1990s, and higher in 1970 with an increasing trend since 1996. They also found differences in trends among summer and fall populations. Spring Chinook have been monitored since 1952, but changes in methods over time have resulted in comparable data since 1994. A correlation analysis was used to detect correlations in trends among populations to determine where factors influencing escapement are occurring within the basin.

Information Relevant to Skagit River Relicensing: This short appendix provides quantitative data on the status and trends of Chinook populations in the Skagit Watershed, including Sauk River and lower mainstem Skagit populations. Time series of escapement since as early as 1952 through 2004 are provided in Figures 1-4. Table 1 provides the actual escapement data for each year and population, which could be used to inform updated status and trends analyses. The results of a correlation analysis are presented in Table 2, which shows correlations between Skagit River Chinook populations with significant correlations detected between many of the populations. The correlation analysis was also used as an indicator for the population status and trends, and they conclude that *"…it would appear that the factors that affect escapement of Lower Sauk summers probably occur primarily on the Lower Sauk summer spawning grounds. Additionally, the factors that affect Upper Sauk spring escapement probably occur primarily outside the Sauk River System. However, it is unclear where the factors that affect the other four Chinook populations primarily occur*." Factors affecting different life stags and populations are not specifically discussed, but differences in habitat uses or distributions during juvenile and adult life stages are presented to explain correlations and lack of correlations among populations, which can provide information to support the development of conceptual life history models. However, the analysis is potentially outdated and would need to be reconsidered with longer time series to confirm patterns identified in this analysis.

SSC and USGS (1999) (Unique Identifier: 171)

Reference	Skagit System Cooperative (SSC) and United States Geological Survey (USGS). 1999. Skagit Chinook life history study progress report number 2. Report prepared for Non-Flow Coordination Committee, Seattle City Light, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and habitat:*** Fish: growth, life history; Monitoring: scale or otoliths, data gaps.								
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration, nearshore rearing and emigration.								
Reaches and Spatial extent	R1-R15, Skagit Estuary, Skagit Bay, Sauk River.								
Linkages to Hydroelectric Operations	NA								

Summary: This report used otolith samples collected in 1994 to explicitly identify juvenile Chinook life history types when migrating to different habitat types (i.e., freshwater, estuarine, and bay). Otolith samples were collected from the upper, middle, and lower river Skagit mainstem and Sauk River. Additionally, samples were also collected in forested riverine tidal, emergent forested transition, and estuarine emergent marsh. Visual and quantitative analyses were performed to provide results on mainstem river samples, forested riverine tidal samples, juvenile Chinook growth within estuarine habitats, and Skagit Bay nearshore samples (this report is 2 out of three and provides results on their analyses for those subset of habitats). They found that growth rate for juvenile Chinook Salmon in the Skagit system was largest in the estuarine emergent marsh, then emergent forested transition, then forested riverine tidal zone and smallest in freshwater.

Information Relevant to Skagit River Relicensing: This report provides information regarding juvenile Chinook Salmon life history patterns throughout the Skagit mainstem as well as different estuarine habitat zones. It also provides growth rates from the different habitat zones. The fork length and otolith radius (core to edge) are useful for estimating the size and growth of fish sampled later in their lives and linear distance from core to beginning to "developmental check" are used to further validate differences between the different patterns. The otolith increments beyond the forested riverine tidal habitat, were larger than increments formed in upper river habitat, but not as large as estuarine emergent marsh or emergent forested transition habitat zones. Methods for otolith collection, preparation, and analysis are also provided in this report, including detailed information on developmental checks, which can be used to inform future analyses and monitoring.

Fish and Habitat: Growth rates for juvenile Chinook from smallest to largest were freshwater, forested riverine tidal, emergent forested transition, and estuarine emergent marsh. Growth in estuarine emergent marsh was three times greater than the average growth rate from forested riverine tidal or emergent forested transition (see Table 1). There were some "atypical" classified otoliths that had a second freshwater region or a second estuarine region. The authors imply that the difference in the two freshwater residency regions could mean that the second freshwater region is not a "true" freshwater habitat but could be that fish reside in slower growing zones of the upper estuary like the forested riverine tidal zone or emergent forested transition zone, and that juvenile Chinook Salmon move throughout the different estuarine zones. Samples from Skagit Bay also support the hypotheses that some late emerging fry that move quickly through the estuary or are possibly pushed out by high river discharge. They indicate that future analyses will be conducted to correlate length, residence period, and timing of the atypical samples at various life stages with water flow and temperature factors to further understand these life history patterns.

Stober et al. (1982) (Unique Identifier: 402)

<table>
<tr><td>Reference</td><td colspan="10">Stober, Q. J., S. C. Crumley, D. E. Fast, E. S. Killebrew, R. M. Woodin, G. Engman, and G. Tutmark. 1982. Effects of hydroelectric discharge fluctuation on salmon and steelhead in the Skagit River, Washington. Report prepared for City of Seattle, Department of Lighting, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish:</u> survival, hatchery, abundance, movement, harvest, distribution; <u>Habitat:</u> instream flow, freshwater. Water Quality and Productivity: dissolved oxygen, temperature. Hydroelectric Operations: flow regulation, life stage flow, stranding, downramping.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: spawning, incubation, emergence. Pink: spawning, incubation, emergence. Chum: spawning, incubation, emergence. Coho: spawning, incubation, emergence. steelhead: spawning, incubation, emergence.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">US of R7, Cascade River, Sauk River, Other upper Skagit tribs, Other Sauk River tribs.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Hydroelectric Operations: flow regulation, stranding, downramping.</td></tr>
</table>

Summary: This extensive report describes the findings of studies designed to establish an ecological baseline for aquatic habitats of the Skagit River between Newhalem and confluence of the Sauk River (US of R7). The rationale for focusing on these reaches was because it was determined that was where most of the impacts resulting from the Skagit Hydroelectric Project would occur. The report begins with a brief introduction of the Skagit Hydroelectric Project and a description of the physical characteristics (instream flow, temperature, and profile and gradient) of the study area. Studies detailing project impacts on salmon and steelhead spawning, incubation, emergence, fry survival, fry stranding and fry rearing are presented as well as behavioral studies on movement. Studies were done in the Skagit River as well as in a laboratory setting. The studies in this report arrived at several conclusions summarized here:

- Escapement levels for summer-fall Chinook, Pink, and Coho were comparable to past years, as well as hatchery escapement levels.
- The greatest area spawned per river mile from aerial photograph data was between Diobsud Creek and Cascade River.
- steelhead began spawning mid-March through June. Approximately 80 percent of the redds occurred in the Skagit mainstem (Newhalem to Sedro Wooley) for 1980 and 1981.
- steelhead spawning occurred two weeks earlier in 1982 than in 1981 and with fewer fish spawning in above the Cascade River.
- Female Chinook remained at their redds during 'moderate' changes in flow. Females would complete their redds if there was several hours of adequate flow each day. A relationship for Chum was not able to be determined due to low numbers of tagged females at redds.
- No correlations were detected between Chum egg survival and dewatering events for the instream incubation flow test that used artificial redds (e.g., egg boxes) planted at different depths at Marblemount Slough and Thornton Creek.

Information Relevant to Skagit River Relicensing: This report provides the results of a collection of studies primarily focused on reaches upstream of the Synthesis Study, but includes information on Reaches R7-R8, Sauk River, and Baker River. Extensive baseline information on fish and habitat, water quality and productivity, modeling tools, and hydroelectric operations topics of interests and metrics are presented. The information here could be used to support the development of hypotheses, compare current conditions to a historical baseline, and development conceptual life history models. While it was not always possible to determine which data were specific to the Study Area for the Synthesis Study, relevant data related the study area, and specific reach names, are called out where possible in the summary section below.

<u>Fish and Habitat</u>: Section 6.1 provides the natural and hatchery spawning escapements from 1978-1981 (Tables 1-2) for summer-fall Chinook, Pink, Chum, and Coho. Natural spawning escapements were found to be comparable to previous years for summer-fall Chinook, Pink, and Coho. Chum had a less than average escapement for 1980 but higher than average escapement in 1978. Table 8 provides the hatchery production and fish plantings from 1978-1982 for Chinook (spring, fall, and summer runs), Coho, Chum, and Pink. Table 9 provides estimated steelhead spawning escapements in the mainstem and tributaries of the Skagit from 1977 to 1982. Tables 3-5 list Chinook Salmon redd counts from 1977- 1981 for sub reaches spanning from Newhalem to the Sauk River from September to October. They found that the reach with the greatest area spawned per river mile was from Diobsud Creek to Cascade River (Table 7).

The same information cited above is also provided for steelhead in Tables 9-13. For steelhead, about 80 percent of the redds were located in the mainstem of the Skagit River and the rest in the Sauk River mainstem for 1980 and 1981. Whereas in 1982, roughly 60 percent of steelhead were in the mainstem Skagit and 40 percent in the Sauk. steelhead distributions had changed along with the timing of peak spawning activity occurring two weeks earlier in May of 1982 than in 1981 (see Table 14 for annual distributions). However, differences between reaches throughout the years were not statistically significant.

Section 6.2 provides information on salmon behavior for Chinook and Chum Salmon spawning in the river during fluctuations in river flow. Chinook females were found to *"stay at their redds through moderate flow" and* left when *"flow reductions nearly completely dewatered some active redds… but returned later after flows increased."* This part of the study indicates that female Chinook would complete and or stay at their redds so long as the flow levels *"provided adequate flows over the redd site for at least several hours each day."* For Chum, not much was known due to tagged fish rarely being seen on redds. Section 6.2 also provides steelhead redd depth to flow relationships, where they found that Gorge discharges resulting in flows below 2,000 cfs jeopardized redds that were spawned during 4,500 cfs at Marblemount. At Rockport, these changes in discharge flow were predicted to not be severe due to tributary inputs (like the Cascade River and Illabot Creek) providing some cushion in flow levels.

Section 6.3 provides steelhead temperature unit requirements and tests of instream flow effects on Chum eggs and alevin. steelhead temperature unit requirements were not available due "*to the length of time between sampling dates*" which "*did not permit accurate estimates of the temperature units for hatching*." The Chum instream flow tests did not find any correlations between dewatering events and egg/alevin survival (Tables 19-21 provide survival ratios for eggs and alevin at various redd depths).

Similar to the instream flow tests in Section 6.3, Section 6.4 describes an in-lab incubation tests for Chinook, Coho, Pink, Chum and steelhead for various life stages (fertilization to eyed stage, eyed to hatching, and fertilization through hatching) for dewatering and static water. This section provides useful survival rates in different dewatering scenarios (0, 5, 8, and 16 hours) in large, medium, and small gravel sizes as well as in static water conditions. Tables 22-25 provide useful quantitative information from the various tests that could be useful for potential life cycle models.

Section 6.5 provides the behavioral studies for alevin survival, general behavior and movement in regard to how alevins behave in the gravel, respond to velocity, dissolved oxygen, and presence of light. The authors found that the size of the gravel directly relates "*to the number of successful migrations with smaller gravel sizes restricting alevin movement.*" The dissolved oxygen studies demonstrated that alevin have the ability to distinguish water sources with low or high dissolved oxygen and move towards the higher oxygenated waters. Tables 42-44 report the percentages of Coho, Chum, and steelhead movement into higher dissolved oxygen tanks. The photo behavior studies found a photo negative relationship for all three species (Coho, Chum, and steelhead) that increased during the early development stage but then reversed to either neutral or positive light behavior as the emergence stage neared.

<u>Hydroelectric Operations:</u> Section 6.6 reports the relationship between ramping rates, daylight, and salmon fry stranding mortality along three sites near Newhalem on the Skagit River. These sites were selected to help understand the effect of how downramping impacted sites further downstream but was limited to areas primarily upstream of the Study Area for the Synthesis Study aside from R7 that includes the Sauk River confluence. They found that with *"greater amount of daylight dewatering at sites farther downstream from Newhalem was a progressively higher incidence of stranded fry. The stranding indices for sites 1, 2 and 3 were generally less than 5, 10, and 40 at each respective site progressing downstream."* Higher ramp rates that were for longer periods of time were associated with higher fry stranding. However, the report states that more data are needed to explore the interaction between daylight and lower rates of downramping since most of the study was done with higher rates of downramping, later in the night. In addition, it is unclear how much of their findings are relevant to the Study Area for the Synthesis Study given that the study focused on the upper Skagit River reaches.

SWC (2011) (Unique Identifier: 113)

Reference	Skagit Watershed Council (SWC). 2011. Plan for habitat protection and restoration in the middle reach of the Skagit River: strategies, treatments, and priorities. Report prepared by Skagit Watershed Council, SRFB 08-2132, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: limiting factors, restoration, climate change, capacity. ***Geomorphology and Landforms:*** history, sediment supply and transport. ***Water Quality and Productivity:*** temperature. ***Modeling tools:*** climate change, hydrology. ***Hydroelectric Operations:*** flood control, flow regulation.									
Species and Life Stages	***Chinook:*** rearing.									
Reaches and Spatial extent	R7-R12, Jackman Creek, Baker River.									
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flood control. ***Fish and Habitat:*** Habitat: instream flow.									

Summary: This report by the Skagit Watershed Council summarizes their plan for "Habitat Protection and Restoration in the Middle Reach of the Skagit River as a framework for implementing ecologically meaningfully restoration and protection actions in the floodplain of the Skagit River between Sedro Woolley and the confluence with the Sauk River." It also builds off of previous analyses and restoration strategies developed for the Skagit River, including the Application of the Skagit Watershed Council's Strategy (Beamer et al. 2000. ID190) and the Skagit Chinook Recovery Plan (SRSC and WDFW 2005, ID175). Through the viewpoint of using process-based restoration scaled to address underlying cause of degradation (e.g., reach versus watershed), this report summarizes their assessment of nine different reaches within the middle Skagit River that are critical to Chinook Salmon recovery. This report also provides summaries of other river planning activities such as: Puget Sound Action Agenda, Skagit Flood Hazard Management Planning, National Marine Fisheries Service Biological Opinion on FEMA's National Flood Insurance Program, Skagit County Shoreline Master Program Update, Skagit Countywide Urban Growth Area Open Space Concept Plan, Skagit River Hydroelectric Project, and the Baker River Hydroelectric Project. These summaries target specific "processes and activities that inform, intersect, or complement the strategies described" in their plan. This report also provides a general overview of the geomorphic history of the Skagit River basin.

Information Relevant to Skagit River Relicensing: This report describes the Skagit Watershed Council's strategy for identifying critical habitats in the middle Skagit River that need to be restored or protected, which would also have the greatest impact on ESA listed Chinook Salmon. The middle reaches included in the strategy are directly related to the Synthesis Study. The report describes limiting factors for Chinook Salmon listed in 2005 Skagit Chinook Recovery Plan, how climate change was considered into their decision process based on Mantua et al. (2010, 077), and current assumptions of habitat conditions and Hydroelectric Operations. Therefore, this source provides information that can support development of conceptual life history models and identification of factors affecting life stages for target salmon species in the Study Area for the Synthesis Study. The report also provides information in Appendices. Appendices A and B provide results from a hydraulic analysis that were commissioned by the SWC, and Appendix C contains maps supporting the identification of protection and restoration actions. However, Appendix C has not currently been archived.

Fish and Habitat: The report provides an overview of the middle Skagit Area, describing the landscape and geomorphology, and current habitat conditions from 2009 aerial photographs. They provide quantitative data for the nine reaches they selected; Table 2 provides length of reaches and the percentage of how much the reach has been modified, Table 3 provides inundation area from the hydrodynamic model with current habitat conditions, Table 4 provides a summary of protected land for each of the nine reaches, and Table 5 provides the current juvenile Chinook Salmon capacity estimates for each habitat type (e.g., natural bar, hydromodified bar). These values from the tables supported identification of critical habitat that fit with the goals of other agencies or plans for restoring Chinook Salmon populations. From their reach analysis and habitat modeling results – Ross Island, Cockreham Island, and Skiyou were the top three highest prioritized reaches (reach R12 through R10). For each of the nine reaches that are roughly located between reaches R7 through reach R12 in the Synthesis Study (Skiyou, Ross Island, Cockreham, Savage, Cape Horn, Baker, Jackman, Aldon, and Rockport), they describe the characteristics of the reach as well as the habitat strategy identified from problems affecting habitat. In addition, 21 project sites were identified in the planning process, nineteen of which were identified as "significant areas of floodplain habitat" (see Table 14 which provides the project and rankings for different categories).

Hydroelectric Operations: Chapter two discusses the relationships of SWC's plan to other river planning activities, in particular relevance to the Synthesis Study, the sections on the Skagit River Hydroelectric Project as well as the Baker River Hydroelectric Project. These sections provide a brief history of the dams and flow regulation and flood control operations. Particularly, the Skagit River hydroelectric has been managing flows for fish since 1985. Chapter four describes the impacts of hydropower and how both the Skagit and Baker "operations have affected Skagit River flows" which are both operated for flood control. These flow requirements have changed the natural peak flow of the Skagit River system in that flows during the spring are lower (when snowmelt would normally cause higher flows), and later summer through mid-winter have higher than normal flows.

SWC (2021) (Unique Identifier: 430)

Reference	Skagit Watershed Council (SWC). 2021. Skagit 2020 monitoring and adaptive management report. Report prepared by Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat*:** Habitat: freshwater, estuary, pocket estuary, status and trends, wetlands, riparian, connectivity; Monitoring: restoration, habitat. ***Geomorphology and Landforms*:** Side and off-channels, floodplain connectivity, large wood, aquatic habitats and landforms, estuarine habitats and landforms, sediment supply and transport. ***Land Use and Cover***: banks and shoreline.									
Species and Life Stages	***Chinook*:** estuary rearing and emigration, nearshore rearing and emigration, rearing									
Reaches and Spatial extent	Skagit Watershed, Skagit Estuary, Skagit Bay, Padilla Bay, Sauk River, other lower Skagit tribs, other upper Skagit tribs, other Sauk River tribs.									
Linkages to Hydroelectric Operations	NA									

Summary: This report is a compilation of independent research and monitoring that took place between 2000 and 2016. The purpose of this report is to provide an adaptive management framework to support collective decision making regarding explicit and implied habitat status and trends indicators from the Skagit Chinook Recovery Plan (2005) and to support recommendations for future monitoring and adaptive recovery management. Four ecosystem components are considered, including tidal delta habitats, pocket estuaries, freshwater ecosystems, and riparian habitats. Recommendations to the Skagit Watershed Council Monitoring and Adaptive Management Subcommittee are provided to support improvements in monitoring, research, habitat protection and restoration, and development of hypotheses. Major findings for each ecosystem component are listed briefly below.

(1) Tidal delta habitats: Overall, the Skagit is gaining tidal delta habitat faster than it is being eroded, mostly due to active restoration projects. However, current rates of restoration are slow and are not projected to meet the desired future conditions outlined in the 2005 Recovery Plan until 2100. Relative sea-level rise and sediment re-routing has resulted in an overall decline of natural progradation, emphasizing the role of active habitat management in creating net gains in tidal habitat. Landscape/habitat connectivity within the delta is highest in the South and North forks and lowest in Swinomish Channel and Padilla Bay. Tidal delta habitat management recommendations are made in light of these findings.

(2) Pocket estuaries: Pocket estuary status was assessed on four metrics — count of pocket estuaries, pocket estuary area/extent of functional channels accessible to juvenile salmon, median distance between pocket estuaries, and median distance of pocket estuaries from natal estuaries. The addition of one pocket estuary, the result of a 94 ha restoration project at Crescent Harbor, improved three out of the four metrics (all except median distance of pocket estuaries from natal estuaries). Research recommendations for pocket estuaries included assessments of climate change vulnerability and drift cell scale sediment dynamics.

(3) Freshwater Ecosystems: Nine freshwater ecosystem indicators were assessed, of which two exhibited positive trends, one exhibited a negative trend, and four exhibited no trend — floodplain extent has remained constant. New freshwater management recommendations were made, and several new freshwater ecosystem indicators were introduced (e.g., large wood recruitment and alluvial fans), that should be included in assessment and monitoring.

(4) Riparian Habitat: One riparian indicator, spatial extent and continuity, was assessed for this report. It was found that riparian re-vegetation efforts by project sponsors and landowners has resulted in a net increase (+880 acres) in functional riparian areas. Riparian management recommendations included repeating land cover classification assessments and adding new indicators to riparian monitoring, such as canopy cover and functional stream shading.

Information Relevant to Skagit River Relicensing: This report presents progress for a suite of key ecological attributes and associated indicators identified as important for tracking Skagit River Chinook Salmon recovery. Appendix 1 contains a complete list of the key ecological attributes and common indicators identified for the study. This list could be useful for formulating recovery and monitoring targets, as well as development of conceptual life history models and identification of factors affecting life stages of target species. The information presented may be viewed in context of the recovery goals established in the Skagit Chinook Recovery Plan (2005). A brief section is devoted to each indicator and includes a "Status and Trends" section which briefly summarizes changes in each indicator over time.

Fish and Habitat: Tables 1 and 2 lists key ecological attributes and associated indicators for estuaries and pocket estuary habitats (Table 1) and freshwater habitats (Table 2) identified in Phase 1 of the Skagit Chinook Recovery Plan (2005), as well as the 2005 status and desired future conditions. These tables provide quantitative and qualitative benchmarks for assessing Chinook Salmon recovery in the Skagit Basin. A GIS mapping exercise characterized the tidal delta habitat types and extent in 2004, which are summarized in Table 4. In 2004, the Skagit tidal delta had 109.14 and 859.11 ha of blind tidal channel and distributary channel, respectively. Average landscape connectivity for Skagit tidal delta blind channels (n = 634) was 0.02752. North Fork blind channels had higher connectivity on average compared to the other geographic strata examined.

The rate of progradation at Central Fir Island and in the South Fork is negative, meaning that habitat is disappearing faster than it is being formed. The North Fork progradation rate was approximately zero, thus tidal delta progradation rates are an area of concern for the Skagit Estuary. Linear regressions of the progradation rates over time (and associated regression equations) are given in Figure 1. Gain and loss of tidal delta extent and mode of change (e.g., channel filling, restoration, spartina removal, erosion and progradation) from 2004 to 2013 is displayed in Table 5. Overall, the Skagit tidal delta gained 149.61 ha and lost 66.6 ha for a net gain of 83.03 ha of tidal delta extent, most of which was from restoration (121.9 ha). Table 6 breaks out the extent of tidal delta gained from the five restoration projects completed between 2004 and 2013, which ranged from 64.6 ha (Wiley Slough) to 3.4 ha (Swinomish Channel fill removal). Figure 4 maps areas of net habitat gains and losses in the Skagit delta as well as locations of habitat restoration projects, which may be useful for directing monitoring efforts at targeted locations. Figure 4 generally shows net habitat gains at restoration sites, with net losses are occurring along the edge of the delta where it interfaces with Skagit Bay.

Twenty-four pocket estuaries were mapped in Whidbey Basin in 2005 (ranging in area from 0.55 ha to 93.85 ha), nine of which were within one day's travel time from the Skagit Estuary for fry migrant Chinook. Fourteen of the twenty-four pocket estuaries had confirmed Chinook Salmon presence. In 2014, one additional pocket estuary was added and the number of pocket estuaries with confirmed Chinook Salmon presence through additional monitoring. Figures 5 and 6 shows the locations of pocket estuaries in 2004 and 2014, respectively. Pocket estuary habitat type and areas are summarized in Table 12, stratified by Skagit Bay, Whidbey Basin outside of Skagit Bay, and all of Skagit Bay. Within Skagit Bay, 8.71 ha of pocket estuaries were classified as channel and impoundment, 34.90 ha were classified as intertidal, and 2.13 ha as backshore. In total, 409.30 ha of pocket estuaries were accessible by juvenile Chinook in 2014. A summary of pocket estuary habitat area accessible in 2014 by habitat type and site is presented in Table 13, and qualitative descriptors of each pocket estuary characterizing impairment is presented in Table 14. Table 15 summarizes pocket estuary trends from 2005 to 2014; in total there was a net increase of 104.78 ha (+34.4 percent) in pocket estuary area in Whidbey Basin. The distance of pocket estuaries to the Skagit Estuary ranged from 0.9 to 54.4 km, with a median distance of 13.9 km. The median distance between pocket estuaries was 3.96 km.

Riparian cover type at the watershed scale (excluding the active channel) is summarized in Table 29, which shows a total of 33,203.9 acres (65.92 percent) classified as forest, 13,391.00 acres (26.59 percent) as altered, 2814.4 acres (5.59 percent) as other natural cover, and 957.4 acres (1.90 percent) as unclassified. Percent functional riparian vegetation in Skagit River tributaries increased from 70 percent in 2006 to 72.4 percent in 2015.

Geomorphology and Landforms: In 1998, 31 percent of the Skagit River floodplain area was considered impaired (either isolated from hydrologic processes or shadowed by roads) compared to 28 percent in 2015, displaying a modest improvement attributable to new floodplain area added through channel migration outside of previously mapped areas (most prominently in the Sauk and Suiattle) and changes in road presence. Backwater habitat perimeter length mapped in 2006 was 23,678 and had declined to 20,064 by 2015.

Land Use and Cover: Edge habitat conditions stratified by rearing range in 1998, 2006, and 2015 is summarized in Table 20, and the same for hydromodified edges is summarized in Table 22. Total hydromodified edge length (excluding non-tidal delta) declined from 49,418 m in 1998 to 39,886 m in 2015.

SWC (2022) (Unique Identifier: 451)

Reference	Skagit Watershed Council (SWC). 2022. Skagit Watershed Council year 2022 strategic approach. Report prepared by Skagit Watershed Council, Mount Vernon, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, floodplain, sediment supply and transport. ***Land Use and Cover:*** land cover, forestry, agriculture, floodplain, banks and shoreline, climate change, data gaps, roads. ***Fish and Habitat:*** Habitat: freshwater, pocket estuary, estuary, nearshore, connectivity, data gaps, riparian, climate change, restoration, barriers, instream flow, limiting factors; Fish: data gaps, life history, rearing; Monitoring: restoration, climate change, data gap.									
Species and Life Stages	***Chinook:*** spawning, rearing, overwintering, estuary rearing and emigration, nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit Estuary, Skagit Bay, Padilla Bay, Finney Creek, Nookachamps Creek (East Fork), Hansen Creek, other Sauk River tribs, other upper Skagit River tribs.									
Linkages to Hydroelectric Operations	***Geomorphology and Landforms:*** floodplain.									

Summary: This document provides an overview of the Skagit Watershed Council's updated approach for 2022. From the previous versions of the Skagit Chinook Recovery Plan, three major habitat types (tidal freshwater and estuary habitats in the delta, shallow nearshore habitats that include pocket estuaries, and freshwater rearing areas in mainstem and tributary floodplains) were limiting Chinook production. Additionally, they identified a fourth "habitat" that is limiting Chinook, is the habitat loss from altered watershed processes that control tributary habitat conditions (e.g., flow regime, riparian functions, and sediment supply changes). After identifying habitats, they refined principles to support restoration and recovery planning as follows: 1) restore processes that form and sustain salmon habitats, 2) protect functioning processes and habitats from degradation, and 3) focus on protection and restoration on the most biologically important areas. These principles were used to identify areas that should be targeted for restoration and ranked them into three Tiers. The three Tiers for the target areas were *"…based on their importance to Chinook Salmon recovery, and on the number of populations that will benefit from habitat protection and restoration actions within each area."*

Information Relevant to Skagit River Relicensing: This document provides the Skagit Watershed Council's updated target areas that will have the greatest potential to increase Chinook Salmon populations. The report also describes the methods for categorization of habitats in the Skagit Watershed, including areas within the Study Area for the Synthesis Study that would be the focus of restoration and protection according to this plan. Maps are provided that show the location of different Tier target areas in the Skagit Watershed for habitat restoration and protection.

Tier 1 target areas include Skagit estuary, riverine tidal delta, and river floodplains. These habitats were categorized as Tier 1 because of their importance in providing rearing habitat for juvenile Chinook for multiple Skagit River populations. For the Skagit estuary and riverine tidal delta, they provide descriptions of the historic extent of those habitats, the rationale for making it a target area, one being that *"in the past 150 years, 73 percent of tidal delta and 98 percent of non-tidal delta habitats have been lost."* They also list out the priority restoration objectives that include restoring distributary channels connecting the North Fork Skagit River to the bayfront. Additionally, the authors list potential challenges that might come with restoring these target areas (such as achieving community support). The floodplain target area was listed in Tier 1 due to the "*floodplain habitats and contributing upland areas have been significantly altered over the past 100+ years due to road building, bank hardening, hydropower operations, timber harvest in riparian and upland zones.*" The authors also provide their rational, one being that 61 miles of the mainstem channel edge have been hardened with riprap and "*31 percent of floodplains have been isolated from the river.*"

Tier 2 target areas were pocket estuaries in nearshore marine area and river floodplains that provide rearing habitat for a Skagit Chinook Salmon population. For nearshore pocket estuary habitat, their rational was that these types of habitats provide "*extended rearing and growth opportunities for these Chinook*" and that "*eight-six percent of the total historic pocket estuary area in close proximity to the Skagit delta was blocked to non-natal salmon use.*" While this is a listed target area, they do not know the full extent of how Chinook Salmon utilize all nearshore marine habitats such as vegetated tidal flats, subtidal flats, and rocky reefs. For the floodplain target area, a description of the habitat is provided, along with a list of specific target areas, their rationale- the main reasoning being that "*Chinook Salmon utilize habitats in the mainstem and floodplain… extensively for migration, spawning, and rearing*." They also list priority restoration objectives such as reconnecting isolated floodplain areas and restoring mainstem edge habitats.

Tier 3 target areas are watersheds that have been identified as having impaired sediment supply or peak flows. These tier 3 target areas have impaired processes that impact Chinook Salmon habitat and were determined to be areas that should be addressed within the next ten years. Some of the priority restoration objectives were to reduce land use (which impacts sediment supply), repair/relocate/or remove structures that contribute to increased erosion or peak flows.

Thompson and Beauchamp (2014) (Unique Identifier: 054)

Reference	Thompson, J. N., and D. A. Beauchamp. 2014. Size-selective mortality of steelhead during freshwater and marine life stages related to freshwater growth in the Skagit River, Washington. Transactions of the American Fisheries Society 143(4):910-925.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: survival, growth, size structure, age structure, life history, data gaps; Habitat: freshwater, ocean.									
Species and Life Stages	***steelhead***: rearing – outmigration.									
Reaches and Spatial extent	Skagit Watershed, including upper and lower Sauk River, Jackman Creek, Finney Creek, Day Creek, upper and lower Hansen Creek, lower Skagit River, and East Fork Nookachamps Creek.									
Linkages to Hydroelectric Operations	NA									

Summary: This study evaluated the freshwater growth and survival from juvenile (ages 0-3) to smolt (ages 1-5) and adult stages of wild steelhead sampled in different precipitation zones of the Skagit River basin. The goal was to determine if size-selective mortality (SSM) could be detected between early and later freshwater stages and between each of these freshwater stages and returning adults and, if so, how SSM varied among life stages and mixed and snow precipitation zones. To detect whether faster juvenile growth in different habitats influenced the probability of survival to later stages, scales from steelhead sampled in different precipitation zones (rain, mixed rain-snow, and snow) at different life stages as juveniles (age range: 0–3), smolts (age range: 1–5), and adults were measured to back-calculate freshwater size at annuli 1, 2, and 3. Estimation of size at annuli among life stages and between mixed and snow zones enabled habitat-specific comparisons of growth rates and size distributions. They found that SSM operated during freshwater and marine life stages, and that survival to smolt and adult life stages were strongly related to early growth during one or more freshwater rearing periods.

Information Relevant to Skagit River Relicensing: This report contains information on SSM, size stricture, and growth of juvenile (ages 0-3) to smolt (ages 1-5) and adult stages of wild steelhead sampled in different precipitation zones of the Skagit River basin and includes data for tributaries of interest for the Synthesis Study. By linking SSM, growth, and life history expression to different precipitation zones within the Skagit River basin, this study provides information to support hypotheses of how climate change could impact Skagit steelhead populations. Furthermore, this study links early growth to SSM that provides support for development of hypotheses and life stage factors affecting Skagit River steelhead. The results presented in this study are related to a previous report included in the Synthesis Study (Thompson and Beauchamp 2016 ID114). The authors indicate that recent studies have highlighted the importance of survival in marine environments for steelhead, but the locations and modes of mortality for steelhead populations in the Salish Sea have not been conclusively determined.

Fish and Habitat: steelhead in the snow zone were significantly larger at annulus 1 compared to those in the mixed rain-snow zone. Size-selective mortality for freshwater and marine was apparent between the juvenile and adult samples at annulus 1 and between each life stage at annuli 2 and 3. Significant SSM was determined in terms of differences in size achieved at annuli 1,2, and 3 among most life stage groups within the mixed and snow zones, but precipitation zone had no effect on size at annuli 2 and 3. Quantitative data on fork length of juveniles and smolts is provided in Tables 1 and 2 as well as scale radius. On average, mean size at annuli in rain zone juveniles was relatively low compared with juveniles sampled in mixed and snow zones. Growth during the first, second, and third years of freshwater rearing strongly influenced SSM leading to the smolt migration, and growth trajectories set during these years appear to have influenced survival in marine environments. Rapid growth between the final freshwater annulus and the smolt migration did not improve survival to adulthood. Survival in the marine environment may be driven by an overall higher growth rate set earlier in life, which results in a larger size at smolt migration. Data on precipitation zone, subbasin, and sample sites with life stage group scale radius data is provided in the appendix. Precipitation zone, subbasin, and sample sites with life stage group scale radius data is provided in the appendix, which is broken down by section and tributaries of interest for the Synthesis Study; including upper and lower Sauk River, Jackman Creek, Finney Creek, Day Creek, upper and lower Hansen Creek, lower Skagit River, and EF Nookachamps Creek. Back-calculated fork lengths (mean and SE), and regression models to predict fork length from scale radius, are provided for age classes/life stages and precipitation zones.

Thompson and Beauchamp (2016) (Unique Identifier: 114)

<table>
<tr><td>Reference</td><td colspan="10">Thompson, J. N., and D. A. Beauchamp. 2016. Growth of juvenile steelhead Oncorhynchus mykiss under size-selective pressure limited by seasonal bioenergetic and environmental constraints. Journal of Fish Biology 89:1720-1739.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal article</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: growth, rearing, diet, size structure; <u>Habitat</u>: climate change, freshwater. Water Quality and Productivity: temperature, climate change, data gaps. Modeling Tools: bioenergetics.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">steelhead: rearing.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Finney Creek, other upper Skagit tribs (Bacon and Illabot).</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: In this paper, the authors developed a bioenergetics model of juvenile steelhead growth in three Skagit River tributaries. The purpose of this model was to examine factors affecting growth during juvenile rearing that could affect survival. Sensitivity analysis was performed to identify target feeding rates and prey energy densities during the growing season which would improve survival to smolt and adult stages. In growth simulations, temperature was the ultimate constraint on growth potential but incremental increases in feeding rate and prey energy density broadened the temperature ranges at which faster growth was possible. These results suggest that chances of survival to later life stages can be improved by increasing feeding rates or prey energy density during summer months when warm water temperatures facilitate faster growth. Growth in freshwater rearing habitats is crucial to survival into later life-stages. Climate change has potential to alter the temperature regimes of tributaries in the Pacific Northwest. Understanding mechanisms affecting growth limitations in rearing habitats can help fisheries managers take actions to improve growth conditions and survival.

Information Relevant to Skagit River Relicensing: This study contains relevant information on steelhead (*O. mykiss*) growth during rearing under alternative temperature and food energy density scenarios in the Skagit River watershed. While the results presented here are theoretical, they have implications for potential future growth and rearing conditions in the Skagit River. This study provides bioenergetics model results and tools that could be used to understand mechanisms affecting or limiting growth and survival in freshwater tributary rearing habitats. The data and model were developed for three tributaries with only one being tributary to the lower Skagit River (Finney Creek). However, the authors suggest the three tributaries are representative of the diversity of habitats used by juvenile *O. mykiss* in the Skagit River basin. Many potentially useful demographic metrics are provided in this report that were either empirically derived from Skagit River populations or other reference populations, and include metrics for size structure, growth, and diet. However, the results also include a number of metrics that were derived from simulations and should be used appropriately. The authors found that temperature was a significant factor limiting growth, and they point to the need for continued water temperature monitoring to support identification of factors limiting growth and how these can be addressed in the face of climate change or restoration. Water temperatures were monitored in the tributaries for different periods of the year in 2011, but some sensors were lost and reference data and interpolations/regressions were used to complete data series for parameterizing bioenergetic models. However, these data are not summarized in the report.

This paper contains tables summarizing fork lengths (mean ± SE) for age 2 and 3 steelhead in three tributaries of the Skagit River. Fork lengths are further broken down into juvenile, smolt, and adult groups. Tables summarizing prey energy density values for various taxa used as inputs to the bioenergetics model are provided. Prey energy densities considered in this paper ranged from a low of 2911 J/g (Diptera larvae-nymph) to a high of 6387 J/g (Coleoptera adult). Additional taxa-specific energy-density values are provided in the table. Average observed prey energy density was 3276 J/g at Bacon creek, 3422 J/g at Illabot, and 4308 J/g at Finney. Inputs and outputs of a bioenergetics model simulating growth, feeding rates, and consumption for juvenile steelhead captured at different life stages are also provided. Simulated growth between annuli in grams ranged from 9.4 g (Finney Creek juveniles) to 53.1 g (Finney Creek adults) and a mean of 20.16 g (SD = 10.75) across all sites and life-stages. Simulated mean daily growth potential (grams per gram per day) under different growth periods (annuli), feeding rates, and energy densities is summarized in a fourth table. Daily growth for age 1 and 2 steelhead roughly doubled at all sites when increasing prey energy density to 5000 J/g.

Todd et al. (2009) (Unique Identifier: 169)

Reference	Todd, S., O. Odum, M. Koschak, and A. McBride. 2009. Quality assurance and methodology for mapping marine shoreline geomorphology. Report by Skagit System Cooperative, La Conner, Washington.								
Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	No	*Spatial Data*	Yes	*Project Related*	No
Topics and Keywords	*Geomorphology and Landform:* estuarine habitats and landforms, nearshore habitats and landforms. *Land Use and Cover:* land cover, banks and shoreline. *Fish and Habitat:* Habitat: nearshore, pocket estuary, status and trends.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Bay, Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: This report describes the methodology implemented for mapping marine shoreline geomorphology in the Puget Sound region, including a framework for the classification of nearshore and estuarine habitats and landforms based on geomorphology. This work was completed by the Salmon and steelhead Habitat Inventory and Assessment Program. The first draft of this work used a dataset that was composed of DNR (Washington Department of Natural Resources) Geology, 10-meter DEMs, ecology drift cells, and DNR hydrography data. The updated quality assurance version of this work relied on a systematic evaluation of recent aerial photos. The intent of this work was to capture a "present day" shoreline geomorphology dataset that could be compared with a "historic" shoreline geomorphology dataset being developed by Puget Sound Nearshore Ecosystem Restoration Program. This could be used to help identify potential nearshore restoration sites and evaluate habitat status and trends metrics.

Information Relevant to Skagit River Relicensing: This dataset maps "present day" shoreline geomorphology at a high level of precision and accuracy within the Puget Sound region, including the Skagit Bay and Padilla Bay nearshore environment. This dataset could be helpful to inform potential geomorphic changes that have occurred along the Skagit Bay and Padilla Bay to evaluate habitat status and trends as well as identify restoration opportunities to address salmon recovery goals and limiting factors (e.g., accessible pocket estuary habitat). While no quantitative summaries are provided from the spatial data developed in this study, the spatial data can be used to support quantification of nearshore habitat metrics.

USACE (2008) (Unique Identifier: 355)

Reference	U.S. Army Corps of Engineers (USACE). 2008. Skagit River flood damage reduction feasibility study, Skagit River basin, sediment budget and fluvial geomorphology. DRAFT. CENWS-ED-TB-HE 6/11/2008. Report prepared by USACE, Seattle District, Washington.									
Source Information	*Type*	Report	*Status*	Draft	*Quantitative Data*	Yes	*Spatial Data*	Yes	*Project Related*	Yes
Topics and Keywords	*Geomorphology and Landform:* change, history, channel migration, climate change, substrate and sediment, sediment transport and supply, large wood, estuarine habitat and landforms, aquatic habitat and landforms, data gaps. *Fish and Habitat:* Habitat: restoration, status and trends, freshwater, estuary. *Modeling Tools*: sediment. *Hydroelectric Operations:* flood control, flow regulation.									
Species and Life Stages	NA									
Reaches and Spatial extent	Reach R1-14, Skagit Estuary, Skagit Bay, Sauk River, East Fork Nookachamps, Finney Creek, Baker River, Jackman Creek, other lower Skagit Tributaries.									
Linkages to Hydroelectric Operations	*Geomorphology and Landform:* sediment transport and supply. *Hydroelectric Operations:* flood control, flow regulation.									

Summary: This report includes a description of the Skagit River's sediment budget and fluvial, estuarine, and nearshore geomorphology. Their objectives were to develop (1) annual basin sediment yield estimates, (2) river and delta channel geomorphology, and (3) nearshore geomorphology to provide a baseline to evaluate potential sediment budget and geomorphic impacts of alternative flood damage reduction and environmental restoration measures. The Skagit River channel is fairly stable with the most migration occurring the middle reach. Channel alignment in the upper basin is predominately controlled by geology and the lower river and estuary are primarily controlled by levees and bank protection, The middle reach has intermittent bank protection, and the active migration zone is up to 2 miles wide.

The average annual sediment yield at Mount Vernon is in the range of 0.6 to 2.8 mcy (0.5 to 2.1 Tg). The major sources of sediment are the Cascade and Sauk rivers. Approximately half the basin does not contribute sediment because the sediment is stored in reservoirs. Storms with daily discharges greater than 50,000 cfs are a major factor in sediment production. These large discharge events can cause upper basin land disturbances and produce an estimated 21 percent of the average annual sediment yield.

Upstream of PRM 17, the Skagit River bed is composed of gravel, cobble, and boulders. Downstream of PRM 17, the riverbed and nearshore delta bottom are mainly sand. The 2.8 mcy (2.1 Tg) annual suspended sediment (SSC) yield at Mount Vernon is composed of approximately 50 percent sand, 50 percent silt and clay are transported through the lower river and into Skagit Bay.

Since 1931, there has been a long-term trend of sediment deposition in the channels downstream of Sedro-Wooley. There has been an overall averaged bed elevation increase of approximately 2.25 ft since 1931. The bed upstream of PRM 15.8 appears to be rising slightly faster than the overall average. Sand deposition has also been occurring in the estuary and on the delta.

Information Relevant to Skagit River Relicensing: This study focuses on developing a sediment budget for the mainstem Skagit River downstream of hydroelectric dams on the upper Skagit and

Baker Rivers, and includes a geomorphic analysis for the mainstem Skagit, Skagit Estuary, and the nearshore of Skagit Bay (although limited information on non-delta associated nearshore habitats are presented). The study determines an average annual sediment yield at Mount Vernon of 0.5 to 2.1 Tg. Subsequent studies, such as Curran et al. 2016, have reported higher annual sediment yields (2.5 Tg). There has been a long-term trend of sediment deposition in the channels downstream of Sedro-Wooley. If there was more sediment being transported in the Skagit River, the amount of sediment deposition could increase more in the future.

Average annual sediment budgets by sub-basin are reported with contributing basin area for 13 sub-basins that include tributaries identified in the Synthesis Study (Sauk River, Jackman Creek, Nookachamps, Finney Creek, and other lower Skagit River tributaries), as well as glaciated areas for sub-basins. Annual suspended sediment yields are reported for Mount Vernon from 1941-2001, as well as changes in thalweg and channel bed for cross sections from the South and North Fork distributaries of the Skagit River delta to river mile 22.4 from 1975-1999. Floodplain conditions, bank conditions and protections, LWD abundance, substrate characteristics, channel patterns, and gradient as well as bed elevations are generally described for this entire extent.

The report links sediment supply and transport to reservoir operation, with approximately half the basin not contributing sediment because the sediment is stored in reservoirs. In addition, temporary storage of flood waters is linked with reduction in flood peaks and sediment yield from the Baker River. The authors identify a data gap for sediment supply and transport, with insufficient sediment data to determine the most significant sediment producing storm conditions in the Skagit Basin including the following recommendations:

- *"Inventory all significant erosion processes and sediment sources active in all sub-basins"*
- *"Identify the gradation of sediments produced in each sub-basin"*
- *"Monitor suspended sediment and bedload transport in the main stem and major tributaries"*
- *"Continue to re-survey channel cross-sections every 10 years or so"*
- *"Refine geomorphic analysis using a time series of aerial photographs"*
- *"Improve the understanding of relationships between subbasin sediment production and channel aggradation through watershed sediment yield modeling and sediment transport modeling."*

USACE (2010) (Unique Identifier: 117)

<table>
<tr><td>Reference</td><td colspan="10">U.S. Army Corps of Engineers (USACE). 2010. DRAFT Skagit river flood risk reduction study, environmental without-project condition report. Report prepared for Skagit River Basin, Skagit County, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Links</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: history, slope, floodplain, substrate and sediment, shallow and deep surface processes, climate change, large wood, aquatic habitats and landforms, nearshore habitats and landforms, channel migration, channel incision, sinuosity. Water Quality and Productivity: dissolved oxygen, turbidity, temperature, nutrients, pH, bacteria, contaminants, climate change. Land Use and Cover: land cover, agriculture, climate change, data gaps, forestry, urban. Fish and Habitat: <u>Habitat:</u> freshwater, estuary, pocket estuary, nearshore, connectivity, limiting factors, climate change, riparian, beaver, instream flow; <u>Fish:</u> status and trends, periodicity. Hydroelectric Operations: flood control.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">All Anadromous species: not specified for some. Chinook: spawning – rearing. Coho: spawning – rearing. Bull Trout: spawning. steelhead (and Cutthroat): spawning.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Watershed.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Geomorphology and Landforms: large wood. Fish and Habitat: <u>Habitat:</u> instream flow.</td></tr>
</table>

Summary: This comprehensive report provides detailed information of the Skagit Watershed's environmental baseline conditions such as the physical properties for soils and sediment, vegetation coverage, and wildlife within the Skagit basin, wetland coverage, and water quality without Hydroelectric Project interactions (meaning that hydroelectric dams are not part of this reports analysis of the Skagit basin's baseline and trajectory). In addition, assumptions about future conditions are outlined for each respected section discussed above and data gaps are identified that can be addressed in future analyses. In particular, predicted climate change impacts are provided and the potential effects on the Skagit Watershed's physical and ecological systems are discussed. Future issues related to climate change identified in the report are changes in basin and riparian vegetation, reduction of large woody debris recruitment, distribution and abundance of fish and wildlife species, and losses of wetland function and habitat.

Information Relevant to Skagit River Relicensing: This report provides extensive information within the Study Area for the Synthesis Study and Skagit Watershed. This report provides an overview of the topography, geology, geomorphology, biological resources (i.e., wildlife, vegetation, fish, and invertebrates) and lists out threatened and endangered species that are in the Skagit Watershed. The amount and type of wetland habitats are described, with the Skagit mostly comprised of palustrine emergent, scrub-shrub, and/or forested wetlands as identified in the National Wetland Inventory (NWI) maps. The report also states that 93 percent of the historic extent of vegetated tidal wetlands has been lost (historic vegetated tidal wetlands was 25,766 acres and now is currently 1,941 acres). Data gaps are identified in the NWI since the maps *"were drawn using aerial photo analysis of vegetation patterns, visible hydrology and geographic position"* and interpretation inaccuracies were common. The water quantity and water quality sections provide flood characteristics of the Skagit system and the reaches that are on the Ecology's 303d list because of not meeting the state's water quality standards for fecal coliform, high temperature, pH, and dissolved oxygen. Turbidity, sediment runoff and chemical contamination and nutrients are also listed as areas of concern for mostly lower reaches within the Skagit Watershed. The report states that with continued logging and other land use practices, turbidity is expected to increase in the lower reaches and Skagit Bay.

The report also provides future condition assessments based on climate change and development scenarios. The report states that *continued maintenance and construction of levees as it exists now… would further constrain the river,"* and continuing to constrain the river would consequently create less complex habitat, decrease benthic invertebrate habitat, decrease further off-channel habitat, river speeds would increase during high flow events. This would also further decrease large woody debris retention and create thinner riparian corridors. This ripple effect would *"directly affect ESA listed species that depend on cold, clean water, organic detritus and benthic invertebrates for food, and LWD and bank complexity for cover."* Table 3 provides projected changes (e.g., warmer summer air temperatures) and if the potential forest impact is a positive or negative change. Figure 3 shows two regions that might be impacted by sea level rise. Additional data gaps are identified that include understanding sediment supply and transport in high flow events, updated riparian habitat surveys, and updated soil surveys.

<u>Fish and Habitat:</u> The report lists out fish species present in the Skagit System and describes spawning generally, but delves deeper into Puget Sound Chinook, Costal/Puget Sound Bull Trout, and Puget Sound steelhead since they are listed as endangered or threatened. For these species, the report provides their respective timing and habitat requirements for spawning. Table 1 provides a summary of the Skagit's salmonids stock status for Chinook, Chum, Coho, Sockeye, and steelhead, and ESA Listed Status are provided in Table 2 that include target species (Chinook, Bull Trout, and steelhead) as well as other non-fish species. Figure 2 shows the distribution of functioning, impaired, or unknown riparian buffer widths from Landsat data for the Skagit Watershed, including the Study Area for the Synthesis Study. Additionally, this report provides a comprehensive description of basin and riparian vegetation and their approximate historic and current coverage in the Skagit system. Current conditions were described as *"fragmented, poorly connected, and provided inadequate protection of habitats and refugia for sensitive aquatic species such as salmon"* due to landscape alteration from *"road building, bank hardening, hydropower operations, timber harvest… and rural development."* Off-channel habitat such as side channels, sloughs, and beaver ponds have been disconnected due to agricultural practices, diking, and bank revetments.

<u>Geomorphology and Landforms:</u> The report indicates that there is no transport of LWD from above the dams by either natural or human processes, and assessments indicate that there is a lack of large wood in the system. They also identify reduced LWD retention due to the prevalence of bank armoring and removal of LWD through flood reduction efforts in the lower reach (RM 19- RM 8). Side channel and off-channel habitat in the lower Skagit River has been reduced and the report identifies diking and land use as contributing factors to the losses of off-channel habitats.

<u>Hydroelectric Operations:</u> While this report does not specifically look at Hydroelectric Operations and how they impact the Skagit system, the introduction provides a brief overview of the dams and how Ross and Upper Baker dam alone *"control 38 percent of the Skagit basin's drainage area; the remaining 62 percent is uncontrolled."* The dams, in combination with a system of levees, were built to provide severe flood control and flooding has become less severe and significant since the building of the dams in the 1920s. Ross and Upper Baker dams are *"operated on a formal basis for flood control and provide a significant reduction to large and small floods."* Other dams along the Skagit and Baker rivers *"provide incidental reduction of flood flows during*

smaller events." The low divide between Sedro-Woolley and Burlington have occasionally overflown, towns in the upper portions of the Skagit Systems such as Hamilton and Lyman experience flooding more regularly. The levees and dams along with urbanization, timber extraction, and building of roads have altered the Skagit's hydrology, from the timing of water infiltration and ability to store water. These changes exacerbate high and low flows, making high flows flashier and low flows lower.

USACE (2013) (Unique Identifier: 118)

Reference	U.S. Army Corps of Engineers (USACE). 2013. Final report: hydrology technical documentation. Report prepared by U.S. Army Corps of Engineers.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Yes
Topics and Keywords	***Geomorphology and Landforms:*** history, channel migration, slope, floodplain, side and off-channels, substrate and sediment, sediment transport and supply. ***Land Use and Cover:*** land cover, banks and shoreline. ***Hydroelectric Operations:*** flow regulation, flood control. ***Fish and Habitat:*** Habitat: instream flow, freshwater; Monitoring: flow. ***Water Quality and Productivity:*** temperature. ***Modeling Tools:*** hydrology.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Watershed including Sauk River, Baker River, Nookachamps Creek, Day Creek, Finney Creek, Hansen Creek, Samish River.									
Linkages to Hydroelectric Operations	***Hydroelectric Operations:*** flow regulation, flood control.									

Summary: This U.S. Army Corps of Engineers report provides their recommendation of a "comprehensive flood risk management plan for the Skagit River floodplain that will reduce flood risk in Skagit County with a focus on downstream of Sedro-Woolley." Their analysis includes a systematic evaluation of the entire Skagit River basin and provides descriptions of the Skagit River, its geomorphology and climate, its tributaries, histories of the dams constructed on Baker River and the upper Skagit River, the types of land coverage and usage, as well as flow patterns from USGS gages. The data from USGS flow gages considered in this report are mostly from 1928 onward, but the analysis provides critical historical context of Skagit River's floods pre- and post-dam construction. This report characterizes flows for 2-, 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year flood events in the Skagit basin.

Information Relevant to Skagit River Relicensing: This report provides information on the entire watershed, but provides extensive information on mainstem reaches within the Study Area for the Synthesis Study and target tributaries including the Sauk River, Baker River, Nookachamps Creek, Finney Creek, Day Creek, and Hansen Creek. It also provides qualitative and quantitative information about the Skagit basin's characteristics such as geomorphology, sediment, topography, climate, stream flows, and flooding. This report mentions seven additional appendices that could have useful flow data but these could not be located and the information presented in those are not described in this annotated bibliography.

Fish and Habitat: Table 1 provides average annual precipitation and associated ranges of greatest to least, mean snowfall, and average temperatures from twelve sites throughout the Skagit Basin from Anacortes to the Ross Dam. Within the climate section, average annual and monthly precipitations, snowfall averages, and storms of 1909, 1990, 1995, and 2003 are given. The storm sections outline the timing of the events that caused the storms listed above (e.g., a weather front and pressure systems) that caused the precipitation to stay over the Skagit basin, causing high amounts of precipitation and flooding. These storm narratives provide some insight to the Skagit's flooding system and how global natural forces interact with it.

The Skagit River system during the fall and winter receives runoff from both rain and snowmelt and shifts to snowmelt runoff during spring. The dam reservoirs are usually refilled during the spring snowmelt and "as a result, the spring peak discharges are generally reduced."

Geomorphology and Landforms: Channel characteristics of the Skagit basin are divided into reaches; international border to Gorge dam, Gorge Dam to Newhalem, Newhalem to Concrete, Concrete to Mount Vernon, and finally Mount Vernon to Skagit Bay. Reach descriptions provide the overall slope of the reach, substrates, general velocities of these reaches and associated travel time of water based on rates of discharges. Table 7 provides summary of stream data for various stream gage stations' average yearly discharge, the average highest and average lowest discharge, and the years of data from each stream gage. Table 8 provides the mean monthly stream flows for the same gages as listed in Table 7. The report states that the Skagit River transports about 10,000,000 tons of sediment annually, composed mostly of sediment that is from glacial origin.

Hydrologic Operations: The flood runoff from uncontrolled watersheds section within the report, states that "flood control at Ross and Upper Baker is sufficient to control floods in the lower valley… with exceedance frequencies of four to five percent (20-25 year event)" but that flood runoff from the Skagit's uncontrolled watersheds can produce major flooding even with flood control regulation at Upper Baker and Ross dams. The Upper Baker and Ross reservoirs are 39 percent of the total Skagit drainage area at Mount Vernon (the remaining 61 percent is uncontrolled watershed); but they have a combined average annual runoff of 32 percent, meaning that Mount Vernon is likely to flood when combined with the uncontrolled watershed runoff. The report then provides flood histories for 1949, 1951,1990, 1995, and 2003. Table 9 provides a summary of historical floods for two gages near Concrete and Mount Vernon on the Skagit River.

The hydrologic study of the Skagit River basin section summarizes the hydrologic analysis for the Skagit Flood Risk Management Feasibility Study. This section provides an overview of different reaches in the Skagit basin (outside the Study Area for the Synthesis Study): Upper Skagit River Basin above Concrete, WA to Ross Dam, Baker River, Sauk River, Cascade River from Marblemount to Concrete, Newhalem to Marblemount, Thunder Creek, and above the Ross Dam. The overviews provide the general land coverage, available gage data, local drainage area, slopes, and elevations. The tables in this section provide summaries related to each of the respected reaches above. For the Synthesis Study, Table 10 through 12 have quantitative information on relevant reaches. Table 10 provides the active flood storage requirements at different elevations and times of year for Upper Baker. Table 11 provides the runoff per square mile for both the Upper and Lower Baker dam inflows for major flood events that provided hourly data. The Sauk River contributes 45 to 64 percent cfs to flood events in the Skagit River (see Table 12). After these descriptions of the respected reaches listed above, the report provides its methodologies for their analysis of the Skagit River's frequency (near Concrete) by: developing a consistent record of data to use, winter flood frequency curve, a hypothetical unregulated hydrograph near Concrete on the Skagit River, and a regulated frequency curve at Concrete. The decision for using Concrete as the Skagit River hydrological frequency analysis was because of the USGS gage #12149000 being located on the Skagit River where it "encompasses 88 percent of the total drainage area of the Skagit River" as well as for the fact that this gage has been measuring flow data since 1924. These sections provide the reasoning and methods for how they used each component to help with their analysis.

Modeling Tools: The final sections of the report focuses on the lower portion of the Skagit River basin, from Concrete to the North and South Forks of the Skagit River, (which encompasses the

Study Area for the Synthesis Study). These last sections combine the methodologies and reasoning behind their regressions analysis into the context of what gage data is available. The reasoning to focus on the lower portion is due to flooding causing the most damage of the lower areas of (Sedro-Woolley to both forks' mouths). Tables 20-25 in these sections shows the 2-, 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year flows at various locations in the Skagit Watershed. A hydraulic model that uses the weighted, regulated discharges from Concrete and tributary flow together to calculate and construct discharge frequency curves. The hydraulic model was used to calculate the "time-varying discharges and stages along the Skagit River instead of a hydrologic model."

Veldhuisen and Couvelier (2006) (Unique Identifier: 162)

<table>
<tr><td>Reference</td><td colspan="10">Veldhuisen, C., and D. Couvelier. 2006. Summer temperatures of Skagit basin headwater streams: results of 2001-2003 monitoring. Report prepared by Skagit River System Cooperative and Upper Skagit Indian Tribe.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Water Quality and Productivity: temperature, data gaps. Land Cover and Usage: land cover, forestry. Geomorphology and landforms: slope, aquatic habitats and landforms. Fish and Habitat: <u>Habitat</u>: riparian, freshwater.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Tributaries.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report evaluates the peak summer temperatures and the response to forest management (i.e., streams in forests, buffers, and or clear cuts). Temperature data were collected in the summer months of 2001 to 2003 in smaller tributaries located at elevations of 300 to 2600 ft throughout the Skagit basin, mostly concentrated in the middle and lower portions where most state and privately-owned timberlands are located. The four objectives of the study were to: 1) characterize temperature regimes during summer peak temperature period, 2) compare observed peak temperatures to other headwater streams in Washington, 3) compare observed peak temperatures to current and proposed regulatory standards, and 4) evaluate the role riparian logging, shade, aspect and channel dimensions in influencing temperature change. Each year had a slightly different monitoring protocol to help answer the reports objectives, and their primary findings are quoted below:

- *"Skagit headwater streams show a range of sensitivities to thermal inputs from surface processes (e.g. sunlight, air temperature). Some sites located close to channel heads had a stable temperature regime moderated by cool groundwater inputs. However, most sites were responsive to day-night and week-to-week changes in heat inputs, and thus appear to be surface-flux driven."*
- *"Maximum temperatures at Skagit headwater sites were generally similar to those previously recorded in headwater streams monitored elsewhere in western Washington, especially during 2001 and 2002 when summer weather was fairly typical. Skagit tributaries were warmer than other sites during the unusually warm and dry summer of 2003."*
- *"Although the majority of monitoring sites did not exceed regulatory temperature standards, a sizable number did. Of the 97 sites over three years, 24 percent exceeded the AA standards currently used and 12 percent exceeded the proposed water temperature system using Core Rearing standards. The less frequent exceedance of the Core Rearing standard suggests that the newer standard is more lenient. This study did not assess which temperature standard is more suitable for supporting downstream fish populations or watershed health."*
- *"Skagit headwater streams, especially those that are surface-flux driven, appear to be sensitive to riparian forest conditions. Clearcut and debris-flow-scoured streams had significantly*

higher maxima and wider daily ranges during warm periods than did forested or buffered sites."

- *"Although temperature maxima generally increased in a downstream direction during the typical summers of 2001 and 2002, downstream warming and cooling were both observed during the unusually warm and dry summer of 2003. This appears to contradict the accepted pattern…that streams experience the greatest warming during the lowest flows. We speculate that temperatures during very low flows are increasingly influenced by groundwater inputs and inter-bed exchange, which have a greater relative influence when surface flows are smallest."*
- *"Buffers comprised of 10-30 m of unthinned forest along each side of headwater streams are largely effective at mitigating increases in temperature maxima. Buffered streams have a greater daily range than fully forested streams, a pattern which resembles clearcut streams. Sparse or blown-down buffers appeared to provide little temperature mitigation."*
- *"Regression analysis suggests that lower gradient streams require more shade and thus wider buffers for equivalent temperature mitigation, relative to steeper streams."*
- *"Further research is needed to determine the effects of temperature changes in headwaters affects biological productivity and the extent that warmed water propagates downstream to potentially affect salmonids. This will strengthen the applicability of these results to riparian management strategies."*

Information Relevant to Skagit River Relicensing: This report provides information on temperatures in headwater tributaries throughout the Skagit River basin on forestry managed lands, including those that drain into the Study Area for the Synthesis Study. Their analysis provides insights into how land use (forestry, buffers, and shading) and geomorphic (slope and groundwater) factors influence temperature patterns in headwater streams of the Skagit Watershed. However, their analysis focused on non-fish bearing streams above the distribution of anadromy, and the data may therefore have more limited relevance to the Synthesis Study. The authors indicate that headwater streams may respond to similar physical processes as larger fish barring streams, and that processes and conditions in header water streams can influence conditions downstream in fish bearing streams. Therefore, some of their key findings are potentially relevant to the Synthesis Study including:

- Lower gradient streams require more shade and wider buffers to ameliorate temperature impacts compared to steeper gradient streams;
- Skagit headwater tributaries appear to be more sensitive to temperature increases in warm dry years than other western Washington systems;
- Groundwater influences can alter the general pattern of increasing downstream temperatures;
- Clearcut and debris-flow effected streams had higher daily ranges and warm periods than forested or buffered streams;
- Seventy-eight percent of their study sites that exceeded the 16°C threshold (Class AA standards, classified as 7-day average of daily maxima temperatures not exceeding 16°C) had upstream areas impacted by timber forest;

- Study sites that did not exceed 16°C, were 87 percent of forested sites and 52 percent of managed streams; and
- Buffers that are 10-30 m of un-thinned forest along each side of headwater streams, are effective at mitigating increases in temperature maxima.

The authors suggest further research to determine the effects of temperature changes in headwater tributaries, and how these changes and processes impact biological productivity as well as the extent of warmer water flowing downstream to potentially affecting salmonids.

Veldhuisen and Haight (2001) (Unique Identifier: 163)

Reference	Veldhuisen, C., and R. Haight. 2001. Predicting 100-year peak flows for small forested tributaries of the Skagit and Samish rivers. Reported by Skagit System Cooperative, Sedro Woolley, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** hydrology. ***Land Use and Cover:*** land cover, forestry. ***Fish and Habitat:*** Habitat: instream flow.								
Species and Life Stages	NA								
Reaches and Spatial extent	East Fork Nookachamps Creek, Day Creek, other Sauk River tribs, other lower Skagit tribs, other upper Skagit tribs.								
Linkages to Hydroelectric Operations	NA								

Summary: This study's goal was to identify a simple and accurate method for estimating 100-year peak flows for small, forested tributaries with basin areas less than 1 mi^2 (however for the study, they included basins up to 10 square miles in the Skagit and Samish rivers. They used gaged tributaries with less than 10 square miles of drainage area, predominantly forestry land (greater than 50 percent forest cover) and had a minimum of 10 years of peak flow data from USGS. Overall, gage data from ten Skagit tributaries and one Samish tributary were used for analysis. Five additional basins that had similar forest cover and climates were used to help develop the prediction equation but weren't used for evaluating the prediction because of their location outside the Skagit basin. They used USGS's "weighted" peak flow values for 100-year peak flow values and annual precipitation data as inputs for their models. Peak flow predictions from their model were compared to observed 100-year peak flows, and fits were compared to two other equations developed in other studies to evaluate how well their new model fit observed data. They found that their new model improved prediction fits (adjusted r^2 value of 0.93) compared to previous models (adjusted r^2 value of 0.78-0.89).

Information Relevant to Skagit River Relicensing: This report provides a 100-year peak flow predictive model for small (< 10 mi^2), forested basins within the Skagit watershed. They also provide detailed information on two other models that they use to compare their model to, but these alternative models could also be considered from the information provided in this report. This model can help estimate streamflow rates during high-magnitude events which is invaluable to design applications such as road crossing structures and habitat enhancement projects. There is a limitation to this model since it was created specifically for small, forested basins, and the model should not be used for basins larger than 10 square miles. However, this model can also be used to help fill data gaps for ungagged small tributaries in the Study Area for the Synthesis Study, which could support hydrologic or hydrodynamic models, or life cycle models for the Synthesis Study.

Modeling Tools: An equation was developed that can be used to predict 100-year peak flows for small, forested basins:

$$Q_{100} = 0.844 \times DA^{0.739} \times AP^{1.229}$$

where Q_{100} is the 100-year peak flow in cubic feet per second, DA is the drainage area in square miles, and AP is the annual precipitation in area inches. This equation had an adjusted r^2 value of 0.93 which was slightly higher than previous equations (see Table 2). In addition, the new equation had smaller slope and closer to 1.0, indicating a better fit to the observed data. Detailed quantitative data and error analysis data are provided in the report that could be extracted to inform additional analyses for the Synthesis Study or other studies (e.g., hydrodynamic modeling).

Veldhuisen and Haight (2003) (Unique Identifier: 164)

Reference	Veldhuisen, C., and R. Haight. 2003. Regression models for estimating mean annual and low flows from Skagit tributaries. Skagit System Cooperative, Sedro Woolley, Washington.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow. ***Modeling tools:*** hydrology, data gaps.									
Species and Life Stages	NA									
Reaches and Spatial extent	Tributaries.									
Linkages to Hydroelectric Operations	NA									

Summary: This brief report for a conference discusses two empirical regression models based on local flow data for small to moderately sized Skagit tributaries (<100 mi^2) to estimate mean and low flows to support a variety of potential applications, including establishment of in-stream flow requirements. Twenty gages within the Skagit or Samish Basin were used (except for Deer Creek, adjacent to the Skagit basin) that had mean annual runoff, and some gages had 2-year 7-day low flow values data as well.

Information Relevant to Skagit River Relicensing: This brief paper provides potentially useful equations to estimate mean annual runoff and low flows for tributaries in the Skagit River watershed based on available gage data, which could be used to inform analyses or modeling of flows in the lower Skagit River and Synthesis Study. Tributary flows are a source of potential variation that attenuate or masks Hydroelectric Operation linkages with flows in the Study Area for the Synthesis Study, and therefore models like the ones developed in this paper are potentially useful evaluating linkages to Hydroelectric Operations. However, the paper does not indicate which tributaries were used in the analysis and additional work or data requests would be needed to determine which gages and tributaries were used.

Modeling Tools: Gage data were normalized by dividing the cfs by the basin area for both mean annual runoff and low flow regression equations. They found that out of the predictive variables, mean annual precipitation was significant ($p<0.001$) whereas basin area and mean elevation variables were not significant. For mean annual runoff, without glacial runoff, their equation was:

$$Mean\ Annual\ Runoff = Basin\ area\ \times (0.0845 \times Mean\ annual\ precipitation) - 2.31.$$

Where Mean Annual Runoff was in cubic feet per second, basin area was basin square miles, and mean annual precipitation was area-weighted over basin in inches. This equation had an adjusted R^2 value of 0.82. For the low flow model, which can work for glacial and non-glacial basins, the equation was:

$$2year7day\ flow = basin\ area\ \times ((0.154\ \times mean\ annual\ precipiation) - (0.000867 \times mean\ annual\ precipitation^2) - c)\ ,$$

Where 2year7day flow was in cubic feet per second, basin area was in square miles, mean annual precipitation was area-weighted over basin in inches, and where c is a constant that is either 5.83

for non-glacial basins and 5.36 for glacial basins. The adjusted R^2 value was 0.74. The authors state that these equations work well in predicting stream flow, but that there is a limitation within these models if the mean annual precipitation is outside the 59 to 125 inch range used to develop the regressions.

Veldhuisen (2018) (Unique Identifier: 166)

<table>
<tr><td>Reference</td><td colspan="10">Veldhuisen, C. 2018. Temporal trends and potential contribution factors to shallow landslide rates in timberlands of the Skagit River basin, Washington. Report by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Land Use and Cover: forestry, roads. Geomorphology and Landforms: history, change, substrate and sediment, sediment supply and transport, data gaps. Fish and Habitat: <u>Habitat:</u> instream flow.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Nookachamps Creek, Hansen Creek, Finney Creek, Jackman Creek, Other upper Skagit tribs (Jordan), Sauk River.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report looked at six sub-basins of the Skagit River (Nookachamps, Hansen, Finney, Jackman, Jordan, and Sauk Prairie Creeks) and their shallow landslide rates from the 1950s to the early 2010s to better understand the potential impacts of landslides on fisheries. They used aerial photographs and landslide inventories from various sources such as the Watershed Analyses mass wasting inventories, the Department of Natural Resources Geology Division's landslide hazard zonation inventories, and Veldhuisen's mapping of the landslides to 2011. Distinctions between landslides that could impact fish habitat were not used due to it being difficult to distinguish if the landslide impacted a small stream from the available aerial photographs. Stream flow data from USGS gages 12189500 and 12201500, located on the Samish and Sauk River, were used to analyze frequency of major storm events as a proxy to high soil moisture (which could trigger landslides). In addition, forest harvest and road construction rates were inferred from forest age data from three major forest landowners. Temporal landslide rates peaked between 1982 to 2001 before dropping from 2002 to 2011. The timing of landslide rates from 1982 to 2001 coincide with when logging rates were highest. Forest practice regulations became stronger in 1987 and revamped in 2001 which coincides with the drop in 2002-2011.

Information Relevant to Skagit River Relicensing: This study provides information on landslide rates in six subbasins within the Skagit River watershed (most of which are tributaries of interest for the Study Area for the Synthesis Study), including information on shallow landslides, history of forestry practices that coincide with landslide rates, and hydrology data from USGS gages that link landslide events to major storm events. Landslides are a major potential source of sediment and episodic sediment supply and transport events and processes can influence watershed processes, formation and maintenance of aquatic and estuary landforms and habitats, and the quality of fish habitat. This study provides landslide rates as well as quantitative data and analyses linking forestry practices and storm events to landslide frequencies, as well as a summary of major sediment types and a brief description of the terrain that encompasses the six basins. Data are generally summarized by tributary basin, therefore making the data directly relevant to each tributary system within the Study Area for the Synthesis Study. They indicate that extended monitoring landslide frequencies are needed to provide greater certainty on the relative strengths of potential driving mechanisms and trends in landslide frequencies. In addition, more definitive analyses of temporal inventories that quantify buffer implementation are needed to explore the relationship between buffers and implementation of buffer management practices and landslide rates. They also indicate that additional analyses of potential impacts of hydropower dams (Baker River and Upper Skagit River Dams) and natural variations in terrain and dynamic river processes in head waters on sediment supply and transport, and consequently their effects on fish and downstream habitats are needed in the Skagit River watershed.

Geomorphology and Landforms: From aerial photographs, shallow landslides greater than 1,000 square feet were counted to create decadal landslide frequencies (number of shallow landslides per square mile per decade). From that, 1982 to 1991 and 1992 to 2001 decades had the highest frequency of landslides, both averaging at 1.01 across all six basins (see snapshot of Figure 2 below). In the 2002-2011 decade, the average decadal landslide frequency was 0.19. Thirty-four percent of landslides were classified as debris flows and were most prevalent in Hansen Creek and Jordan Creek sub basins. Out of the 42 landslides identified in 2002-2011, 78 percent originated from areas last logged prior to 1987 or on roads. Only 10 percent of the landslides originated in sites that were logged since 2001. Overall, 34 percent of landslides were classified as debris flows, which are the most damaging of shallow landslide types. Deep-seated and small shallow landslides are estimated to contribute 36 percent and 17 percent of landslide sediment volume delivered to Skagit tributaries, although the authors do not evaluate sediment volume from the landslides identify in this study. A summary table of potential factors contributing to reduced landslide observations is provided (Table 3), which provides useful information on processes and linkages to resource conditions.

Fish and Habitat: Stream flow records were used to analyze storm events impacted the subbasins, and average annual peak flows are reported for 1952-2010 for Samish and Sauk River gages. Increase in discharge events after 1975 were apparent and could potentially explain the increase landslide rates during the 1980s and 1990s. However, there were major flows in 2004, 2007, and 2009, which did not coincide with the low frequency of landslide rates during 2002-2011. The authors indicate that sediment volume is a more appropriate metric to consider with respect to landslide impacts on fish habitat, but they did not evaluate sediment volume due to potential errors from estimating volume from aerial imagery. However, they propose that landslide frequency is an adequate proxy for that avoids the inherent errors of measuring depth or sediment delivery through remote sensing methods.

Land Use and Land Cover: After analyzing logging rates, which peaked in the 1980s, they found that there was a consistent relationship between landslides and harvest from 1970s to 1990s (the relative flat line period shown in the snapshot of Figure 5 below). It is predicted that forest practice mitigations got better after 1987 when stronger regulations were adopted and then expanded in 2001 that included additional restrictions on logging and road operations. Forest buffers on unstable slopes were slightly common in the 1990s but then were mandatory after 2001. They indicate that forest roads are a significant trigger for landslides in the Skagit River basin.

Volkhardt et al. (2006) (Unique Identifier: 404)

<table>
<tr><td>Reference</td><td colspan="10">Volkhardt, G., D. Seiler, S. Neuhauser, L. Kishimoto, C. Kinsel. 2006. Annual Report: 2005 Skagit River wild 0+ Chinook production evaluation. Report prepared by Washington Department of Fish and Wildlife for Seattle City Light.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: abundance, survival, fecundity, size structure, hatchery, density dependence, periodicity, data gaps; <u>Monitoring</u>: abundance; <u>Habitat</u>: instream flow, limiting factors. Water Quality and Productivity: turbidity, temperature.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: incubation, outmigration. Coho: outmigration. Chum: outmigration. steelhead: outmigration. Pink: outmigration. Sockeye: outmigration. Bull Trout: NA. Other species: Cutthroat.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R7-R13, US of R7.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: The objective of this report is to identify factors limiting production of (primarily) Chinook Salmon in the Skagit River. This report summarizes downstream migrant monitoring for Chinook Salmon in the Skagit River in 2005. This report represents the sixteenth year of downstream migrant monitoring led by the WDFW in the Skagit River, which was initiated in 1990 as concerns mounted over the poor stock status of Puget Sound Chinook Salmon. A major goal of the WDFW monitoring program is to identify limiting factors affecting Chinook Salmon production. Downstream migrants were sampled from January 21 to July 25, 2005, using a floating inclined-plane screen trap and a screw trap. Trap efficiency was calibrated through mark-recapture of hatchery and wild fish and included assessments of day and night efficiency and migration. The authors conclude that flow during the incubation period can explain most of the inter-annual variation in estimates of egg-to-migrant survival rates. The 2005 production was lower than was predicted based on flow. The authors speculate that a higher-than-average spawning population in 2004 may have induced a density dependent response on outmigrants in 2005. In addition, low flow conditions affecting outmigrating Chinook survival may have resulted in lower production. The authors recommend continued monitoring, and extended seasonal monitoring, to expand the range of spawning abundances and outmigration periods captured to improve our understanding of density dependence and limiting factors on production in the Skagit River watershed.

Information Relevant to Skagit River Relicensing: The data presented in this report are relevant to the Synthesis Study because it describes the state of juvenile outmigration for Chinook and Coho Salmon in the Skagit River in 2005, factors related to outmigration abundance/timing, and patterns relative to previous monitoring years (1990-2005). The primary mainstem trap is located within the Study Area for the Synthesis Study (near Mt. Vernon), but the data are presented at the watershed scale. Duration and timing of downstream migration are reported with numerous tables summarizing downstream migrant salmonid captures (including daily catches in the mainstem as an appendix and detailed methods for expansions of estimates based on capture efficiencies). They also provide maps of juvenile trap locations and hatchery release locations in the Skagit River watershed. Several quantitative metrics are summarized in the report which can potentially inform a life-history model. This report also provides hatchery production estimates, which may be important for considering wild-hatchery interactions. Some specific data on fish and habitat topics of interest provided in this report are described in more detail below.

Fish and Habitat: Over 90 percent of total downstream migration occurred between January and April. Roughly 50 percent of the wild age-0 Chinook outmigrants passed the mainstem monitoring traps by March 21. Migration timing was earlier than the median migration date observed between 1997 and 2004. Tables 2 and 3 show downstream migrant captures for all salmonid species encountered (Chinook, Coho, Sockeye, Pink, Chum, steelhead, and native char [which we assume to be Bull Trout]) 1990 - 2005. Extrapolations from catch in juvenile salmon traps estimated 4.6 x 10^6 age-0 wild Chinook for the 2004 brood year. Capture efficiencies for scoop and screw traps derived from a mark-recapture study are displayed in Table 6. Daily and weekly estimates of abundance are provided for all species. An estimated 25,175 adult Chinook returned to the Skagit River in 2004. Tables 4 and 5 display catch/hour, day:night catch ratios, hatchery:wild catch ratios, flow (cfs), turbidity, hours fished, and dates. Appendix A contains tables of total daily catches for Chinook, Chum, Pink, Sockeye, steelhead, and Cutthroat Trout. Table 11 contains data on mean fork length, standard deviation, range, sample size, and catch of wild age-0 Chinook from scoop and screw traps. Figure 8 displays mean fork length + range at each statistical week during monitoring. Average fecundity was reported at 5,500 eggs/female. Average survival to migration of wild Chinook was estimated at 0.0738 based on potential egg deposition of the number of estimated females (11,329). Estimated in-river survival of hatchery Chinook was 0.098. Low survival rates were partly attributed to very low flows during 0+ Chinook outmigration. Previous years survival estimates are available in Table 12.

Woodin et al. (1984) (Unique Identifier: 405)

<table>
<tr><td>Reference</td><td colspan="10">Woodin, R. M., S. C. Crumley, Q. J. Stober, and G. Engman. 1984. Skagit River interim agreement studies volume ii salmon and steelhead studies. Report prepared for City of Seattle, Department of Lighting, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat</u>: instream flow, freshwater; <u>Fish</u>: survival, rearing. Hydroelectric Operations: downramping, flow regulation, stranding.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: rearing. Pink: rearing. Chum: rearing. Coho: rearing.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">R7, US of R7.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Hydroelectric Operations: downramping; flow regulation, stranding.</td></tr>
</table>

Summary: This report for the City of Seattle discusses the effects of downramping (reduction in flow in response to declining power demand) on rates and timing of stranding in salmon fry in the Skagit River (1980-1983). The timing of downramping events significantly influenced salmon fry stranding on gravel bars. The authors observed fewer stranding instances when downramping occurred before dawn than after (post-dawn downramping increased stranding rates by a factor of 10.5). The rate of the downramp event (change in flow over time) was not correlated with stranding for pre-dawn events, but a positive correlation between fry stranding and downramping rates was observed in post-dawn trials. Tributary inflows were observed as moderating hydroelectric downramping effects on fry stranding rates. Dewatering of potholes associated with low tributary inflow was a contributing factor to stranding related mortality. This study offers two major recommendations for minimizing fry stranding mortality related to hydroelectric downramping. The first is a recommendation to establish minimum adequate flow levels which will maintain surface water over preferred salmon fry habitats during the rearing period. The second recommendation is that downramping should be timed such that the full effect of flow reduction is carried downstream before dawn, because of an apparent reduced dependence on substrate for refuge during darkness.

Information Relevant to Skagit River Relicensing: This study primarily focuses on reaches upstream of the Study Area for the Synthesis Study but includes portions of Reach R7 at the Sauk River confluence. The influence of downramping and downstream effects have implications for how hydroelectric operations can influence fry mortality and stranding, as well as how timing and intensity of downramping can help mitigate negative effects. The reaches upstream of the Sauk River confluence were determined to be the area of primary concern relative to downramping and fry stranding, but the study provides potentially relevant information for Reach R7 and how tributary flows mitigate downramping effects (which is potentially useful for the Study Area for the Synthesis Study given the downramping effects would be expected to further attenuate with increasing distance and input of tributary flows). Quantitative data is presented for fry abundance, streamflow, and downramp lag times. Tables report abundance of salmon fry collected by electrofishing and numbers stranded for each species (Chinook, Pink, Chum, and Coho) observed in March and April 1980-1983.

Fish and Habitat: Abundance data from electrofished and stranded fry are presented in Tables 1 – 3. Sporadic measurements of Chinook fry length were taken throughout the study and tables are provided reporting fork length summaries. Fork lengths averaged 41.2 mm (range: 33 – 52 mm; n = 694).

Hydroelectric Operations: Minimum tributary inflows at Marblemount to maintain marginal water levels in potholes at Rockport were reported. With a base flow of 2,300 cfs at Gorge Powerhouse, tributary inflow conditions must result in 3,700 cfs at Marblemount to ensure adequate marginal water levels in potholes at Rockport. However, specific flow values are subject to change with the morphological conditions within the reach. Roughly 7.5 hours of lag time was required for the entire downramp event to transfer from Gorge Powerhouse to Rockport. Summaries of downramping rates, times, and tributary inflows are provided for the 1980 – 1983 study period in Table 4. Stranding data is presented for each of three sites sampled (Thornton Creek/County Line, Marblemount, and Rockport). Stranding at Thornton Creek/County Line ranged from 0-17 fry per observation with a mean of 3.0 (n = 20). At Marblemount, stranding ranged from 0-38 and a mean of 9.2 (n = 28). Finally at Rockport, stranding ranged from 0-131 fry with a mean of 30.6 (n = 29).

Woodward et al. (2017) (Unique Identifier: 121)

Reference	Woodward, A., G. Kirby, and S. Morris. 2017. Skagit River coho salmon life history model- user's guide. Report prepared by U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 2017–1125, Reston, Virginia.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: periodicity, size structure, age structure, abundance, survival, harvest, density dependence, climate change, data gaps; Habitat: instream flow, ocean, freshwater, climate change, capacity, restoration, data gaps. ***Geomorphology and Landforms:*** scour. ***Water Quality and Productivity:*** turbidity, primary productivity, temperature, data gaps. ***Modeling Tools*:** life cycle, climate change.									
Species and Life Stages	***Coho:*** full life cycle***.*** ***Pink***: spawning.									
Reaches and Spatial extent	Skagit Watershed, including Baker River and Sauk River.									
Linkages to Hydroelectric Operations	NA									

Summary: This technical report serves as a user guide that summarizes the development, inputs, and outputs of a system dynamics model for Skagit River Coho Salmon. Much of this report is devoted to detailed summaries of how various factors may affect the Coho Salmon life history parameters informing the model, thus serving as a comprehensive resource for understanding Coho Salmon life cycle dynamics in the Skagit River. The model uses the Ricker stock-recruitment curve to estimate smolt production from returning adult abundance. The model calculates three main quantities: 1) Predicted smolts – the expected number of smolts based on spawner abundance and the Ricker production curve, 2) Realized smolts – calculates the expected effects of varying streamflow conditions, including summer low flow, winter scouring threshold, and turbidity, on smolt production, and 3) Escapement – fish remaining after subtracting ocean mortality and harvest. Since Coho population dynamics fluctuate in response to whether it is a Pink Salmon return year, the model alternates between two variations on the Ricker curve to account for Pink return year status. The authors indicate that the model can potentially be used to: (1) evaluate relative differences between climatic regimes or management actions, (2) describe how much annual variation can be explained by factors, (3) validate model with future data, (4) test for sensitivity to predictors, (5) public outreach, and (6) improving monitoring programs and restoration actions.

Information Relevant to Skagit River Relicensing: The model presented here is intended as a predictive tool for users to explore relationships between Coho Salmon production dynamics and several environmental factors in the Skagit River. They identify assessing restoration success as one potential application of the model. Parameter estimates of various relationships are provided and links to multiple data sources used to parameterize the model are also provided. Novel data are not presented, although the report provides detailed summaries of how various factors may affect the Coho Salmon life history parameters informing the model. Therefore, this source provides extensive information to inform development of hypotheses, conceptual life history models, and life stage factors for Coho in the Skagit River. Many of the references are for other systems or populations, but multiple references for Skagit River populations are provided and described.

The authors caution that the model is expected to become obsolete as future environmental conditions deviate from current baselines which are based on data from ~1990 – 2016. Data gaps identified by the authors include inadequate understanding of marine survival factors and potentially incomplete harvest data. In addition, several important limitations to the model are discussed, pointing to avenues for future study that include; (1) expanding the scope of the conceptual model, (2) extending the time series of the calibration, (3) adding additional factors (e.g., marine and freshwater predation), (4) including interactions in the model, (5) adaptive management for future changes or perturbations in the system (e.g., invasive species, adaptations/shifts in life history expression with changing conditions), (6) improved integration of ocean conditions, (7) refined spatial resolution, (8) improved temporal resolution, and (9) integration of stochasticity.

Fish and Habitat: Summary tables of metrics used to build and calibrate the model are provided in appendices and include abundance estimates for escapement and smolts, and smolt to adult survival for 1989 – 214 brood years. Background text indicates that Coho typically have a 3-year life cycle, with spawning occurring between late November and early February. Fry emerge in spring and juveniles grow in freshwater habitat from summer through winter and smolt the following spring before migrating to the ocean. However, small Coho may remain in freshwater for an additional year. The ocean phase can last anywhere from a few months to up to 30.

The model allows users to adjust baseline carrying capacity to account for changes in habitat through restoration, aggradation, sediment deposition, or changes in water temperature. Numbers are provided for unit changes in smolt production based on habitat availability. Restored areas in side channels can be expected to correspond to an additional 0.391 smolts/m^2 or 0.298 smolts/m^2 in tributaries (Beechie et al., 1994). Background text indicates that higher summer flows are associated with increased numbers of returning adults. Higher summer flows increase habitat availability. Climate change is expected to further reduce flows and lengthen the duration of summer low flows. In addition, winter high flows are projected to become more frequent (and subsequently increase mortality resulting from high flows and scouring). The information presented in the background text may be of value for informing Hydroelectric linkages to flow.

Geomorphology and Landforms: Peak flow thresholds to determine scouring events were set at 20,000 cfs (average daily peak) for flows in November through December when spawning occurs. It was previously known that flows above 54,400 cfs were known to be scouring flows in the Sauk so the threshold was set at 50,000 cfs for the Sauk. Fraction of production lost due to scouring flows was modeled at 0.2. The authors acknowledge that a fixed fraction of productivity loss over a certain flow threshold is an oversimplification and note several factors that can influence production loss due to scouring flow. These include the timing of scour events during the spawning period, scouring depth, and variations in annual flow regime within the river basin.

Water Quality and Productivity: The background information discusses several temperature thresholds for Coho Salmon based on estimates from other studies. Water temperatures between 18 ºC and 27 ºC are largely considered unsuitable for Coho Salmon. Some climate change scenarios (NorWeST project) indicate that August temperatures may reach 18-20 ºC in 24 km of the South Fork Skagit and in parts of Hanse, Day, and Finney Creek by the 2080s. Areas of the Nookachamps may reach temperatures as high as 20 – 30 ºC. Background information on turbidity outlines the challenges in using turbidity as a direct measure of suspended particles, nonetheless it is a useful index. Turbidity values at low as 18 NTU can have deleterious effects on fish survival and/or behavior. In addition, effects depend on exposure durations and whether or not pollutants co-occur. Alternatively, turbidity has also been observed to substitute as cover from predation. The effects of turbidity are complex and, at times, contradictory. Given the complex dynamics associated with turbidity, the authors settled on using number of days above 30 NTU to encapsulate both a high NTU exposure and duration (number of days) within the model. A quadratic relationship between days with turbidity > 30 NTU and residual deviations in predicted smolts was used to evaluate the choice of metric (Days above 30 NTU), which was consistent with literature accounts of turbidity effects and thus considered sufficient for the model.

Modeling Tools: The model uses a range of data sources for inputs that include fish abundance (smolt and escapement), size structure (fork lengths), harvest, and ocean mortality (survival); habitat metrics including instream flow; ocean conditions including PDO, NPGO, and SL; and water quality and productivity including Chlorophyll-a and turbidity. They also reference other studies that related ocean conditions to ocean mortality of Coho Salmon for Baker River. Model relationships used in the model are summarized in Tables 2, 3, and 5 from the report.

WWAA (2010) (Unique Identifier: 159)

<table>
<tr><td>***Reference***</td><td colspan="10">Western Washington Agricultural Association (WWAA), National Marine Fisheries Service (NMFS), and Washington Department of Fish and Wildlife (WDFW). 2010. Skagit Delta tidegates and fish initiative implementation agreement.</td></tr>
<tr><td>***Source Information***</td><td>***Type***</td><td>Report</td><td>***Status***</td><td>Final</td><td>***Quantitative Data***</td><td>Yes</td><td>***Spatial Data***</td><td>Yes</td><td>***Project Related***</td><td>No</td></tr>
<tr><td>***Topics and Keywords***</td><td colspan="10">***Fish and Habitat***: Habitat: restoration, barriers, estuary, capacity, riparian; Fish: periodicity, life history, diet, distribution. ***Land Use and Cover:*** agriculture, banks and shoreline. ***Geomorphology and Landforms:*** substrate and sediment, sediment supply and transport, large wood, log jam, floodplain connectivity. ***Water Quality and Productivity:*** temperature, pH, dissolved oxygen, nutrients, contaminants.</td></tr>
<tr><td>***Species and Life Stages***</td><td colspan="10">***Chinook:*** rearing. ***steelhead***: rearing. ***Bull Trout:*** rearing. ***Coho:*** rearing. ***Chum***: rearing.</td></tr>
<tr><td>***Reaches and Spatial extent***</td><td colspan="10">Skagit Estuary, Skagit Bay, and Padilla Bay including the Swinomish Channel.</td></tr>
<tr><td>***Linkages to Hydroelectric Operations***</td><td colspan="10">NA</td></tr>
</table>

Summary: This report describes the Skagit Delta Tidegates and Fish Initiative, which is a collaborative multi-stakeholder process convened by the Western Washington Agricultural Association. This Agreement was established in March 2006 and is intended to last 25-years, with the purpose of identifying pathways to support regulatory processes for the maintenance and restoration of tide gates and floodgates that are under the ownership of or control of the Drainage, Irrigation, and/or Diking Districts that have signed the Agreement. The Agreement is also designed to facilitate the restoration of functional estuary habitat in the Skagit Estuary that has *"…the least possible impact to established agricultural lands in the Skagit Delta, and their related infrastructure."* The Agreement is linked to the objectives of the Skagit Chinook Recovery Plan and stipulates that up to 2,700 acres of delta agricultural lands may be converted to estuarine habitat, and they include specific projects identified in Appendix D of the Skagit Chinook Recovery Plan. Collectively, these projects are estimated to have the capacity to produce 1.35 million smolts based on the analyses developed in the Skagit Chinook Recovery Plan. A total of 121 tide gate and floodgates are identified in this Agreement associated with these projects. A key objective of the Agreement is to streamline the regulatory process for maintaining tidegates and floodgates in addition to restoration of habitat associated with the tidegate and floodgate infrastructure. The responsibility of funding is placed on the restoration community and the Agreement also provides the framework for a credit banking process that will provide a system of checks and balances to support actions associated with this Agreement. The report provides extensive information on regulatory processes and requirements to support streamlined restoration and maintenance activities covered by the Agreement and includes sections (Parts) that cover: (Part 2) Framework for development and implementation, (Part 3) Permitting – tide gate and floodgate repair and replacement, (Part 4) Resource protection and conservation measures, (Part 5) Administration and management, (Part 6) Dispute resolution, (Part 7) Estuary restoration project funding considerations, (Part 8) Default and severability, and (Part 9) signatories to the Agreement. Appendices provide forms, checklists, and other supporting documentation for the Agreement.

Information Relevant to Skagit River Relicensing: This report provides relevant information on restoration of estuary habitat in the Skagit Estuary and provides a framework to support restoration actions that balance the needs of agricultural land uses and Chinook Salmon recovery goals associated with the Skagit Chinook Recovery Plan. The Agreement is wholly focused on the areas within the Study Area for the Synthesis Study and specifically focuses on restoration actions designed to support recovery targets for Chinook Salmon. However, much of the quantitative data and information presented in this report are derived directly from the Skagit Chinook Recovery Plan and associated appendices. The Agreement utilizes projects identified in the Skagit Chinook Recovery Plan to establish targets for restoration associated with the Agreement and identifies 121 specific tide gate and floodgate infrastructure associated with these projects that are considered in this Agreement. Extensive information on regulatory processes and requirements and best management practices (BMPs) are provided in the report to support the objectives of the Agreement and streamline the restoration process to support salmon recovery goals and agricultural land uses. Maintenance, repair, and replacement actions as well as restoration actions identified in the Agreement are described with linkages to potential impacts to fish and the report provides BMPs and guidelines to mitigate these potential impacts. Appendix A provides the most relevant information, with detailed descriptions of project areas and watercourses covered by the Agreement, which includes qualitative descriptions of habitat conditions and sources of impairments. Appendix B also provides descriptions of protected species and habitats within the Agreement coverage area, which includes Bull Trout, Chinook Salmon, and steelhead and the habitats that they rely on.

Fish and Habitat: Tables are provided from the Skagit Chinook Recovery Plan that provide potential estuarine area, potential channel area, connectivity index, and potential smolt capacity for projects identified in the Agreement (Tables 1-1 and 1-2). Spatial data are presented in maps showing potential restoration areas and actions identified in the Skagit Chinook Recovery Plan (Figure 2-1A) as well as watercourses and their classification (Figure 2-2) within the Skagit Estuary. An inventory of tide gate and floodgate infrastructure are provided in Tables 2-1 and 2-2, which provides priority ratings, name/location, size and type of pipe and lid construction, and maintenance activities organized by diking district. The location of these tide gates and floodgates are shown in Figures 2-3A through 2-3C. Appendix A provides detailed, but mostly qualitative, water course descriptions for projects identified in the Agreement which provide qualitative descriptions of habitat conditions and impairments to habitat quality including dominant substrate characteristics, sediment supply and transport, fish passage barriers and limited fish use (juvenile Chum, Coho, and Chinook), bank and shoreline conditions/modifications, large woody debris (LWD) and log jams, riparian conditions, floodplain connectivity, and water quality (e.g., temperature, pH, dissolved, oxygen, and various contaminants).

Appendix B provides descriptions of current habitat conditions and extent for the Skagit Estuary, Padilla Bay, Skagit Bay, and Samish Bay but limited citations are provided for the data and information presented. Table B-2 provides a list of fish species present and critical habitat by management jurisdiction for fall Chinook, spring Chinook, summer Chinook, summer steelhead, winter steelhead, and Bull Trout. In addition, narratives of listing status and designation of critical habitats as well as descriptions of basic life histories, periodicity, diet, and distribution are provided for Chinook, steelhead, and Bull Trout. Current conditions for the Skagit Estuary are described as having 6,316 acres of estuarine/riverine tidal habitat with 2,508 acres of estuarine emergent marsh, 2,471 acres of emergent forested transition marsh, and 1,337 acres of forested riverine tidal habitat. Channel area estimates are 1,436 acres of mainstem channel, 215 acres of subsidiary channels, 59 acres of large blind tidal channels, and 232 acres of small blind tidal channels. They indicate current conditions represent a 72 percent loss of total estuarine habitat from historical conditions, with the 84 percent loss of riverine tidal habitat, 66 percent loss of estuarine forested transition habitat, and 68 percent loss of estuarine emergent marsh habitat. Riparian conditions are rated as poor along sloughs and streams in the Skagit Estuary, and much of the Skagit Bay's eastern shoreline and the much of the Swinomish Channel are cited as having less than 10 percent overhanging riparian vegetation. The report indicates that nearly all of the historic salt marsh associated with Padilla Bay has been disconnected from tidal processes due to diking and drainage, but the amount of current or lost habitat are not quantified aside from 454 wetlands identified in the Padilla Bay watershed. Several sections of Padilla Bay shoreline are cited as having less than 10 percent overhanging vegetation. Padilla Bay has one of the largest intertidal eelgrass beds in the western United States, and the report indicates that eelgrass bed extent may have increased in area due to the diversion of Skagit River freshwater away from Padilla Bay. The report also indicates significant eelgrass beds in Skagit Bay and these are recommended for protection to support salmonids. Restoration of hydraulic connectivity between the North Fork Skagit River and Swinomish Channel is identified as a priority project in the Skagit Chinook Recovery Plan, and this would increase connectivity and fish passage between the Skagit Estuary and Padilla Bay habitats.

Land Use and Cover: Spatial data are presented in maps showing diking districts (Figure 2-1). Information on banks, levees/dikes, and shoreline armoring for project sites are provided in Appendix A. Appendix B provides descriptions of the Skagit Estuary, Padilla Bay, Skagit Bay, and Samish Bay with general information on land cover and predominant land uses. Riparian conditions are rated as poor along sloughs and streams in the Skagit Estuary, with 90 percent of landcover converted to non-forested use. Land use in the Padilla Bay drainage area is mostly agricultural (65 percent), and sediment toxicity and eutrophication are concerns for Padilla Bay. Most of the shoreline associated with Padilla Bay has been hydromodified with most shoreline leveed or riprapped. Swinomish Channel shorelines are extensively modified by levees, dikes, riprap, and bulkheads.

Water Quality and Productivity: This report indicates contaminated sediments (phenols and phthalates) have been documented in Padilla Bay, but no sources are cited. Land use in the Padilla Bay drainage area is mostly agricultural (65 percent), and sediment toxicity and eutrophication from increased nutrients delivered by sloughs are cited as concerns for Padilla Bay. Riparian conditions are rated as poor along sloughs and streams in the Skagit Estuary, with 90 percent of landcover converted to non-forested use and the authors claim that this is likely linked to high water temperatures found in many of these streams. The report indicates water quality in Skagit Bay is "good." Appendix A provides detailed, but mostly qualitative, water course descriptions for projects identified in the Agreement which provide qualitative descriptions of water quality and productivity concerns that include temperature, pH, dissolved, oxygen, and various contaminants and toxicity related topics.

Yang and Khangaonkar (2009) (Unique Identifier: 336)

Reference	Yang, Z., and T. Khangaonkar. 2009. Modeling tidal circulation and stratification in Skagit River estuary using an unstructured grid ocean model. Ocean Modelling 28(1-3):34-49.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Modeling Tools****:* hydrology, bathymetry. ***Water Quality and Productivity****:* salinity. ***Fish and Habitat****:* Habitat: nearshore, estuary. ***Geomorphology and Landforms:*** history.									
Species and Life Stages	NA									
Reaches and Spatial extent	R13-R15, Skagit Bay.									
Linkages to Hydroelectric Operations	***Modeling Tools****:* hydrology.									

Summary: This study presents an unstructured grid coastal ocean model to characterize tidal circulation, salinity stratification, and freshwater plume dynamics in the Skagit River estuary and Skagit Bay. Simulated results are presented under spring and neap-tide conditions and under low and high river flow scenarios and were calibrated to two-week periods in June 2005 and May 2006 and 2005 bathymetry data. The model results suggested that the Skagit River estuary is highly stratified, but that destratification can result from high river flood discharges, and that wind induced surge can significantly influence tidal elevations, currents, and wetting and drying processes in the shallow coastal areas of Skagit Bay.

Information Relevant to Skagit River Relicensing: This model provides a 3D model that can be used to simulate water flows, velocities, depth, salinity, and physical processes (e.g., salt intrusion, wetting and drying) in the Skagit River estuary and Skagit Bay, which are linked to river flow through oceanographic modelling. The model also provides a bathymetric grid and elevation is an important driver of transport and exchange processes in estuaries. The researchers found that salinity intrusion length in the Skagit River estuary scales proportionally to river flow at the -1/4 power, and that salt intrusion in the North Fork can reach River Mile 2 under low flow conditions. In contrast, high river flow conditions result in a strong river plume that pushes salt intrusion out approximately 1 km seaward from the river mouth. The authors also provide potentially useful information on the history of modifications in the Skagit River estuary and its delta that have influenced habitat formation and maintenance processes, including the construction of the jetty in 1938 along the norther river bank of the North Fork to prevent sediment transport into the Swinomish Channel. The Swinomish Channel has been dredged since the 1890s and is dredged every 3-4 years to a depth of 3.6 m.

The relationships characterized here and modeling tools developed have implications related to potential Hydroelectric Operations where flow regulation in the Skagit River may affect environmental conditions in the estuary. Model outputs are spatial and can be used to produce grids, transects, and vertical profiles of velocity, depth, and salinity at 5-sec time steps (but the model would require large processing power and calibration data to run for additional time periods), which could potentially support simulation or testing of Hydroelectric Operation scenarios. The authors indicate that flows at the USGS stream gauge at Mt Vernon, located 25 km upstream of the estuary mouth, are influenced by diurnal peaking cycles of power generation at upstream hydropower dams, but quantitative summaries of the influence are not explicitly provided in the report but are assumed to be accounted for in the model.

Zimmerman et al. (2015) (Unique Identifier: 331)

Reference	Zimmerman, M.S., Kinsel, C., Beamer, E., Connor, E.J., and Pflug, D.E. 2015. Abundance, survival, and life history strategies of juvenile Chinook Salmon in the Skagit River, Washington. Transactions of the American Fisheries Society 144(3):627–641.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	Links
Topics and Keywords	***Fish and Habitat**:* Fish: abundance, density dependence, survival, rearing; life history, fecundity, size structure, periodicity; Habitat: instream flow, freshwater, restoration, connectivity. ***Modeling Tools:*** adult returns, juvenile production.									
Species and Life Stages	***Chinook***: outmigration, incubation, overwintering, spawning, emergence.									
Reaches and Spatial extent	Skagit Watershed, including Sauk River and lower Skagit River populations.									
Linkages to Hydroelectric Operations	***Chinook***: outmigration, incubation, overwintering, spawning, emergence. ***Fish and Habitat**:* Fish: survival, rearing; life history; Habitat: instream flow. ***Modeling Tools:*** adult returns, juvenile production.									

Summary: This study is 16-year time series analysis (1993 – 2008) correlating streamflow data to Chinook Salmon abundance and survival across multiple life history stages in the Skagit River, Washington. The objective of this study was to further understand of how abundance and life history diversity of Chinook Salmon out-migrants are related to spawner abundance and stream flows during egg incubation. A model selection analysis was used to evaluate the spawner-out-migrant relationship, and to test for density-dependent survival across life history stages. The authors hypothesized that juvenile rearing would be a density-dependent process, while survival during incubation would reflect density-independent mechanisms (e.g., magnitude of peak flow events). The authors concluded that while overall survival in the Skagit River was a density-independent process mediated by flow events during egg incubation, the composition of out-migrants (fry, subyearling parr, and yearlings) could be explained as a density-dependent function of spawner abundance. The implications of this study for Chinook Salmon recovery are discussed in the context of flow regulations for the Skagit River Hydroelectric Project.

Information Relevant to Skagit River Relicensing: This study reports quantitative data on fish and habitat with linkages to Hydroelectric operations. Data collection for this study took place in the Skagit River mainstem (R7-R13 +US), including rotary screw traps located in the lower Skagit River study area at river kilometer 27, and findings are generalized to scale of the entire river system by focusing on out-migrant survival and spawner abundance. Several key findings relevant to the Synthesis Study and potential Hydroelectric Operations strategies:

- Freshwater survival of Chinook Salmon in the Skagit River is largely density-independent, due to flow mediated survival during incubation, and may be impacted by sustained moderate flow events just as much as short-duration high flow events.
- Because survival during the incubation period is a density-independent process correlated with the magnitude of peak stream flow events, overall survival in the river system is independent of spawner abundance.
- While overall survival is density-independent, the composition of juveniles post-emergence implies density-dependence during juvenile rearing. Continued efforts to improve quantity,

quality, and connectivity of habitats (e.g., restoration) important to juvenile stages (i.e., backwaters, side-channels, off-channel habitats, and log-jams) is therefore considered important to improving out-migrant survival.

- Reducing the duration of moderate flows is likely to increase survival of summer-run Chinook Salmon in the Upper Skagit River, because they are the population most directly impacted by flow regulations due to the location of their spawning grounds.

Fish and Habitat: This study provides data on abundance, survival, and fecundity estimates for six populations of Chinook Salmon in the Skagit River system. In addition, coefficients for several spawner-out-migrant models and for models relating out-migrant abundance to flow are provided that could be used to inform life cycle models. Escapement of 2,158 – 10,051 females between 1993 and 2008 (72 percent Upper Skagit River Chinook). 3.5 x 10^6 outmigrants per brood year (Avg.). Potential egg deposition averaged 32 million eggs per year (12-62 million eggs per year). Supplemental data for egg deposition estimates are also available. Yearly fry migrant production was 905,000 – 6,553,000, parr migrant production was 537,000 – 2,188,000, and yearling production was 6,000 – 97,000. Subyearling outmigrants represent 96.3-99.9 percent of the total freshwater production. The proportion of fry migrants increased with increasing total outmigrant abundance.

Incubation periods are described for several populations, including Sauk River and the lower Skagit River populations (see Table 1). Example plots of weekly abundance showing bimodal migration patterns are provided. Fecundity estimates by population with length and total estimated egg deposition and standard deviation are provided for all size populations (see Table 3). Subyearling fry are 40-50 mm FL and spend little time rearing in freshwater habitats, compared to subyearling parr that rear for several months in freshwater with an average size of 75 mm FL. Yearling smolts overwinter in freshwater habitats and are larger than 99 mm FL prior to outmigration. Adult females ranged in size from 83-92 cm among six populations. Fecundity was positively correlated with FL, and was different among spring, summer, and fall runs. Egg-to-outmigrant survival ranged from 0.045 – 0.215 from 1993 to 2008 (270 – 1,230 out-migrants per female), which is equivalent to 270-1,230 outmigrants/female. Egg-to-outmigrant survival was negatively correlated to four out of six flow metrics tested, including basin peak flows, proportion RI > 2, stock peak flows, and proportion RI >1.

Annual peak flows and recurrence intervals are provided in supplemental data, and include the Sauk River, and the proportion of incubation flows exceeding 1-year recurrence intervals was different among the populations. Boxplots are provided showing streamflow metrics among populations, including the Sauk River and lower Skagit River.

Linkages to Hydroelectric Operations were identified in the finding that density-independent survival of Skagit River Chinook Salmon was linked to both magnitude and duration of peak flow events during the egg incubation period, and the relationships they identified could be used to inform Hydroelectric Operation strategies. Although they note that upper Skagit River summer Chinook are most directly influenced by regulated flows, the density dependent relationships identified in this paper would suggest that flow regulation influences on survival or abundance could influence expression of life histories in the lower Skagit River study area. They cite other studies that indicate the magnitude of observed flows were almost 2x higher prior to dam construction and populations of Chinook salmon were persistent in the basin with these flows, and that variables other than just flow are needed to understand present-day low abundances.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT G

TIER 2 ANNOTATED BIBLIOGRAPHIES

1.0 OVERVIEW

This Attachment provides annotated bibliographies for sources categorized as Tier 2. For each identified source, the original abstract or executive summary was copied from the original source if it was provided, otherwise a brief summary was written. All sections labeled "Abstract" are directly copied from the source, otherwise, sections are labeled "Summary." Nine references were written in the Tier 1 Annotated Bibliography notation before the Tier 2 annotated bibliography style was decided upon. A header is provided for each source that gives a high-level summary of the key information for each reference including the source type, topics, species, life stages, and reaches covered; whether spatial or quantitative data are provided; and whether Project Related data or information are provided. The *Linkages to Hydroelectric Operations* field provides a list of the topics and keywords or species and life stages that are linked to Hydroelectric Project Operations in the source, and these represent a subset of the topics and keywords, or species and life stages included in the source. References are organized alphabetically and chronologically by the citation ID. Each annotated bibliography contains a citation ID that can be used to easily navigate to annotated bibliographies using the navigation pane.

2.0 TIER 2 ANNOTATED BIBLIOGRAPHIES

Anchor QEA (2009) (Unique Identifier: 506)

<table>
<tr><td>Reference</td><td colspan="10">Anchor QEA, LLC. 2009. Final geospatial methodology used in the PSNERP comprehensive change analysis of Puget Sound. Prepared for U.S. Army Corps of Engineers and WDFW by Anchor QEA, Seattle, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: nearshore habitats and landforms. Fish and Habitat: <u>Habitat</u>: nearshore, estuary, wetlands, restoration. Land Use and Cover: banks and shoreline.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) was initiated in September 2001 by the Seattle District Army Corps of Engineers (Corps) as a General Investigation (GI) Study, based on a feasibility cost-sharing agreement (FCSA) between the Corps and the Washington Department of Fish and Wildlife (WDFW). The purpose of a GI Study is to establish a partnership between the federal government and the local sponsor to investigate water resources problems and opportunities; the product of this investigation is a Feasibility Study. The PSNERP GI is a large-scale, comprehensive initiative to protect and restore the natural processes and functions in the nearshore environments of Puget Sound. This preface provides the background to the following report, Geospatial Methodology Used in the PSNERP Comprehensive Change Analysis of Puget Sound, which describes an integrated geodatabase that comprehensively characterizes physical conditions affecting nearshore environments of Puget Sound. This report is expected to be included, as an appendix, in a scientific document written in the future by the PSNERP Nearshore Science Team (NST), which will provide a more complete explanation of the analytical framework and findings of the PSNERP Change Analysis. Because it is produced earlier than the encompassing future document, it will serve as an introduction to the PSNERP Change Analysis and to complement metadata associated with the geodatabase.

Baker (2018) (Unique Identifier: 390)

Reference	Baker, J. L. 2018. The Fisher Slough case study: seven-year monitoring summary: measuring outcomes for fish, farms and flooding. 2018. Salish Sea Ecosystem Conference, Seattle, Washington.								
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related*** No
Topics and Keywords	***Fish and Habitat:*** <u>Habitat:</u> restoration; <u>Monitoring:</u> restoration, habitat, abundance.								
Species and Life Stages	***Chinook, Coho, Chum:*** not specified.								
Reaches and Spatial extent	R15 (Fisher Slough on the South Fork).								
Linkages to Hydroelectric Operations	NA								

Summary: This proceeding is a case study of Fish Slough restoration near the South Fork of the Skagit River. It provides an overview of the context and objectives of the project, which targeted restoring freshwater marsh for juvenile Chinook Salmon, passage for adult Coho and Chum spawners, and improve flood storage while also protecting adjacent farms. The main project elements were floodgate replacement, drainage reroute, and levee setback and marsh restoration. In addition, the project measured many variables post restoration. Converting the farmland into marsh, increased the flood storage capacity 5 times and 10 times more juvenile Chinook Salmon use the site (22,000 more juvenile Chinook per year). In addition, to biological responses, the project offered economic benefits including additional jobs and businesses hired to help.

Barker (1979) (Unique Identifier: 254)

Reference	Barker, M. 1979. Summary of travel time from tagging studies, 1950-1974. Technical Report 48. Washington Department of Fisheries, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: movement, status and trends; Monitoring: biotelemetry.									
Species and Life Stages	***Chinook, Chum, Coho, Pink:*** migration.									
Reaches and Spatial extent	Skagit Bay, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: During the years 1950 through 1974, over 14 tagging studies were conducted in Puget Sound waters on returning Salmon stocks. Due to the limited scope and/or success of many of these studies, the results often went unreported or were analyzed for purposes other than travel time.

This report describes the travel time by species from the area of tagging to the area of recovery in terms of the 1978 Puget Sound Commercial Salmon Management and Catch Reporting Areas (Figures 1 and 2).

Bartz et al. (2015) (Unique Identifier: 002)

Reference	Bartz, K. K., M. J. Ford, T. J. Beechie, K. L. Fresh, G. R. Pess, R. E. Kennedy, M. L. Rowse and M. Sheer. 2015. Trends in developed land cover adjacent to habitat for threatened salmon in Puget Sound, Washington, USA. PloS one 10(4):e0124415.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Land Use and Cover***: land cover, commercial, floodplain, urban. ***Fish and Habitat***: Habitat: nearshore, estuary, freshwater, status and trends, restoration; Monitoring: restoration, habitat.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: For widely distributed species at risk, such as Pacific salmon (Oncorhynchus spp.), habitat monitoring is both essential and challenging. Only recently have widespread monitoring programs been implemented for salmon habitat in the Pacific Northwest. Remote sensing data, such as Landsat images, are therefore a useful way to evaluate trends prior to the advent of species-specific habitat monitoring programs. We used annual (1986-2008) land cover maps created from Landsat images via automated algorithms (LandTrendr) to evaluate trends in developed (50-100 percent impervious) land cover in areas adjacent to five types of habitat utilized by Chinook Salmon (O. tshawytscha) in the Puget Sound region of Washington State, U.S.A. For the region as a whole, we found significant increases in developed land cover adjacent to each of the habitat types evaluated (nearshore, estuary, mainstem channel, tributary channel, and floodplain), but the increases were small (<1 percent total increase from 1986 to 2008). For each habitat type, the increasing trend changed during the time series. In nearshore, mainstem, and floodplain areas, the rate of increase in developed land cover slowed in the latter portion of the time series, while the opposite occurred in estuary and tributary areas. Watersheds that were already highly developed in 1986 tended to have higher rates of development than initially less developed watersheds. Overall, our results suggest that developed land cover in areas adjacent to Puget Sound salmon habitat has increased only slightly since 1986 and that the rate of change has slowed near some key habitat types, although this has occurred within the context of a degraded baseline condition.

Bates (1999) (Unique Identifier: 447)

Reference	Bates, K. 1999. Fish passage design at road culverts: a design manual for fish passage at road crossings. Report prepared by Washington Department of Fish and Wildlife, Olympia, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: barriers, restoration.								
Species and Life Stages	***Coho, Other species (Cutthroat):*** not specified.								
Reaches and Spatial extent	Other lower Skagit tribs.								
Linkages to Hydroelectric Operations	NA								

Abstract: This manual is for the design of permanent new, retrofit, or replacement road crossing culverts that will not block the migration of salmonids. The manual is intended for use by designers of culverts including private landowners and engineers. The level of expertise necessary to use this manual varies depending on site conditions and the design option selected. For all but the no-slope design option (described below), it is assumed that the designer has a basic background of hydraulic engineering, hydrology, and soils/structural engineering to accomplish an appropriate design.

This manual also provides an example of stream simulation design for Pringle Creek, a lower Skagit tributary. The example provides the problems associated with the old culvert as well as the solution to fixing the culvert to address those problems. It also provides the associated costs (in 1998 dollars) for fixing the culvert.

Beamer and Henderson (2015) (Unique Identifier: 125)

Reference	Beamer, E., and R. Henderson. 2015. Fir Island Farms technical memo- before restoration fish monitoring 2015. Memorandum to Washington Department of Fish and Wildlife, National Oceanic Atmospheric Association and The Nature Conservancy.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, estuarine habitats and landforms. ***Water Quality and Productivity:*** temperature, salinity, dissolved oxygen, primary productivity. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** <u>Fish:</u> abundance, hatchery, distribution; <u>Habitat:</u> barriers, estuary, restoration; <u>Monitoring:</u> abundance, water quality, restoration.									
Species and Life Stages	***Chinook, Chum:*** estuary rearing and emigration, outmigration.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary.									
Linkages to Project Operations	NA									

Summary: This report presented findings from monitoring efforts at Fir Island Farms in response to planned restoration that includes dike setback within the Skagit Bay estuary. Although this report only focuses on data from 2015, the overall study aims to include monitoring efforts for two seasons prior to and following the restoration efforts (from 2015-2018, see Beamer et al. 2018, ID213). During the monitoring efforts in 2015, a total of six sites were sampled with beach seines at three sites downstream and three sites upstream of a gravity operated top hinged tide gate located on No Name Slough that would be removed during restoration. These same sites were established as index sites to be used for the entirety of the study and were chosen because their physical characteristics were predicted to be minimally impacted by restoration and dike removal. Fish caught while seining were identified and counted by species, and environmental conditions at the time of sampling were recorded. Catches included Chinook and Chum Salmon as well as forage fish species (Three-Spine Stickleback, Pacific Herring, Surf Smelt, Staghorn Sculpin, Starry Flounder, English Sole, Shiner Perch, Peamouth, and American Shad). All results were presented in tables and included total fish counts by species and location, average maximum water depth, average surface and bottom temperature, average surface and bottom salinity, and average surface and bottom dissolved oxygen.

Information Relevant to Skagit River Relicensing: This report provides quantitative data on fish counts by species and environmental conditions within a restoration site that represent pre-restoration conditions. This data could potentially be used to draw conclusions on how target species including Chinook and Chum Salmon are impacted by restoration and their use of estuary habitats. This information can inform development of conceptual life history models for target species and life stages, as well as help inform identification of key factors affecting these species (e.g., tide gates and fish access to estuary habitats).

<u>Fish and Habitat</u>: Sampling during the study occurred from February 2015 to August 2015, and there were 12 days of sampling over that time period. Fish species and habitat data were collected during beach seine sampling along with the site, date, percent of set area, and time of sampling. Fish were identified and counted by species, and salmon of hatchery-origin were sacrificed for coded-wire tag reading. Total fish caught by species, including juvenile Chinook and Chum

Salmon, are shown in Table 2, which includes a mean catch per unit effort (beach seine set). The pre-restoration sampling resulted in a total of 14 Chinook and 1 Chum observed upstream of the tide gate, presumably due to the fact that the gate would leak during flood tides and allow passage. Results of the study were not discussed in detail within the report, but the data presented clearly show that there were significantly more fish present downstream of the tide gate than upstream of it.

Water Quality and Productivity: Environmental conditions were recorded along with sampling and included temperature, salinity, dissolved oxygen, and depth. Table 3 provides average maximum water depths, Table 4 provides average water temperatures (surface and bottom), Table 5 provides average water salinity (surface and bottom), and Table 6 provides average dissolved oxygen. (surface and bottom). The report also stated that velocity, substrate class, and vegetation class were recorded for each site during sampling, however that data was not presented in the report. Velocity, specifically, was not noted because there was no measurable velocity at the time of the study for any of the sites.

Beamer and LaRock (1998) (Unique Identifier: 003)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. M., and R. G. LaRock. 1998. Fish use and water quality associated with a levee crossing the tidally influenced portion of Browns Slough, Skagit River estuary, Washington. Report for Skagit County Diking District No. 22, Burlington, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: substrate and sediment, estuarine habitats and landforms. Water Quality and Productivity: temperature, dissolved oxygen, pH, salinity, primary productivity. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Fish:</u> abundance, distribution, rearing, size structure, periodicity; <u>Habitat:</u> barriers, estuary, connectivity; <u>Monitoring</u>: restoration, water quality, abundance, habitat, data gaps.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration, outmigration. Chum: estuary rearing and emigration, outmigration. Coho: estuary rearing and emigration, outmigration. Other species: NA.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary, Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report describes monitoring that took place following the construction of a levee with two top hinge gated culverts on a portion of Browns Slough in the Skagit River Delta, as well as the addition of a manually operated culvert 4 years later that allowed fish passage and tidal inundation that had previously been impeded. The purpose of the study was to evaluate the levee's impact on fish use, water quality, and habitat conditions near the location of the levee in Browns Slough and the effectiveness of the added culvert for fish passage. Three sites both upstream and downstream of the levee were used for sampling (6 in total), and fish abundance, water quality, and habitat type were recorded for each of the sites over 6 sampling events from April-May 1995. All sampling occurred while the culvert gate was fully opened and during peak juvenile salmon use. A total of 11 fish species were sampled including Chinook, Chum, Coho, Cutthroat, Smelt, Three-spine Stickleback, Sculpin (Prickly and Staghorn), Starry Flounder, Shiner Perch, and Peamouth Chub. All species were found upstream of the levee, suggesting that there was no impediment of movement of estuarine fishes. The results of the study showed that the manually operated culvert on the cross levee provided sufficient passage of fish and did not cause a significant difference in water quality on either side of the levee that would impact fish passage.

Information Relevant to Skagit River Relicensing: This report provides quantitative data on water quality and fish abundances in estuarine habitats that could be used to inform conceptual life history models for estuarine dependent target species, as well as informing the identification of factors affecting life stages. This is especially relevant given that other studies have identified estuary rearing habitat as a limiting factor for Chinook production (delta rearing fry), and restoration of tidal connectivity is a primary restoration strategy for increasing delta fry rearing capacity (Beamer et al. 2005, ID005). The study area in this report includes a levee that was later modified to restore fish passage through the addition of a manually operated floodgate, which is located at the downstream most fringe of the Skagit estuary near the outlet of Browns Slough into Skagit Bay. The modification of the levee and its impacts on the estuary habitat and fish abundances could be used to inform other restoration efforts. Additionally, implications on habitat loss and modification and estuarine habitat restoration were provided in the report. The original cross levee converted the habitat upstream from tidally influenced blind channel and saltmarsh habitat to palustrine open water and freshwater habitat and prevented the passage of fish. Although the addition of the manually operated culvert helped to restore this habitat, there was still an overall loss of estuarine habitat area and a reduction in the area inundated and time of inundation upstream of the levee that could lead to fewer feeding opportunities for Chum in particular. Regardless of these lasting effects, the restoration of fish passage through the culvert and access to estuary habitat on both sides of the levee indicate that similar alterations to culverts could still be a valid technique to restore habitat.

<u>Fish and Habitat:</u> Tidal stages and habitat types were determined at the time of sampling for each of the sites. Tidal stages were recorded as high, ebb, low, and flood, and habitat type was classified as channel, impounded, or marsh based on morphology, substrate, and depth. Locations of sampling sites in relation to the cross levee as well as roads and dikes within the Browns Slough are depicted in Figures 2 and 3. High tide magnitude and timing varied significantly between the two sides of the levee, with high tide occurring later and at a smaller magnitude on the slough side than the bay side (downstream). This difference was demonstrated in Figure 5 in the report. Mean depths at sampling sites varied by habitat type. Mean depths from deepest to shallowest were impounded (4.05 m), channel (1.52 m), and marsh (0.37 m).

Sampling occurred during the first rearing season following the addition of the gated culvert to the cross levee from early April to early May 1995. About 24,000 fish were caught in total including 11 different species, and that catch data is provided in Table 1. Of the beach seine sets completed, Chinook were present in 84 percent, Chum were present in 86 percent, and there was no significant difference in mean catch between the two sides of the levee. Figure 6 presents the average densities for juvenile Chinook and Chum within the study area. Mean juvenile Chinook density was significantly lower in impounded and marsh habitats than in channel habitat, but there was no significant difference for juvenile Chum densities across the habitats. Given the low statistical power of the tests, it could not be concluded that densities were the same across habitats for Chum. Further analyses between sites only used samples that had been collected in channel habitats. In addition to variation by habitat type, there was also variation in abundance of Chum and Chinook by tidal stage. Figures 7 and 8 show the profiles for Chinook and Chum Salmon juvenile abundances by tidal stage within the study area. When juvenile salmon densities were compared between Browns Slough and other similar sites, Browns Slough had intermediate density values.

Juvenile salmon beach seine data were sorted by tidal stage and week sampled, and individual catches were converted to percentage of total weekly catch by tidal stage. These values were then averaged by tidal stage and site, plotted to create a catch profile, and used to determine whether more habitat work would be necessary. Additional habitat restoration work is suggested within the study area whenever values immediately upstream of the levee (Site 3) are less than those immediately downstream of the levee (Site 4).

Results of the study showed that there was a greater average proportion of juvenile Chinook at Site 4 than Site 3 at 3 of the 4 tidal stages observed. There was only a greater proportion of Chinook at Site 3 than Site 4 during low tide. These results were the opposite for juvenile Chum Salmon, and high tide was the only time at which the proportion of Chum was higher at Site 4 than Site 3. In scenarios for both species when Site 4 values were less than Site 3 values, mitigation is required based on the guidelines listed above. Due to the high variability in abundances for both species, further analyses were conducted using a larger sample size that included the whole study area instead of just Sites 3 and 4. Variability in abundances in sampled tidal areas were attributed to their schooling behavior and resulted in the assumption that their densities were consistently underestimated.

The timing of juvenile salmon through the study matches the typical timing curves for the species as they would be outmigrating and occupying different habitats naturally (without levee present), and fork lengths were consistent across sites and increased over time. Both of these observations would suggest that the manually operated gate while in the open position does not interfere with fish passage.

Appendix 1 of this report contains eight tables containing a majority of the quantitative data from the study. Table 1 shows habitat characteristics and catch of salmon and trout species, and Table 2 shows the catch data for non-salmon/trout species. Tables 3-6 show results for statistical comparisons of juvenile Chinook and Chum densities by habitat type. Tables 7 and 8 show juvenile Chinook and Chum densities and percent daily catch in channel habitats and were used in the analyses between sites downstream of the levee (3) and upstream of the levee (4).

General observations on movement were also recorded for Chinook and Chum. Both species were observed in schools moving with the current and feeding near the surface. Chinook were seen delaying their movement through lower velocity areas that potentially provided better feeding opportunities, but Chum did not delay their movement. Data gaps in monitoring were also noted at the end of the report. It was suggested that future research utilize the information from this study but make an effort to decrease the factors that contributed to variability. The two main suggestions were that future monitoring should account for the high levels of variability in fish data collection if differences in fish abundance are a monitoring objective, and that future monitoring should measure sufficient samples of fish growth and survival if they are important monitoring objectives.

<u>Water Quality and Productivity:</u> The water quality parameters that were measured in this study were temperature, depth, conductivity, salinity, pH, and dissolved oxygen. Data for all of the parameters including means and standard deviations by site and tidal stage, plots of those means, maximum and minimum measurements, and comparisons between parameters of Site 3 (downstream of levee) and 4 (upstream of levee) are presented in Appendix 2. Some of the parameters at Sites 3 and 4 were then compared to Class A marine water standard values:

- "Lowest concentration of dissolved oxygen: 6 milligrams per liter (mg/L).
- Maximum water temperature: 16 degrees Celsius.
- Range of pH factor: 7.0 to 8.5."

As parameter data compares to the standards listed above, dissolved oxygen remained within standards for all measurements, the water temperature exceeded standards at all stations in the profile, and pH also exceeded the standard at all stations. There were two dissolved oxygen readings, 3.7 mg/L and 3.8 mg/L that did fall below the standards on April 4th and 5th of 1995 in site 5A which includes a scour hole. Differences in temperature on either side of the levee were greatest during flood flows, and temperatures were not consistently higher on one side throughout the study. The flood flow phase also resulted in the greatest difference in pH between Sites 3 and 4, but that difference was only 0.3 pH. The greatest differences in conductivity and salinity occurred during low tide, and there were varying levels of stratification and homogeneity throughout the study. The Skagit River provides a great amount of variation in salinity from day to day as flows vary and contribute different levels of fresh water to the saltwater system. Other than the more homogenous nature of the water parameters immediately downstream of and caused by the levee, it was determined that the levee did not have an effect on parameters or exacerbate them in any way. The parameters above and below the levee were similar, and any deviation from the standards appeared to be of natural causes.

Beamer and Wolf (2011) (Unique Identifier: 184)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., and K. Wolf. 2011. Measurements of landscape connectivity for blind tidal channel networks and selected pocket estuary outlets within the Skagit tidal delta and bay. Report prepared by Skagit River System Cooperative Research Program, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, estuarine habitats and landforms, nearshore habitats and landforms, channel migration. Modeling Tools: connectivity. Land Use and Cover: banks and shoreline. Fish and Habitat: Habitat: estuary, pocket estuary, nearshore, connectivity, restoration; Fish: movement; Monitoring: restoration, habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: outmigration, estuary rearing and emigration, nearshore rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary, Padilla Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report explains the importance of landscape connectivity as it relates to salmon recovery. In the Skagit estuary in 2003, landscape connectivity explained 68 percent of seasonal Chinook Salmon densities that resulted in the following additions to the Skagit Chinook Recovery Plan: *"Restoration of habitat connectivity within the delta because of the loss of historic connectivity due to human-caused blocking of distributary channels, and Application of concepts of habitat connectivity as a means to prioritize and predict outcomes of specific delta and pocket estuary restoration sites."* Given the importance of connectivity, a GIS layer of point data, *LandscapeConnectivity_Skagit2000*, was created to calculate landscape connectivity between the mouths of blind tidal channel networks within the Skagit tidal delta and pocket estuaries in their adjacent nearshore areas to aid in recovery and monitoring efforts. These sites were selected from two intermediary GIS layers, *fish_direction* and *tidelta2000* that contain pathways of juvenile Chinook and habitat polygons, respectively. *Fish_direction* arcs were chosen using those layers, and landscape connectivity values were calculated based on the length of an arc and bifurcation index (Bi). Arc lengths were multiplied by Bi, summed for arcs with multiple routes in the same fish migration pathway, and divided into 1 (1/sum) to get the landscape connectivity value. Sub-delta polygons were then chosen and compared based on their connectivity values.

Information Relevant to Skagit River Relicensing: This report describes landscape connectivity data as well as the calculations and methodology used to create connectivity values from GIS data. These methods could potentially be used to evaluate connectivity of other portions of the study area and to guide restoration in the areas already evaluated. These methods have been applied in more recent studies to develop additional time steps of connectivity for the Skagit estuary (Greene et al 2021, ID056), and landscape connectivity concepts and data can be used to inform development of conceptual life history models as well as factors affecting target species and life stages for the Skagit River Relicensing SY-01 Synthesis Study. The report included multiple figures that show the area that was used for different steps in the process of determining the connectivity values. The special strata/sub-delta polygons used for comparisons in the report were determined based on juvenile Chinook monitoring and restoration from Greene and Beamer (2006, ID231).

<u>Fish and Habitat</u>: There were 643 GIS data points representing blind tidal channel networks in the Skagit delta and pocket estuaries. The average landscape connectivity value across all of the points was 0.02815, however that value varied greatly across strata. The average, standard deviation, and sample size of landscape connectivity values per spatial strata are presented in Figure 4. The order of highest to lowest average connectivity values were the North Fork, South Fork, Central Fir Island, Skagit Bay pocket estuaries, Stanwood-Camano, and then Swinomish Channel to S. Padilla Bay. The Swinomish Channel to S. Padilla Bay had the lowest average value because it includes the North Fork Jetty and McGlinn Island Causeway greatly impact fish movement. Central Fir Island also experienced lower connectivity through sloughs (Brown, Hall, and Dry) that decreased the number of historic fish migration pathways.

Figure 1 shows the point data for the tidal delta blind channel and pocket estuary locations selected as well as the *fish_direction* arcs showing projected pathways for juvenile Chinook through these habitats. Figure 3 presents a long-term monitoring site, Cattail Saltmarsh along with the arcs determined from the *fish_direction* layer and subsequent landscape connectivity calculations. The point data are shown in Figures 5 and 6. In Figure 5, blind channel and pocket estuary points are colored according to spatial strata, and in Figure 6, point data are presented and colored according to the range of landscape connectivity values. Appendix A and B contain the methodology for determining bifurcation order rules for *tidelta2000* polygons and *fish_direction* arcs beyond the edges of the *tridelta2000* data layer, which can be applied to develop additional datasets.

Beamer and Wolf (2016) (Unique Identifier: 185)

<table>
<tr><td>Reference</td><td colspan="10">Beamer E., and K. Wolf. 2016. Changes in landscape connectivity within the North Fork Skagit River tidal delta, 2004 through 2015. Report prepared for NOAA/WRCO SRFB Skagit HDM Project under agreement P104051-A102542-n/a by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, channel migration, estuarine habitats and landforms. Modeling Tools: connectivity. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Fish:</u> abundance, rearing, periodicity, movement, life history, density dependence; <u>Habitat:</u> connectivity, estuary, nearshore; <u>Monitoring:</u> abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: outmigration, estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: The purpose of this report was to calculate landscape connectivity values resulting from avulsion of the North Fork resulting in a new distributary. This report supports the Skagit Chinook Recovery Plan in which landscape connectivity was used in carrying capacity models to predict the benefit of restoration projects in the recovery plan on the Chinook population. The scope of work for the study was to create a new GIS fish_path layer from more recent (2013) orthophoto, discuss differences between fish_path layers from 2004 to 2013, calculate landscape connectivity values to five fish sampling sites within the North Fork Skagit tidal delta, and examine trends in connectivity using juvenile Chinook Salmon densities. The new layer was created based on the 2013 orthophoto and compared to the previous layer from 2004. Landscape connectivity was calculated from these layers for the North Fork Skagit tidal delta, and the layers combined with seasonal juvenile Chinook Salmon densities were used to calculate connectivity to fish sampling sites in the tidal delta and Fir Island Bay fringe. It was reported that landscape connectivity of the Skagit tidal delta explains about 59 percent, but up to 89 percent, of seasonal variation in juvenile Chinook densities, however the changes to connectivity caused by the addition of the new distributary are not large enough to observe significant changes in fish distribution through landscape connectivity plots.

Information Relevant to Skagit River Relicensing: This report provided both quantitative and spatial data relating to landscape connectivity and juvenile Chinook densities that could be used to evaluate how landscape connectivity affects salmon populations. Over time, this approach can be used to evaluate or predict changes to landscape connectivity with natural change and restoration, and therefore inform Chinook recovery planning. Landscape connectivity is an important factor influencing estuary rearing and emigration life stages for Chinook Salmon, and therefore the models and data used in this study can be used to inform conceptual life history models and identification of factors influencing life stages for target species for the Skagit River Relicensing SY-01 Synthesis Study.

<u>Modeling Tools:</u> The fish_path GIS layers from 2004 and 2013 (figure 1) were used to compare changes to the landscape over time and showed the pathways that Chinook would take in order to reach rearing habitat. They also quantified distributary bifurcation orders (Bi) for habitats within

the Skagit tidal delta. Values for landscape connectivity are greater than 0 and less than one, with higher values representing more connectivity. The equation used to calculate landscape connectivity for each of the five fish sampling sites is provided in the report and described in other sources considered in the Skagit River Relicensing SY-01 Synthesis Study.

Figure 2 provides the GIS maps of the North Fork Skagit tidal delta that also includes Bi values in both 2004 and 2013. The changes in landscape connectivity in the North Fork Skagit River observed between 2004 and 2013 were lower connectivity for Dunlap Bay-Sullivan Slough, similar connectivity for the North Fork Skagit River main distributary-Swinomish Channel, and increased connectivity for marshes south of North Fork Skagit River. A new distributary had formed between 2004 and 2013 (around 2006) that created a more direct migration path for Chinook with a similar Bi value to other pathways. Landscape connectivity was then calculated for 5 fish sampling sites within the North Fork Skagit tidal delta located near the distributary formed in 2006. Juvenile Chinook density values for each of the 5 sites were calculated from the Skagit Intensively Monitored Watershed project data. The density values for this study were called "seasonal juvenile Chinook density," and the calculation was based on average monthly density, the number of days in a month, and the first and last months sampled.

<u>Fish and Habitat:</u> A GIS layer was created with the 5 sample sites for both years (2004 and 2013) and used to calculate landscape connectivity values to the sites (shown in Figure 4). Connectivity values for the 5 sites were summarized in Table 2. The changes in connectivity to the different sites varied in significance but remained relatively stable for all sites. Connectivity has begun to decline for Cattail Saltmarsh and Ika Saltmarsh following the end of the study in 2013 as the new distributary widens. Landscape connectivity for the 2 bayfront sites, Browns SI Barrow Channel and Browns SI Diked Side, using the new distributary increased by 20 percent from 2006-2015, however it still had a 14 percent lower connectivity value than Freshwater Slough due to a longer distance and unfavorable flow direction. Comparisons between landscape connectivity at each of the sites to seasonal juvenile Chinook densities were presented in Figure 5. It was determined that a statistical approach would be necessary to determine whether the new distributary significantly changed the distribution of juvenile Chinook.

Appendix 1 includes the metadata for the GIS data layers used in the report, and Appendix 2 presents site maps from 2013 and 2015 with routes taken and landscape connectivity calculations which can be used to develop additional datasets.

Beamer et al. (2003) (Unique Identifier: 193)

Reference	Beamer, E., A. McBride, R. Henderson, and K. Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Report prepared by Skagit System Cooperative, Research Department, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, sediment transport and supply, estuarine habitats and landforms. ***Land Use and Cover:*** agriculture, urban, banks and shoreline. ***Fish and Habitat:*** Habitat: estuary, pocket estuary, nearshore, ocean, connectivity, limiting factors, restoration; Fish: diet, density dependence, survival, predation, life history, rearing, size structure, growth; Monitoring: abundance, otoliths.								
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration, nearshore rearing and emigration. ***Coho, steelhead, Other species:*** not specified.								
Reaches and Spatial extent	Skagit estuary, Skagit Bay, Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: This report uses previous research to identify pocket estuaries as a priority habitat for juvenile Chinook within the Skagit Bay that requires research and restoration. It was estimated that estuarine delta habitat has shrunk by 80 percent, adversely affecting the juvenile Chinook that use these areas as rearing habitat. The delta habitat in its current state is a limiting factor for wild juvenile Chinook populations because their size and abundance are density dependent in estuarine habitats. The pocket estuaries within the study area are essential from providing fry migrant salmon with extended rearing and growth opportunities throughout the winter and spring as well as more protection from predators than other habitats. Pocket habitat is explained along with their benefits in providing juvenile salmon with refuge from predators, and their degradation and potential for habitat restoration is discussed. The report suggests that pocket estuary restoration should be pursued to benefit Chinook in the fry migrant life history stage, but that delta restoration remain the primary focus of restoration efforts within the Skagit Bay.

Information Relevant to Skagit River Relicensing: Information regarding juvenile Chinook use of pocket estuary and delta habitats is presented in this report. The quantitative data along with information presented on juvenile use of different estuarine habitats at different life history stages and time of year could be used to inform conceptual life history models for target species. The identification of pocket estuary and delta habitats as limiting factors in Chinook populations are of particular interest, and restoration of these habitats is suggested to increase the success of populations of this target species. Spatial data is also provided including a map of historic and present pocket estuary habitats. Some of these habitats fall within the area of the Skagit River Relicensing SY-01 Synthesis Study and could be used as sites for potential restoration.

Fish and Habitat: When smolt outmigration levels are above 2,500,000, the proportion of fry migrants in the population increases. This is also related to the density dependence in the delta and results in the displacement of juveniles from rearing habitat in the delta and into Skagit Bay. Nearshore systems are also stressed as important habitat for recovery of Chinook because the success of life stages that occur in the nearshore environment significantly influence adult spawning recruitment.

Use of pocket estuaries by juvenile Chinook is "non-natal," and all juveniles utilizing the habitat have migrated there from their natal streams. Figure 4 shows the abundance and average fork length of juvenile Chinook utilizing different habitat types within the Skagit Bay at different times throughout the year. It shows that the use of pocket estuary habitat closely resembles use of Skagit Delta, and that juveniles are more abundant in pocket estuaries than in nearshore or offshore habitats.

Utilization of pocket estuary habitat is dependent on life history stage and size of Chinook. Fry migrants predominantly use the pocket estuary habitat from February to May, and larger fish use the offshore habitats later in the season (May-August). Juveniles start off at similar sizes in February, but sizes begin to differ over the rearing period. During rearing before May, juveniles are larger in the pocket estuary habitat than the nearshore habitat, but juveniles in the nearshore habitat were larger after May as fish were making their way out of estuary and delta habitats and into the nearshore and offshore habitats. The larger size of juveniles in pocket estuary habitats before May could be either because the fish in the habitats are more isolated or that these habitats are more productive. It was also hypothesized that pocket estuaries provide a refuge for Chinook fry from predators. This hypothesis was based on "(1) preliminary data establishing a relationship between predator size and prey size, and (2) applying the relationship to size and abundance data of potential predator species and juvenile Chinook found in both pocket estuary and adjacent nearshore habitat." The preliminary data related to this hypothesis included predator/prey relationships based on diet samples of 101 predators across different species and ranging in length from 42 mm to 640 mm. The analysis of the diet samples showed that frequency of fish included in predator diets was dependent on length of fish, with all fish predating on other fish being above 75 mm. The results of the analyses by length and habitat type are shown in Figures 5a-d. From this data, it was shown that Chinook fry were exposed to much less predation in the pocket estuary habitat than in in the nearshore habitat.

Pocket estuaries have experienced significant loss and degradation, reducing the amount of shallow, protected habitat for migrant fry to rear in. Nearly 656 acres of pocket estuary habitat have been degraded or removed, and even more habitat has been made inaccessible by tide gates, roads, fills within tidal wetlands, and dredging. Although pocket estuary was proposed as a priority for restoration to benefit Chinook populations, it was stressed that this restoration should be performed in addition to, not in place of, delta restoration. Delta habitat provides necessary habitat for different life history types than pocket estuary, and it covers a greater area. The potential for pocket estuary is limited to only 583 acres, but restoration for delta habit could cover up to 20,000 acres.

Beamer et al. (2004) (Unique Identifier: 194)

Reference	Beamer, E., R. Henderson, and K. Wolf. 2004. Bull trout use of Swinomish Reservation waters. Report prepared by Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms, sediment transport and supply. ***Water Quality and Productivity:*** temperature. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: freshwater, pocket estuary, nearshore, restoration; Fish: abundance, diet, life history, size structure, age structure.								
Species and Life Stages	***Bull Trout:*** full life cycle. ***Coho, Chinook, Other species:*** not specified.								
Reaches and Spatial extent	Skagit estuary, Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: This report describes how bull trout use Swinomish Reservation waters based on existing data collected by the Skagit River System Cooperative (SRSC) Research Program. The same general relationships between fish and habitat use and Skagit Bay Bull Trout population trends have been provided as a draft report (Beamer and Henderson 2004) to the Puget Sound Bull Trout Technical Recovery Team (TRT) via Fred Goetz of the TRT and United States Army Corps of Engineers (USACOE).

Current bull trout population size within the Swinomish Reservation waters has increased 4-fold since 1995. Age structure of bull trout in Skagit Bay has also become older and more complex. From 1996 through 1998, 95 percent of the population was sub-adult sized, and too young to reproduce. From 1999 through 2003, a tri-modal length distribution of fish indicates sub-adult, first year spawner, and mature spawner sized fish are present. Together, these population factors (more abundance and multiple age classes) should make the current Skagit Bay bull trout population more resilient to threats to its population than a decade ago. Since we are also investigating habitat use by bull trout during a time where more individual bull trout are present, we are more likely to be detecting true habitat preferences by bull trout rather than making random observations of presence or absence.

We describe bull trout use for four habitat areas found within the Swinomish Reservation. They are: freshwater streams (Figure 1), lagoon or saltmarsh dominated “pocket” estuaries (Figure 2), shoreline areas in Skagit Bay (also Figure 2), and historic delta areas within and along Swinomish Channel (Figure 3). We also describe the potential importance of habitat in terms of its direct or indirect use by bull trout. Direct use refers to the idea that bull trout are present in a specific habitat area performing a necessary life cycle function such as spawning, rearing/foraging, or seeking refuge (e.g., from predation and/or environmental stressors). Indirect use refers to habitats that support food-web elements/organisms upon which bull trout depend. Indirect use conclusions are established by observing abundant prey resources (known to be regionally consumed by anadromous bull trout) within specific habitat types.

Beamer et al. (2004) (Unique Identifier: 195)

Reference	Beamer, E., A. McBride, and R. Henderson. 2004. Lone Tree Pocket estuary restoration 2004 fish sampling and pre-restoration project monitoring report. Report prepared by Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, estuarine habitats and landforms. ***Water Quality and Productivity:*** salinity. ***Modeling Tools:*** bathymetry. ***Fish and Habitat:*** Habitat: instream flow, barriers, pocket estuary, nearshore, restoration; Fish: abundance, distribution, age structure, periodicity, hatchery; Monitoring: restoration, data gaps, habitat, abundance, flow.								
Species and Life Stages	***Chinook, Coho, Pink, Chum, steelhead:*** estuary rearing and emigration, nearshore rearing and emigration. ***Other species (Stickleback, Prickly Sculpin, Staghorn Sculpin, Shiner Perch, Surf Smelt, Sandlance, Herring):*** not specified.								
Reaches and Spatial extent	Skagit Bay, Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: The primary objective for the Lone Tree Creek and Lagoon Pocket estuary project is to increase the size and ecological capacity of the Lone Tree pocket estuary by restoring tidal hydrology to the historic lagoon and freshwater hydrology and sediment dynamics (transport and deposition) in Lone Tree Creek. The plans to restore tidal hydrology to the upper wetland of Lone Tree Lagoon primarily is removal of an undersized, perched culvert and replace it with a bridge, thus increasing the tidally influenced area of the lagoon (Figure 1). In the wetland area upstream of the culvert (referred to as the restoration project area) we hypothesized the following immediate (i.e., within one year after the culvert is removed) responses to restoration.

Hypothesis 1 - The tidal prism will increase above the culvert, as indicated by an increased frequency and area of tidal inundation.

Hypothesis 2 - The frequency and degree of estuarine mixing, as demonstrated by increased salinity above the culvert, will increase.

Hypothesis 3 - The fish community will change from a sparse to absent freshwater community to a more abundant and diverse community dominated by estuarine species.

This report describes pre-restoration water surface elevation, salinity, and fish use conditions. These data will be used to test the restoration hypotheses described above. We followed the protocols and schedule presented in the Lone Tree Pocket estuary Restoration Fish Sampling Plan written by E. Beamer and others, February 2004. This report also includes recommendations for future monitoring based on this first year of data collection.

Beamer et al. (2006) (Unique Identifier: 006)

Reference	Beamer, E. M., A. McBride, R. Henderson, J. Griffith, K. Fresh, T. Zackey, R. Barsh, T. Wyllie-Echeverria, and K. Wolf. 2006. Habitat and fish use of pocket estuaries in the Whidbey Basin and North Skagit County bays, 2004 and 2005.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, substrate and sediment, sediment transport and supply, estuarine habitats and landforms, data gaps, aquatic habitats and landforms. ***Water Quality and Productivity:*** primary productivity, bacteria, salinity. ***Modeling Tools:*** habitat, connectivity, hydrology. ***Land Use and Cover:*** land cover, banks and shoreline. ***Fish and Habitat:*** Fish: growth, survival, rearing, life history, periodicity, density dependence, hatchery, data gaps; Habitat: estuary, pocket estuary, nearshore, connectivity, restoration, invasive species, instream flow; Monitoring: data gaps, abundance, flow, habitat.									
Species and Life Stages	***Chinook:*** incubation, estuary rearing and emigration, nearshore rearing and emigration. ***Pink, Chum:*** estuary rearing and emigration, nearshore rearing and emigration. ***Bull Trout:*** not specified. ***Other species (Surf Smelt):*** not specified.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary, Padilla Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: Estuaries exist anywhere along the coast where geologic and hydrologic conditions create a partially enclosed, diluted marine body of water. They vary in scale, depending on the size of the enclosure and the amount of freshwater dilution. A large estuary like Puget Sound may itself contain river mouth estuaries and small-scale 'pocket' estuaries with more dilute marine water relative to the surrounding estuary. Pocket estuaries form behind coastal accretion landforms, at coastal embayments, or at small creek mouths (McBride et al. 2005). Compared to adjacent intertidal habitat, pocket estuaries have: (1) substrates, intertidal gradients, and vegetation consistent with low energy environments, and (2) local surface and/or groundwater freshwater inputs that depress salinity during some part of the year, usually winter and spring.

Skagit Bay research conducted in 2002 found that wild fry migrant Chinook Salmon appear to prefer non-natal pocket estuaries compared to other adjacent nearshore habitat areas (Beamer et al. 2003). Evidence suggests that juvenile Chinook in pocket estuaries experience improved growth and higher survival than fish in surrounding nearshore or offshore areas during the period from February through May. Preliminary results from fish sampling in 2003 further support earlier work and find that pocket estuaries serve a nursery role for a number of other fish species including surf smelt – an important salmon prey resource. Additionally, accretion shore forms protecting pocket estuaries appear to be linked to bull trout use (Beamer et al. 2004). These results suggest that pocket estuaries are an important ecological niche for some salmon life history types and other estuarine/marine fish species.

Our understanding of Chinook Salmon ecology in pocket estuaries has thus far been limited to sites within Skagit Bay. The results shown in Beamer et al. (2003) directly relate to Skagit Bay and Skagit-origin Chinook Salmon, but may not infer the true importance of the pocket estuaries in a larger spatial and ecological setting. Therefore, we have expanded our research to the Whidbey Basin of Puget Sound and north Skagit County bays (Fidalgo, Padilla, and Samish) in order to better understand the potential role of pocket estuaries in larger scale nearshore habitat restoration

and salmon recovery planning. This report summarizes habitat and fish use data collected in and around pocket estuaries of Whidbey Basin and north Skagit County bays. This research was conducted as part of our ongoing investigation into how salmon utilize nearshore habitats. This has been a collaborative project between the Stillaguamish, Samish, Tulalip, Sauk-Suiattle and Swinomish Indian Tribes, with technical support and field involvement from NOAA Fisheries. The project was started in 2004 with funding made available by the Northwest Straits Commission.

Beamer et al. (2006) (Unique Identifier: 197)

Reference	Beamer, E. M., R. Henderson, and K. Wolf. 2006. Effectiveness monitoring of the Deepwater Slough restoration project for wild juvenile Chinook salmon presence, timing, and abundance. Report prepared by Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, change. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** <u>Habitat:</u> estuary, restoration, connectivity; <u>Fish:</u> abundance, rearing, distribution, density dependence, movement; <u>Monitoring:</u> abundance.								
Species and Life Stages	***Chinook:*** estuary rearing and emigration, nearshore rearing and emigration.								
Reaches and Spatial extent	Skagit estuary, Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: The Deepwater Slough Restoration Project is located in the South Fork Skagit River delta. The project was constructed in August and September of 2000 by removing 2.77 miles of dike and restoring tidal and river hydrology to 221 acres of historic estuary (Figure 1). These natural hydrologic processes are expected to restore the area to naturally functioning estuarine marsh and channel habitats over time.

The monitoring plan called for use of “reference” and “treatment” sites after project construction to answer questions regarding juvenile salmon presence/absence and abundance within the project area. Blind tidal channels (also called dentritic channels) and distributary channels were selected near the project area for use as reference sites (Figure 1). Results from the reference sites were compared to results from treatment sites located within the area where dikes were removed. Treatment sites also consisted of blind tidal channels and distributary channels. The treatment sites were located in channels that juvenile salmon were not able to access until dikes were physically removed in the summer of 2000 (Figure 1). We sampled both reference and treatment sites from March through July on a bi-weekly basis. Fyke trap methods were used to sample in blind tidal channels and beach seine methods were used to sample in distributary channels. Methods are described in Beamer et al. (2005) and are attached as Appendix 1 of this document. We also monitored sites throughout the larger Skagit estuary (Figure 2). We used results from these sites to better interpret the results from specific Deepwater Slough restoration sites.

Beamer et al. (2006) (Unique Identifier: 198)

Reference	Beamer, E., A. Kagley, and K. Fresh. 2006. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Harrington Lagoon, 2005. Report prepared by Skagit River System Cooperative and Northwest Fisheries Science Center.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, substrate and sediment, sediment transport and supply. ***Water Quality and Productivity:*** primary productivity, temperature, salinity. ***Land Use and Cover:*** urban. ***Fish and Habitat:*** Habitat: pocket estuary, connectivity, restoration, nearshore; Fish: life history, abundance, size structure, periodicity, distribution; Monitoring: water quality, abundance.								
Species and Life Stages	***Chinook, Chum, Coho, Pink:*** estuary rearing and emigration, nearshore rearing and emigration. ***Other species (Sculpin, Shiner Perch, Threespine Stickleback, Arrow Goby):*** not specified.								
Reaches and Spatial extent	Skagit Bay, Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: Fish use studies of pocket estuaries in the Whidbey Basin started in 2002. At first, research was limited to understanding juvenile Chinook Salmon use of sites within Skagit Bay (Beamer et al. 2003). In 2004, study expanded to sites throughout Whidbey Basin, Fidalgo Bay and Samish Bay via a cooperative effort that was partially funded by the Northwest Straits Commission. The focus of the expanded research is to understand landscape scale patterns of fish usage including what species and life history types use these systems, how connectivity or position within the larger landscape affects fish use, and how patterns of fish use relate to protection and restoration of these systems. This expanded research effort has continued voluntarily in 2005 and included sampling in Harrington Lagoon with the help of Island County WSU Beach Watchers. The focus of this report is on fish abundance and size in Harrington Lagoon during 2005. Although we primarily report only fish abundance and size in this one system, we will also briefly consider results within the context of the larger Whidbey Basin study of pocket estuaries. The results of this study can be used to inform local citizens about fish populations currently using the Harrington Lagoon area. The results may also be useful to Island County, or other agencies and groups interested in Puget Sound salmon recovery or nearshore fish ecology.

Beamer et al. (2007) (Unique Identifier: 199)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., R. Henderson, and K. Wolf. 2007. Juvenile salmon and nearshore fish use in shoreline and lagoon habitat associated with Turners Bay, 2003-2006. Report prepared by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: estuarine habitats and landforms. Water Quality and Productivity: salinity, temperature, secondary productivity. Modeling Tools: hydrology. Fish and Habitat: <u>Habitat:</u> restoration, limiting factors, pocket estuary, nearshore, instream flow, connectivity, capacity; <u>Fish:</u> abundance, distribution, size structure, life history, periodicity, hatchery, diet; <u>Monitoring:</u> abundance, water quality, habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum, Pink, Coho: estuary rearing and emigration, nearshore rearing and emigration, outmigration. Bull Trout, steelhead: estuary rearing and emigration, nearshore rearing and emigration. Other species (Cutthroat, Shiner Perch, Surf Smelt, Herring, Sandlance, Anchovy): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Restoration and protection of Turners Bay was identified as a priority in the Skagit Chinook Recovery Plan (page 202 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook Salmon originating from the Skagit River. The Swinomish Planning Department has sponsored a habitat change analysis (McBride 2007) that identifies restoration and protection actions that could be taken within Turners Bay, and in its adjacent watershed and drift cells, for the benefit of the nearshore ecology of Turners Bay.

The Skagit River System Cooperative (SRSC) Research Program has collected fish data from sites within Turners Bay as part of their research on the factors limiting populations of wild Chinook Salmon. SRSC has continued to collect fish data at sites within Turners Bay as part of its long term monitoring plan for wild Chinook Salmon recovery (Greene and Beamer 2006).

We analyzed fish data from 2003 through 2006 for this report to document the nearshore fish assemblage using habitats within Turners Bay. This report also identifies the importance of protecting and restoring Turners Bay for the benefit of juvenile salmon with an emphasis on Endangered Species Act (ESA)-listed wild Chinook Salmon.

Beamer et al. (2009) (Unique Identifier: 200)

Reference	Beamer, E., R. Henderson, and K. Wolf. 2009. Lone Tree Creek and pocket estuary restoration: progress report for 2004-2008 fish monitoring. Report prepared by Skagit River System Cooperative Research Program, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, sediment transport and supply, change, history. ***Water Quality and Productivity:*** salinity. ***Land Use and Cover:*** land cover. ***Fish and Habitat:*** Habitat: restoration, wetlands, estuary, instream flow, riparian, pocket estuary, nearshore, ocean, capacity; Fish: abundance, distribution, life history, periodicity; Monitoring: abundance.									
Species and Life Stages	***Chinook, Chum, Coho:*** estuary rearing and emigration. ***Other species (Pacific Staghorn Sculpin, Three-spined Stickleback, Shiner Perch):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The primary objective for the Lone Tree Creek and Lagoon Pocket estuary project is to increase the size and ecological capacity of the Lone Tree pocket estuary by restoring: (1) tidal hydrology to the historic drowned channel part of the lagoon and (2) freshwater hydrology and sediment dynamics (transport and deposition) in Lone Tree Creek. The plan to restore tidal hydrology to the upper wetland of Lone Tree Lagoon was primarily to remove an undersized, perched culvert and replace it with a bridge, thus increasing the tidally influenced area of the lagoon (Figure 1). This restoration work was completed in September 2006 by the Swinomish Indian Tribal Community and its partners, creating a drowned channel estuary approximately 1246 square meters in size at mean high tide. The drowned channel estuary is shown in Figure 2 as a dark pink polygon.

In the wetland area upstream of the culvert we hypothesized the following immediate (i.e., within one year after the culvert is removed) responses to restoration:

Hypothesis 1 – Tidal prism will increase above the culvert.

Hypothesis 2 – Estuarine mixing above the culvert will increase.

Hypothesis 3 – The fish community above the culvert will change from a sparse-to-absent freshwater community into a more abundant and diverse community dominated by estuarine species.

This report describes results for monitoring sites upstream of the culvert for three years prior to the restoration project being completed in September of 2006 (pre-project) and two years of monitoring afterward (post-project).

Beamer et al. (2009) (Unique Identifier: 201)

Reference	Beamer, E., J. Haug, C. Rice, and K. Wolf. 2009. Final report nearshore fish assemblages in reference and spartina removal sites located in south Skagit Bay. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, substrate and sediment, sediment transport and supply. ***Water Quality and Productivity:*** primary productivity, secondary productivity. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: restoration, nearshore, estuary, connectivity, ocean, invasive species; Fish: density dependence, abundance, periodicity; Monitoring: genetics, abundance, habitat.									
Species and Life Stages	***Chum, Chinook, Pink, Coho:*** estuary rearing and emigration, nearshore rearing and emigration, outmigration. ***Other (Surf Smelt, Shiner Perch, Pacific Staghorn Sculpin):*** not specified.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Spartina is an invasive, non-native, salt-tolerant vascular plant in Puget Sound. It was intentionally introduced in Puget Sound near Stanwood in 1961 and because of its invasive nature, the Washington Department of Fish and Wildlife began a Spartina eradication program in southern Skagit Bay in the late 1990s. The objective of this study is to evaluate the effect of Spartina removal treatment on the fish assemblage, including juvenile salmon, in the southern Skagit Bay near the town of Stanwood, Washington.

In 2007 we made 185 beach seine or fyke trap sets catching 9,852 fish of 12 different species within a study area comprised of reference and treatment habitat types relative to Spartina removal. In 2008 we made 94 beach seine or fyke trap sets catching 4,471 fish of 15 different species. Juvenile salmon utilize habitat within treated Spartina marshes. Juvenile Chum, Chinook, and Pink Salmon were captured in both reference (flooded mudflat, blind tidal channels within native marshes) and treated Spartina marsh (flooded and blind channel) habitats. We also demonstrate that other fish species utilize habitat within treated Spartina marshes including these dominant nearshore species: surf smelt, shiner perch, Pacific staghorn sculpin.

Fish assemblages in reference mudflat flooded intertidal habitat were similar to fish assemblages in flooded mudflat w clone intertidal habitat (e.g., treated Spartina marshes) over the two years sampled. Mudflat w clone areas used to be Spartina marsh, but were successfully treated and have now reverted to a physical habitat similar to mudflat, which is a natural reference habitat. These results suggest that Spartina marshes that are treated and revert toward a mudflat condition are likely to have fish assemblages similar to mudflats never colonized by Spartina.

Fish assemblages in native marsh blind channels were similar to the fish assemblages in blind channels found in clone areas (i.e., treated Spartina marshes) in one of the two years sampled. This result suggests that blind channel habitat within successfully treated Spartina marshes can result in fish assemblages similar to those in blind channel habitat in native marsh.

Since all fish habitat within the study area is intertidal, differences in elevation by habitat types will directly relate to the frequency, depth, and duration of tidal inundation. Lower elevation habitats will be wetted more frequently, to a deeper depth, and for a longer period of time than higher elevation habitats. Relative difference in fish access opportunity to the surface elevation of each habitat type is ordered greatest to least: reference mudflat, mudflat w clones (treated Spartina marsh), Spartina marsh, and native marsh. We also found Spartina marshes have less blind channel area than native marshes when standardized by marsh area. These results suggest that mudflats colonized by Spartina are less accessible to fish than both the original mudflat (as a result of increased elevation), but also when compared to native marshes which have approximately triple the blind channel habitat area.

Beamer et al. (2011) (Unique Identifier: 133)

Reference	Beamer, E., B. Brown, and K. Wolf. 2011. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Dugualla Heights lagoon, 2011. Report prepared by Skagit River System Cooperative Research Program for Whidbey Camano Land Trust, Greenbank, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms. ***Water Quality and Productivity:*** dissolved oxygen, temperature, salinity, primary productivity, secondary productivity. ***Fish and Habitat:*** Fish: abundance, distribution, periodicity, density dependence; Habitat: pocket estuary, nearshore, restoration, connectivity; Monitoring: abundance, water quality.									
Species and Life Stages	***Chinook, Chum, Coho:*** estuary rearing and emigration, nearshore rearing and emigration. ***steelhead, Sockeye:*** not specified. ***Bull Trout:*** nearshore rearing and emigration. ***Other species (Threespine Stickleback, Pacific Staghorns, Shiner Perch, Surf Smelt, Cutthroat Trout):*** not specified.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Restoration and protection of Dugualla Heights Lagoon was identified as a priority in the Skagit Chinook Recovery Plan (page 216 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook Salmon originating from the Skagit River. In 2009 the area was protected with a conservation easement and a restoration feasibility study was funded by Washington State's Salmon Recovery Funding Board (SRFB), with the project's sponsor being the Whidbey Camano Land Trust (http://www.wclt.org/projects/dugualla-heights-conservation-easement/). Restoration concepts at Dugualla Heights include improvement of tidal connectivity and fish passage to the lagoon from Skagit Bay.

As part of the feasibility study, the Skagit River System Cooperative Research Program is responsible for presenting a report to Whidbey Camano Land Trust describing fish use of the study area before restoration. The objective of beach seining at Dugualla Heights in 2011 was to collect data on the fish assemblage, including juvenile salmon, present in the waters of Dugualla Heights Lagoon and shoreline areas of Skagit Bay near the outlet of the lagoon. Data from this monitoring effort are used to document fish species composition and relative fish abundance prior to any restoration completed at this site. Pre-restoration project fish results serve as a basis for measuring the response of the fish community to restoration at Dugualla Heights.

Beamer et al. (2012) (Unique Identifier: 204)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., B. Brown, and K. Wolf. 2012. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Dugualla Heights lagoon, 2012. Report prepared by Skagit River System Cooperative Research Program for Whidbey Camano Land Trust.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: estuarine habitats and landforms. Water Quality and Productivity: dissolved oxygen, temperature, salinity, primary productivity, secondary productivity. Fish and Habitat: <u>Fish:</u> abundance, distribution, periodicity, density dependence; <u>Habitat:</u> pocket estuary, nearshore, restoration, connectivity; <u>Monitoring:</u> abundance, water quality.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum, Coho, Pink: estuary rearing and emigration, nearshore rearing and emigration, outmigration. steelhead, Bull Trout, Sockeye, Other species (Cutthroat): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Restoration and protection of Dugualla Heights lagoon was identified as a priority in the Skagit Chinook Recovery Plan (page 216 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook Salmon originating from the Skagit River. In 2009, the area was protected with a conservation easement and a restoration feasibility study was funded by Washington State's Salmon Recovery Funding Board (SRFB), with the project's sponsor being the Whidbey Camano Land Trust (http://www.wclt.org/projects/dugualla-heights-conservation-easement/). Currently the Dugualla Heights lagoon is connected to Skagit Bay by a 30-inch concrete culvert 280 feet long. Restoration concepts at Dugualla Heights include improvement of tidal connectivity and fish passage to the lagoon from Skagit Bay.

As part of the feasibility study, the Skagit River System Cooperative Research Program is responsible for presenting a report to Whidbey Camano Land Trust describing fish use of the study area before restoration occurs at the outlet of the lagoon. Results from this monitoring effort document fish species composition and relative fish abundance inside the lagoon and the adjacent nearshore habitat near the outlet of the lagoon prior to any restoration completed at this site. Pre-restoration project fish results serve as a basis for measuring the response of the fish community to restoration at Dugualla Heights. In this report we present results from our second year of monitoring. The first year of monitoring was reported in Beamer et al. (2011).

Beamer et al. (2013) (Unique Identifier: 207)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. M., W. T. Zackey, D. Marks, D. Teel, D. Kuligowski, and R. Henderson. 2013. Juvenile Chinook salmon rearing in small non-natal streams draining into the Whidbey Basin. Report prepared for Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: slope, estuarine habitats and landforms, sediment transport and supply, sinuosity, change. Modeling Tools: habitat, data gaps. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat:</u> barriers, estuary, pocket estuary, nearshore, connectivity, status and trends, capacity, instream flow, data gaps; <u>Fish:</u> abundance, distribution, growth, survival, rearing, life history, periodicity, hatchery, size structure, density dependence, movement; <u>Monitoring:</u> abundance, genetics.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum, Pink: estuary rearing and emigration, outmigration, nearshore rearing and emigration. steelhead: rearing. Coho: spawning, outmigration, rearing, estuary rearing and emigration. Other species (Cutthroat): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary, Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: We electrofished 63 small coastal streams draining into the Whidbey basin for juvenile Chinook Salmon presence. The small streams sampled ranged in watershed size from 3 to 1,862 hectares and had channel slopes ranging between<1 percent to 38 percent for the electrofished reaches. Bankfull channel width of the electrofished stream reaches ranged from 0.8 to 6.9 meters.

In 32 of the 63 streams we found juvenile Chinook Salmon present on at least one of the 474 sampling event days over the six year study period (2008 – 2013) in which we caught a total of 1,879 juvenile Chinook Salmon. Juvenile Chinook Salmon presence rates ranged from 0 percent to 100 percent, depending on stream. Most juvenile Chinook Salmon were caught in the months of January through May each year. Juvenile Chinook Salmon body size found in the small streams was similar to or larger than juvenile Chinook Salmon body size found in adjacent nearshore habitat from January through April. After April, juvenile Chinook Salmon were larger in nearshore areas than in small streams. While in small streams, individual juvenile Chinook Salmon reared an average of 38.5 days and grew 0.23 mm/day.

Statistical analysis suggests that four factors influence whether juvenile Chinook Salmon are present within Whidbey Basin small streams: 1) distance to nearest Chinook Salmon bearing river, 2) stream channel slope, 3) watershed area, and 4) presence and condition of culverts at the mouth of a stream. Streams further from Chinook Salmon bearing rivers and with steeper channel slopes had lower juvenile Chinook Salmon presence rates. A minimum watershed size of approximately 45 hectares with channel slopes less than 6.5 percent may be necessary before juvenile Chinook Salmon potential exists. We found culverts at stream mouths likely cause upstream migration problems for small fish such as Chinook Salmon fry.

Streams of the size in this study are often not considered salmon habitat because many flow seasonally and do not provide habitat for spawning salmon. However, we found that numerous small streams entering the Whidbey Basin do provide rearing habitat for fry migrant Chinook Salmon originating from the three nearby rivers (Skagit, Snohomish, and Stillaguamish). These

same small streams are not well mapped and may be subject to inadequate protection as fish habitat. Better mapping of small streams and a predictive model for juvenile Chinook Salmon potential would help managers better protect this unique habitat type.

Beamer et al. (2014) (Unique Identifier: 188)

Reference	Beamer, E., R. Henderson, C. Ruff, and K. Wolf. 2014. Juvenile Chinook salmon utilization of habitat associated with the Fisher Slough Restoration Project, 2009 - 2013. Report prepared for The Nature Conservancy, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, change, floodplain, aquatic habitats and landforms, substrate and sediment. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity, primary productivity, secondary productivity. ***Modeling Tools:*** habitat, juvenile production, bathymetry. ***Land Use and Cover:*** agriculture, banks and shoreline. ***Fish and Habitat:*** Habitat: instream flows, connectivity, riparian, wetlands, estuary, capacity, restoration; Fish: abundance, rearing, periodicity, distribution, density dependence, size structure, growth, hatchery, movement, condition; Monitoring: abundance, water quality, habitat, restoration, scale or otoliths.									
Species and Life Stages	***Chinook, Coho, Chum:*** estuary rearing and emigration, outmigration. ***steelhead, Other species (Cutthroat):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Fisher Slough Restoration Project, located in the south fork Skagit River tidal delta near the town of Conway, is intended to help recover the six populations of wild Chinook Salmon present within the Skagit River and its natal estuary. The restoration project was phased in three parts. Project Element 1, completed in 2009 was to improve fish passage and tidal inundation to areas upstream of the floodgate and to protect adjacent farmland from flooding by replacing an existing floodgate with a new floodgate within Fisher Slough at the Pioneer Highway crossing. Project Element 2 resolved a drainage conflict preventing implementation of the final restoration Project Element. Project Element 3, completed in 2011, was a dike setback in order to allow more of the agricultural area to be inundated by tidal and freshwater hydrology, increasing fish carrying capacity. The juvenile Chinook Salmon monitoring results related to Project Elements 1 and 3 are presented in this report for all years of monitoring: 2009 – 2013. Now with five years of monitoring data and all restoration elements complete, we answered five key questions in this report:

(1) Did tidal habitat area increase following dike setback restoration at Fisher Slough? (Chapter 3) 2. Does restoration at Fisher Slough influence water temperature and dissolved oxygen? (Chapter 4)

(2) Is juvenile Chinook Salmon presence within Fisher Slough influenced by variable local environmental conditions, such as water temperature, dissolved oxygen, depth, and velocity? (Chapter 5)

(3) How did floodgate operation vary over the juvenile Chinook Salmon monitoring period for all years? (Chapter 6)

(4) Did the dike setback restoration and floodgate operation influence juvenile Chinook Salmon abundance, density, and size? (Chapter 7)

The restoration of freshwater tidal marsh habitat extent and connectivity within Fisher Slough as a result of the dike setback in combination with current floodgate operation provided significant benefits to fingerling Chinook Salmon rearing in the Skagit River estuary. In addition to creating 45.9 acres of additional juvenile rearing habitat, the combined effects of the dike setback and current floodgate operation significantly changed the seasonal dynamics of dissolved oxygen and water temperature in a way that provided benefits to estuarine resident Chinook utilizing the habitat. Dike setback increased water temperature in both magnitude of seasonal maximum and spatial variation upstream of the floodgate in a way that likely allowed mobile juvenile Chinook to maximize growth during the spring and early summer months. We detected an order of magnitude (10×) increase in habitat use by juvenile Chinook Salmon in Fisher Slough upstream of the floodgate, consistent with habitat use observed at other reference sites throughout the Skagit tidal delta. This increase is predominantly associated with the dike setback and current operation of the floodgate to allow fish passage during slack and flood stages of the tide cycle. The combination of dike setback and current floodgate operation translated to an increase in the smolt carrying capacity of Fisher Slough by 21,823 estuary rearing Chinook Salmon smolts per year based on two years of monitoring after dike setback (2012 and 2013).

Beamer et al. (2014) (Unique Identifier: 210)

Reference	Beamer, E., J. Demma, and R. Henderson. 2014. Kukutali preserve juvenile Chinook salmon and forage fish assessment. Report prepared by Skagit River System Cooperative for Swinomish Indian Tribal Community.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, estuarine habitats and landforms, substrate and sediment. ***Water Quality and Productivity:*** turbidity, contaminants, salinity, temperature, dissolved oxygen. ***Modeling Tools:*** juvenile production, habitat. ***Fish and Habitat:*** Habitat: connectivity, estuary, pocket estuary, nearshore, instream flow, wetlands, restoration; Fish: abundance, size structure, growth, density dependence, rearing, life history, periodicity, survival; Monitoring: abundance, water quality, habitat.								
Species and Life Stages	***Chinook:*** estuary rearing and emigration, nearshore rearing and emigration. ***Other species (Surf Smelt, Sand Lance):*** spawning.								
Reaches and Spatial extent	Skagit Bay, Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: Kukutali Preserve is located on the northeast side of Skagit Bay within the reservation boundaries of the Swinomish Indian Tribal Community. This assessment provides information on juvenile Chinook Salmon and forage fish using the Preserve's beaches and is intended to: a) help inform a management plan for the Preserve, and b) provide juvenile Chinook Salmon seasonal and abundance data necessary for determining the feasibility of restoration alternatives being considered for Kiket Lagoon.

Regarding juvenile Chinook Salmon and Kiket lagoon, we found juvenile Chinook Salmon currently use Kiket Lagoon in a manner consistent with the timing, abundance and fish size patterns of other Skagit Bay pocket estuaries. Increasing the lagoon's wetted area, if feasible, would benefit Skagit Chinook Salmon populations. Protecting existing lagoon habitat from loss and degradation could be improved by ensuring freshwater flowing into the lagoon does not damage fish and other native biota. We also found juvenile Chinook Salmon distributed on both sides of the tombolo connecting Fidalgo Island to Kiket Island. We do not predict an increase in juvenile Chinook Salmon use of Kiket Lagoon solely from increased tidal connectivity across the tombolo.

Related to forage fish, we found surf smelt eggs on Kukutali Preserve beaches with summer spawning dominant. Actions that adequately protect beach substrate and egg incubation conditions should be part of the Preserve's management plan and should include maintaining healthy coastal sediment and marine riparian zone processes on Preserve beaches.

Beamer et al. (2015) (Unique Identifier: 011)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E., R. Henderson, and B. Brown. 2015. Juvenile Chinook salmon utilization of habitat associated with the Wiley Slough Restoration Project, 2012-2013. Report prepared by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: estuarine habitats and landforms, substrate and sediment, sediment transport and supply. Water Quality and Productivity: salinity, temperature, dissolved oxygen, primary productivity. Modeling Tools: habitat. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat:</u> restoration, capacity, estuary, pocket estuary, connectivity, wetland; <u>Fish:</u> abundance, density dependence, periodicity, distribution, hatchery, movement, rearing; <u>Monitoring:</u> restoration, abundance, water quality.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Coho, Chum: estuary rearing and emigration, outmigration. steelhead: estuary rearing and emigration. Other Species (Three-spine Stickleback, Starry Founder, Peamouth Chub, Cutthroat): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Restoration of Skagit River delta habitat was identified as a priority to help recover Skagit Chinook Salmon listed as Threatened under the Endangered Species Act. The Wiley Slough Restoration Project was completed in 2009. Fish monitoring was conducted within restored habitat area of the Wiley Slough Restoration Project in 2012 and 2013. The monitoring design primarily consisted of a post-treatment (i.e., after restoration) stratified random design using beach seines to capture fish.

The monitoring effort caught over 22,000 fish representing at least 23 fish species, including 7 species of salmon (genus: Oncorhynchus). Unmarked juvenile Chinook Salmon dominated the catch of salmon. Unmarked juvenile Chinook Salmon density varied within the Wiley Slough Restoration Project by lobe, year, and season, but not habitat type. The Wiley Slough lobe had higher densities of juvenile Chinook Salmon than the Teal Slough lobe; higher densities of juvenile Chinook Salmon were found in 2013 than in 2012; seasonal use of restored areas by juvenile Chinook Salmon began in February, peaked from April through June, then declined afterward. Juvenile Chinook Salmon density did not vary by channel and impoundment. In general, juvenile Chinook Salmon are using the restored areas of both Wiley and Teal Slough lobes at seasonal density levels consistent with other long term monitoring sites in the Skagit River estuary. An estimated 88,206 (37,326-139,086, 95 percent CI) and 247,692 (128,973-366,412, 95 percent CI) unmarked juvenile Chinook Salmon used restored habitat of the Wiley Slough Restoration Project in 2012 and 2013, respectively.

Based on two years of monitoring the number of juvenile Chinook Salmon that used the restored areas of the Wiley Slough Restoration Project: 1) exceeded the updated carrying capacity estimate based on actual restored channel habitat, and 2) exceeded the Skagit Chinook Recovery Plan's estimated benefit to juvenile Chinook Salmon. However, the number of juvenile Chinook Salmon that used the restored areas were somewhat less than predicted by the carrying capacity estimate that included all wetted areas (29 hectares of channel and impoundment combined). Sustainable channel conditions are reached after natural hydrologic and sedimentation processes achieve a

balance at the site. Sustainable channel area is estimated at 2.03 hectares (0.50-8.25, 95 percent CI) suggesting total habitat area will be less than the 29 hectares currently present. Thus, actual juvenile Chinook Salmon carrying capacity could change within the Wiley Slough Restoration Project based on how channel/impounded areas evolve over time.

The issue of restored habitat conditions within recently restored areas using dike setback design and the long-term sustainability of that habitat may be an emerging theme for estuary restoration adaptive management. This issue is of particular importance when restoration projects are intended to achieve specific goals, such as recovery of listed Chinook Salmon populations. If as-built restoration conditions are not in a sustainable state, then a false sense of restored benefits might be accepted without sufficient monitoring and adaptive management of projects.

Beamer et al. (2016) (Unique Identifier: 211)

Reference	Beamer, E., B. Brown, K. Wolf, R. Henderson, and C. Ruff. 2016. Juvenile Chinook salmon and nearshore fish use in habitat associated with Crescent Harbor Salt Marsh, 2011 through 2015. Report prepared by Skagit River System Cooperative Research Program for U.S. Department of the Navy.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, estuarine habitats and landforms. ***Water Quality and Productivity:*** temperature, salinity, dissolved oxygen, primary productivity. ***Modeling Tools:*** habitat. ***Fish and Habitat:*** Habitat: pocket estuary, estuary, restoration, connectivity, instream flows, wetlands, nearshore, barriers; Fish: rearing, periodicity, abundance, distribution, density dependence, growth, movement, size structure, hatchery, life history; Monitoring: restoration, water quality, abundance.								
Species and Life Stages	***Chinook, Chum, Pink:*** estuary rearing and emigration, nearshore rearing and emigration, outmigration. ***Coho, Sockeye:*** estuary rearing and emigration, nearshore rearing and emigration. ***Other species (Sculpin, Three-spined Stickleback, Shiner Perch, Cutthroat):*** not specified.								
Reaches and Spatial extent	Skagit estuary, Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: Study area and purpose of report: Crescent Harbor Salt Marsh and shoreline are part of the Puget Sound nearshore located within the Whidbey Basin (Figure 1). Crescent Harbor Salt Marsh is part of a group of nearshore habitats referred to as pocket estuaries. Pocket estuaries are partially enclosed bodies of marine water that are connected to a larger estuary (such as Puget Sound) at least part of the time, and are diluted by freshwater from the surrounding watershed upland at least part of the year (after Pritchard 1967).With respect to Puget Sound Chinook Salmon, these small estuaries are differentiated from larger scale river estuaries because the watersheds they are associated with are too small to support spawning Chinook Salmon populations; thus we call them non-natal estuaries with respect to juvenile salmon use (Beamer et al. 2003). Pocket estuaries are an important habitat for wild Chinook Salmon fry early in the year once they leave their natal estuary and enter nearshore areas of Whidbey Basin (Beamer et al. 2003, Beamer et al. 2006).

Restoration and protection of Crescent Harbor Salt Marsh was identified as a priority in the Skagit Chinook Recovery Plan (page 204 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook Salmon stocks. The restoration project area lies within the confines of Naval Air Station Whidbey Island (NASWI), and with the U.S. Navy as a willing land owner, restoration was completed by Skagit River System Cooperative (SRSC) and NASWI in 2009 through funding by the Salmon Recovery Funding Board (SRFB) and the Estuary and Salmon Restoration Program (ESRP). Restoration design built upon an initial assessment and restoration plan completed for NASWI and Island County Public Works (PWA and UW WET 2003). Restoration actions mainly consisted of: a) increasing tidal connectivity within the historic marsh area, and b) replacing the system's outlet channel tide gate with a Mabey-Johnson bridge, thus restoring tidal flooding and fish access to more than 200 acres of Crescent Harbor Salt Marsh (Figure 2). More information about the restoration actions can be found at: http://skagitcoop.org/programs/restoration/crescent-harbor-salt-marsh/.

In response to the completed restoration at Crescent Harbor Salt Marsh, we monitored fish use of the restored areas and its adjacent nearshore beaches from 2011 through 2015 over the juvenile Chinook Salmon rearing period for pocket estuaries (January through June). The fish monitoring design for the Crescent Harbor Salt Marsh Restoration Project is a post-treatment (i.e., after restoration) stratified (lobes within the restored area) design. Limited pre-restoration project fish data for Crescent Harbor Salt Marsh are reported in PWA and UW WET (2003) for comparison.

Monitoring questions addressed in this report are:

(1) How does local environment vary by year, season, and spatial strata within the Crescent Harbor Salt Marsh Restoration Project?

(2) What fish species are present within the restored area?

(3) How does juvenile Chinook Salmon density vary by year, season, and spatial strata within the Crescent Harbor Salt Marsh Restoration Project?

(4) How does seasonal juvenile Chinook Salmon density in the restored Crescent Harbor Salt Marsh compare with nearby natural pocket estuaries?

Beamer et al. (2018) (Unique Identifier: 012)

Reference	Beamer, E, K. Wolf, and K. Ramsden. 2018. GIS census of pocket estuaries accessible to juvenile salmon in the Whidbey basin and western shore of Whidbey Island, 2014. Report for Whidbey Basin Salmon Recovery Lead Entities, prepared by Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, change, sediment transport and supply. ***Modeling Tools:*** hydrology. ***Land Use and Cover:*** banks and shoreline, urban. ***Fish and Habitat:*** Habitat: pocket estuary, nearshore, barriers, restoration, connectivity, invasive species; Fish: movement, distribution; Monitoring: habitat, abundance.									
Species and Life Stages	***Chinook, Chum, Coho:*** nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: Pocket estuaries are partially enclosed embayments found along the shoreline that are created by coastal landforms and/or antecedent geology and topography (stream valleys, coastal low lands), that often have depressed salinity compared to adjacent marine waters due to small streams, ground water, and surface runoff. Pocket estuaries are typically low energy groups of habitats including tidal channels, salt marshes, driftwood, and impoundments. The habitats within the pocket estuary are maintained by a variable combination of wave, tidal, and fluvial processes, from which specific pocket estuary types are delineated.

Pocket estuaries and small independent streams draining into nearshore areas within the Whidbey Basin are known to be an important rearing habitat for fry migrant Chinook Salmon originating from the three Chinook Salmon bearing rivers of the Whidbey Basin (Beamer et al 2003, Beamer et al 2006b, Beamer et al 2013). Within the Whidbey Basin juvenile Chinook Salmon use of pocket estuaries is described as 'non-natal' use because juvenile Chinook Salmon do not originate from the small streams often draining directly into the pocket estuaries. These small streams are too small support Chinook Salmon spawning and are often not flowing at the time of Chinook Salmon spawning. All Chinook Salmon utilizing pocket estuaries must find them via migration pathways from their natal river and estuary, and then into pocket estuary habitats associated with the adjacent marine basin. Natal use of Whidbey Basin pocket estuaries and small streams is possible for Chum and Coho Salmon, depending on stream size and other watershed characteristics (Beamer et al 2013). Because of the importance of pocket estuaries to Chinook Salmon, restoration and protection of pocket estuaries has been a priority for Island County and other Whidbey Basin Chinook Salmon recovery plans.

All salmon recovery plan areas in Puget Sound have active capital habitat restoration programs yet little is known about the status of all salmon habitat together. The status and trend of habitat critical to Puget Sound Chinook Salmon populations is not known, yet many local Puget Sound Salmon Recovery Plans have stated goals of protecting existing habitat and/or achieving a net gain in habitat. Keeping track of restored habitat is only one part of the habitat equation for tracking salmon recovery. Without monitoring data, it is only an opinion as to whether existing salmon habitat is gaining or losing ground over time. As expected, opinions vary on the status and trend

of salmon habitat. Several recent reports have attacked the tenet that existing salmon habitat is not currently being lost (Carman et al 2010; Judge 2011; NWIFC 2012). These reports have, in part, led the Puget Sound Region to more seriously track the status and trends of salmon habitat. Tracking the status and trends of salmon habitat has been included in the regional effort to develop and implement Monitoring and Adaptive Management Plans (MAMP) for all local chapters of the Puget Sound Chinook Recovery Plan. The MAMP process is being led by the Puget Sound Partnership (PSP) but implemented at the local (i.e., Lead Entity) level. A set of Common Indicators for monitoring Puget Sound Chinook Salmon habitat (e.g., Fore 2015) has been generally accepted by Lead Entities in order to guide and make monitoring consistent across all of Puget Sound. Pocket estuary habitat extent, count, and connectivity are included in the Common Indicator set.

Knowledge of the extent and connectivity of pocket estuary habitat is one of the three highest priority data gaps for salmon habitat status and trends monitoring for WRIA 6 (Island County Lead Entity RFP, July 13, 2015). This monitoring project fills the knowledge gap with 2014 results. Combining the results from this project with the results from the Skagit Monitoring Pilot Project (Beamer et al. 2015), funded by PSP Interagency Agreement #2015-64, creates a trend result for Whidbey Basin pocket estuary habitat for the first decade of Puget Sound Chinook Recovery Plan implementation. This project also provides results for pocket estuaries along the western Whidbey Island shoreline (herein ‘West Whidbey’) in 2014. West Whidbey pocket estuaries presumably provide juvenile salmon rearing opportunity for a mixture of Puget Sound salmon populations (Wait et al 2007). Indicators measured by this project are: 1) count of pocket estuaries accessible to juvenile salmon, 2) the extent of accessible pocket estuary habitat by type, and 3) their landscape position (i.e., connectivity), expressed as two separate metrics: distance between pocket estuaries and distance from nearest Chinook Salmon natal river) (Table 1.1).

Beamer et al. (2018) (Unique Identifier: 213)

Reference	Beamer, E. M., R. Henderson, K. Wolf, J. Demma, and G. Hood. 2018. Juvenile Chinook salmon response to dike setback restoration at Fir Island Farms in the Skagit River tidal delta, 2015-2018. Report prepared by Skagit River System Cooperative, Research Program, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms. ***Water Quality and Productivity:*** salinity, temperature, dissolved oxygen. ***Modeling Tools:*** habitat. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Fish: periodicity, abundance, rearing, density dependence, size structure, growth, competition, hatchery; Habitat: restoration, barriers, connectivity, capacity; Monitoring: restoration, habitat, abundance, water quality, data gaps.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration, outmigration. ***Coho, Pink, Bull Trout, Chum:*** estuary rearing and emigration. ***Other species (Three-spined Stickleback, Starry Founder, Peamouth, Staghorn Sculpin):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Located within the Skagit River tidal delta, the Fir Island Farms Restoration project restored approximately 53 hectares (131 acres) of tidal marsh and tidal channels. We monitored habitat conditions and fish use of the restored area and reference sites during the juvenile Chinook Salmon outmigration period for two years pre- (2015 and 2016) and post-restoration (2017 and 2018).

Prior to the dike setback, the existing gravity operated tide gate was expected to prevent fish and salt water from entering pre-existing channels 'inside' of Fir Island Farms. However, we observed the tide gate leaking and measured water surface elevation fluctuations synchronous with daily tidal cycles suggesting Fir Island Farms 'inside' habitat areas before restoration were subject to some tidal influence and potential passage of estuarine fish species into 'inside' areas of Fir Island Farms prior to restoration.

Over the four years of beach seine sampling, we caught over 80,000 fish comprised of 21 different species. Juvenile Chinook were caught upstream of the tide gate in 2015 and 2016 before restoration occurred confirming that the leaking tide gate did allow upstream fish passage. After restoration, in 2017 and 2018, juvenile salmon and estuarine fish species catches increased upstream of the removed tide gate, while three-spine stickleback catches declined. Prior to restoration in years 2015 and 2016, wild juvenile Chinook abundance for 'inside' habitat of Fir Island Farms was estimated at 118 and 566 fish per year. Following restoration, we estimated a total annual Chinook abundance in the 'inside' habitat areas of 50,522 and 11,124 in 2017 and 2018. We hypothesize that the large increase in juvenile Chinook abundance following restoration was due to unobstructed fish access to newly restored habitat and a ~30-fold increase in potential rearing habitat in the form of newly wetted area. Analysis of seasonal density of juvenile Chinook Salmon at Fir Island Farms compared to long term monitored reference sites in the Skagit tidal delta suggests that the restored habitat of Fir Island Farms is utilized by juvenile Chinook consistent with levels of other areas within the Skagit tidal delta. Predicted juvenile Chinook carrying capacity for the Fir Island Farms restored area varies by tens of thousands of fish per year as a function of predicted habitat amount, from 8,000 to 50,000 juvenile Chinook. The 50,000 fish

estimate is most consistent with habitat conditions observed in 2017 and 2018. Predictions of channel allometry suggests tidal channel area at Fir Island Farms will decline from the 7+ hectares observed immediately after restoration to a sustainable equilibrium amount of 2.22 hectares (0.89-5.52 80 percent CI) hectares. Consistent with projected declines in channel area, we hypothesize that use of the restored area by juvenile Chinook will also decline.

Prior to restoration, the magnitude in difference in annual growth rates of juvenile Chinook Salmon upstream of the tide gate compared to reference sites, as inferred by seasonal changes in fork length, was highest compared to juvenile Chinook encountered in the 'inside' area post restoration. Presumably the low densities of juvenile Chinook in the habitat upstream of the tide gate prior to restoration resulted in low competition for food and space. After restoration, the size difference between fish in the restoration site and those in the adjacent reference sites decreased. Although many mechanisms may have influenced this observation, we hypothesize that this 5 inferred reduction in growth may be due to increased competition for food as a result of increased fish abundance, despite the increase in juvenile rearing habitat.

We suggest periodic monitoring of habitat (channels, hydrology, vegetation) coupled with juvenile fish monitoring to determine the trajectory of fish response to habitat as they move toward their sustainable equilibrium conditions. The frequency of monitoring can be determined based on the expected rate of change in habitat trajectory.

Beamer (2007) (Unique Identifier: 215)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. 2007. Juvenile salmon and nearshore fish use in shoreline and lagoon habitat associated with Ala Spit, 2007. Report prepared for Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: substrate and sediment, estuarine habitats and landforms, nearshore habitats and landforms. Water Quality and Productivity: primary productivity, salinity, temperature. Modeling Tools: hydrology, bioenergetics. Fish and Habitat: <u>Habitat:</u> connectivity, instream flows, pocket estuary, nearshore, restoration; <u>Fish:</u> diet, predation, periodicity, life history, size structure, density dependence, distribution, abundance, rearing; <u>Monitoring:</u> abundance, water quality, habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum: estuary rearing and emigration, nearshore rearing and emigration, outmigration. Bull Trout: estuary rearing and emigration. Other species (Surf Smelt, Herring, Sandlance, Shiner Perch, Stickleback, Starry Flounder, Gunnel, Pacific Staghorn Sculpin): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary, Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Restoration and protection of Ala Spit and Lagoon was identified as a priority in the Skagit Chinook Recovery Plan (page 214 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook Salmon originating from the Skagit River. Island County has sponsored a feasibility study to identify restoration and protection actions that could be taken in the Ala Spit or Lagoon area, and in its adjacent drift cell.

The Skagit River System Cooperative (SRSC) Research Program is responsible for presenting a report to Island County through its consultant, Herrera Environmental Consulting Inc., describing the nearshore fish assemblage using fish data collected during late winter through spring of 2007 by beach seining. This report also includes updated information from other SRSC studies that aids understanding of juvenile salmon and the nearshore fish assemblage at Ala Spit and Lagoon, including:

(1) Juvenile salmon migration pathways from the Skagit River to shorelines in northern Skagit Bay.

(2) Annual variability in juvenile salmon populations found in nearshore habitats from Skagit Chinook monitoring.

Beamer (2010) (Unique Identifier: 456)

<table>
<tr><td>Reference</td><td colspan="10">Beamer, E. 2010. A big picture story in the Skagit tidal delta. Proceedings by the Habitat Work Schedule Committee.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Proceedings</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> restoration; <u>Monitoring:</u> restoration.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary and Skagit Bay (in particular Wiley Slough, Swinomish Channel corridor, Smokehouse, and McGlinn Island).</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This proceedings presentation discusses the importance of monitoring restoration projects after restoration has been completed. The presentation stresses that monitoring after restoration is essential for "total success" and allows for adaptative management. Wiley Slough, Smokehouse phase 1 and 2, Swinomish Channel fill removal, Rainbow Marsh, and McGlinn Island connectivity restoration projects are provided as examples of how to evaluate if ids (particularly Chinook) inhabit newly restored areas.

Beamer (2014) (Unique Identifier: 219)

Reference	Beamer, E. 2014. McElroy Slough beach seine summary results for unmarked juvenile Chinook salmon: 2014. Memorandum to Skagit Fisheries Enhancement Group, Mount Vernon, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, movement; Habitat: barrier. ***Water Quality and Productivity:*** salinity, temperature.								
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration.								
Reaches and Spatial extent	Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Summary: This memo summarizes unmarked juvenile Chinook beach seining results from the McElroy Slough during February to June of 2014. Samples were taken up- and downstream of the tidegate, and the sampling period was designed to capture the period when juvenile Chinook Salmon utilize estuarine habitats and if juvenile Chinook were able to move up- or downstream of the tidegate. In addition to seining, temperature and salinity samples were taken up- and downstream of the tidegate. The results showed that juvenile Chinook Salmon were able to move up- and downstream of the tidegate, but densities were lower upstream of the tidegate. They also found that abundances varied by year and that the juvenile Chinook use of McElroy Slough was seasonal.

Beamer (2015) (Unique Identifier: 220)

Reference	Beamer, E. 2015. South Fork Dike setback restoration project area. Memorandum to Skagit County, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, distribution; Monitoring: restoration; Habitat: connectivity. ***Water Quality and Productivity:*** dissolved oxygen.									
Species and Life Stages	***Chinook:*** rearing – outmigration.									
Reaches and Spatial extent	R15.									
Linkages to Hydroelectric Operations	NA									

Abstract: This memo:

(1) Summarizes fish and environmental (dissolved oxygen) monitoring data collected at the South Fork Dike Setback restoration project area during 2012 and 2014 in order to provide context to predictions of juvenile Chinook Salmon carrying capacity estimates for four restoration alternatives.

(2) Presents juvenile Chinook carrying capacity estimates for alternatives described in the April 24, 2015 memorandum to Jeff McGowan from Susan Tonkin and others.

Beechie et al. (2006) (Unique Identifier: 126)

Reference	Beechie, T., E. Buhl, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. Hydrologic regime and the conservation of salmon life history diversity. Biological Conservation 10:560-572.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow; Fish: life history, size structure, periodicity, climate change; Monitoring: climate change, flow.									
Species and Life Stages	***Chinook:*** spawning, outmigration.									
Reaches and Spatial extent	Puget Sound, Skagit Watershed, Sauk River.									
Linkages to Hydroelectric Operations	NA									

Abstract: Life history diversity of imperiled Pacific salmon *Oncorhynchus* spp. substantially contributes to their persistence, and conservation of such diversity is a critical element of recovery efforts. Preserving and restoring diversity of life history traits depends in part on environmental factors affecting their expression. We analyzed relationships between annual hydrograph patterns and life history traits (spawn timing, age at spawning, age at outmigration, and body size) of Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*) to identify environmental indicators of current and historic diversity. Based on mean monthly flow patterns, we identified three hydrologic regimes: snowmelt-dominated, rainfall-dominated, and transitional. Chinook populations in snowmelt-dominated areas contained higher proportions of the stream-type life history (juvenile residence >1 year in freshwater), had older spawners, and tended to spawn earlier in the year than populations in rainfall-dominated areas. There are few extant Puget Sound populations dominated by the stream-type life history, as several populations with high proportions of stream-type fish have been extirpated by construction of dams that prevent migration into snowmelt-dominated reaches. The few extant populations are thus a high priority for conservation. The low level of genetic distinction between stream-type and ocean-type (juvenile residence <1 year in freshwater) life histories suggests that allowing some portion of extant populations to recolonize habitats above dams might allow re-expression of suppressed life history characteristics, creating a broader spatial distribution of the stream-type life history. Climate change ultimately may limit the effectiveness of some conservation efforts, as stream-type Chinook may be dependent on a diminishing snowmelt-dominated habitat.

Bilby and Villarin (2009) (Unique Identifier: 392)

Reference	Bilby, R. E., and L. A. Villarin. 2009. Effects of development on coho salmon and implications for salmon recovery. Weyerhaeuser County, Federal Way, Washington.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow, restoration. Fish: abundance, data gaps. ***Land Use and Cover:*** land cover, urban, agriculture, forestry.									
Species and Life Stages	***Coho:*** migration – spawning.									
Reaches and Spatial extent	Skagit, Stillaguamish, Snohomish and Lake Washington watersheds.									
Linkages to Hydroelectric Operations	NA									

Summary: This presentation provides an overview of how land use affects Coho abundance. They analyzed escapements at various locations within four basins: Skagit, Stillaguamish, Snohomish and Lake Washington. These sites were chosen due to the availability of annual data from 1984 to 2001. However, the presenters specify the difficulty in assessing fish responses when there is a lack of data due to few long records of smolt production, and juvenile specific abundance data whereas most studies collect data on returning adult salmon when the freshwater habitat is the least impactful. For their analysis, they used annual spawner abundance estimates for each index site to calculate the percent of total abundance at all sites that each site supports each year. They also discuss pre-spawn mortality and potential factors causing Coho in urban streams to die. The presentation ends with ideas on how to retain salmon in areas of rapid growth, including restoration, increasing forest land value, and identifying high productivity sites.

Bilby et al. (no date) (Unique Identifier: 090)

Reference	Bilby, R. E., G. R. Blair, K. P. Currens, K. L. Fresh, and R. R. Fuerstenberg. No date. Factors limiting progress in salmon recovery, draft. Report prepared by Puget Sound Partnership Salmon Science Advisory Group, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: limiting factors, restoration; Monitoring: restoration; Fish: abundance.									
Species and Life Stages	***Chinook, steelhead, Chum, Bull Trout:*** not specified.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: In this paper, we examine reasons why Pacific salmon in the Puget Sound may not be showing signs of improvement to habitat restoration programs and conclude with some suggestions that may improve effectiveness of efforts in Puget Sound. The analysis provided is not intended as a criticism of efforts to date. In fact, there is evidence that many restoration actions have had beneficial effects of aquatic habitats. (Krall et al. 2020). However, progress towards salmon recovery goals has been much slower than anticipated and some understanding of why may be helpful in to improving the effectiveness of restoration programs moving forward.

Bledsoe et al. (1989) (Unique Identifier: 072)

Reference	Bledsoe, L. J., D. A. Somerton, and C. M. Lynde. 1989. The Puget Sound runs of salmon: an examination of the changes in run size since 1896. Canadian Special Publication of Fisheries and Aquatic Sciences 105.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, harvest, hatchery.									
Species and Life Stages	***Chinook, Coho, Chum, Pink, Sockeye:*** not specified.									
Reaches and Spatial extent	Puget Sound, Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: With the development during this century of the Puget Sound region of Washington State, USA, came changes to many factors having a potential impact on the productivity of wild salmon runs. This study estimates indices of the annual sizes of these runs over as long a period as data allow and attempts to determine whether the runs have changed with time. Since the available data do not extend backwards to the same point in time for all species and areas, the period from 1896 to 1975 has been broken into three shorter intervals. For each period one or more methods to estimate indices of run size have been used. Regression techniques are used to detect any time trends in run indices. The analysis was unable to indicate with statistical confidence that the wild run of Chinook and Coho Salmon to all of Puget Sound was substantially different between 1975 and 1896, however, runs to specific areas within the Sound probably have decreased. Wild run estimates over a 10-year period contained too much variability to conclude that a change occurred even when means decreased; estimates over a 40-year period did show significant changes for some species and area combinations. Although the average catches for Puget Sound of Chum and Pink Salmon are shown to be less in 1975 than the turn of the century, the inherent year-to-year variability of catch precludes a conclusive statistical demonstration of this change. Ten-year average Puget Sound catch estimates for wild Chinook and Coho from 1966 to 1975 (0.13 and 0.65 million, respectively) were lower than turn of the century estimates (0.34 and 1.13 million, respectively) with statistical significance exceeding P=0.001.

Bortleson et al. (1980) (Unique Identifier: 338)

Reference	Bortleson, G. C., M. Chrzastowski, and A. K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound region, Washington (No. 617).								
Source Information	***Type***	Dataset	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** history, nearshore habitats and landforms, estuarine habitats and landforms.								
Species and Life Stages	NA								
Reaches and Spatial extent	Puget Sound, Skagit Bay, Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: River mouth deltas and associated wetlands have a historical and continuing importance to human activities. Deltas in the Puget Sound region attracted early development because they were flat-lying, near water, and contained relatively large tracts of unforested land. These characteristics fostered the conversion to farmlands, port facilities, and centers of commerce and industry.

Delta areas in the Puget Sound region have undergone considerable change, both natural and man-related, since their first occupancy by non-Indian settlers. Until recent years, little thought was given to the environmental values of wetlands and the impacts of man's activities there. As the effects of these activities on the natural qualities of wetlands have become more widely known and better appreciated, information documenting past changes has been needed by planners, environmental groups, local agencies, and others concerned with the development and well-being of the delta areas. In response to this interest and need, comparisons of old and new maps delineating historical shoreline and wetland changes have been compiled for 11 major river deltas in the Puget Sound region as shown on the accompanying maps. These maps document (1) shoreline changes, both natural and man-induced, since early non-Indian settlement, (2) loss of wetland habitat, and (3) patterns of land-use changes on delta lands. Also presented are discussions of some overall planning considerations related to shoreline and wetland changes. In addition, this report may serve as a basis for future studies of geologic and hydrologic conditions and processes in the delta areas.

The areas studied are shown in figure 1 and listed below:

- Sheet 2. Nooksack River and Bellingham Bay, and Lummi River and Lummi Bay
- Sheet 3. Samish River and Samish Bay
- Sheet 4. Snohomish River and Possession Sound
- Sheet 5. Skagit River and Skagit Bay
- Sheet 6. Stillaguamish River and Port Susan
- Sheet 7. Duwamish River and Elliot Bay
- Sheet 8. Puyallup River and Commencement Bay

- Sheet 9. Nisqually River and Nisqually Reach
- Sheet 10. Skokomish River and Annas Bay
- Sheet 11. Dungeness River and Dungeness Bay

The approach used, in general, was to locate and obtain the oldest authoritative maps of the areas and then to compare those historical maps with the most current topographic maps. The historical-map data were then carefully transferred, by optical projection and manual plotting, to film copies of the modern maps of 1:24,000 scale. No attempt was made to show the progression of change in the delta areas and, therefore, intermediate-age maps are not shown in this series. However, for some map compilations, intermediate-age source materials were used to help verify or evaluate the overall changes.

These maps are one of a series of products being prepared by the Puget Sound Earth Sciences Applications Project to present basic information and interpretations of an environmental protection in the Puget Sound region. The work was begun at the request of U.S. Fish and Wildlife Service and Justice Department, and received financial support by the Bureau of Indian Affairs.

Boyer and Madsen (2006) (Unique Identifier: 221)

Reference	Boyer, D., and S. Madsen. 2006. Prairie Creek feasibility study. Report prepared by Skagit System Cooperative and Sauk-Suiattle Indian Tribe.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, channel migration, channel incision, sinuosity, floodplain, side and off-channels, floodplain connectivity, substrate and sediment, sediment transport and supply, large wood, aquatic habitats and landforms. ***Water Quality and Productivity:*** temperature. ***Modeling Tools:*** hydrology. ***Land Use and Cover:*** land cover. ***Fish and Habitat:*** Habitat: instream flow, riparian, wetlands, barriers, freshwater, connectivity, limiting factors, capacity, restoration; Fish: distribution; Monitoring: flow, water quality, data gaps.									
Species and Life Stages	***Chum:*** spawning. ***Coho:*** spawning, outmigration. ***Other species (Cutthroat Trout):*** not specified.									
Reaches and Spatial extent	Other Sauk River tribs.									
Linkages to Project Operations	NA									

Abstract: This feasibility study examines restoration opportunities for the Prairie Creek and Unnamed Creek watersheds with special focus on the alluvial fan and floodplain reaches of the Prairie Creek Drainage (WRIA 04.1069) located in the Sauk Prairie Watershed Administrative Unit of the Skagit River basin. It identifies physical and biological impediments to watershed processes that impact fish utilization and habitat quality between the interface with the Sauk River floodplain and the upper reach of feasibly accessible fish habitat, a total of 1.4 miles (2.25 km) for the existing Prairie Creek channel. It also provides recommendations for restoration actions to correct these impediments. Restoration actions recommended in this report focus on restoring naturally sustaining channel forming processes, sediment delivery, and hydrology; increasing channel complexity and floodplain connectivity; restoring salmon access to the lahar terrace and alluvial fan; and restoring riparian habitat between a perched culvert barrier and the forested alluvial fan at the base of Prairie Mountain.

Breithaupt et al. (2010) (Unique Identifier: 414)

Reference	Breithaupt, S., Smith, D., and T. Khangaonkar. 2010. Hydrodynamic analyses of restoration actions in the flood plain. Pages 1-10 *in* M. L. Spaulding, editor. Estuarine and Coastal Modeling, American Society of Civil Engineers.									
Source Information	***Type***	Book	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, floodplain connectivity. ***Modeling Tools:*** hydrology. ***Fish and Habitat:*** Habitat: instream flow, freshwater, limiting factors, connectivity, restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	R11, R12 (Gilligan Creek Restoration Site RM 28.5).									
Linkages to Project Operations	NA									

Abstract: Over the last century, considerable near-shore tidal marshland as well as upriver freshwater habitat has been lost due to diking for agriculture, flood protection, and other development. While efforts to restore degraded coastal/estuarine habitats and re-establish migratory pathways for salmon, receive considerable attention and are supported through complex 3-D coastal circulation modeling, upstream restoration actions are sometimes neglected. The traditional approach of modeling upstream reaches has been to utilize one-dimensional hydraulic models developed for FEMA flooding analyses. While this approach may be sufficient for engineering design for peak flood protection, it is inadequate for most high flow events where flood waters often leave the channel and flow across the floodplain in a complex manner. This paper presents a hydrodynamic modeling analysis of the Skagit River and its floodplain to evaluate the effect of a proposed restoration project on flooding. It also shows the feasibility and advantages of using an unstructured multidimensional model for conducting such analyses. The site was located at approximately RM 28.5, within the lower Skagit River floodplain but upstream of tidal influence. The restoration proposal involves removal of a section of the existing dike as it is thought to be degrading habitat of the floodplain downstream by preventing flow into historic channels that could potentially provide refugia for salmon during migration. Previously a hydrodynamic model of the Skagit Basin including the Skagit Bay, estuary, and the flood plain was developed using the unstructured, three-dimensional model FVCOM. The approach used in the current study was to include the river channel and floodplain in the model domain, with inflow specified at the upstream end covering approximately 37 miles of river channel and floodplain. Because the study area is above tidal influence, measure water surface elevation data were used as the downstream boundary conditions. The results show the change in hydrodynamic conditions from the proposed project. A brief discussion is given on the potential of the modeling approach to provide the connectivity needed to properly analyze the Skagit River system from the North Cascades Mountains to the Skagit Bay for water quality, food web dynamics, and climate change.

Brophy et al. (2019) (Unique Identifier: 021)

<table>
<tr><td>Reference</td><td colspan="10">Brophy, L. S., C. M. Greene, V. C. Hare, B. Holycross, A. Lanier, W. N. Heady, K. O'Connor, H. Imaki, T. Haddad, and R. Dana. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PloS one 14(8):e0218558.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, history, estuarine habitats and landforms. Modeling Tools: hydrology, bathymetry, habitat. Fish and Habitat: <u>Habitat:</u> estuary, wetlands, connectivity, status and trends.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary as well as all estuaries on the Pacific Coast.</td></tr>
<tr><td>Linkages to Project Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Effective conservation and restoration of estuarine wetlands require accurate maps of their historical and current extent, as well as estimated losses of these valued habitats. Existing coast-wide tidal wetland mapping does not explicitly map historical tidal wetlands that are now disconnected from the tides, which represent restoration opportunities; nor does it use water level models or high-resolution elevation data (e.g., lidar) to accurately identify current tidal wetlands. To better inform estuarine conservation and restoration, we generated new maps of current and historical tidal wetlands for the entire contiguous U.S. West Coast (Washington, Oregon, and California). The new maps are based on an Elevation-Based estuary Extent Model (EBEEM) that combines lidar digital elevation models (DEMs) and water level models to establish the maximum historical extent of tidal wetlands, representing a major step forward in mapping accuracy for restoration planning and analysis of wetland loss. Building from this new base, we also developed an indirect method for mapping tidal wetland losses, and created maps of these losses for 55 estuaries on the West Coast (representing about 97 percent of historical West Coast vegetated tidal wetland area). Based on these new maps, we estimated that total historical estuary area for the West Coast is approximately 735,000 hectares (including vegetated and nonvegetated areas), and that about 85 percent of vegetated tidal wetlands have been lost from West Coast estuaries. Losses were highest for major river deltas. The new maps will help interested groups improve action plans for estuarine wetland habitat restoration and conservation, and will also provide a better baseline for understanding and predicting future changes with projected sea level rise.

Campbell et al. (2017) (Unique Identifier: 023)

Reference	Campbell, L. A., A. M. Claiborne, and J. H. Anderson. 2017. Successful juvenile life history strategies in returning adult Chinook from five Puget Sound populations; age and growth of Chinook salmon in selected Puget Sound and coastal Washington watersheds. Salish Sea marine survival project 4: 2017 annual report. Report prepared by Washington Department of Fish and Wildlife, Fish Program, Science Division.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** contaminants. ***Fish and Habitat:*** <u>Habitat:</u> estuary; <u>Fish:</u> survival, growth, life history, age structure, size structure, sex structure, hatchery, data gaps.									
Species and Life Stages	***Chinook:*** outmigration, migration, ocean.									
Reaches and Spatial extent	Puget Sound, including Skagit Watershed.									
Linkages to Project Operations	NA									

Abstract: This report provides results for two research topics funded under the Salish Sea Marine Survival Project to examine early marine survival in Chinook Salmon as it relates to life history expression and growth. The first, an otolith microchemistry project examining juvenile life history strategies of surviving adults and the second investigating the relationship between early marine growth (inferred from fish scales), marine survival, and ocean conditions.

Otolith Project — In this study, we used otolith chemistry to reconstruct the juvenile life history of Chinook Salmon returning to 5 Puget Sound populations. This report provides definitive evidence that small fry sized (35-60mm) Chinook Salmon survive early migration from their natal habitat and comprise as much as 35 percent of the returning adults. Survival/success of juvenile Chinook fry (fish <60mm) was greater in the two populations we sampled in Northern Puget Sound (Nooksack and Skagit Rivers) while the success of the fry life history was low (<5 percent) in adult populations examined from the Cedar River, Green River and Puyallup River (mid and South Puget Sound). This work shows compelling evidence that the smallest migrants (sometimes viewed as excess production) survive and contribute to adult returns. We discuss the differences in life history expression we observed and propose how the lack of the fry life history in mid and southern Puget Sound may be related to early marine survival. Of special note is apparent correlation between estuary/delta habitat condition, pathogen and contaminate exposure and life history success at the very beginning of the marine migration. Though this research was conducted on many individual adult Chinook (n~450) our inference to specific geographic locations (n=5) and return years (n=1) is low. Therefore, caution is advised when making any corollary inference. This work does show compelling evidence that life history expression and survival of the fry life history is severely limited in 3 of the most developed and contaminated estuaries within Puget Sound. These findings are relevant to life history theory, habitat restoration, survival, and stock recovery efforts.

Scale Project —In this study, we used scale analysis of returning adults to examine the relationship between early marine growth and survival for 3 Puget Sound and 2 coastal populations of Chinook Salmon. In total, we examined scales from 2,604 individuals over 7 outmigration years characterized by relatively poor, average, and good survival from 1976 to 2008. We observed a

positive relationship between growth during the first year at sea and survival for adults returning to the Skagit, Green/Duwamish, and Puyallup Rivers. In addition, growth of age 3 fish from north and mid Puget Sound was a useful predictor of cohort survival (age 3 to 5). Conversely, we observed no evidence of a relationship between growth and survival for fish returning to the Quillayute River but, on average, fish returning to northern costal Washington grew 14 percent (SD = 9 percent) more during the first year at sea than Puget Sound populations. These results support previous research that factors influencing early marine growth (i.e., prey abundance and quality) are important to the survival of Puget Sound Chinook Salmon. In addition, early marine growth may be a useful biological indicator for pre-season forecasting of Chinook Salmon populations in Puget Sound.

CGS (2017) (Unique Identifier: 027)

Reference	Coastal Geologic Services (CGS). 2017. Beach strategies phase 1 summary report: identifying target beaches to restore and protect. Report prepared by CGS for Estuary and Salmon Restoration Program, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, nearshore habitats and landforms, scour. ***Land Use and Cover:*** urban, banks and shoreline, data gaps. ***Fish and Habitat:*** Habitat: estuary, pocket estuary, nearshore.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound.									
Linkages to Project Operations	NA									

Abstract: This document describes significant updates to coastal data for the Puget Sound region. CGS has updated and refined historical and current records, including:

- New high-resolution shore armor mapping for 367 miles (15 percent) of Puget Sound shoreline, with elevation, condition, and material attributes (214 of these miles for Island County; CGS 2016c).
- A compilation of existing Sound-wide shore armor.
- Shore armor and shoretypes disentangled to answer the question of where historical feeder bluffs are located, using complimentary remote assessment and field-based methods.
- Comprehensive historical shoretype mapping for all other armored shores.
- Pocket beach mapping, updated at higher resolution using more recent aerial imagery.
- New measures of fetch (the over-water distance over which wind-generated waves form), to update erosion potential.
- Corrected net shore-drift cells and incorporated divergence zones, including renaming all drift cells in a consistent way.
- Drift cells were turned into *linear referencing* routes, which allow simple GIS queries to answer what is up-drift or down-drift of anything else.
- The Washington Department of Fish and Wildlife (WDFW) residential shoreline (real estate) parcel dataset was augmented to include all non-residential parcels.
- Land parcels adjacent to shore were extended waterward to connect with rich coastal data.

All components included in the *Beach Strategies Geodatabase* conform to the Washington Department of Natural Resources (WDNR) ShoreZone shoreline (2001), making this data compatible with many existing Washington State coastal datasets.

In combination with the data structures in the companion *Nearshore Geospatial Framework* project, these data will enable refined nearshore restoration and conservation planning. For example, the improved historical feeder bluff inventory, used in conjunction with armor mapping and net shore-drift cell data, could be readily applied to identify priority areas for shore armor removal restore critical sediment transport mechanisms and to promote forage fish spawning habitat restoration.

Future work will involve community stakeholder workshops to create an online mapping tool to apply these data to answer Sound-wide coastal restoration questions.

Funding for *Beach Strategies* comes from the Estuary and Salmon Restoration Program (ESRP) Learning Project, RCO #14-2308P. The Historical Feeder Bluff mapping amendment to *Beach Strategies* was funded by the Puget Sound Partnership. Island County boat-based armor mapping was funded by the Salmon Recovery Funding Board, the NOAA Pacific Coastal Salmon Recovery Fund, and the United States Environmental Protection Agency under Assistance Agreement [PC-00J90301] National Estuary Program funds. The associated *Nearshore Geospatial Framework* project was completed for the Puget Sound Partnership.

Coastal Geologic Services (CGS) (2020) (Unique Identifier: 028)

Reference	Coastal Geologic Services (CGS). 2017. Appendix A of beach strategies phase 1 summary report: identifying target beaches to restore and protect. Report prepared by CGS for Estuary and Salmon Restoration Program, Olympia, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, data gaps, large wood, climate change. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: restoration, connectivity, nearshore, pocket estuary, wetlands.								
Species and Life Stages	***Other (Surf Smelt, Sand Lance):*** spawning-rearing. No listed salmon species but discusses salmonids in general: nearshore rearing and emigration.								
Reaches and Spatial extent	Puget Sound.								
Linkages to Hydroelectric Operations	NA								

Abstract: This document describes Phase 2 of the Beach Strategies for Puget Sound project. Phase 2 builds on Phase 1 data (CGS 2017) to create tools for prioritizing the protection and restoration of Puget Sound beaches and bluffs. The Coastal Geologic Services, Inc. (CGS) team has performed spatial and statistical queries and developed metrics to address the following nearshore priorities (for restoration and protection) in beach systems:

- Sediment Supply processes
- Forage Fish Spawning support
- Pocket Beaches

Beach Strategies Phase 2 incorporated feedback from end-users at multiple stages in order to develop meaningful and valuable tools to inform beach restoration and protection efforts in the Puget Sound region. End user values are reflected in methods used to develop the evaluation framework, modules, and metrics. The results of end-user outreach efforts were used to construct an online mapping tool that enables users to explore management recommendations at a desired scale of analysis (drift cell or bluff), investigate underlying data used to develop management recommendations, and specify ranges of user-defined values.

An evaluation framework was developed to assess conditions within beach systems by building on fundamental conceptual linkages and values from previous efforts focused on Puget Sound recovery within beach systems (Cereghino et al. 2012, Schlenger et al. 2012, Simenstad et al. 2011, Greiner 2010) and an iterative outreach process with end-users. The framework consists of three modules: sediment supply, forage fish spawning, and pocket beaches. A fourth module that was focused on the assessment of sediment supply and transport to support barrier embayment systems was developed but was put on hold due to data shortcomings.

Each module consists of a range of queries and metrics that were designed to convey on-the-ground conditions along a zero to one gradient. Metrics reflect nearshore process degradation and/or the potential benefit of restoration or protection of a given unit of shore. Restoration and protection management recommendations were assigned based on the combined degradation and potential benefit at multiple nested scales from net shore-drift cells to shoreforms and reaches of armored and unarmored bluff. Management recommendations include prioritized drift cells, bluff reaches and pocket beaches for restoration and protection (conservation) throughout the region for each module.

All metrics, interim data, and management recommendations are presented in project web maps and are included in the project geodatabase. Data sources used in metrics are also included in the project web maps. Guidance and discussion of how to use the Beach Strategies Phase 2 products, data limitations, and considerations for future studies are also discussed in the report.

Outputs include priority areas for process-based restoration and protection at multiple scales; within drift cells, shoreforms (pocket beaches) and reaches of armored and unarmored shore. Priority reaches of shore are ranked within the large drift cells in which they are found and include management recommendations.

All components included in the Beach Strategies Geodatabase conform to the Washington Department of Natural Resources (WDNR) ShoreZone Inventory (2001) shoreline, making this data spatially compatible with many existing Washington State coastal datasets. This can enable end-users to integrate Beach Strategies outputs with other locally available, higher resolution data to further focus their management strategies in their areas of interest.

Christiaen et al. (2022) (Unique Identifier: 306)

Reference	Christiaen B., Ferrier L., Dowty P., Gaeckle J., and Berry H. 2022. Puget Sound Seagrass Monitoring Report, monitoring year 2018-2020. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, Washington								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** scour. ***Water Quality and Productivity***: temperature, nutrients, dissolved oxygen, turbidity, pH, primary productivity, secondary productivity, salinity. ***Fish and Habitat:*** <u>Habitat:</u> status and trends, nearshore; <u>Monitoring:</u> habitat.								
Species and Life Stages	NA								
Reaches and Spatial extent	Puget Sound.								
Linkages to Project Operations	NA								

Abstract: The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of State-Owned Aquatic Lands for the benefit of current and future residents of Washington State. DNR's stewardship responsibilities include protection of native seagrasses, such as eelgrass (*Zostera marina*) and surfgrass (*Phyllospadix spp.*), important components of nearshore ecosystems in greater Puget Sound. DNR monitors abundance and depth distribution of native seagrasses to determine status and trends in greater Puget Sound through the Submerged Vegetation Monitoring Program (SVMP). Sound wide monitoring was initiated in 2000. The monitoring results are used by DNR for the management of State-Owned Aquatic Lands, and by the Puget Sound Partnership as one of 25 Vital Signs to track progress in the restoration and recovery of Puget Sound.

Key findings:

The San Juan Islands and Cypress Island emerges as a region of concern.

- The San Juan Islands and Cypress Island has been identified as a region of concern, where sites with declines in eelgrass area significantly outnumber sites with increases, both over the long-term (2000-2020) and in recent years (2015-2020). Over the long-term there were 16 sites with eelgrass declines and 4 sites with increases (out of 89 sites sampled in the region). In recent years there were 15 sites with eelgrass declines and no sites with increases.
- Some of the largest eelgrass losses in the San Juan Islands have occurred in embayments. The most notable examples are Westcott Bay on San Juan Island (near total loss), Reef Net Bay on Shaw Island (> 60 percent loss), Shallow Bay on Sucia Island (~ 75 percent loss), and Swifts Bay on Lopez Island (~50 percent loss).
- Local declines are likely due to a variety of stressors, such as physical damage, local water quality impairments, and eelgrass wasting disease.

River delta eelgrass bed dynamics.

- In both the Skokomish and the Nisqually deltas, eelgrass populations fluctuated by over 50 percent between 2000 and 2020.

- At a site in Skagit Bay (flats20), almost 200 ha of eelgrass was lost between 2004 and 2020. The rate of decline increased in recent years. Eelgrass loss at this location was likely due to erosion caused by an avulsion of the north fork of the Skagit River. The overall loss of eelgrass in Skagit Bay is more extensive, as adjacent sites were impacted as well.

Other site-level eelgrass bed dynamics.

- Out of 214 randomly selected panel sites, a similar number of sites declined (n = 38) and increased (n = 33) between 2000 and 2020. However, in recent years (2015-2020) sites with declines in eelgrass area (n = 32) outnumbered sites with increases (n = 9).
- Between 2000 and 2020, there were more declines than increases at sites with small eelgrass beds, while there were more increases than declines at sites with medium and large beds. Between 2015 and 2020, there were more declines than increases regardless of bed size.

Soundwide eelgrass area was relatively stable over the long term (2000-2020).

- Soundwide eelgrass area increased between 2004 and 2016, but declined between 2016 and 2020. The magnitude of these changes was relatively small as compared to the total amount of eelgrass present in greater Puget Sound.
- Overall, eelgrass populations were relatively stable between 2000 and 2020. The relative stability sets Puget Sound apart from many other developed areas, where substantial system-wide declines are ongoing.
- The annual estimates of soundwide eelgrass area were 21,283 +/- 1,5711 ha in 2018, 23,512 +/- 1,864 ha in 2019, and 22,845 +/- 1,864 ha in 2020. The 3-year soundwide average for 2018-2020 was approximately 22,100 +/- 1,100 ha (Figure A).
- The Puget Sound Eelgrass Vital Sign Indicator target of 20 percent increase in soundwide eelgrass area by 2020 has not been met. Stressors that affect seagrass in Puget Sound will likely need to be reduced to achieve significant soundwide gains in eelgrass area, depth distribution, and overall health.

Cichosz and Barber (2008) (Unique Identifier: 480)

Reference	Cichosz, T., and M. E. Barber. 2008. Review of Skagit County water quality monitoring program. Report prepared by State of Washington Water Research Center, Pullman, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity***: temperature, nutrients, dissolved oxygen, turbidity, pH, salinity, data gaps.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Project Operations	NA									

Abstract: At the request of Skagit County, we conducted an external review of their current water quality monitoring program. The scope of work included eight tasks related to the assessment of the Program's goals and procedures, describing available methods for determining whether streams are unable to meet water quality standards due to natural conditions, examining the potential impacts of water quality on salmon, responding to public comments concerning the Program, recommending next steps, and providing cost estimates for these steps.

Overall, we found the monitoring program to be very effective as a trend monitoring program to assess water quality conditions within the County. This conclusion is based on the review of data, peer-reviewed literature, project reports, a field reconnaissance trip, and personal communication with Skagit County staff. Our two main recommendations with regard to the use of the seasonal Kendal test to identify trends was that the existing procedure should be modified to account for variability in stream discharges and that the data should be analyzed using each month as a "season." We also recommended a procedure for determining when there is sufficient data for trend identification which County personnel can easily incorporate into future reports.

Given the variability of site conditions, land uses, development pressures, and drainage basin characteristics, we believe that while the current program may identify problem areas, additional information will be necessary spatially and temporally in order to definitively identify the cause and effect relationships needed for enforcement action (so called "triggers for corrective action"). Task 7 recommended and ranked eleven possible areas for future avenues of work that could help strengthen the existing program. Ultimately, more sites that are closer together (e.g., upstream and downstream of a particular land use) may be required in order to categorically defend any assumed cause-effect outcome.

The costs of these recommendations ranged from low to very high and thus may not be fully implementable by the County. The recommendations and ranking attempted to balance out cost versus necessity based on our professional experience and scientific procedures found in the published literature. Incorporating flow into the statistical analysis was the area we felt most strongly about as this will help eliminate variability caused by storm events and climate change impacts. However, this may require an additional 1/4 time person at the County and budget for installation of stream gauges.

Clifton and Smith (2018) (Unique Identifier: 222)

Reference	Clifton, B. C., and D. Smith. 2018. Comparison of deterrents to reduce elk rubbing and herbivory in a Skagit River restoration planting, Washington. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: <u>Habitat:</u> riparian, restoration.								
Species and Life Stages	NA								
Reaches and Spatial extent	R10.								
Linkages to Hydroelectric Operations	NA								

Abstract: Salmon habitat restoration projects have reforested around 800 hectares in the Skagit River watershed from 2008 to 2017 but coincident growth of the North Cascades Elk Herd has complicated these efforts. *Cervus canadensis* (elk) browse terminal and primary lateral branches and wound bark on seedlings, resulting in reduced growth, vigor and survivorship. This impacts restoration success and increases reforestation costs. Few studies have compared the efficacy and shortcomings of methods to reduce *C. canadensis* damage within a restoration setting. This study aimed to 1) compare the efficacy of paper bud caps, companion planting with *Picea sitchensis* (Sitka spruce*),* and Plantskydd® topical repellent in reducing *C. canadensis* browse; and 2) test the efficacy of Plantskydd® topical repellent in reducing bark wounding on seedlings at the Savage Slough Restoration Project site near Concrete, Washington. We found that Companion planting and Plantskydd® application significantly reduced browse damage, whereas paper bud caps had no significant effect. Furthermore, Plantskydd® application did not significantly reduce bark wounding. While Plantskydd® application or companion planting can reduce *C. canadensis* browse in restoration plantings, thereby increasing success rates and decreasing costs, Plantskydd® application is more expensive per hectare than companion planting.

Clifton et al. (2018) (Unique Identifier: 223)

Reference	Clifton, B. C., W. G. Hood, and S. R. Hinton. 2018. Floristic development in three oligohaline tidal wetlands after dike removal. Ecological Restoration 36(3):238-251.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: estuary, wetlands, invasive species, restoration, connectivity; Monitoring: restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit estuary (Deepwater Slough, Milltown Island, and Wiley Slough and two reference sites within 300 m of the restoration sites).									
Linkages to Project Operations	NA									

Abstract: The decline of salmon populations has intensified tidal wetland restoration efforts throughout the Pacific Northwest, but few results are available monitoring the trajectory of these efforts over time. In three oligohaline tidal wetlands, dike removal restored tidal influence to provide juvenile salmon rearing habitat in the South Fork Skagit River Delta, Washington, USA. This study compared up to 13 years of vegetation development in these restoration sites to reference tidal marsh sites using remote sensing and transect surveys. While native emergent plant communities and open water dominated the most recently restored site (41.6 percent and 39.5 percent cover), invasive species present prior to restoration dominated the earlier restored sites. *Typha angustifolia* (narrow leaf cattail) overran one site (60.7 percent cover), and *Phalaris arundinacea* (reed canarygrass) the other (40.0 percent cover). *Typha angustifolia* also covered 37.5 percent of the reference sites. Combined elevation distribution of invasive species overlapped that of native species, suggesting direct competition in this environment. Furthermore, the ability of pre-established invasive species to persist in the subsided restoration sites at elevations outside of reference occurrence ranges affected the native species elevation distributions. The authors hypothesize that despite sufficient native propagule dispersal, competition from persistent invasive species resulted in simplified community structures with reduced native herbaceous and scrub-shrub cover. In potential restoration sites dominated by non-native *T. angustifolia* and *P. arundinacea*, managers should consider their control to facilitate native species colonization. In new restoration sites where plant communities are still evolving, they should monitor invasive species cover and composition to keep levels below the that of the reference site condition.

Clifton (2015) (Unique Identifier: 224)

Reference	Clifton, B. C. 2015. Crescent Harbor Salt Marsh restoration 2013-2015 vegetation monitoring report. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms. ***Water Quality and Productivity:*** primary productivity, secondary productivity. ***Land Use and Cover:*** agriculture. ***Fish and Habitat:*** Habitat: estuary, wetlands, restoration, invasive species; Monitoring: restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: Botanical inventories are being conducted as part of the Crescent Harbor Salt Marsh Restoration monitoring documentation. Vegetation surveys of the marsh surface were conducted in July of 2009 (pre-project), June of 2011, September of 2013, June of 2014 and August of 2015. Descriptions of the 2009 and 2011 surveys can be found in The Crescent Harbor Salt Marsh Restoration As-Built Report (SRSC, 2009) and in the Crescent Harbor Salt Marsh Restoration 2010-2011 Monitoring Report (SRSC, 2011). This document outlines results from the 2013 to 2015 surveys.

The 300-acre marsh is owned by the Naval Air Station Whidbey Island and located near the town of Oak Harbor on the northeastern shore of Whidbey Island. It was historically the largest open barrier island salt marsh on Whidbey Island. In the early 1900s, the marsh was diked and drained for agriculture and grazing, and cut off from fish access and tidal exchange, except through ground water. However, in 2009, several actions were taken to restore fish access and tidal flow to the site.

Collias et al. (1973) (Unique Identifier: 332)

Reference	Collias, E., C. A. Barnes, and J. A. Lincoln. 1973. Skagit Bay study dynamical oceanography: final report. Department of Oceanography, University of Washington, Seattle.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, dissolved oxygen, nutrients, contaminants. ***Fish and Habitat:*** Habitat: ocean. ***Modeling tools:*** hydrology.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay (including waters east of Deception Pass and south until Polnell Point to Rocky Point on Camano Island).									
Linkages to Hydroelectric Operations	NA									

Abstract: At the request of Seattle City Light and Snohomish County Public Utility District No. 1, the University of Washington Department of Oceanography studied the physical and chemical properties and circulation of the saline waters adjacent and in the approaches to Kiket Island located in the northern part of Puget Sound, Washington. The primary objective was to provide base-line information needed for estimating probable temperature changes and dispersion of heat that might be released in cooling water from a proposed 1000-megawatt thermonuclear power-plant to be located on Kiket Island. Measurements included temperature, salinity, dissolved oxygen, soluble phosphate, nitrate, silicate, currents, water levels, and meteorological observations made near water level. Intensive field studies were conducted from February 1970 through October 1971. Some observations of water properties and tide were made before, and of meteorological conditions and tide after this period. The above measurements were supplemented by dye studies conducted in the field by the Applied Physics Laboratory, temperature records made near shore by the Fisheries Research Institute in connection with their biological studies, and observations of dye behavior and surface circulation in our tidal model. This report describes the principal features of water properties at time periods ranging from subtidal to annual with emphasis being placed upon the thermal regime. Detailed information is given in separate appendices, records, and references. Significant results from this study include the following:

In summer, surface temperatures in the main channels passing Kiket Island are among the lowest within Puget Sound, averaging 11.7 C from June to August, or 2.5°C lower than found southward through Possession Sound. Principal contributing factors are vigorous tidal mixing superimposed on a net northward flow of cold upwelled water from Saratoga Passage. Near shore waters away from strong currents are up to 6°C warmer than those at mid-channel. Maximum diurnal ranges at fixed locations approach 4°C and hourly changes occasionally exceed 2°C. Diurnal ranges showed an annual average of 0.8°C and hourly variations with diurnal periods a standard deviation of 0.2°C. Since large changes in temperature may occur rapidly and over short distances, the common concept of “near” and “far” fields as well as flushing models based upon uniform mixing are invalid for the Kiket Island area.

The temperature increase from cooling water will but little exceed the average hourly variability and will be difficult to detect against the natural background if discharged through a suitable diffuser at a favorable mid-channel location.

The proposed site at Kiket Island appears to be one of the most favorable within Puget Sound proper for dispersing added heat and managing its effect upon ambient waters.

Collins and Sheikh (2005) (Unique Identifier: 031)

<table>
<tr><td>Reference</td><td colspan="10">Collins, B. D., and A. J. Sheikh. 2005. Historical reconstruction, classification, and change analysis of Puget Sound tidal marshes. Report prepared for Washington Department of Natural Resources, Aquatic Resources Division, Olympia, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, history, nearshore habitats and landforms. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat:</u> estuary, pocket estuary, nearshore, wetlands, restoration, connectivity; <u>Monitoring:</u> habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound.</td></tr>
<tr><td>Linkages to Project Operations</td><td colspan="10">NA</td></tr>
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Abstract: This report presents the results of an investigation into the historical nearshore environment of the Puget Sound region. Our geographic scope includes the marine shoreline in Washington State inland of Cape Flattery, inclusive of the south coast of the Strait of Juan de Fuca, Hood Canal, Puget Sound Proper, the San Juan Islands, and the mainland coast north to Canada. The geographic extent is the same as the “Puget Sound Nearshore” defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP).

The largest portion of this project’s scope was to create digital data, with a secondary goal of regional analysis. We georeferenced 125 gray-scale scanned originals of US Coast & Geodetic Survey (USC&GS) topographic sheets (T-sheets) that encompass the Puget Sound Nearshore. We digitized the T-sheets and then edge mapped them to create a Geographic Information Systems (GIS) database with continuous coverage of the entire Puget Sound shoreline. We coordinated methods and data development with the Point No Point Treaty Council, which is undertaking a related study of changes to the nearshore of the Hood Canal, western Admiralty Inlet, and the Strait of Juan de Fuca. We then used this data to reconstruct the historical nearshore environment, by making use of a number of other sources that supplemented and cross-referenced the T-sheet, including records of the federal land survey, following methodology developed over several years (Collins et al. 2003), In order to compare the historical and current conditions of the nearshore environment, we created a geodatabase of current conditions by digitizing from recent aerial photographs, supplemented with existing digital data. This report accompanies this digital data.

We concentrated on one facet of the nearshore environment, tidal wetlands. Our study supplements and expands on an inventory made 120 years ago (Nesbit 1885) of the condition of Puget Sound’s tidal wetlands at the time of Euro-American settlement. Specifically, we created a spatially explicit digital database, useful for making a variety of analyses, to provide the starting point for more detailed site-level investigations, and to guide restoration efforts. We used additional cross-referencing sources to add descriptive and quantitative detail. We used our reconstruction to create a landform and process based classification of tidal wetlands for structuring a historical description and to compare it with comparable mapping of the current condition of Puget Sound’s nearshore, and present a brief summary analysis here. Additional analysis of our data would supplement our

regional quantitative summary with additional information including more detail on the nature and causes of change to wetlands.

Other analyses that could be made with our digital data, in addition to the focus on tidal wetlands reported on here, include using the T-sheets to extend an earlier study of change to kelp distribution (Thom and Hallum 1990) back another 20-60 years prior to the inventory by Rigg (1915) and providing a cross-referencing source to Rigg's examination. The data could also provide a base layer for analysis of some types of change that might have occurred in the last century and a half to erosional and accretionary patterns of the region's shoreforms. The data includes ecological and land use data useful for various other types of analyses.

Collins (1998) (Unique Identifier: 226)

<table>
<tr><td>Reference</td><td colspan="10">Collins, B. 1998. Preliminary assessment of historic conditions of the Skagit River in the Fir Island area: implications for salmonid habitat restoration. Report prepared for Skagit System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: substrate and sediment, sediment transport and supply, large wood, log jam, history, estuarine habitats and landforms. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat</u>: estuary, wetlands, climate change, status and trends, beaver, restoration.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
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Abstract: This investigation describes current and historic conditions of distributary and blind-tidal channels of the lower Skagit River, downstream from where it branches into the North and South forks and forms Fir Island before entering Skagit Bay. The study is pan of a larger effort by the Skagit System Coop to document salmonid habitat use and estimate historic habitat loss and its potential for future restoration.

Fir Island is a relatively small portion of the river's historic delta. Prior to late-19th century river diking, floodwaters and associated suspended sediment commonly exited to Samish Bay and Padilla Bay as well as to Skagit Bay. According to several map sources, historically at least one-half of the delta was perennially wet, consisting of tidal marsh, fresh-water marsh, or open channels. A persistent logjam nearly a mile long at the town of Mount Vernon presented an obstruction to floodwaters, and contributed to the routing of floodwaters onto the Skagit Flats and to Padilla and Samish bays. Removal of the jam in the late 1870s and the later completion of an effective diking system together increased the efficiency with which floodwater was routed to the Fir Island area. This enhanced routing of floodwater to Fir Island was later counterbalanced beginning in the 1930s by headwaters dams which substantially reduced flood peaks.

The river historically stored and transported vast amounts of large woody debris. Records of the federal "snagging" program provide an indication of the amounts of debris that accumulated in the river. For example, 35,000 snags were removed from the lower Skagit River in the two decades prior to 1910. Snags included very large pieces: the snag-boat captain's records include the largest-diameter snag removed each year from Puget Sound rivers. The maximum diameter ranged between 3.7 m and 5.2 m in the 1898-1909 period. It is likely that such large snags had significant geomorphic effects such as retaining and sorting sediment and scouring pools. The very large number of pieces would also have significantly affected stream productivity and the organic matter budget. Debris transported in floods also tended to plug distributary channels, especially in the South Fork. By the turn of the century, streamside forests were logged along the two forks and along the mainstem as far upstream as the Sauk River, and snagging continued into the last few decades of this century, together effecting a century-long reduction in the supply of woodv debris from streamside forests and the amount of in-channel debris.

Diking of the sloughs on Fir Island is responsible for the greatest loss of distributary channel area. Dikes have closed the upstream and downstream ends of Hall, Brown, and Dry Sloughs—the sloughs which cross Fir Island—and eliminated flow through them. Dikes also closed off a smaller area of sloughs in the South Fork, including Wiley Slough. On the other hand, delta progradation and marsh development have increased the area of the North Fork and South Fork and smaller distributary channels associated with both. While the spatial distribution shifted, the overall area of distributary channels remained roughly constant from 1889 (the date of the earliest reliable mapping, by the U.S. Coast & Geodetic Survey) to 1991. There was an overall loss within the landward estuarine-emergent-forest transition zone ("transition zone") and a gain in the bayward estuarine emergent zone. Distributary channel area is not presumed to have changed in the first few decades of settlement prior to 1889, because no sloughs had yet been closed to dikes.

Between about 1860 and 1889, roughly two-thirds of blind-tidal channel area was cut off from tidal influence as much of the estuarine emergent zone and the transition zone were diked and converted to agricultural use. The pre-diking extent of the estuarine emergent zone and the transition zone were estimated from several sources, predominantly information on vegetation found in field notes of surveyors under contract to the General Land Office in the late 1860s and early 1870s, and from U.S. Coast & Geodetic Survey mapping. Blind tidal channels continued to be cut off from tidal flow as diking continued after 1889 and as tidal marsh has eroded between the North and South forks, presumably because of the loss of sediment from Brown, Dry and Hall slough systems. On the other hand, there has been significant accretion—and gains in area of blind tidal channels—in both forks since 1889. In the South Fork, most accretion occurred earlier (prior to 1937, when the first aerial photos are available) in the South Fork, and later (since 1937) in the North Fork. This may reflect an increase in flow from the South to the North forks at about the turn of the century. The total area of blind tidal channels is roughly half of the estimated area before diking. There were also substantial losses in the north-adjoining Sullivan Slough area and to the south of Fir Island; these were not quantified for this report. Most losses have been from the transition zone, and most gains in the estuarine emergent zone, which is important to the extent to which blind channels serve different, potentially limiting, habitat functions in the two zones.

Because of the large loss to the area of blind tidal channels, there is a great potential to restore the quantity of physical salmonid habitat by restoring these tidal channels, which are predominantly in the transition zone. Restoration opportunities include allowing tidal channels to redevelop in diked-off areas by reopening these areas to tidal influence. It is also possible that restoring the supply of sediment to the marsh on the delta front (i.e. between the two forks) would allow now-eroding saltmarsh in the estuarine emergent zone to rebuild. There is also a large potential to restore habitat quantity by restoring flow to those distributary sloughs that were blocked by dikes—the interior sloughs on Fir Islands, and sloughs in the deltas of the North and South forks. Opportunities to restore the quality of habitat include increasing the supply of large woody debris.

Collins (2000) (Unique Identifier: 227)

Reference	Collins, B. 2000. Mid-19th century stream channels and wetlands interpreted from archival sources for three north Puget Sound estuaries. Report prepared for Skagit System Cooperative, Bullitt Foundation, and Skagit Watershed Council.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** history, change, estuarine habitats and landforms, large wood. ***Land Use and Cover:*** floodplain. ***Fish and Habitat:*** Habitat: riparian, wetlands, estuary, beaver.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit estuary, Padilla Bay, Skagit Bay, Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: This report presents Arc/Info GIS maps of historic (pre-European settlement, or approximately 1860) channels and wetlands in the Skagit-Samish delta and Stillaguamish estuary, and the Snohomish River valley and explains the methods used to create the maps.

Primary sources of information are: (1) U. S. Coast & Geodetic Survey (USC&GS) charts from 1884 to 1893 (Figure 3); (2) General Land Office (GLO) maps from 1866 to 1877; (3) U. S. Army Corps of Engineers maps; (4) topographic maps; (5) field notes from the GLO surveys; (6) soil surveys, from as early as 1909; (7) government reports, and (8) accounts by settlers. The GLO field notes were an especially important source of information supplemental to map sources. At over 800 points, the notes provided diameter, species, and distance to nearly 1,400 witness trees; general descriptions of vegetation and hydrology; and quantitative observations on water depths and flooding.

Estuarine wetlands, mapped by use of various sources and methods, were extensive in the floodplains of each of the three rivers, accounting for at least one-half of land area in each area. The Snohomish River valley and Skagit-Samish delta also had extensive freshwater wetlands (freshwater wetlands include riverine-tidal areas in which tidal backwater augmented flooding effects). Freshwater wetland was more than four times the extent of estuarine wetlands in the Snohomish and the two were equal in the Skagit-Samish delta. Field observations from the GLO notes allow estimates of seasonal inundation in some of the larger marshes. For example, Marshland, a 1,900 ha wetland on p. ii the floodplain of the Snohomish River, was inundated in February 1871 in at least half and as much as 90 percent of its area to a depth of more than two-thirds of a meter. Freshwater wetlands on the Stillaguamish delta were less extensive than on the Skagit-Samish delta and the Snohomish valley.

Each estuary had numerous distributary and blind-tidal channels. Channel types mapped are: mainstem, distributary, blind-tidal, connecting, floodplain slough, and tributary. For each channel type, segments are broken out in the estuarine-emergent, estuarine-scrub-shrub, tidal-freshwater, and freshwater zones and area summed for each. The Skagit-Samish delta, because of its diverging-spreading form, is dominated by estuarine channels, while the confined and low-gradient Snohomish River estuary is dominated by tidal-freshwater distributary channels. Channels in the confined Stillaguamish valley are also dominantly estuarine but have a relatively small area because of the relatively steep valley.

Diking, ditching, and filling greatly diminished the extent of freshwater and estuarine wetlands and blind tidal channels on each of the three river deltas. In the Skagit and Stillaguamish rivers, nearly all wetlands had been diked, drained, and ditched by early in the 20th century. In the Snohomish valley, change was more gradual but nonetheless nearly all wetlands had been altered by the middle of the 20th century.

Cordell et al. (2012) (Unique Identifier: 032)

Reference	Cordell, J. R., L. Stamatiou, J. Toft, and E. Armbrust. 2012. Initial biological responses at a restored floodplain habitat, Hansen Creek, Washington. Report prepared by Wetland Ecosystem Team, University of Washington for Upper Skagit Indian Tribe, Sedro-Woolley, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** secondary productivity. ***Fish and Habitat:*** Habitat: freshwater, riparian, restoration; Fish: abundance, diet, rearing; Monitoring: restoration, abundance.									
Species and Life Stages	***Coho, steelhead:*** rearing.									
Reaches and Spatial extent	Hansen Creek.									
Linkages to Project Operations	NA									

Abstract: Streams with intact floodplain connections are important to juvenile salmonids during their freshwater residence, providing refuge during periods of high flow as well as prey produced in emergent marsh and terrestrial riparian habitats. Habitat restoration was undertaken in 2009-2010 on lower Hansen Creek, Washington, with the goal of recovering these important lower elevation freshwater floodplain functions. The project converted 140 acres of isolated floodplain into 53 acres of alluvial fan and 87 acres of flow-through wetlands. To quantify the initial biological responses at the Hansen Creek alluvial fan restoration site and provide a baseline of data for future comparisons, we conducted invertebrate and fish sampling at the restored habitats. The study was conducted from September 2010 through September 2011 in three areas within the restoration site, and in one reference area outside the project area. We collected diets from juveniles of Coho Salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*), the two dominant salmonids in the creek. Salmonid abundances and diets were also sampled during periodic seasonal flooding that occurred on the restored floodplain. Insects were sampled with fallout traps once-monthly March through September, and neuston invertebrates were sampled once on the floodplain during an inundation event in April and once at the in-channel sites in June. Visual snorkel fish surveys were attempted January through May, and successfully completed June through August. Sampling to assess the Biological Index of Biotic Integrity (B-IBI) was completed in September 2010 and September 2011.

Diets of both steelhead trout and Coho Salmon consisted of aquatic drift, terrestrial insects, and benthic prey items. In general, higher instantaneous rations, a measure of feeding intensity, were recorded from diets of juvenile Coho Salmon collected during periodic inundation events than during regular monthly sampling in the channels. Despite relatively warm water temperatures and decreased visibility due to high turbidity, the floodplain appeared to provide favorable feeding opportunities to salmonids, likely due to greater availability of drift and emergent insect prey. Terrestrial insect numbers peaked in July and August. The floodplain site had consistently higher insect abundances, and always had significantly different fallout trap assemblages compared to the other sites. Neuston organisms collected in the main channel habitats were dominated by chironomid larvae while those collected during inundation consisted of other types of insects and planktonic organisms. The three reaches sampled for B-IBI all scored in the fair range in both 2010 and 2011, except for one reach, which scored in the good range in 2010.

One of the goals of this study was to evaluate methods for future sampling at the Hansen Creek restoration site. Insect fallout trap and B-IBI sampling are common techniques that will provide data that is comparable to other sites, and our results from the neuston nets indicate that they can provide information that the other methods do not. The methods we used for catching salmonids were arrived at after trying several techniques early in the study. High flows and turbidity during much of the year precluded visual collection methods, and a combination of dip nets with block-and-sweep net samplings was conducted. These methods were probably not completely effective at capturing larger more evasive salmonids or at quantifying salmonids in complex habitats. In the future, a better method would be multiple-pass depletion electrofishing paired with visual snorkel surveys when visibility allows, such as the Basin-wide Visual Estimation Technique. Pole seining in the inundated areas was effective for obtaining juvenile salmonids for diets, but we were not able to generate densities using this method. Also, fishing with pole seines in the floodplain area will likely become more difficult as the vegetation community matures. In this case, additional fishing methods such as fyke nets or traps could be used.

Davis et al. (2020) (Unique Identifier: 034)

Reference	Davis, M. J., J. W. Chamberlin, J. R. Gardner, K. A. Connelly, M. M. Gamble, B. R. Beckman, and D. A. Beauchamp. 2020. Variable prey consumption leads to distinct regional differences in Chinook salmon growth during the early marine critical period. Marine Ecology Progress Series 640:147-169.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: estuary, pocket estuary, nearshore; Fish: diet, rearing, growth; Monitoring: scale or otolith.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration, nearshore rearing and emigration, outmigration.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Project Operations	NA									

Abstract: Growth during the early marine critical period is positively associated with survival and recruitment for Pacific salmon *Oncorhynchus* spp., so it is important to understand how certain foraging strategies may bolster growth in estuarine and marine environments. To elucidate how spatiotemporal and demographic differences in diet contribute to growth rate variability, we analyzed stomach contents in tandem with morphometric and hormonal indices of growth for subyearling Chinook Salmon *O. tshawytscha* captured in Puget Sound, Washington, USA. Regional dietary patterns indicated that fish caught in northern Puget Sound ate insects in the estuarine and nearshore habitats, followed by decapod larvae, euphausiids, or forage fish in the offshore zone. In southern Puget Sound, fish ate insects in the estuary but were more likely to eat mysids and other crustaceans in the nearshore zone. In the marine habitats adjacent to the San Juan Islands, subyearlings ate forage fish, and their stomachs were as much as 1.4 to 3 times fuller than salmon captured in other regions. Scale-derived growth rates and insulin-like growth factor-1 levels showed distinct growth advantages for San Juan Islands fish which were strongly associated with the early adoption of piscivory. However, consumption of larger crustaceans such as mysids and euphausiids was also associated with greater relative growth regardless of where individuals were captured. These findings highlight how spatiotemporal differences in prey quantity, prey profitability, and individual foraging strategies result in variable growth rates among salmon populations. Specifically, they emphasize the role of piscivory in promoting early marine growth for out-migrating Chinook Salmon.

Dean et al. (2000) (Unique Identifier: 035)

Reference	Dean, T., Z. Ferdaña, J. White, and C. Tanner. 2000. Skagit estuary restoration assessment: identifying and prioritizing areas for habitat restoration in Puget Sound's largest rural estuary. Esri Conference Proceedings, May 30, 2000.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms. ***Land Use and Cover:*** land cover, banks and shoreline, floodplain, forestry, agriculture, urban, roads. ***Fish and Habitat:*** Habitat: estuary, connectivity, restoration.									
Species and Life Stages	***Chinook:*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Project Operations	NA									

Abstract: Spurred by proposed Endangered Species Act listings of Puget Sound salmon and other marine species, we developed a GIS site selection tool to identify and prioritize restoration and conservation targets throughout the Sound. For the Restoration Blueprints, we used ARC GRID and ArcView to create a coincidence model based on historic tidal influence, seasonal and tidal flooding, hydrologic zones, ecological sustainability, land use and land cover, and parcel density. These criteria are based on principles of landscape ecology and ease of restoration. This analysis for the Skagit estuary could be applied to any rural delta in the Puget Sound/Georgia basin.

Dean et al. (2001) (Unique Identifier: 393)

Reference	Dean, T., Z. Ferdaña, J. White, and C. Tanner. 2001. Identifying and prioritizing sites for potential estuarine habitat restoration in Puget Sound's Skagit River Delta. Puget Sound Research 1-13.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms. ***Land Use and Cover:*** land cover, banks and shoreline, floodplain, forestry, agriculture, urban, roads. ***Fish and Habitat:*** <u>Habitat:</u> estuary, connectivity, restoration.								
Species and Life Stages	***Chinook:*** not specified.								
Reaches and Spatial extent	Skagit estuary.								
Linkages to Project Operations	NA								

Abstract: The sub-estuaries of Puget Sound—the major river deltas—have suffered a collective 80 percent loss of tidal marsh habitats in the past 150 years. To restore balance, function and health to our ecosystem and natural resources, People for Puget Sound is looking for opportunities to reverse this loss by restoring salt marsh and other estuarine intertidal habitats. The goals of this study are to identify the extent of habitat loss in Puget Sound's Skagit River estuary and to identify and rank areas that would be appropriate for restoring estuarine habitat for the benefit of Chinook Salmon (*Oncorhynchus tshawytscha*) and other threatened or endangered species. No survey of the pre-diked delta exists, so we estimated historic conditions by looking at relics of historic sloughs on aerial photos and comparing them to the U.S. Geological Survey topographic quadrangle maps. Our results show that the Skagit delta has lost approximately 23,825 acres of estuary habitat—more than 37 square miles, or 93 percent of historic coverage. We then developed seven scoring criteria based on principles of landscape ecology and ease of restoration, and used existing data sets to create a Geographic Information System to characterize and analyze the region. The results show a total of 8,847 acres of high-priority potential estuarine restoration areas, mostly located in the area between the North and South forks (distributaries) of the Skagit River, known as Fir Island.

Des Roches (2022) (Unique Identifier: 516)

Reference	Des Roches, S., J. R. LaFuente, H. S. Faulkner, J. R. Morgan, B. S. Perla, M. Metler, M. N. Dethier, and J D. Toft. 2-22. Shoreline Armor Removal Can Restore Variability in Intertidal Ecosystems. Ecological Indicators 140:109056.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: nearshore habitats and landforms. ***Land Use and Cover***: banks and shoreline. ***Fish and Habitat***: Habitat: nearshore, restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: Humans have drastically modified marine nearshore ecosystems through shoreline armoring. Armor, in the form of seawalls and bulkheads, reduces the mean abundance of key ecological features of shoreline ecosystems, such as the amount of beach wrack, the number of beached logs, and the density of supratidal invertebrates. Armor also affects the physical and biological composition and diversity of these important ecological responses – altering the makeup of beach wrack and invertebrate species, for example. Less is known, however, about changes in variability – both over time and space – of ecological responses across natural, restored, and armored shores. Temporal and spatial variation in physical and biological variables can themselves be indicators of ecosystem health and effectiveness of restoration. Working alongside community (citizen) scientists, we found that beach wrack (a nutrient and habitat resource), logs (an element of habitat structure), and supratidal invertebrates (part of the consumer community) often increased following restoration. Further, not only were wrack, logs, and invertebrates on average more abundant and diverse at natural (never armored) shore types compared to armored shore types, but they also frequently had higher variance. In many cases, variance of ecological responses in restored shore types were more similar to natural shore types than armored shore types, indicating a positive effect of restoration. We found that differences among sample sites, rather than across sample years, explained more of the variation in ecological responses across all shore types. Because shoreline armoring is a pervasive human activity, public perception of this variability is key to the social context of restoration success. Participation in data collection through community science endeavors is one way to encourage an appreciation for natural variability within and across landscapes. We implore that shoreline monitoring efforts should evaluate and communicate ecosystem variability as a key indicator of restoration success.

Dinnel and Apple (2013) (Unique Identifier: 230)

Reference	Dinnel, P., and J. Apple. 2013. Community beach seining at Ship Harbor, Fidalgo Island, Washington, August 2013. Report prepared by Shannon Point Marine Center, Western Washington University, Anacortes, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** <u>Fish:</u> abundance; <u>Monitoring:</u> abundance.									
Species and Life Stages	***Other species:*** not specified.									
Reaches and Spatial extent	Puget Sound (Ship Harbor).									
Linkages to Project Operations	NA									

Abstract: One of the goals of the Northwest Straits Commission is to facilitate citizen science by training local citizens on how to collect scientific data and monitor the status of our marine resources and habitats. A second goal of the Commission is to provide education and outreach activities for local communities. The purpose of the Community Beach Seining project is to address both of these goals by using community volunteers to collect fish monitoring data and interact with interested community citizens by including them in the sampling efforts and data collection.

Beach seining at Ship Harbor is continuing, in part, the fish sampling initiated at this location in 2010 as part of Skagit County Marine Resources Committee's (Skagit MRC) Cannery Pond Evaluation Project, which was primarily conducted by a WWU graduate student (Dinnel and Seyl 2011). Continuation of fish sampling in 2011, 2012, 2013 and beyond will provide a longer term fish database for this North Fidalgo Island (west Guemes Channel) location, which is not being monitored for fish by any other organization. All data collected will be forwarded to Skagit River Systems Cooperative, which maintains an extensive database for seine sampling in Skagit County waters, especially in relation to juvenile salmonid species.

This report summarizes the Community Beach Seine sampling conducted at Ship Harbor on 19 June and 15 August, 2013. Data from these two sampling periods are presented in this report, which also includes comparisons to three previous sampling efforts at Ship Harbor (August 2011, June 2012 and August 2012). Additional information and data from these three previous sampling efforts may be found in two earlier reports (Dinnel and Apple 2012a, 2012b).

Dragovich et al. (2000) (Unique Identifier: 132)

Reference	Dragovich, J. D., D. T. McKay Jr., D. P. Dethier, and J. E. Beget. 2000. Holocene Glacier Peak lahar deposits in the lower Skagit River valley, Washington. Washington Geology 28(1/2):19-21.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, history.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: This journal article describes volcanic deposits and lahar locations from Glacier Peak in the surrounding Skagit valley. A brief history of Glacier Peak's eruptions is provided as well as information on how borings throughout the valley showed evidence of lahar runout deposits east of Mount Vernon. Maps are provided with locations of different lahar deposits from various eruptions.

Eames et al. (1981) (Unique Identifier: 258)

Reference	Eames, M., T. Quinn, K. Reidinger, and D. Haring. 1981. Northern Puget Sound 1976 adult coho and chum tagging studies. State of Washington Department of Fisheries, Technical Report 64:217.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, harvest, hatchery, distribution, sex structure, size structure.								
Species and Life Stages	***Coho, Chum:*** migration. ***Pink, Chinook, Sockeye:*** not specified.								
Reaches and Spatial extent	Skagit, Nooksack, Nisqually, Skokomish, Snohomish, Stillaguamish watersheds, Lake Washington.								
Linkages to Hydroelectric Operations	NA								

Abstract: On February 12, 1974, the United States District Court for Western Washington entered its decision in the case United States vs. State of Washington (Civil Wo. 9213), often referred to as the Boldt Decision. With this the State of Washington assumed increased responsibilities in the management of the Puget Sound salmon resource. In response to these new demands and with the assistance of funds appropriated by the United States Congress to assist in implementation of the Boldt Decision, the Washington Department of Fisheries (WDF) undertook Puget Sound Coho (Oncorhynchus kisutch) and Chum (0. keta) tagging studies in 1976 and 1977. The purpose of these studies was to obtain adult Coho and Chum escapement estimates in selected river systems, along with information on run timing, exploitation rates, and commercial gear selectivity in terminal fishing areas.

In 1976, we conducted tagging studies on the Coho runs to the Snohomish and Skagit River systems and the Chum runs to the Skagit and Nooksack River systems. Concurrently, the U.S. Fish and Wildlife Service (USFWS) and various Indian Tribes conducted joint tagging studies on the Coho run to Lake Washington, the Coho stocks in Port Susan-Gardner and Chum runs to the Nooksack, Skagit, Nisqually, and Skokomish River systems.

We repeated our efforts in 1977 on the Nooksack and Skagit systems and expanded our Snohomish Coho study to a combined Coho and Chum tagging study. In 1977 the USFWS essentially repeated the previous year's studies less the Coho study in Port Susan-Gardner. This report covers the tagging studies conducted by WDF in 1976.

ESA et al. (2019) (Unique Identifier: 040)

Reference	Environmental Science Associates (ESA), Puget Sound Partnership, and Washington Department of Ecology. 2019. Appendix A: pilot application of criteria and methods to characterize floodplain conditions. Memorandum to Puget Sound Partnership and Washington Department of Ecology, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, floodplain connectivity. ***Land Use and Cover:*** floodplain.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: This memorandum constitutes the summary document for Task 2.3 of the Floodplains Vital Sign Spatial Data Refinement Project. As noted in ESA's scope of work, the content of this document is formatted and designed for integration into the Final Project Report (Task 1.0). This document synthesizes the results of the application of the draft criteria and methods to the three pilot watersheds; summarizes the process for engaging local experts from pilot watersheds; and describes the outcomes of the pilot efforts. This document also provides a set of decision rules for incorporating local data into future pilot watershed efforts.

ESA et al. (2019) (Unique Identifier: 041)

Reference	Environmental Science Associates (ESA), Washington Department of Ecology, and Puget Sound Partnership. 2019. Floodplain condition assessment and vital sign refinement. Memorandum to Puget Sound Partnership and Washington Department of Ecology.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, floodplain connectivity, large wood, data gaps. ***Land Use and Cover:*** floodplain, agriculture. ***Modeling Tools:*** habitat, juvenile production. ***Fish and Habitat:*** Habitat: restoration.									
Species and Life Stages	***Chinook:*** not specified.									
Reaches and Spatial extent	Skagit Watershed, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: This memorandum constitutes the summary document for Task 2.4 of the Floodplains Vital Sign Spatial Data Refinement Project. As noted in ESA's scope of work, the content of this document is formatted and designed for integration into the Final Project Report (Task 1.0). This document summarizes the progress and analytical outcomes of the Advisory Committee meetings; synthesizes the results of the application of the refined criteria and methods for the regional floodplain extent and conditions assessment; and evaluates the results with the existing Floodplain Vital Sign indicator target of restoring 15 percent of degraded Puget Sound floodplain area with recommendations for how to develop a new target.

ESA (2018) (Unique Identifier: 038)

<table>
<tr><td>Reference</td><td colspan="10">Environmental Science Associates (ESA). 2018. 2018-2022 action agenda proposed near term action: 2018-0726 Puget Sound regional riparian cover mapping standards and implementation. Prepared for Puget Sound Partnership, Olympia, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>No</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Modeling Tools: habitat. Fish and Habitat: <u>Habitat:</u> riparian, restoration; <u>Monitoring:</u> habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">NA</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Watershed, Puget Sound.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
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Summary: This document provides a proposed near term action plan to map the riparian cover in the Puget Sound Region. The document focuses on the basics of the NTA plan including location, stakeholders, cost estimates, partners, etc. presented in a brief outline format. A brief description of the NTA is also provided: *ESA developed an approach and methodology for mapping riparian cover and assessing riparian conditions using a combination of remotely-sensed data in combination with high-resolution local data and regional data layers as a part of a riparian assessment for the Skagit Watershed Council. This NTA would build off of work completed in the Skagit Watershed to develop a standardized approach and to extend riparian cover mapping to other watersheds in the Puget Sound and would leverage WDFW's High Resolution Land Cover Mapping and WDNR's Photogrammetry team. With support from the Puget Sound Partnership, ESA and project partners would work closely with local experts to refine and standardize riparian mapping methods for the region that can support PSP's Vital Signs program, NOAA's Common Indicators, and local or Tribal needs.*

ESA (2019) (Unique Identifier: 042)

Reference	Environmental Science Associates (ESA). 2019. Floodplains spatial data refinement for monitoring project: geospatial methodology report. Report prepared by ESA for Puget Sound Partnership, Project D170337.00, Olympia, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, floodplain connectivity. ***Land Use and Cover:*** floodplain, agriculture.								
Species and Life Stages	***All anadromous species (salmonids in general), steelhead:*** not specified.								
Reaches and Spatial extent	Puget Sound.								
Linkages to Hydroelectric Operations	NA								

Abstract: The Floodplains Spatial Data Refinement project was initiated by the Washington State Department of Ecology (Ecology) and Puget Sound Partnership (Partnership, PSP) to establish the foundation to assess, monitor, and report information regarding the Partnership's Floodplain Implementation Strategy, Vital Sign, and Common Indicator. The purpose of the project is to develop consensus for a regional floodplain "footprint" and condition assessment of the floodplain across all (17) major rivers in the Puget Sound to help monitor progress in protecting and restoring floodplain conditions. This Geospatial Methodology Report provides details on the data sources and methods for development of the floodplains extent and conditions assessment mapping.

This project was guided by an Advisory Committee who established the criteria and methods for integrating existing geospatial datasets of floodplain boundaries and land cover/land use to delineate floodplain extent and assess the function within the delineated floodplain areas. This committee provided oversight and feedback to the project over the 12-month timeframe.

In addition to the Advisory Committee, three pilot watersheds were selected for this project to support the refinement of methods and data sources based on guidance from local experts in each watershed. The pilot watersheds were the Green-Duwamish, Stillaguamish and Dungeness Rivers.

Ford (2022) (Unique Identifier: 517)

Reference	Ford, M.J., editor. 2022. Biological Viability Assessment Update for Pacific Salmon and steelhead Listed Under the Endangered Species Act: Pacific Northwest. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-171.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: status and trends, abundance, harvest, predation, hatchery, age structure. ***Modeling tools:*** juvenile production. ***Land Use and Cover:*** land cover.									
Species and Life Stages	***Chinook, Coho, Sockeye, Chum, Pink, steelhead:*** not specified.									
Reaches and Spatial extent	Skagit Watershed, Puget Sound, other watersheds.									
Linkages to Hydroelectric Operations	NA									

Abstract: In the Pacific Northwest, there are currently 18 evolutionarily significant units (ESUs) or distinct population segments (DPSes) of Pacific salmon and steelhead listed as threatened or endangered under the Endangered Species Act of 1973 (ESA). The ESA requires that the National Marine Fisheries Service (NMFS) review the status of listed species under its authority at least every five years and determine whether any species should be removed from the list or have its listing status changed. NMFS is conducting such a review in 2020–21 (USOFR 2019). The NMFS West Coast Region (WCR) is responsible for the five-year review process for Pacific salmon and steelhead (Oncorhynchus spp.) and for decision-making regarding any proposed changes in listing status. This report provides updated information and analyses on the biological viability of the listed species, focusing primarily on trends and status in abundance, productivity, spatial structure, and diversity. The information in the report will be incorporated into WCR's review, and WCR will make final determinations about whether changes in listing status are or are not warranted, taking into account not only biological information but also ongoing or planned protective efforts and recovery actions.

Several ESUs/DPSs were evaluated to have declining trends in overall status since the last review. Upper Willamette River steelhead (O. mykiss) and Chinook Salmon (O. tshawytscha) were evaluated to have declining viability due to chronically declining abundance and persistent concerns regarding spatial structure and diversity. Snake River sockeye (O. nerka) were evaluated to have a declining viability trend, the result of abundance declines combined with very high vulnerability to climate change. In contrast, a few ESUs/DPSes were evaluated to be improving in viability. Lower Columbia River Chinook Salmon were evaluated to have an increasing viability trend, the result of natural spawner increases in multiple populations, combined with dramatic improvements in the fraction natural-origin spawners in several populations. Columbia River Chum Salmon (O. keta) also showed marked improvement in abundance for several extant populations, although many historical populations remain extirpated or at extremely low abundance. Puget Sound steelhead also showed some evidence of improving viability, with the reversal of some previous strongly negative trends.

Ford (2011) (Unique Identifier: 135)

Reference	Ford, M. J. (editor). 2011. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-113, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: abundance, status and trends, hatchery, harvest, life history, genetics, climate change; Habitat: restoration, climate change.									
Species and Life Stages	***Coho, steelhead***: not specified.									
Reaches and Spatial extent	Puget Sound, Skagit Watershed, Sauk River.									
Linkages to Hydroelectric Operations	NA									

Abstract: This technical memorandum summarizes updated information on West Coast Pacific salmon (*Oncorhynchus spp*.) since the last status review in 2005 related to evolutionarily significant unit/distinct population segment (ESU/DPS) boundaries, status, and trends in abundance, productivity, spatial structure, and diversity. The current report focuses solely on the ESUs/DPSs in the northwest region. A similar report has been compiled by the Southwest Fisheries Science Center summarizing status information for ESUs/DPSs in the southwest region.

In the last formal status review in 2005, the biological review team categorized each ESU as either 1) in danger of extinction, 2) likely to become endangered, or 3) not likely to become endangered, based on the ESU's abundance, productivity, spatial structure, and diversity. In the current report, for each listed ESU/DPS, we summarize whether there is new information since 2005 to indicate that the ESU is likely to have moved from one of the three biological risk categories to another. We focus only on the biological risk category and recognize that listing status is a function of the biological status and trends of the listed species as well ongoing protective efforts, which were not evaluated in this report.

One of the notable differences between 2010/2011 and the last status review in 2005 is the development of viability criteria for all listed salmon ESUs. NMFS initiated its salmon recovery planning in 2000 and the 2005 status review incorporated information that was available from the recovery planning process at that time. In particular, in 2000 NMFS published guidelines for developing viability (recovery) criteria for Pacific salmon and launched a series of regional technical recovery teams (TRTs) to develop viability criteria for each listed ESU/DPS. However, at the time of the 2005 status review, only one TRT (for Puget Sound Chinook Salmon [*O. tshawytscha*]) had produced final viability criteria and no formal recovery goals had been adopted for any ESU/DPS. In contrast in 2010, all ESUs/DPSs have TRT-developed viability criteria and several have formal recovery goals. Where possible, therefore, our review summarizes current information with respect to the viability criteria developed by the TRTs or the recovery goals identified in final recovery plans.

Overall, the information we reviewed does not suggest that a change in biological risk category is likely for any of the currently listed ESU/DPSs. Some of the information we reviewed indicates that a further review of ESU/DPS boundaries may be appropriate, particularly the northern

boundary of Puget Sound Coho Salmon (O. kisutch) and the boundaries between lower and middle Columbia River ESUs/DPSs of Chinook and Coho Salmon and steelhead (*O. mykiss*).

Fugro Northwest (1980) (Unique Identifier: 136)

Reference	Fugro Northwest. 1980. Executive summary of geologic feasibility studies for proposed Copper Creek Dam. Report prepared for Seattle City Light, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply.									
Species and Life Stages	NA									
Reaches and Spatial extent	Other upper Skagit tribs (Copper Creek).									
Linkages to Hydroelectric Operations	NA									

Abstract: This presents Fugro Northwest, Inc.'s executive summary of the geologic feasibility studies for the proposed Copper Creek Dam. The summary includes a figure showing the area mapped during the investigation for the "day-lighting" of the inferred NE trending fault in the Skagit River valley, an outcrop and structural map of the fault relationships near Bacon Point, and a revised geologic and structural map of the Copper Creek Dam area based on the additional geological information given in the "Report on additional geologic studies for proposed Copper Creek Dam" (September 15, 1980). Additionally, we have included a letter further describing the techniques used to develop earthquake probability estimates in these studies.

The summary, summarizes all of the work done by Fugro Northwest, Inc., and their consultants that have previously been reported in the "Preliminary report on geologic feasibility studies for Copper Creek Dam" (September 1979), "Interim report on geologic feasibility studies for Copper Creek Dam" (December 1979), and "Report on additional geologic studies for proposed Copper Creek Dam" (September 1980). No new data or conclusions are presented in this summary and the reader is referred to these previous reports for a full data presentation and discussion.

Furlong (2017) (Unique Identifier: 394)

<table>
<tr><td>Reference</td><td colspan="10">Furlong, W. 2017. Restoring the Skagit River delta: habitat restoration and farmland reclamation on Fir Island. Public Land & Resources Law Review 38:103-148.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>No</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: history. Land Use and Cover: agriculture, banks and shoreline. Fish and Habitat: <u>Habitat</u>: estuary, restoration, climate change.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: full life cycle. Chum: not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary, R13.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This law review article critically examines the legal context, specifically the history of Tribal treaty fishing rights, that led to the development of the Skagit Chinook Recovery Plan as a component of the larger Puget Sound Salmon Recovery Plan. In particular, the recent decision by the Ninth Circuit Court of Appeals in *Washington v. United States 2018*, which upheld an earlier decision that the State of Washington has a duty to repair or replace dysfunctional road culverts that block migrating salmon, sets forth a legal precedent which at least implies a retroactive duty on behalf of the state to restore degraded habitats where a vitiation of treaty rights can be demonstrated. The Skagit River delta, especially the area today known as Fir Island where the river bisects into the North and South Forks, was historically a perennially wet emergent estuarine marsh ecosystem that supported delta rearing salmon (especially Chinook). Following European-American settlement, the majority of the historic emergent estuarine marsh was converted into arable farmland through decades of extensive hydraulic engineering to remove all tidal influence. Due to more than a century of economic development centering on agriculture, the community on Fir Island has long opposed farmland reclamation and salmon habitat restoration projects on the island. Despite long-standing community opposition and skepticism, the recent success of three habitat restoration projects in the Skagit River delta (Wiley Slough, Fir Island Farms, and Fisher Slough) was achieved through strong community buy-in and balancing private land-owner needs (i.e., flood control) with habitat restoration goals. Thus, habitat restoration on Fir Island is an example of a successful community-stakeholder engagement approach and presents a way forward for habitat restoration projects in the future.

Gallagher (1979) (Unique Identifier: 251)

Reference	Gallagher, A. F. 1979. An analysis of factors affecting brood year returns in the wild stocks of Puget Sound chum (Oncorhynchus keta) and pink salmon (Oncorhynchus gorbuscha). Master's thesis. University of Washington, Seattle.									
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, turbidity, salinity; ***Fish and Habitat:*** Habitat: freshwater, estuary, nearshore, ocean, instream flow; Fish: abundance, competition, survival, genetics, life history, hatchery, data gaps; Monitoring: abundance.									
Species and Life Stages	***Chum, Pink:*** full life cycle.									
Reaches and Spatial extent	Puget Sound including Skagit River.									
Linkages to Project Operations	NA									

Abstract: This study examines those factors in the early life history, both freshwater and marine, that may affect survival and cause fluctuations in the abundance of the Pink (*Oncorhynchus gorbuscha*) and Chum Salmon (*Oncorhynchus keta*) stocks of the Puget Sound. Data were compiled from historical records on factors thought to be significant in affecting egg, fry, and early estuarine survival. These data were then entered into a multiple-regression analysis of Pink and Chum Salmon brood-year returns. The 14 brood years from 1959 to 1972 were evaluated. In addition, attention was given to differences in life history strategies, their mechanisms, and to evidence of interspecific competition between the species.

A distinct odd-even pattern of variation is shown to exist in the total run, total brood run, and age at return of the brood of Chum Salmon stocks of Puget Sound. This pattern is probably an aspect of a Pink Chum interaction in which the presence and absence of Pink Salmon affects the abundance and age at return of the Chum brood of the same year. In addition, the magnitude of Chum Salmon escapement is shown to have a negative effect on pink brood return two years later.

Regression results from this study support a "Pink-Chum interaction hypothesis," and suggest that Pink influence on Chum takes place in the early marine environment, with Chum influence on Pink Salmon taking place in the freshwater spawning grounds. The regression results were also highly significant in predicting brood-year returns.

Both the genetic and competitive components of the Pink Chum interaction are discussed, with simulation of the age at return of the Chum brood suggesting a genetic mechanism that may control the observed odd-even year variation in the Puget Sound Chum stocks.

A re-evaluation of Chum Salmon hatchery and wild-stock management strategies is recommended. Such a re-evaluation should consider the observed odd-even year patterns of variation in the Chum data and the possible adverse effects of Chum Salmon hatchery-induced perturbations on wild stocks. In addition, a research program should be developed that will attempt to define the mechanism of the Pink Chum interaction, with particular concern being given to establishing its genetic and competitive components.

Gamble et al. (2018) (Unique Identifier: 044)

Reference	Gamble, M.M., K.A. Connelly, J.R. Gardner, J.W. Chamberlin, K. I. Warheit, and D. A. Beauchamp. 2018. Size, growth, and size-selective mortality of subyearling Chinook salmon during early marine residence in Puget Sound. Transactions of the American Fisheries Society 147:370-389.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms. ***Water Quality and Productivity:*** temperature. ***Fish and Habitat:*** Fish: abundance, survival, growth, rearing, life history, size structure, movement, hatchery, data gaps; Habitat: estuary, nearshore, connectivity, status and trends; Monitoring: abundance, scale or otoliths, biotelemetry.									
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration, nearshore rearing and emigration. ***Coho, Sockeye, Chum, Pink:*** estuary rearing and emigration, nearshore rearing and emigration. steelhead***:*** outmigration.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary, R8 (location of hatchery)-R13, Ocean.									
Linkages to Hydroelectric Operations	NA									

Summary: Drastic declines in the marine survival rates of Chinook Salmon have been observed since 1980, and the survival rates for subyearling Chinook of hatchery origins have averaged less than 1 percent over the past 30 years. Similar declines have not been observed in adjacent areas, leading researchers to believe that the problem lies somewhere within the Puget Sound. Previous studies have shown a high correlation between marine survival and size during the first marine summer both within years and among years for juvenile Chinook. The purpose of this study was to further investigate findings from previous research on the strong positive relationship between body mass of juvenile Chinook Salmon during midsummer in the epipelagic zones of the Puget Sound and marine survival. This suggests that early marine growth is crucial to survival, however fine-scale analyses are needed to make connections to critical growth periods and habitats. This study sought to *"(1) describe occupancy patterns across estuarine delta, nearshore marine, and offshore epipelagic habitats in Puget Sound; (2) describe changes in FL (fork length) and weight observed across habitats and time; (3) evaluate evidence for size-selective mortality; and (4) illustrate how marine survival of the stocks studied may be affected by variation in July weight."* This was accomplished through the sampling of both hatchery fish and fish of natural origin in which scale samples, FL, and wet weights were taken. Samples were taken in 2014 and 2015 from fish prior to their release from hatcheries on the Nooksack, Skagit, Snohomish, and Nisqually rivers; subyearlings in estuarine or nearshore habitats from late January-late October; and juveniles in offshore habitats from early May-early August. Results showed that in both years, natural-origin fish were smaller than hatchery-origin fish and had longer habitat occupancy. Subyearlings were also larger with a faster growth rate in offshore habitats when compared to estuary and nearshore habitats, but there was little evidence to suggest that there is size-selective mortality acting on populations across the different habitats in the Puget Sound.

Information Relevant to Skagit River Relicensing: This study presented quantitative data on the growth, size, and mortality rates of juvenile Chinook Salmon in the Puget Sound, which included populations from the Skagit River. Size-selective mortality was the primary focus for evaluating marine survival for this study and is a convenient metric to use in this case because it incorporates the effects of biological processes and statuses with behavior. It was suggested that size-selective mortality data for the Puget Sound can improve future monitoring efforts, conservation and restoration efforts, and predictions for marine survival. As it relates to the Skagit River Relicensing SY-01 Synthesis Study, information can be used to determine which habitats and factors have the greatest effects on the growth and overall survival of Chinook as well as better understand the timing and usage of habitats during certain life history stages. It was noted that the results of the study could have been impacted by the abnormally high sea surface temperatures over the time of the study period that extended into coastal regions. Sea surface temperatures were more than 2.5°C warmer than average in February 2014, and in 2015, they were 1.3°C warmer than those in 2014, which could have potentially led to an increased use of offshore habitat as opposed to nearshore habitats to avoid warmer waters. Data specific to the Skagit River Relicensing SY-01 Synthesis Study are described in more detail below.

There were many suggestions for future studies to fill gaps in data that were not covered in the study. It was suggested that more comparisons between natural- and hatchery-origin stocks that are genetically similar could be used to determine differences in growth rates, that further analyses should be conducted with a control for the relationship between variation in circulus deposition rate over time, and that a relationship should be determined between interannual variation in early marine growth and size-selective mortality. Additionally, future studies should take place over a longer timespan to make stronger connections between factors and survival and reveal patterns in survival that could exist due to other factors including oceanic conditions. Future studies were also suggested to compare the growth of Chinook stocks across different regions in order to identify key factors affecting marine survival in each region.

<u>Fish and Habitat:</u> Sampling of juvenile Chinook took place in both 2014 and 2015 across different habitats occupied during their first marine summer. Measurements for fish of hatchery-origin started prior to their release and included scale samples, FL measurements, and wet weights as well as identification methods including adipose fin clipping, coded wire tagging, and/or thermal otolith marking. One of the hatcheries used in the study was the Marblemount Hatchery located within the Skagit River Relicensing SY-01 Synthesis Study Area (Reach R8). Sampling of estuary and nearshore habitats took place every two weeks from late January to late October, and offshore habitats were sampled from early May to early August, which included the Skagit estuary\and Skagit Bay. During sampling, salmon were counted, measured, weighed, marked with a caudal fin clip, identified based on origin and stock (based on marking methods previously listed), and scale samples were taken. Table 1 includes the data from those samples and includes sample size per habitat type and data for Skagit River spring and summer hatchery fish (Marblemount) and upper Skagit River summer natural origin fish.

The analyses were both stock specific and separated by year, and therefore data specific to Skagit River populations can be extracted from the figures and tables presented in this report. Regression models were used to evaluate the changes in FL and weight between habitats (Table 2), and geometric mean regression models paired with linear regressions and back-calculated FLs (Figure 8) were used to determine relationships between scale morphometrics and size-selective mortality. A previously developed regression model was also used for marine survival estimates from July weights in offshore habitats. Figure 7 provides habitat specific growth histories for each stock and habitat type, and Table 4 provides projected survival estimates for each stock with means and standard error. General patterns are described in the results and discussion based on the regional dataset, and these are described below. The results may be generally applicable to Puget Sound

Chinook populations, or data reported for specific Skagit populations may be extracted and used to inform the Skagit River Relicensing SY-01 Synthesis Study.

Over the course of the study, 7,020 subyearlings were sampled in 2014 and 3,680 were sampled in 2015, and seven hatchery-origin stocks and two natural-origin stocks were identified from those samples. Stocks were qualified as having 10 or more fish located in at least 2 habitats within their natal watersheds. Peak occupancies for different habitats fell within early May to late July, and peaks occurred in estuary and nearshore habitats before offshore with the exception of one hatchery stock that had simultaneous peaks. Peaks occurred earlier in 2015 than in 2014 which could have been attributed to either a faster transition between habitats or the earlier release of hatchery stocks in that year. Fish of natural origins were also shown to have a more protracted out-migration than the hatchery-origin stocks.

Analyses of fork length and weight distributions showed that fish were larger (longer and heavier) in 2015 than in 2014, hatchery fish were larger than natural-origin fish over both years, and fish in the offshore were larger than those in any other habitat for both years. Growth rates did differ significantly by habitat with length growth rates being higher in offshore habitat than nearshore or estuary and weight growth rates being higher offshore than in hatchery and estuary. Comparisons of circulus counts showed that counts were lower in the estuary than the nearshore and therefore, that younger fish utilized the estuary, and older (larger) fish used the nearshore habitat.

Given the results of the study, it was decided that there was little evidence that size-selective mortality was a strong factor to the survival of subyearling Chinook from marine entry to early August over both years in the Puget Sound. It was also concluded that given the lack of substantial differences between the metrics of natural-origin and hatchery-origin stocks, that they did not experience a difference in size-selective mortality patterns. When the results of this study were compared to those of previous studies, it could be determined that early marine growth throughout the midsummer is crucial for the survival of Chinook, but it does not depend on a particular type of habitat. It was also noted that the survival estimates for both hatchery-origin and natural-origin stocks of Chinook in the Puget Sound were lower than the marine survival rates of adjacent areas by between 1.3 and 1.7 percent.

Graybill (1979) (Unique Identifier: 252)

Reference	Graybill, J. P. 1979. Role of depth and velocity for nest site selection by Skagit River pink and chum salmon. Proceedings of the 1978 northeast Pacific pink and chum salmon workshop. Pacific Biological Station, Nanaimo, BC.								
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow.								
Species and Life Stages	***Pink, Chum:*** spawning.								
Reaches and Spatial extent	US of R7, R7-R9.								
Linkages to Hydroelectric Operations	***Fish and Habitat:*** Habitat: instream flow.								

Abstract: Two components of discharge, depth and velocity, and their role in nest site selection, were investigated for naturally spawning Pink and Chum Salmon in the Skagit River between Newhalem and Concrete, Washington. Spawning ground surveys indicated that Skagit Pink Salmon spawned from late September to late October with peak spawning in the first two weeks of October. Chum Salmon spawned from early November to late December with peak spawning during the first two weeks of December. Skagit River streamflow is regulated by three hydroelectric power plants upstream of the study area. The long-term effect has been to augment the natural flows during the time that salmon are spawning.

Greene (presenter) (2018) (Unique Identifier: 045)

Reference	Greene, C. 2018. Rearing capacity for winter-run Chinook salmon in mainstem, floodplain, and estuary habitats. Presentation for Watershed Program Open House Northwest Fisheries Science Center, Seattle, Washington.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain. ***Water Quality and Productivity:*** salinity. ***Modeling:*** life cycle, hydrology, connectivity. ***Fish and Habitat:*** <u>Habitat:</u> estuary, limiting factors, freshwater, capacity, restoration, instream flows; <u>Fish:</u> rearing, density dependence, size structure, movement, survival, predation, data gaps; <u>Monitoring:</u> habitat, restoration									
Species and Life Stages	***Chinook:*** rearing, estuary rearing and emigration, nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit estuary, Skagit River (mainstem-reach not specified), Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: This proceedings document provides a presentation on the rearing capacity of winter-run Chinook in mainstem, floodplain, and estuary habitats. This presentation addresses three big habitat questions:

(1) *Is there enough high quality habitat to support freshwater & estuarine rearing?*

(2) *Do proposed water management actions adversely affect rearing habitat?*

(3) *How can habitat restoration actions improve conditions for juvenile salmon?*

These questions were addressed through a multitude of different models including life cycle models that incorporate habitat capacity and the effects of conservation measures. Specific examples of juvenile Chinook response to water management were presented for Yolo Bypass and Skagit estuary. Capacity was estimated for fry in different habitats (river and floodplain, delta, and bay) and habitat types through the winter-run model also provided in the presentation. Additional models, HEC-RAS, were used to map the different habitat types previously listed and paired Poisson regression models to predict presence/absence and incorporate connectivity into the model. Lastly, habitat capacity and smolt survival were predicted using Enhanced Particle Tracking Models in which factors such as predation and restoration can be manipulated to simulate different scenarios. The conclusions drawn from the presented research were that habitat capacity is plentiful for fry across all rearing environments, but it is most limited in San Francisco Bay. It was also concluded that most of the habitat capacity includes lower quality habitats and capacity is expected to change along with river flow in rearing habitats.

Greene and Beechie (2004) (Unique Identifier: 047)

Reference	Greene, C. M., and T. J. Beechie. 2004. Consequences of potential density-dependent mechanisms on recovery of ocean-type Chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 61:590-602.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** juvenile production; ***Fish and Habitat:*** Habitat: freshwater, estuary, nearshore, ocean, capacity; Fish: density dependence, survival.									
Species and Life Stages	***Chinook:*** full life cycle.									
Reaches and Spatial extent	Puget Sound including Skagit River.									
Linkages to Project Operations	NA									

Abstract: Restoring salmon populations depends on our ability to predict the consequences of improving aquatic habitats used by salmon. Using a Leslie matrix model for Chinook Salmon (*Oncorhynchus tshawytscha*) that specifies transitions among spawning nests (redds), streams, tidal deltas, nearshore habitats, and the ocean, we compared the relative importance of different habitats under three density-dependent scenarios: juvenile density independence, density dependent mortality within streams, delta, and nearshore, and density-dependent migration among streams, delta, and nearshore. Each scenario assumed density dependence during spawning. We examined how these scenarios influenced priorities for habitat restoration using a set of hypothetical watersheds whose habitat areas could be systematically varied, as well as the Duwamish and Skagit rivers. In all watersheds, the three scenarios shared high sensitivity to changes in nearshore and ocean mortality and produced similar responses to changes in other parameters controlling mortality (i.e., habitat quality). However, the three scenarios exhibited striking variation in population response to changes in habitat area (i.e., capacity). These findings indicate that nearshore habitat relationships may play significant roles for salmon populations and that the relative importance of restoring habitat area will depend on the mechanism of density dependence influencing salmon stocks.

Greene et al. (presenters) (2018) (Unique Identifier: 048)

Reference	Greene, C. M., E. M. Beamer, R. Henderson, R., J. Chamberlin, J. Hall, J. H. Anderson, M. Pouley, M. Davis, S. Hodgson, and C. Ellings. 2018. Density-dependent and landscape effects upon estuary rearing in Chinook salmon: insights from long-term monitoring in four Puget Sound estuaries. Salish Sea Ecosystem Conference, Bellingham, Washington.									
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** bioenergetics. ***Fish and Habitat:*** Habitat: connectivity, estuary, wetlands; Fish: density dependence, competition, predation, life history, rearing, hatchery, distribution, abundance, growth, periodicity.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Summary: This proceedings document provides information on how different density-dependent factors and landscapes affect Chinook Salmon rearing in estuarine habitats. The landscape features shown to influence the distribution and abundance of rearing fish are channel types, habitat types, landscape connectivity, and estuary systems. In addition, the other traits that are considered to be density-dependent in these Chinook populations are estuary growth and size, estuary residence time, proportion of migrants entering Puget Sound as fry, and the smolt-adult return rate. Lastly, the negative relationship between hatchery (marked) and native (unmarked) Chinook populations is presented. Analyses showed that there were seasonal declines in unmarked fish after hatchery fish had been released. Proposed causes of these declines in natural populations are competition for food, induced early migration, introgression of genotypes for rapid outmigration, and transmission of pathogens. A framework for restoration decisions based on these conclusions is provided at the end of the presentation.

Greene et al. (2012) (Unique Identifier: 051)

Reference	Greene, C., J. Hall, E. Beamer, R. Henderson, and B. Brown. 2012. Biological and physical effects of "fish-friendly" tide gates. Report prepared for Washington State Recreation and Conservation Office, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, secondary productivity***.*** ***Modeling Tools:*** juvenile production. ***Fish and Habitat:*** Habitat: instream flow, barriers, estuary, connectivity, limiting factors; Fish: abundance, rearing.									
Species and Life Stages	***Chinook:*** rearing.									
Reaches and Spatial extent	R15, Skagit estuary.									
Linkages to Project Operations	NA									

Abstract: A number of restoration techniques exist to counter widespread estuary habitat and connectivity loss across the Pacific Northwest, ranging from dike breaching and removal to installation of "fish-friendly" or self-regulating tide gates (SRTs). However, the physical and biological effects of these techniques have not been rigorously examined. In this report, we focus on the effects of SRTs, and examine their effectiveness in two different ways. First, we used a spatially extensive design to compare three site types: SRTs, flap gates, and unimpeded reference sites. The study compared ten SRT sites located from the Columbia River estuary north to Samish Bay in northern Puget Sound, five traditional flap gate sites (designed to drain freshwater but prevent tidal inundation and saltwater intrusion), and five unimpeded reference sites. Second, we used a temporally extensive design at three SRT sites to determine changes in upstream cumulative densities of Chinook Salmon across the rearing season, relative to downstream values, before and after SRTs were installed.

In the spatially extensive study, we studied physical metrics upstream and downstream of tide gates and at reference sites during three visits spanning the primary spring-summer fish rearing period. We also sampled fish and invertebrates above and below tide gates and at reference sites. We found that site type appeared to affect a number of physical metrics including connectedness, water elevation, and temperature, but the degree to which each of these site types affected these physical metrics varied. In addition, densities of Chinook Salmon (*Oncorhynchus tshawytscha*) and estuary rearing fish species were much greater at reference sites compared to sites with either flap gates or SRTs. For other species, overall patterns did not strongly distinguish densities between reference sites and flap gate or SRT sites.

In the temporally extensive study, the upstream/downstream ratio of Chinook Salmon cumulative density at all SRTs was higher than at a traditional flap gate. The cumulative density ratio at this site increased 6-fold after a passive flap gate was replaced with an SRT, indicating that SRTs can improve habitat use by salmon. However, cumulative density ratios decreased 7-fold when a passive and manually manipulated side-hinged gate was replaced with a SRT, and this measure at all three SRT sites was an eighth to a tenth that of reference channels.

Together, these findings indicate that SRTs vary substantially based on design and operation and consequently vary in performance, depending upon the metric of interest. For estuarine-dependent

species in general and juvenile Chinook Salmon in particular, SRTs support habitat use above gates much less than natural channels and a little better than traditional flap gates. For other anadromous salmon species that may spawn in creeks above tide gates, SRTs do not appear to strongly inhibit passage or juvenile rearing density. These findings suggest that estuary restoration with SRTs will have limited benefits for juvenile Chinook Salmon and other estuarine-dependent species, but can result in some improvement in connectivity and rearing habitat quality compared to traditional flap gate designs. SRT designs and operation standards that maximize connectivity, and site selection criteria that focus on reconnection of large amounts of habitat may overcome some of the limitations of reduced habitat use associated with SRT installation. These potential reductions can successfully be evaluated by comparing the benefits of SRT installation with those of other estuary restoration techniques (e.g., dike breaching or setback).

Greene et al. (2012) (Unique Identifier: 052)

Reference	Greene C., C. Rice, L. Rhodes, B. Beckman, J. Chamberlin, J. Hall, A. Baxter, J. Cordell, and S. Naman. 2012. Evaluating the status of Puget Sound's nearshore pelagic foodweb final report: November 28, 2012. Report prepared by Northwest Fisheries Science Center, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, nutrients, dissolved oxygen, pH, contaminants, turbidity, salinity, primary productivity, secondary productivity***. Land Cover and Use:*** land cover, agriculture, urban, banks and shoreline. ***Fish and Habitat:*** Habitat: estuary, pocket estuary, nearshore, ocean, limiting factors; Fish: abundance, diet, hatchery; Monitoring: habitat, water quality.									
Species and Life Stages	***Chinook, Chum, Coho, steelhead, Pink, Other species:*** not specified.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Project Operations	NA									

Abstract: The pelagic zone is a large and important component of Puget Sound's ecosystem, but basic information is lacking on differences among oceanographic basins, linkages between abiotic features, water quality, and pelagic biota, and the effects of anthropogenic activities. This dearth of information complicates our ability to identify useful metrics to measure the pelagic zone's key characteristics determining ecological health. To address these issues, we conducted a multitrophic level assessment in six oceanographic basins within Puget Sound using a sampling scheme designed to detect both basin-wide differences and relationships between pelagic ecosystem attributes and land use in catchments surrounding sites. We measured over 20 potential indicators of nearshore pelagic ecosystem health at 79 sites in six oceanographic basins of Puget Sound. These metrics included measurements of abiotic conditions and nutrient availability, and abundance and diversity of phytoplankton, bacteria, zooplankton, jellyfish, and pelagic fish species. In many taxa from lower to middle trophic levels, and for a comprehensive suite of abiotic attributes, we observed strong seasonal and spatial structure. South Sound and Hood Canal had the most reduced dissolved oxygen and pH, highest relative abundance of jellyfish, and lowest abundance of forage fish and fish species richness. In contrast, Rosario (north of Fidalgo Island) and Whidbey Basins were characterized by relatively few abiotic or nutrient problems, few deviations in the abundance of different groups of microbes and phytoplankton, relatively high densities of non-gelatinous (i.e., not jellyfish) zooplankton, and high fish species richness and relatively high forage fish abundance. Admiralty Inlet and the Central Basin scored in between this range, although they too exhibited high jellyfish abundance and reduced forage fish abundance and fish species richness relative to Rosario and Whidbey Basins. Furthermore, many of the potential indicators we measured were sensitive to land use, with a general pattern that abiotic and lower trophic patterns were most sensitive, and patterns in fish abundance and diversity were the least sensitive. We found positive relationships between land use and jellyfish abundance, as well as shifts of jellyfish diets to lower trophic levels in sites with greater land use. These findings provide empirical support for the bifurcated foodweb hypothesis, which predicts that stressors from development simplifies foodweb structure, leading to cascading effects on middle trophic levels like planktivorous salmon and forage fish, and favoring jellyfish and other consumers of

microplankton. Despite these patterns, land use rarely explained more than 5 percent of the variation in observed data, indicating a dominant marine influence and the potential for resilience of Puget Sound's pelagic waters to anthropogenic influence. The strong spatial structure observed in our results indicates that different pelagic food webs exist across the system. Consequently, target conditions, current health status, or both, cannot be uniform across greater Puget Sound. These are critical considerations for management of the Puget Sound ecosystem, and we expect that further analysis of our results in the context of other studies will improve our understanding of the underlying causes of the patterns we observed across Puget Sound.

Greene et al. (2017) (Unique Identifier: 055)

Reference	Greene, C., J. Hall, D. Small, and P. Smith. 2017. Effects of intertidal water crossing structures on estuarine fish and their habitat: a literature review and synthesis. Report for Skagit Climate Science Consortium, Anacortes, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology:*** sediment transport, scour. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity, climate change. ***Fish and Habitat:*** <u>Habitat:</u> barriers, estuary, pocket estuary, nearshore, connectivity, limiting factors, climate change, instream flow, invasive species, capacity, restoration, data gaps; <u>Fish:</u> swimming speeds, rearing, data gaps.									
Species and Life Stages	***Chinook, Chum, Coho, steelhead, Pink, Bull Trout, Pacific Lamprey***: outmigration, estuary rearing and emigration, migration. ***Other species:*** not specified.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Project Operations	NA									

Abstract: For hundreds of years, people have built water crossing structures to enable the transportation of people, livestock, vehicles, and materials across rivers and other bodies of water. These structures have often created barriers to fish passage, an issue which has recently drawn intense scrutiny due to concerns over impacts to anadromous fish. While much work has focused on the impacts of *freshwater* crossing structures, *intertidal* structures have received less attention. This may be due to the importance of passage for adult anadromous fish in freshwater, and that bidirectional flows in intertidal environments complicate interpretation of structures as barriers. Intertidal water crossing structures likely have adverse impacts on juvenile life stages of fish due not only to impacts to passage, but also to impacts to estuarine habitats extensively used by these species as rearing environments. Examining the impacts of intertidal water crossing structures only through the lens of fish passage therefore misses key aspects to how these structures can affect fish.

In this report we review literature on intertidal water crossing structures and how they affect fish that depend on intertidal habitats for passage during migration or for extended rearing during early life stages. Our findings are important for establishing fish passage criteria, providing design guidelines, and identifying key data gaps for future research of intertidal water crossing structures.

We address the six general questions in the following sections:

What are the primary intertidal water crossing structures and how do hydraulics function at these structures? (Section 2)

Classic intertidal water crossing structures include culverts, tidegates and other tidal muting structures, and causeways and bridges. These devices allow water conveyance through channels under the structures. In addition, structures with much larger footprints such as road and railroad grades as well as dikes and levees cross intertidal wetlands, thereby obstructing tidal flow across the wetland surface as well as within channels. Hydraulic engineering of structures has often focused on 1) conveying drainage through embankments, 2) attenuating the vertical range of tidal action, 2) restricting tidal action to channels, and 4) reducing channel size.

What habitat types and natural processes are affected by structures? (Section 3)

There are four primary habitat types (shoreforms) within which structures are likely to impact intertidal physical processes and biotic communities: (1) large river deltas, (2) coastal creek confluences, (3) coastal embayments, and (4) lagoons. While other shoreforms comprise nearshore ecosystems, these four types are most sensitive to losses in connectivity and associated impacts to habitat quantity, habitat quality, or biotic communities. These four shoreforms share landforms and vegetation types at a smaller spatial scale, which are the common habitat types that fish utilize. The occurrence and distribution of intertidal habitats are outcomes of several geomorphic processes. Historical glacial and tectonic processes have created the underlying geology, while river flow, tidal inundation, wave action, and longshore currents continue to shape habitat features through processes such as erosion and deposition. In large river deltas, riverine and tidal processes dominate, while in coastal creek confluences, fluvial processes are more offset by wave and current action, resulting in smaller intertidal footprints. Lagoons are formed behind spits and other features created primarily by sediment deposition. Embayments, a larger habitat feature that can encompass lagoons and coastal creek confluences as smaller spatial units, are maintained by erosion and scour from tides and currents. Intertidal water crossing structures have the potential to disrupt all processes influencing sediment transport.

To date, Washington State has many inventoried intertidal water crossing structures along major transportation corridors. Most of the intertidal crossings in Washington State are associated with development (either agricultural or commercial/residential) and transportation corridors (roads and railroads) in large river deltas and coastal creek confluences. Inventories and preliminary GIS analysis by WDFW indicates 872 intertidal culverts exist along state and local transportation corridors in the Puget Sound area (See Appendix 1). While many of these were not explicitly associated with specific shoreforms, 16 percent of the records occurred in large river deltas, 13 percent occurred in embayments, and 5 percent were associated with lagoons. Coastal creek confluences can occur in a number of different contexts, and so may account for a larger percentage of these sites than other shoreforms. It should be stressed that this inventory is incomplete: it does not include many crossing structures that are associated with private roads, dikes, and drainage district structures.

What species in Washington ecosystems are likely most impacted by intertidal water crossing structures? (Section 4)

A variety of species utilize intertidal habitat types for both passage to and from freshwater and for extended rearing. Key species which are of economic and cultural importance include many salmonids as well as some marine fishes with early rearing in intertidal environments. We highlight the species associated with each main shoreform and identify those with extended residence as well as those that are more likely to be migrants. Chinook, Coho, and Chum Salmon are three culturally important species that show evidence of extended residence in a number of these intertidal environments. Populations of all three species are federally listed as Threatened under the Endangered Species Act in many watersheds in Washington. In addition, common members of marine species intertidal communities such as Pacific Herring, English Sole, and Shiner Surfperch also exhibit extended residence in certain habitat types. Due to their protracted residence in intertidal environments, these species might be expected to show the greatest sensitivity to impacts from intertidal water crossing structures as a consequence of both restrictions to passage and to changes in habitat quality or quantity. Other listed species such as steelhead, Bull Trout, and Eulachon may use these systems briefly or only during migration, and so would be expected to be more sensitive to intertidal water crossing structures as barriers to movement. Conversely, nonnative species such as Smallmouth and Largemouth Bass are considered nuisance species that exploit habitats impacted by intertidal water crossing structures.

Species that use intertidal habitats naturally reside in them anywhere from hours to months. Some anadromous species like steelhead may take advantage of the marine transition to adjust osmoregulation, and this physiological switch can be completed within a couple of days. Other species such as young-of-the-year Chinook Salmon and certain flatfish may reside in intertidal habitats for weeks to months, taking advantage of the abundant food and relative safety of these habitats to rapidly grow from small life stages. Within intertidal habitats, these species rely on riverine and tidal processes to facilitate movement at small spatial scales into areas inundated at high tide and out of areas that dry at low tide.

Movement abilities increase with size, such that individuals < 15 cm in length can be influenced by tidal currents, while species > 15 cm can readily move against some tidal and river flow velocities. Even the smaller life stages use gravity, rheotaxis, and vertical migration to find favorable microenvironments (e.g., low velocities or salinities) to adjust residence time.

How are fish affected by impacts of structures during passage during periods of residence? (Section 4)

Fundamentally, water crossing structures impede bi-directional flow of water and movements of fish in channels and other wetland environments during portions of the tidal cycle, relative to movements in natural intertidal environments. This disproportionately affects smaller fish, which use these habitats as extended rearing environments but which are more likely to be constrained by hydraulic modifications. Of particular importance for small estuarine-dependent life stages is the role of tidal and riverine flows to facilitate passive movement in rearing habitats.

Based on a broad scientific literature spanning many regions of the world, we developed conceptual models for impacts of intertidal water crossing structures upon passage and habitat quality and quantity. These structures may reduce passage as a consequence of impacts from structure dimensions (e.g., culvert length and cross sectional area), slope of structure compared to the natural water course, tidally influenced water depth and heights of water drops (sometimes called perches), and whether the structure is gated and how it operates. Structures may also reduce habitat quality and quantity landward of water crossings by impacting salinity, inundation height and area, water residence, temperature, sedimentation, and dissolved oxygen. These processes affect both vegetation and the resulting assemblages of fish and their prey. Many studies have demonstrated large changes to fish communities associated with intertidal structures. However, isolating population impacts of these changes from other cumulative effects is challenging. Part of the challenge stems from determining the right temporal scales that matter. For example, restoration of tidal processes can readily benefit fish passage, but ameliorating legacy impacts to habitat quality and quantity may take many years.

How do scientific findings inform potential management? (Section 5)

Science-based management decisions must be made in the context of law and policy as well as multiple land use planning decisions. While these aspects are not in the scope of this scientific review, our synthesis does offer scientific guidance on management of fish and their habitats. We focus on inventory, monitoring, design and operation standards, incorporating impacts of climate change, and decision support frameworks.

Inventory – Inventories of intertidal water crossing structures have lagged behind those focused on freshwater structures. Our review suggests that inventoried intertidal water crossings will often receive higher priority for enhancement than freshwater passage barriers, primarily because of their greater potential to impact connectivity of the entire network. Greater focus on inventorying intertidal structures, with updated information that delineates a structure as a potential barrier, will help put intertidal crossings on a similar footing as freshwater structures. Multiple inventories (e.g. barrier and habitat impact inventories) can address the different impact pathways by which structures influence fish populations.

Monitoring and assessment – Monitoring and assessment are often desirable and sometimes required to evaluate the extent to which particular water crossing structures create barriers to fish passage and residence, or to verify that changes to structures for the purpose of habitat restoration actually produce the anticipated responses in fish and their habitat. Our review suggests a number of characteristics that are useful to monitor and assess for determining whether intertidal structures affect fish passage and residence, as well as habitat quantity and quality.

Design and operation standards – the general rule of thumb for designing and operating intertidal structures with the least amount of disruption to tidal and fluvial processes will likely best serve estuarine fish populations. However, a strong tradeoff exists between societal values for habitat protections for estuarine species, and for opportunities for shoreline access and development by people. This tradeoff invariably will result in various proposed structural designs that achieve a compromise between these values. Better quantification of these trade-offs will allow for more transparent evaluation of potential impacts and therefore more informed societal decisions.

Incorporating impacts of climate change – previous research in freshwater systems indicate that water crossing structures generally need to be bigger to address impacts of changes in river flow. As yet unaddressed for intertidal structures are additional impacts of sea level rise, which would also argue for larger (and taller) water crossing structures. Design life considerations should incorporate longer-term climate projections to allow the same functionality across a structure's life span. Cumulative impacts of climate change, including impacts to river flow, sea level rise, and increased temperature should be considered when determining likely long-term impacts to habitat quantity and quality.

Decision support – In addition to the above implications, guidance for fish passage and rearing can include a range of tools from reduced complexity decision frameworks for rapid assessment to more expert-level hydraulic model analysis. These would be expected to become more complex and affect multiple metrics as guidance moves from simple determination of passability to evaluation of impacts upon habitat quality and quantity as well as long-term climate impacts. We highlight four tiers of guidance whereby different standards might be developed to advance assessments past fish passage guidance to these other aspects: inventory of structures, evaluations of fish passage, combined evaluations of fish passage and rearing, and projections of climate impacts.

What are the major information gaps? (Section 6)

Numerous information gaps exist concerning intertidal water crossing structures, and some surprisingly simple questions regarding the impacts of intertidal water crossing structures upon fish populations remain unanswered because we lack information on local movement dynamics and the population consequences of lost access and changes in habitat quality and quantity. Moreover, additional research is needed to estimate combined effects of changes in freshwater and sea level rise on impacts to hydraulics and design life of intertidal water crossing structures. Addressing these information gaps will require a combination of observations of fish movements (perhaps in experimental test beds), hydraulic modeling, population modeling to examine impacts in the context of fish life cycles, and models that better integrate multiple climate stressors.

Haight (2002) (Unique Identifier: 232)

Reference	Haight, R. 2002. An inventory and assessment of the Finney Creek Riparian Forest. Report prepared for Skagit System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** slope, substrate and sediment, sediment transport and supply, scour, large wood, floodplain. ***Fish and Habitat:*** Habitat: riparian.								
Species and Life Stages	NA								
Reaches and Spatial extent	Finney Creek.								
Linkages to Project Operations	NA								

Abstract: Finney Creek is a major tributary to the Skagit River. Finney is important for fish but has been degraded by past logging practices and is currently deficient in coarse woody debris. This inventory is intended to quantify riparian forest conditions, determine what coarse woody debris recruitment potential the riparian forest currently provides, and identify what management action might be appropriate to improve riparian function. In order to accomplish this, a systematic sample of the riparian forest was conducted along 10 miles of the portion of Finney Creek accessible to anadromous fish. Data collected include species, diameter, height, distance from the channel, as well as understory composition. Systematic sampling is considered a good way of characterizing entire riverine systems, as data are spatially defined under such designs. Changes in riparian forest attributes are readily captured, and proportional relationships are easily exploited. The systematic design of this study captured spatial changes in forest structure and composition at 500' intervals. We are able to directly extrapolate the forest area occupied by landform classifications based on the number of plots occurring in a given class. Spatial orientation of vegetation provides increased insight with regard to the state of the riparian forest. This inventory and assessment project is a stand -alone assessment of the riparian condition of this once very productive salmonid habitat, and is linked to an inventory project of the entire Skagit River Basin. The project also serves as an umbrella for development of various linked projects involving riparian forest composition, forest-stream interaction, and riparian growth and yield.

Summary of Key Points:

- The majority of conifer (>60 percent) occurring within 150 horizontal feet of the creek were found to exist within only 14 percent of the plots, which occurred along two one-mile reaches of bedrock canyon.
- Conifer presence was found to be dominated by small diameter trees, with 87 percent of the conifers measured being less than or equal to 10" in diameter at breast height.
- The stream-adjacent habitat represented by hardwood-dominated plots composes the bulk of riparian habitat in the study area, with 302 acres composed of 70 percent or more hardwood.
- In order to reach a reasonable state of riparian function with regard to coarse woody debris, establishing and retaining conifer will be necessary.

- Successful establishment of conifers on areas directly adjacent to Finney Creek may require additional active management approaches such as understory planting and overstory thinning, especially in areas heavily dominated by hardwoods.
- The relative-elevation plot metric 'Average height above channel' shows potential as a useful surrogate for landform, and is valuable as a continuous, quantitative variable.

Haley (2002) (Unique Identifier: 482)

Reference	Haley, R. 2002. Skagit County baseline water quality monitoring project: final report. Report prepared by Skagit County Public Works, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality:*** dissolved oxygen, temperature, pH, turbidity, nutrients, bacteria. ***Fish and Habitat:*** <u>Monitoring:</u> water quality.									
Species and Life Stages	NA									
Reaches and Spatial extent	Hansen Creek, Wiseman Creek, Nookachamps Creek, other upper Skagit tribs, other lower Skagit tribs.									
Linkages to Project Operations	NA									

Abstract: The Baseline Monitoring Project collected water quality data in and around the agricultural areas of Skagit County for over two years. This information provides a basis for comparison for future assessments of water quality in those areas, and also provides an indication of the current state of water quality in Skagit County's agricultural areas.

The data collected indicated that streams in Skagit County do not always meet state water quality standards. Most streams meet most of the standards most of the time, but during critical low summer flows temperature and dissolved oxygen can fall short of the standards. Fecal coliform levels fluctuate greatly throughout the year, and only two streams met the state standard for fecal coliform.

The data also indicate that each stream must be considered separately, as blanket statements will not accurately characterize individual streams. For example, Mannser Creek did not exceed the state water quality standard for temperature at any time during this study, yet it consistently did not meet the standard for dissolved oxygen. In Red Cabin Creek, the next stream to the east, the dissolved oxygen standard was met during each visit but the stream occasionally exceeded temperature standards.

There is little evidence of any strong trends in water quality from the Baseline Project. Differences in climate between the years of the study appear to be a major factor in influencing temperature maximums and dissolved oxygen minimums for many streams. A longer period of monitoring and more sophisticated methods will be required to identify trends independent of seasonal variation. Skagit County intends to conduct more formal trends analysis with the recently-implemented Skagit County Monitoring Program (Skagit County 2003b).

Nineteen of the 27 sample locations in the Baseline Project are included in the Skagit County Monitoring Program. This Program will continue to track water quality in Skagit County agricultural areas for at least six years. This body of data, along with the Baseline Project data, should allow an indication of trends in water quality that bridge differences in yearly climate.

Hall and Roni (2018) (Unique Identifier: 073)

Reference	Hall, J., and P. Roni. 2018. Final- Literature review summary results to support SBI development. Memorandum prepared by Cramer Fish Sciences for Puget Sound Partnership.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: nearshore, estuary, freshwater, wetlands; Fish: density dependence, rearing, movement; Monitoring: abundance.									
Species and Life Stages	***Chinook, Coho, Chum, Pink, steelhead:*** rearing-outmigration. ***Bull Trout, Other species (Cutthroat):*** full life cycle.									
Reaches and Spatial extent	Puget Sound, Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: This memo responds to your request for a nearshore juvenile salmon density literature review, summaries of existing and updated juvenile salmon density databases, and advising the Salmon Benefit Index (SBI) Advisory Team in development of the SBI (Contract #2018-48). This memo summarizes the literature review effort and results with brief methods and results sections as requested in the statement of work. The summaries in this memo and the general methods for the review, synthesis, and summaries were developed in coordination with the SBI Advisory Team as per the statement of work. In addition to this memo, the final database produced from this work will be delivered as an excel spreadsheet based on the template provided by the PSP.

Hall and Shannahan (2009) (Unique Identifier: 367)

Reference	Hall, J., and J. P. Shannahan. 2009. Management of beaver in constructed off-channel spawning habitat for salmon on the upper Skagit River floodplain. Report prepared by Hall and Associates Consulting, Inc. and Upper Skagit Indian Tribe for Skagit River Non-Flow Plan Coordinating Committee.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Water Quality:*** temperature. ***Fish and Habitat:*** Habitat: instream flow, beaver, barriers, freshwater, connectivity; Fish: abundance, predation, distribution.									
Species and Life Stages	***Chum, Coho:*** spawning, emergence, rearing, migration.									
Reaches and Spatial extent	US of R7, Other upper Skagit tribs.									
Linkages to Project Operations	NA									

Abstract: In this paper, we describe the construction and evaluation of a beaver control device that incorporates a fish ladder installed in place of a beaver dam and beaver exclusion devices to prevent beaver from blocking fish passage within two constructed spawning channels on the upper Skagit River floodplain. Direct observations of the fish ladders during 2007 and 2008 spawner surveys indicate that adult Chum and Coho were able to successfully navigate the fish ladder to reach constructed spawning habitat upstream of the fish ladders. However, these structures do not appear to alter beaver behavior as hypothesized. Therefore, installation of these fish ladder and beaver exclusion structures may only be appropriate where beaver typically construct a single dam within a channel. Installation of beaver exclusion fencing with 6-inch wide and 8-inch tall openings, and complete coverage of the bottom and top of the exclusion cage, was an effective means of preventing beaver damming within the exclusion while providing adult Chum and Coho passage. Therefore, we recommend that beaver exclusion fences, similar to those described here, be used to prevent beaver access to problem areas where beaver dam construction creates fish passage barriers and increased removal effort.

Hall et al. (2018) (Unique Identifier: 058)

<table>
<tr><td>Reference</td><td colspan="10">Hall, J. E., C. M. Greene, O. Stefankiv, J. H. Anderson, B. Timpane-Padgham, T. J. Beechie, and G. R. Pess. 2018. Large river habitat complexity and productivity of Puget Sound Chinook salmon. PLoS ONE 13(11):e0205127.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Journal</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>No</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology: side and off channels, floodplain, floodplain connectivity, log jam, change. Modeling Tools: juvenile production. Fish and Habitat: <u>Habitat:</u> freshwater, instream flow, restoration; <u>Fish:</u> abundance, density dependence.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: spawning, incubation, rearing, outmigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound.</td></tr>
<tr><td>Linkages to Project Operations</td><td colspan="10">NA</td></tr>
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Abstract: While numerous studies have shown that floodplain habitat complexity can be important to fish ecology, few quantify how watershed-scale complexity influences productivity. This scale mismatch complicates population conservation and recovery strategies that evaluate recovery at regional or multi-basin scales. We used outputs from a habitat status and trends monitoring program for ten of Puget Sound's large river systems to examine whether juvenile Chinook Salmon productivity relates to watershed-scale habitat complexity. We derived habitat complexity metrics that quantified wood jam densities, side and braid to main channel ratios, and node densities from a remote sensing census of Puget Sound's large river systems. Principal component analysis revealed that 91 percent of variance in these metrics could be explained by two principal components. These metrics revealed gradients in habitat complexity across Puget Sound which were sensitive to changes in complexity as a result of restoration actions in one watershed. Mixed effects models revealed that the second principle component term (PC2) describing habitat complexity was positively related to log transformed subyearling Chinook per spawner productivity rates from 6–18 cohorts per watershed. Total subyearling productivity (subyearlings per spawner) and fry productivity (subyearling fry per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed peak flow recurrence interval, suggestive of reduced survival due to egg destruction during floods. Total subyearling productivity (subyearlings per spawner) and parr productivity (subyearling parr per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed spawner density, suggestive of density dependent limits on juvenile rearing habitat. We also found that coefficient of variation for log transformed subyearling productivity and subyearling fry productivity rates declined with increasing habitat complexity, supporting the idea that habitat complexity buffers populations from annual variation in environmental conditions. Therefore, we conclude that our watershed-scale census-based approach provided habitat complexity metrics that explained some of the variability in productivity of subyearling juveniles among Chinook Salmon populations. Furthermore, this approach may provide a useful means to track and evaluate aggregate effects of habitat changes on the productivity of Endangered Species Act (ESA) listed Chinook Salmon populations over time.

Hall et al. (2021) (Unique Identifier: 491)

Reference	Hall, J., S. Burgess, K. Ross, D. Small, R. Gatchell, T. Beechie, C. Greene, J. Chamberlin, O. Stefanki, and B. Timpane-Padgham. 2021. Mapping tidal restrictions and tidal wetlands to support identification and evaluation of restoration opportunities in Puget Sound: synthesizing and updating regional data to create an updated and consistent spatial database of tidal restriction features for Puget Sound's large river deltas. Report prepared by Cramer Fish Sciences, Washington Department and Fish and Wildlife, and National Oceanic and Atmospheric Administration for Washington State Restoration and Conservation Office and Estuary and Salmon Restoration Program.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** floodplain**.** ***Fish and Habitat:*** Habitat: barriers, connectivity, data gaps.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound.									
Linkages to Project Operations	NA									

Abstract: Substantial habitat loss has occurred in tidal wetland habitats throughout Puget Sound's large river delta systems (Simenstad et al. 2011), and thus Pacific salmon (*Oncorhynchus* spp.) populations with estuarine-dependent life stages, and especially Chinook Salmon (*O. tshawytscha*), have been negatively affected (Simenstad et al. 1982; Simenstad and Cordell 2000; Beamer et al. 2005; Bottom et al. 2005a). Regional datasets exist related to mapping of tidal restrictions and tidally influenced habitat in the Puget Sound from federal, state, regional, county, and Tribal agencies. However, significant data gaps exist within the region as datasets differ greatly in their structure, extent, resolution, completeness, and time period. This project (PRISM 18-2250P, WRCO 2019a) addresses these data gaps by developing consistent and updated regional mapping data of (1) tidal restrictions (e.g., levees, dikes, floodgates, culverts, etc.), (2) current tidal wetland extent, and (3) potential tidal wetland extent for Puget Sound's large river deltas.

We gathered 43 local, statewide, and regional datasets including 253 vector layers mapping tidal restriction and tidal wetland features for Puget Sound large river deltas to create a spatial database of relevant regional datasets through web searches and outreach with regional data stewards and agencies. Using these compiled datasets, aerial imagery, and other reference data (e.g., oblique shoreline imagery, LiDAR, National Hydrography Dataset [NHD]), we synthesized and updated potential tidal restriction features for Puget Sound's large river deltas to produce a feature dataset of polylines in a single spatial database. These features were classified by primary feature type (e.g., roads, dikes/levees, armor) and water crossing feature types (e.g., bridges, culverts, floodgates) (Figure 1). Restrictions were further classified by their impacts on tidal connectivity (e.g., unrestricted, partial, significant, and completely restricted features) based on their feature type and condition. We used Pacific and Marine Estuarine Partnership Potential Wetland Extents to delineate areas within potential tidal influence based on elevation (PMEP 2018) and our mapped tidal restriction network to segment and assign connectivity classifications to tidal wetland habitats. These wetlands were classified based on the tidal restriction features that immediately surround the wetland feature (feature connectivity) and based on downstream or seaward features

that would impact cumulative connectivity to a wetland feature based on its landscape position (landscape connectivity).

As part of this project and our approach, we contacted over 95 regional experts and data stewards to identify potential data sets and review methods, data structure, feature mapping accuracy, and the utility of the datasets and features to support salmon recovery and restoration planning. Data were uploaded to an ESRI ArcGIS Online data portal in coordination with WDFW, which facilitated review and comment by multiple parties and reviewers were asked to provide comments on restriction and wetland feature's existence, type, connectivity impacts, and fish passage based on their local knowledge. This approach allowed us to leverage local area expertise and we were able to integrate feedback from 21 regional exerts into the final datasets. Field validation surveys were also performed for 38 primary features and 150 water crossing features to evaluate accuracy of our approach, including evaluating errors in feature identification and classification using aerial imagery, and to classify a subset of the features that were listed as unknowns after regional data review was completed. We also used Washington Department of Fish and Wildlife (WDFW) protocols to perform barrier evaluations to support integration and updates with the Fish Passage Barrier and Diversion Screening Inventory database (FPDSI) (WDFW 2019a, b).

In total we mapped 863 miles of tidal restrictions, 2,971 water crossing features, and 30,274 hectares of current and potential tidal wetland habitat for 17 of Puget Sound's large river deltas using regional data, remote sensing, regional review, and field surveys. All wetlands classified as completely disconnected for either feature tidal connectivity or landscape tidal connectivity were classified as potential wetland extent, while all wetlands classified as unrestricted, partially restricted, and significantly restricted for landscape connectivity were classified as current tidal wetland extent. In total, the final dataset includes:

- 763 miles of complete tidal restrictions
- 22 miles of significant tidal restrictions
- 12 miles of partial tidal restrictions
- 44 miles of unrestricted crossings
- 21 miles of unknown restrictions
- 2,971 water crossing features
- 11,845 hectares of current tidal wetland habitat (unrestricted, partially restricted, or significantly restricted)
- 18,429 hectares of potential wetland habitat

Of the water crossing features mapped, 54 percent were not previously included in regional data sources and were mapped using aerial and oblique imagery, regional review, and field validation. Additionally, we mapped 85 miles features (dikes/levees, roads, and armored banks) that were not previously in the regional data. This represents a significant increase in the completeness of regional data for tidal restriction features for Puget Sound's large river deltas, and these results indicate that combining remote sensing with regional data synthesis, regional review, and field validation was an effective approach.

However, numerous unknown features still exist within the datasets that could not be classified using aerial imagery or available regional data, but this updated spatial inventory of features can be used to support targeted field validation efforts to improve the accuracy and completeness of these datasets. Similarly, this updated spatial inventory of water crossing features can be used to support evaluation and identification of potential fish passage barriers and updating the WDFW's Fish Passage Barrier and Diversion Screening Inventory database (FPDSI) (WDFW 2019a, b; WDFW 2020). Evaluating and restoring fish passage barriers in tidally influenced habitats represents a significant restoration opportunity and priority in the Puget Sound region. Additionally, we used simple rule-based classifications for tidal connectivity that was used to develop consistent classifications of connectivity impacts. This rule-based framework could be refined in the future to include more levels or a gradient of impacts with the inclusion of other physical information for features in the database (e.g., feature elevations, dimensions). Furthermore, landscape wetland connectivity classifications were assigned based on visual interpretation of flow paths of tidal connectivity and these could be improved by attributing features with network information. For example, a topographically-derived flow path could be used to attribute features with network or flow path information that could be used to refine landscape connectivity and automate updates as feature status changes (e.g., through field validation or restoration).

In addition to developing an updated and consistent reginal spatial database of tidal restriction and tidal wetland features for Puget Sound's large river deltas, one of our objectives was to make these data readily accessible to support salmon recovery planning. These spatial databases will be available through WDFW's ArcOnline mapping application that will be available to the public, and links will be added to the PRISM and Salish Sea Wiki project pages. Guidelines for maintaining and updating these datasets will be developed as part of another ESRP Learning Project (PRISM 20-1941, WRCO 2019c). In addition, that ESRP learning project (PRISM 20-1941, WRCO 2019c) will also apply the tidal restriction and wetland mapping protocols to the rest of the Puget Sound shoreline to produce a complete and regionally consistent spatial database of tidal restrictions and wetlands for the Puget Sound region. The datasets created from this project and the next ESRP Learning Project can be used for restoration planning (such as identifying or prioritization of restoration opportunities), as well as for evaluating progress towards recovery targets (such as the miles of complete restrictions converted to unrestricted, or the area of completely restricted wetlands converted to unrestricted.

Hayes et al. (2011) (Unique Identifier: 161)

Reference	Hayes, M. C., S. P. Rubin, R. R. Reisenbichler, F. A. Goetz, E. Jeans, and A. McBride. 2011. Marine habitat use by anadromous bull trout from the Skagit River, Washington. Marine and Coastal Fisheries 3(1):392-410.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Habitat: nearshore; Fish: distribution, movement, periodicity. ***Geomorphology and Landforms***: nearshore habitats and landforms. ***Land Use and Cover***: banks and shoreline.									
Species and Life Stages	***Bull Trout***: migration, outmigration.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: Acoustic telemetry was used to describe fish positions and marine habitat use by tagged Bull Trout *Salvelinus confluentus* from the Skagit River, Washington. In March and April 2006, 20 fish were captured and tagged in the lower Skagit River, while 15 fish from the Swinomish Channel were tagged during May and June. Sixteen fish tagged in 2004 and 2005 were also detected during the study. Fish entered Skagit Bay from March to May and returned to the river from May to August. The saltwater residency for the 13 fish detected during the out migration and return migration ranged from 36 to 133 d (mean ± SD, 75 ± 22 d). Most Bull Trout were detected less than 14 km (8.5 ± 4.4 km) from the Skagit River, and several bay residents used the Swinomish Channel while migrating. The Bull Trout detected in the bay were associated with the shoreline (distance from shore, 0.32 ± 0.27 km) and occupied shallow-water habitats (mean water column depth, <4.0 m). The modified-minimum convex polygons (MMCPs) used to describe the habitats used by 14 bay fish showed that most areas were less than 1,000 ha. The mean length of the shoreline bordering the MMCPs was 2.8 km (range, 0.01–5.7 km) for bay fish and 0.6 km for 2 channel residents. Coastal deposits, low banks, and sediment bluffs were common shoreline classes found within the MMCPs of bay fish, while modified shoreline classes usually included concrete bulkheads and riprap. Mixed fines, mixed coarse sediments, and sand were common substrate classes found within MMCPs; green algae and eelgrass (*Zostera* spp.) vegetation classes made up more than 70 percent of the area used by Bull Trout. Our results will help managers identify specific nearshore areas that may require further protection to sustain the unique anadromous life history of bull trout.

Hayes et al. (2013) (Unique Identifier: 419)

Reference	Hayes, M.C., R. Hays, S. P. Rubin, D. M. Chase, M. Hallock, C. Cook-Tabor, C. W. Luzier, and M. L. Moser. 2013. Distribution of Pacific lamprey Entosphenus tridentatus in watersheds of Puget Sound based on smolt monitoring data. Northwest Science 87(2):95-105.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** <u>Fish:</u> genetics, abundance, distribution, condition, size structure.									
Species and Life Stages	***Pacific Lamprey:*** rearing- outmigration, migration.									
Reaches and Spatial extent	Skagit Watershed, Puget Sound (Nooksack, Stillaguamish, Snoqualmie, Bear, Cedar, Green, Puyallup, Nisqually, Deschutes, Skokomish, Tahuya, Dewatto, Hamma-Hamma, Duckabush, Little Quilcene, Salmon Dungeness).									
Linkages to Hydroelectric Operations	NA									

Abstract: Lamprey populations are in decline worldwide and the status of Pacific Lamprey (*Entosphenus tridentatus)* is a topic of current interest. They and other lamprey species cycle nutrients and serve as prey in riverine ecosystems. To determine the current distribution of Pacific Lamprey in major watersheds flowing into Puget Sound, Washington, we sampled lamprey captured during salmonid smolt monitoring that occurred from late winter to mid-summer. We found Pacific Lamprey in 12 of 18 watersheds and they were most common in southern Puget Sound watersheds and in watersheds draining western Puget Sound (Hood Canal). Two additional species, Western Brook Lamprey (*Lampetra richardsoni)* and River Lamprey *(L. ayresii)* were more common in eastern Puget Sound watersheds. Few Pacific Lamprey macrophthalmia were found, suggesting that the majority of juveniles migrated seaward during other time periods. In addition, "dwarf" adult Pacific Lamprey (< 300 mm) were observed in several watersheds and may represent an alternate life history for some Puget Sound populations. Based on genetic data, the use of visual techniques to identify lamprey ammocoetes as *Entosphenus* or *Lampetra* was successful for 97 percent (34 of 35) of the samples we evaluated.

Hayman (2001) (Unique Identifier: 309)

Reference	Hayman, B. 2001. Skagit recovery goals. Memorandum to Jim Scott. Appendix H *in* Skagit recovery plan. Report prepared by Skagit River System Cooperative and Washington Department Fish and Wildlife.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Modeling Tools***: adult returns. ***Fish and Habitat***: Fish: abundance, status and trends.								
Species and Life Stages	***Chinook***: migration, spawning.								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Summary: This document is a memorandum of the Skagit Recovery Goals prepared by the Skagit River System Cooperative to discuss Chinook recovery goals and planning. The memorandum explains the agreement between group members to use the May 25, 2001 Ecosystem Diagnosis Treatment (EDT) model outputs for best estimates of Skagit adult Chinook capacity and productivity under Properly Functioning Conditions (PFC) because they were consistent with recent and historic estimates. A key factor in the agreement was the observed summer/fall adult recruitment numbers, which had previously been derived from the Chinook Technical Committee model but are now estimated from coded-wire tag studies. It was determined that the coded-wire tag derived estimates of summer/fall adult recruitment more closely correlated with observed recruitment and EDT model estimates of current productivity. The agreement between the EDT projection and observed values gives credence to the model to be used for PFC and historic conditions. Comparison to historic data (BY 1952) indicates that the EDT model produces estimates within the range of observed production. Using the EDT model outputs under static long-term marine survival conditions, the estimate of adult Chinook capacity in the Skagit River is roughly 200,000 individuals. This number is in line with the numbers reported in the most recent National Marine Fisheries Service (NMFS) status review at the time.

Heller (1980) (Unique Identifier: 139)

Reference	Heller, P. L. 1980. Multiple ice flow directions during the Fraser glaciation in the lower Skagit River drainage, northern Cascade Range, Washington. Arctic and Alpine Research 12(3):299-308.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: glaciers and snowpack.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: Stratigraphic mapping and pebble-count data suggest that ice flowed in three different directions in the lower Skagit drainage of the northern Cascade Range during the Fraser Glaciation (~10K to 20K BP). Glacier reconstructions suggest that till exposed at one site in the lower Skagit Valley was deposited by a Baker Valley glacier that flowed westward down the Skagit Valley during the early part of the Fraser Glaciation (Evans Creek Stade). Stratigraphic relations show that the Cordilleran Ice Sheet subsequently advanced up the Skagit Valley and into the Baker Valley during the Vashon Stade. Flow-direction indicators, as well as clast compositional variations in till and recessional deposits of Vashon age, indicate that this upvalley, eastward-advancing glacier was later overwhelmed by southeast-flowing ice of the Cordilleran Ice Sheet which entered the Baker Valley across the valley divide to the northwest.

Henderson and Beamer (2017) (Unique Identifier: 236)

<table>
<tr><td>Reference</td><td colspan="10">Henderson, R., and E. Beamer. 2017. Dugualla DOT Lagoon fish monitoring in 2017. Memorandum to Salmon Recovery, Island County Department of Natural Resources, Coupeville, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, substrate and sediment. Water Quality and Productivity: salinity, temperature, dissolved oxygen, primary productivity. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Fish:</u> hatchery, periodicity, distribution, rearing; <u>Habitat</u>: pocket estuary, restoration; <u>Monitoring:</u> restoration, abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum: estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Summary: This report presents the findings from a fish monitoring study conducted in the Dugualla Department of Transportation Lagoon from April-July 2017 following tidal exchange restoration efforts that took place after the Davis Slough Bridge was replaced. Dugualla DOT Lagoon was created in 2016 as part of the restoration project to mitigate wetland impacts and restore tidal exchange on portions of a diked pocket estuary within Dugualla Bay (in Skagit Bay). Monitoring in 2017 took place in the year following the restoration, and sampling took place twice per month in April, May, and June and once in July. Beach seining was conducted periodically during this time period; over six total sites were used, four inside of the lagoon on the perimeter of the excavated shoreline and two outside of the lagoon. Fish caught were identified and counted by species, and hatchery fish were identified by coded-wire tags, which were collected for reading. In addition to catch data, the environmental conditions at each site at the time of sampling were recorded including the salinity, temperature, dissolved oxygen, velocity, depth, substrate, and aquatic vegetation class.

Information Relevant to Skagit River Relicensing: This is a brief monitoring report for a restoration site, which provides some quantitative data that can inform the development of conceptual life history models by describing how target species use pocket estuary habitats. Fish count data presented in this report could potentially be used in the Skagit River Relicensing SY-01 Synthesis Study to show how target species are impacted by disturbances, use pocket estuary habitats, and respond to restoration. Two target species, Chum and Chinook Salmon were present in the study area, and the average catch per beach seine set for unmarked juvenile Chinook in the study area per month is presented in Figure 2. Environmental data collected during this study was not included in the report, but total catch by species data was included in Table 2. Juvenile Chinook and Chum were found both inside and outside of the lagoon, and 11 different fish species were caught in total. The report states that since sampling began in April, there was no catch data for the first three months of juvenile Chinook rearing, which takes place in the pocket estuary habitat from January-June, with peaks in March. Minimum spatial data are provided by the report, which includes a site map (Figure 1) that shows the location of sampling sites that could be used to inform future sampling efforts.

Henderson et al. (2007) (Unique Identifier: 238)

Reference	Henderson, R., A. Kagley, K. Fresh, E. Beamer, A. McBride, and K. Wolf. 2007. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Race Lagoon, 2006 and 2007.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, substrate and sediment, estuarine habitats and landforms, sediment transport and supply. ***Water Quality and Productivity:*** temperature, salinity, primary productivity. ***Fish and Habitat:*** Habitat: instream flow, pocket estuary, nearshore, freshwater; Fish: distribution, abundance, rearing, life history, size structure, periodicity, growth; Monitoring: abundance, water quality.									
Species and Life Stages	***Chinook:*** outmigration, nearshore rearing and emigration. ***Chum:*** nearshore rearing and emigration. ***Pink:*** nearshore rearing and emigration. ***Other:*** not specified.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Summary: This report focused on sampling of Race Lagoon but is part of series of reports on the use of pocket estuary habitats by fish for a largescale study within the Whidbey basin. Race Lagoon was sampled twice per month from 2006-2007 to gain a better understanding of the species and life history types of fish utilizing the pocket estuary and nearshore habitat over time. Beach seine nets were used to sample fish populations inside of the lagoon and in adjacent nearshore habitat outside of the lagoon (spit sites) in order to compare the fish assemblages between the different locations. Fish abundance and size were recorded as a part of the sampling process. Physical habitat parameters including tidal stage, substrate type, water temperature, salinity, and depth were also measured at sampling sites for comparison of fish use by habitat conditions. The suggested use of the study findings is to inform local stakeholders of the species in Race Lagoon and to provide local agencies with more information regarding the recovery of salmon populations and nearshore fish ecology.

Information Relevant to Skagit River Relicensing: This report provided quantitative data on fish assemblages and sizes within lagoon habitats and adjacent nearshore habitats that may be useful for the Skagit River Relicensing SY-01 Synthesis Study. In particular, the study provided information on timing of juvenile salmon species in these habitats, fish densities, and fork length comparisons between the habitats that can inform the development of conceptual life history models and identification of factors affecting life stages for target species. The report also provided quantitative data relating to the conditions of Race Lagoon and the ways in which it is impacted by the Skagit River, which also informs the identification of factors affecting resource conditions. The report noted that although there are now homes lining the lagoon, there are no major impacts to the geomorphology of the lagoon.

Water Quality and Productivity: Water quality was measured based on tidal stages, substrate type, surface and bottom water temperatures, surface and bottom salinities, and maximum depth seined. Sampling occurred in different tidal stages within and outside of the lagoon. Sampling in the lagoon was mainly during ebb tides, and sampling of the adjacent nearshore habitat was in the flood stage or high water. Average depths sampled were below one meter, and the substrates of the sample sites differed by habitat. Within the lagoon, sites had mostly mixed fines and mud, but substrate in nearshore habitats was predominately gravel. Table 2 provides summaries of substrate composition among sites. Differences in substrates were attributed to different waves and tidal energies that deposit finer grains within the lagoon due to lower energy and coarser grained sediments to the split with higher energies.

Salinity in the Race Lagoon and the adjacent nearshore habitat is presumed to be largely affected by the flows of the Skagit River since it is the nearest lagoon to the Skagit River, and the Skagit is the largest source of freshwater to the lagoon. In 2006, salinities were very similar between the two habitats, but salinities in the lagoon were 1.6 to 3.4 parts per thousand higher than those in the adjacent nearshore habitat between March-May. Salinities in both habitats were also lower in 2007 than 2006 likely due in part to the two freshets that occurred on the Skagit River in March of 2007. There were seasonal increases in water temperatures over the study period with temperatures in the lagoon ranging from 5.9°C to 11.6°C in 2006 and 7.5°C to 13.7°C in 2007, and temperatures outside of the lagoon ranging from 5.9°C to 10.6°C in 2006 and 7.5°C to 11.7°C in 2007. Over time during the study period, the temperatures inside of the lagoon increased at a faster rate, and the differences in temperatures between the two habitats also increased. Figures 4A-4C and 5A-5C provide salinity, temperature, and Skagit River flow data for 2006 and 2007.

Fish and Habitat: This report included quantitative data on fish assemblage and habitat use over time that included species of interest for the Skagit River Relicensing SY-01 Synthesis Study. The areas sampled for this study were typically less than four feet deep with relatively homogenous habitat features and were sampled using a beach seine. Sites were chosen so that different habitat types could be compared inside the lagoon and outside of the lagoon, in the adjacent nearshore habitat. Juvenile Chinook, Chum, and sub-yearling Pink Salmon comprised about 20 percent of the total catch in 2006 and 63 percent in 2007 with the remaining catch including Surf Smelt, Herring, Pacific Sandlance, Sculpins, 3-Spine Stickleback, Shiner, Perch, Pile Perch, Starry Flounder, Tubesnouts, and Arrow Goby. Each of these species, with the exception of the Tubesnout, were found in higher abundances in the lagoon compared to nearshore habitat outside of the lagoon for both years. The total catch by species data is located in Table 3. Further data are presented for each of the three salmon species, including monthly salmon densities with average fork length per species in Figures 6A-F and 7A-F.

Juvenile Chinook represented 3 percent of the salmon catch in 2006, and only two individuals were caught in 2007 (~0.1 percent of total salmon catch). For both years, Chinook were caught exclusively in the lagoon sites, and their abundance varied with the time of year. The peak of Chinook presence in 2006 was in March with density decreasing until the end of the study period in May, and the two individuals in 2007 were caught in April. This resulted in densities of 306 salmon per hectare and 12.3 salmon per hectare of area seined, respectively. This drastic difference in densities is likely attributed to a decrease in the number of wild juvenile salmon outmigrating from the Skagit River from 2006 to 2007. In 2006, about 6.2 million wild juveniles outmigrated from the river, but only 1.7 million outmigrating individuals were recorded in 2007. Fish size varied by month over the course of the study suggesting that the salmon were rearing in the area. All of the Chinook caught were wild individuals measured at sub-yearling fork lengths and average sizes of 48 mm in February, 49.5 mm in March, 54.5 mm in April (49 mm for the two caught in April 2007), and 60 mm in May.

Juvenile Chum Salmon made up 25.2 percent of the salmon catch in 2006, and sub-yearling Chum were the vast majority of the total salmon catch in 2007 at 99.9 percent. Chum Salmon were not observed in February of either year but were caught in both the lagoon and adjacent nearshore habitat from March-May of both years. Densities for Chum were about 4 times greater in 2007 than in 2006. The distribution was equal for Chum between the two habitats in March, peak densities for both habitats occurred in April, and densities in the lagoon were 4 times that of the nearshore habitat in 2006 and 3 times that in 2007. Trends in size of the salmon generally showed an increase in fork length from March to May for both years in both habitats, but the salmon in the lagoon were larger on average than those outside of the lagoon.

In 2006, sub-yearling Pink Salmon were the dominate salmonid caught at 71.7 percent of the salmonid catch, but only one juvenile was caught in 2007. Pink Salmon were caught both inside and outside of the lagoon for all months in the 2006 sampling period, and the one individual caught in 2007 was inside of the lagoon in April. The abundance of Pink Salmon increased drastically from February to March in 2006 for both habitat types, and peaks in densities occurred in April. At the peak, there were more than 5x as many individuals in the lagoon than in the adjacent nearshore habitat. Trends in sizes for Pink Salmon were the same as those for the other two salmon species, with increases in fork length being observed from February to May and a difference of about 3 to 5 mm in fork length between fish in the adjacent habitat to those in the lagoon (those in the lagoon being larger).

Overall, there was a higher fish density and species diversity within the lagoon habitat than along the adjacent nearshore habitat for both years of the study. Fish densities and assemblages varied per month and year during the study period. There was a peak of density in the nearshore habitat in March of 2006 with a density of 5,000 fish per hectare and a peak in April in 2007 of 5,800 fish per hectare. Both of these peaks were driven by the presence of juvenile salmon. Increases in densities within the lagoon were recorded for each month in 2006, and the peak occurred in May. In 2007, fish density was about half that observed in 2006, and the peak density was in April and was also driven by juvenile salmon populations.

Herrera Environmental (2017) (Unique Identifier: 427)

Reference	Herrera Environmental. 2017. Conceptual restoration plan: Carey's slough tributary to the Skagit River Hamilton, Washington. Prepared by Herrera Environmental Consultants for Skagit Fisheries Enhancement Group.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and landforms:*** history, floodplain connectivity. ***Water quality and productivity:*** temperature, dissolved oxygen, pH, contaminants. ***Land Cover and Use:*** land cover. ***Fish and Habitat:*** Habitat: barriers, restoration, capacity. ***Modeling tools:*** hydrology, data gaps.									
Species and Life Stages	***Chum, Coho, Chinook, steelhead:*** not specified.									
Reaches and Spatial extent	Other lower Skagit River tribs.									
Linkages to Hydroelectric Operations	NA									

Abstract: In 2016, the Skagit Fisheries Enhancement Group (SFEG) was awarded a grant from the Washington State Salmon Recovery Funding Board (SRFB) to develop an integrated conceptual plan for restoring salmon habitat associated with Carey's Slough. The plan is intended to provide a roadmap for implementing a coordinated suite of habitat restoration actions over the next decade or so. The restoration plan has been developed to be consistent with the local Skagit Chinook Recovery Plan (SRSC and WDFW 2005); the Skagit Watershed Council's Strategic Approach (SWC 2015), and the Biological Opinion on the National Flood Insurance Program issued by National Oceanic and Atmospheric Administration, Fisheries Service (NOAA Fisheries 2008). It considers sequencing of potential restoration actions, including a general consideration of land acquisitions needed to support various restoration activities.

This plan represents the first step of a multi-phase, multi-year project. Like any successful restoration project, it depends heavily of the support and buy-in of local landowners. SFEG and Herrera Environmental Consultants, Inc. (Herrera) worked closely with the Town of Hamilton (Town) government and local landowners to identify constraints and opportunities for habitat restoration that fit with the goals and values of the surrounding community. The project team believes they have identified a reasonable path forward that, when implemented, will restore habitat in Carey's Slough and the surrounding floodplain.

Hinton et al. (2005) (Unique Identifier: 242)

Reference	Hinton S., J. Blank, A. McKain, G. Hood, et al. 2005. Wiley Slough estuarine design report. Report prepared by Washington Department of Fish and Wildlife, Skagit Watershed Council, Skagit River System Cooperative, Seattle City Light, and U.S. Fish and Wildlife Services.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** land cover. ***Fish and Habitat:*** <u>Habitat:</u> restoration, estuary, instream flow, barriers; <u>Fish:</u> abundance, distribution, movement; <u>Monitoring:</u> restoration, habitat, abundance. ***Modeling tools:*** bathymetry. ***Geomorphology and Landforms:*** substrate and sediment, sinuosity, channel migration.									
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Wiley Slough Restoration Project is a collaborative project between the Washington Department of Fish and Wildlife (WDFW), the Skagit Watershed Council, the Skagit River System Cooperative, Seattle City Light, the US Fish & Wildlife Service, and others. This project was proposed and funded for preliminary construction design by the Washington State Salmon Recovery Funding Board in early spring of 2003. The intent of this collaboration is to develop a detailed set of construction recommendations and actions that will restore historic tidal and riverine processes on a publicly owned parcel of land located on Fir Island, near the town of Conway, Washington (Figure 1.0). The goal of said restoration is to benefit the diversity of fish and wildlife species that rely on estuaries, including salmon and a wide variety of migratory birds.

The directive of this design project is to rehabilitate natural processes within the confines of publicly owned land located at the historic Wiley Slough distributary channel of the South Fork of the Skagit River delta. Project objectives include the need for self-sustaining estuarine habitat for the benefit of indigenous fish, wildlife and vegetation communities common to the Puget Sound fiord ecosystem. To this end, our design approach focuses on restoring important physical processes (tidal and riverine flooding). The project is designed in a way that protects interests of adjacent land owners, the agricultural community, and WDFW obligations while promoting wildlife oriented recreational activities consistent with the restoration objectives.

Hood et al. (2018) (Unique Identifier: 143)

<table>
<tr><td>Reference</td><td colspan="8">Hood, W. G., E. M. Beamer, and R. Henderson. 2018. Juvenile salmon density on marsh surfaces versus within tidal channels. Proceedings of the Salish Sea Ecosystem Conference, Seattle, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Proceedings</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td></tr>
<tr><td></td><td colspan="8">Project Related: No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="8">Geomorphology and Landforms: estuarine habitats and landforms. Water Quality and Productivity: primary productivity, secondary productivity. Fish and Habitat: <u>Habitat:</u> estuary, restoration, wetlands, instream flow; <u>Fish:</u> abundance, density dependence, movement, distribution, data gaps; <u>Monitoring:</u> abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="8">Chinook, Chum, Coho: estuary rearing and emigration. Other species (Stickleback, Peamouth, Shiner Perch): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="8">Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="8">NA</td></tr>
</table>

Abstract: Use of tidal marsh surfaces by juvenile salmon in Pacific Northwest estuaries has generally been ignored by ecologists, engineers and planners involved in salmon habitat restoration. IN contrast, fish use of marsh plains has been documented in many other parts of the world. Are Pacific Northwest marshes and exception to the pattern of fish use that is so common elsewhere? For three consecutive years, fish were sampled bi-monthly in tidal channels and on tidal marsh plains of the Skagit Delta to answer this question. Juvenile Chinook and Chum Salmon, as well as Sticklebacks were the most consistently caught and abundant fish in channels and on the marsh surface, but eight other fish species were also found on the marsh surface. While fish densities were much higher in tidal channels than on marsh surfaces, marsh surface area was much greater than channel area, so Sticklebacks and juvenile Chum were potentially 50 percent more numerous on the marsh surface than in channels. However, due to their high channel densities, juvenile Chinook were nevertheless more abundant in tidal channels than on the marsh surface; those on the marsh surface amounted to 40 percent of those in tidal channels. The ratio of marsh surface to channel fish density peaks late in the season for all three fish species, which may be a response to increased prey production over the marsh plain. The substantial use of the marsh surface by juvenile salmon that we observed suggests estuarine habitat restoration for salmon recovery should not neglect the direct value of vegetated marsh plains to juvenile salmon. Tidal marsh habitat for juvenile salmon is more than just tidal channels. Partial habitat restoration that only restores tidal flow to channels and not to adjacent marshes, e.g., using self-regulating tide gates (SRTs), has a direct impact on juvenile salmon habitat use.

Hood (2004) (Unique Identifier: 140)

Reference	Hood, W. G. 2004. Deepwater slough restoration monitoring report: 2000-2003. Report prepared by Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, sinuosity, substrate and sediment, sediment transport and supply, large wood, estuarine habitats and landforms, floodplain connectivity. ***Water Quality and Productivity:*** secondary productivity. ***Modeling:*** habitat (topology and vegetation). ***Land Use and Cover:*** agriculture, urban, floodplain. ***Fish and Habitat:*** Habitat: beaver, estuary, restoration, invasive species, riparian, wetlands; Fish: predation, diet; Monitoring: habitat, restoration, data gaps.									
Species and Life Stages	***Chinook, Chum:*** estuary rearing and emigration. ***Other species (Stickleback):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: *The Need for Restoration:* Dramatic losses of natural habitat have occurred in the Skagit delta since Euro-American settlement, 150 years ago (Fig. 1). Agricultural and urban development in the delta have led to the loss of more than 70 percent of estuarine emergent wetlands and 90 percent of estuarine scrub-shrub, riverine scrub-shrub, riverine forested, and palustrine emergent, scrub-shrub, and forested wetlands (Bortleson et al. 1980, Collins & Montgomery 2001). This extensive habitat loss has led to significant declines in fish and wildlife, of which the best documented is that of Chinook Salmon, which are listed as threatened under the Endangered Species Act (ESA) (64 Federal Register 14308, March 24 1999). Due to their ESA status and cultural, economical, and political significance there is considerable interest in increasing Chinook Salmon populations in the Skagit basin. Because estuarine rearing habitat is the most significant limitation to Chinook production in the basin (Beamer et al. 2003), there is considerable interest in estuarine habitat restoration.

Location of the Restoration Site: The Deepwater Slough restoration site is located near the mouth of the South Fork Skagit River (48°19' N, 122° 22' W), approximately 2.5 km southwest of Conway, Washington (Fig. 2). The lower reaches of the Skagit River in this area are tidal fresh water, while adjacent tidal marshes are fresh to oligohaline.

Restoration Goals and Strategy: The proximate goal of the Deepwater Slough Restoration Project was to restore natural processes, functions, conditions and biological responses within the project area (Klochak et al. 1999). Specifically, the project sought to restore riverine and tidal flooding (and ensuing functions, habitat conditions, and biological responses) to the site by removing dikes surrounding the project area.

The ultimate goal of the Deepwater Slough Restoration Project was to provide rearing habitat to juvenile salmon as a consequence of restoring natural hydrological and sedimentary processes. The purpose of providing rearing habitat was to increase the production of salmonids, particularly ESA-listed Chinook Salmon.

This process-based restoration strategy was chosen to minimize the need for expensive engineering or maintenance of infrastructure, to facilitate natural site evolution, and to allow holistic, system-

scale restoration rather than single-species management. Restoration of natural riverine and estuarine processes to the site should lead to the natural development and evolution of estuarine habitat to the benefit of a wide variety of estuarine-dependent fish and wildlife.

The Restoration Process: The 480-acre (195 ha) Deepwater Slough site is owned by the Washington Department of Fish and Wildlife (WDFW), which has managed the area for waterfowl since the 1940s. WDFW allowed restoration on 205 acres, but maintained 275 acres in traditional waterfowl management, i.e., planting of agricultural grains for waterfowl food and controlled seasonal flooding (Fig. 3). The US Army Corps of Engineers (USACE) entirely removed dikes from areas to be restored, and built new dikes (of the removed dike material) for areas to be maintained in traditional management (Fig. 4). Large remnant channels in the restoration site were reconnected to tidal channels outside the dike by excavating through the dike footprint to match cross-sections of remnant channels with external channels (Fig. 5). This was done for three large channels in the west lobe of the restoration site and three in the east lobe. No vegetation planting or alteration of existing vegetation occurred.

The Need for Monitoring: Monitoring of restoration projects is universally acknowledged as important by scientists specializing in habitat restoration; e.g.,

"Monitoring is the fulcrum for salmon recovery. The balance of science, effective use of resources, and policy decisions that will recover salmonids depends on scientifically valid monitoring to measure success and reduce uncertainty." (ISP 2000)

"The monitoring program is a valuable tool to determine restoration success. ...a carefully designed monitoring program lies at the heart of adaptive management"(Thom and Wellman 1996).

Many restoration projects are failures because they are poorly planned and/or monitored (NRC 1992). For example, Frissell and Nawa (1992) examined 161 aquatic habitat enhancement structures on 15 streams in western Oregon and Washington and found over 18 percent had failed outright, and 60 percent were damaged or ineffective. Without monitoring, restoration failures go undetected and uncorrected. Conversely, when restoration successes occur and are clearly documented they serve to inspire additional restoration; success breeds success. Most importantly, monitoring allows the accumulation and later application of new knowledge and experience gained from restoration and associated monitoring projects.

Hood (2004) (Unique Identifier: 141)

Reference	Hood, W. G. 2004. Indirect environmental effects of dikes on estuarine tidal channels: thinking outside of the dike for habitat restoration and monitoring. Estuaries 27(2):273-282.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms, sediment transport and supply, sinuosity, floodplain, large wood. ***Water Quality and Productivity:*** secondary productivity, primary productivity. ***Land Use and Cover:*** floodplain, agriculture. ***Fish and Habitat:*** Habitat: estuary, wetlands; Monitoring: habitat, restoration.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration. ***steelhead, Bull Trout, Other species (Cutthroat Trout, Dolly Varden):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: While the most obvious effects of dike construction and marsh conversion are those affecting the converted land (direct or intended effects), less immediately apparent effects also occur seaward of dikes (indirect or unintended effects). I analyzed historical photos of the Skagit River delta marshes (Washington, U.S.) and compared changes in estuarine marsh and tidal channel surface area from 1956–2000 in the Wiley Slough area of the South Fork Skagit delta, and from 1937–2000 in the North Fork delta. Dike construction in the late 1950s caused the loss of 80 ha of estuarine marsh and 6.7 ha of tidal channel landward of the Wiley Slough dikes. A greater amount of tidal channel surface area, 9.6 ha, was lost seaward of the dikes. Similar losses were observed for two smaller North Fork tidal channel systems. Tidal channels far from dikes did not show comparable changes in channel surface area. These results are consistent with hydraulic geometry theory, which predicts that diking reduces tidal flushing in the undiked channel remnants and this results in sedimentation. Dikes may have significant seaward effects on plants and animals associated with tidal channel habitat. Another likely indirect dike effect is decreased sinuosity in a distributary channel of the South Fork Skagit River adjacent to and downstream of the Wiley Slough dikes, compared to distributary channels upstream or distant from the dikes. Loss of floodplain area to diking and marsh conversion prevents flood energy dissipation over the marsh surface. The distributary channel has responded to greater flood energy by increasing mean channel width and decreasing sinuosity. Restoration of diked areas should consider historic habitat loss seaward of dikes, as well as possible benefits to these areas from dike breaching or removal. Habitat restoration by breaching or removal of dikes should be monitored in areas directly affected by dikes, areas indirectly affected, and distinct reference areas.

Hood (2004) (Unique Identifier: 243)

Reference	Hood, W. G. 2004. Likely scaling of basin area with some marine riparian zone functions. Proceedings of the DFO/PSAT sponsored marine riparian experts workshop, Tsawwassen, British Columbia.								
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, nearshore habitats and landforms. ***Fish and Habitat:*** Habitat: riparian, wetlands, nearshore.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Summary: This proceedings document presents the relationship between watershed basin area and stream delta marsh area. This analysis was completed through GIS, USGS topographic map, and historical USGS T-sheet use for watershed delineation paired with regression analyses. Results showed that there was a strong relationship between basin area, delta marsh area, and lagoon area. When basin area was compared between coves, points, and straight coastlines, there were significant differences that suggested that freshwater inputs and the suspended and dissolved materials entering the system varied by coastline form. Spatial and quantitative data were developed as part of the project and are not provided in the summary report.

Hood (2006) (Unique Identifier: 244)

Reference	Hood, W. G. 2006. Deepwater slough restoration monitoring: channel cross-section comparisons, 2000-2006. Report prepared by Skagit River System Cooperative for U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms, history, sediment transport and supply, side and off-channels. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: restoration, estuary; Monitoring: habitat, restoration.									
Species and Life Stages	***Chinook:*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Deepwater Slough was restored through dike removal in the summer of 2000 to provide in-channel habitat and restore an important migratory corridor for juvenile Chinook and other salmon in the Skagit Delta. Dikes blocking the channel were removed from a site near the upstream end of the distributary channel and 1000m downstream from this location. Geomorphic changes quickly followed dike removal, particularly upstream of the upstream dike. Changes in planform geometry from 2000 to 2002 have been previously reported (Hood 2003). This report provides additional planform 1 monitoring results for 2004 and comparisons of channel cross-section changes from 2000 to 2005. The monitoring results reported here are preliminary. The site will likely continue to evolve in coming years and increasingly resemble natural tidal marshes. The great unknown is, at what rate will change occur?

Hood (2006) (Unique Identifier: 395)

Reference	Hood, W. G. 2006. A conceptual model of depositional, rather than erosional, tidal channel development in the rapidly prograding Skagit River Delta (Washington, USA). Earth Surface Processes and Landforms 31:1824-1838.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, channel migration, sediment transport and supply, large wood, estuarine habitats and landforms, substrate and sediment. ***Modeling:*** sediment. ***Land Use and Cover:*** floodplain, forestry, banks and shoreline.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The origin and growth of blind tidal channels is generally considered to be an erosional process. This paper describes a contrasting depositional model for blind tidal channel origin and development in the Skagit River delta, Washington, USA. Chronological sequences of historical maps and photos spanning the last century show that as sediments accumulated at the river mouth, vegetation colonization created marsh islands that splintered the river into distributaries. The marsh islands coalesced when intervening distributary channels gradually narrowed and finally closed at the upstream end to form a blind tidal channel, or at mid-length to form two blind tidal channels. Channel closure was probably often mediated through gradient reduction associated with marsh progradation and channel lengthening, coupled with large woody debris blockages. Blind tidal channel evolution from distributaries was common in the Skagit marshes from 1889 to the present, and it can account for the origin of very small modern blind tidal channels. The smallest observed distributary-derived modern blind tidal channels have mean widths of 0·3 m, at the resolution limit of the modern orthophotographs. While channel initiation and persistence are similar processes in erosional systems, they are different processes in this depositional model. Once a channel is obstructed and isolated from distributary flow, only tidal flow remains and channel persistence becomes a function of tidal prism and tidal or wind/wave erosion. In rapidly prograding systems like the Skagit, blind tidal channel networks are probably inherited from the antecedent distributary network. Examination of large-scale channel network geometry of such systems should therefore consider distributaries and blind tidal channels part of a common channel network and not entirely distinct elements of the system. Finally, managers of tidal habitat restoration projects generally assume an erosional model of tidal channel development. However, under circumstances conducive to progradation, depositional channel development may prevail instead.

Hood (2009) (Unique Identifier: 145)

<table>
<tr><td>Reference</td><td colspan="8">Hood, W. G. 2009. Habitat monitoring strategy for the tidal Skagit Delta: integrating landscape and site-scale perspectives. Report prepared by Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>No</td><td>Spatial Data</td><td>No</td></tr>
<tr><td></td><td colspan="6"></td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="8">Fish and Habitat: Habitat: estuary, restoration, connectivity, invasive species; Monitoring: habitat, restoration, water quality; Fish: abundance, distribution, periodicity. Geomorphology and Landforms: estuarine habitats and landforms.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="8">Chinook: estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="8">Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="8">NA</td></tr>
</table>

Abstract: Science-based habitat restoration depends on making and testing (i.e., monitoring) predictions of the outcome of a proposed restoration. To this end several predictive models are currently being developed for the Skagit Delta system. They include: [1] a predictive model of tidal marsh vegetation, based on elevation (hydroperiod), soil salinity, and sediment grain size, with the possibility of relating these variables to blind and distributary tidal channel geometry; [2] a predictive model of blind tidal channel allometry that provides insight into cumulative effects, historical anthropogenic legacies, and design guidance, with potential use as an indicator of system function or dysfunction (Hood 2007a); and [3] a sophisticated 3-D hydrodynamic model of the system that will allow prediction of water quality, sedimentation/erosion, and particle transport (e.g., juvenile Chinook Salmon movement). Further elaboration and validation (including restoration monitoring) of these models is a high priority. Likewise, development and testing of predictive/descriptive models of distributary network geometry, and development and testing of marsh accretion models that account for vegetation effects are also high priorities. These models will be used to guide restoration planning and design, restoration monitoring and evaluation, baseline monitoring/system characterization, and system trend monitoring. Restoration monitoring is essential to evaluate restoration tactics and strategies, as well as newly developed design tools (i.e., predictive models). Trend monitoring allows change detection relevant to broader management concerns such as climate change impacts, basin-scale flood management, or urban sprawl.

Due to anticipated programmatic and financial constraints the monitoring strategy described here has limited itself to a few priority areas of effort. Important issues have been omitted that in an ideal funding environment would have been included, e.g., developing and testing predictive models of prey production for juvenile Chinook Salmon such as benthic detritivores and herbivores. Understanding and quantitatively predicting prey relationships to habitat variables would be useful not only to better understand and design habitat restoration for juvenile Chinook Salmon, but also for other predators on these organisms, such as waterfowl and shorebirds. Waterfowl and shorebird monitoring has also been omitted even though there is a great need for better understanding of their ecology in Pacific Northwest coastal systems and considerable societal interest in their management. Nutrient geochemistry has been neglected because this issue is beyond the expertise of the author of this monitoring strategy.

The monitoring strategy presented here will require periodic updating as new information is acquired, models are improved, goals change, or funding improves. It is not meant to support inflexible prescription or proscription of monitoring or research effort in the Skagit Delta or elsewhere. Rather it provides guidance and a rationale for the monitoring and research directions that are currently being pursued or should be pursued in the Skagit Delta.

Hood (2010) (Unique Identifier: 396)

Reference	Hood, W. G. 2010. Delta distributary dynamics in the Skagit River Delta (Washington, USA): extending, testing, and applying avulsion theory in a tidal system. Geomorphology 123:154-164.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, channel migration, substrate and sediment, sediment transport and supply, slope, estuarine habitats and landforms, floodplain, sinuosity. ***Modeling Tools:*** hydrology. ***Land Use and Cover:*** agriculture, floodplain, banks and shoreline.									
Species and Life Stages	***Chinook:*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Analysis of historical aerial photos shows that Skagit Delta (Washington, USA) distributary dynamics are consistent with the Slingerland and Smith model of avulsion dynamics where the ratio of the water surface slopes of the two branches of a bifurcation predicts avulsion stability. This model was extended to predict distributary inlet (upstream) width and bankfull cross-sectional area. The water surface gradient ratio for a bifurcation pair predicted distributary width well; the lowest R^2 was 0.61 for the 1937 data points, but R^2 ranged from 0.83 to 0.90 for other year-specific regression lines. Gradient ratios were not constant over the historical record; from 1937 to 1972 the mainstem river channel lengthened by 1250 m in the course of marsh progradation, while distributary lengthening was comparatively negligible. Consequently, the gradient advantage of the distributaries increased and their channels widened. After the mainstem river terminus stabilized from 1972 to the present, the distributaries continued to lengthen with marsh progradation, so that distributary gradient advantage steadily declined and the distributaries narrowed. While distributary cross sections were not available for the historical period, they were surveyed in 2007 near the distributary inlets. Gradient ratio was more closely related to distributary inlet bankfull cross sectional area (R^2= 0.95) than to minimum distributary width for any photo year examined. Applying this form of analysis to Skagit Delta distributaries that have been dammed in the course of agricultural development suggests that their restoration to stabilize eroding marshes at their outlets and recover salmon migration pathways would be feasible without significant risk of full river avulsion.

Hood (2012) (Unique Identifier: 144)

Reference	Hood, W. G. 2012. Beaver in tidal marshes: dam effects on low-tide channel pools and fish use of estuarine habitat. Wetlands 32:401-410.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, history, change***. Land Use and Cover:*** agriculture, floodplain, commercial, urban. ***Fish and Habitat:*** Fish: density dependence, abundance, distribution, rearing, predation, diet, movement; Habitat: beaver, estuary, riparian, climate change; Monitoring: abundance, habitat.									
Species and Life Stages	***Chinook, Chum, Coho:*** estuary rearing and emigration, outmigration. ***Other species (Sculpin, Three-spine Stickleback, Starry Flounder, River Lamprey):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Beaver (*Castor* spp.) are considered a riverine or lacustrine animal, but surveys of tidal channels in the Skagit Delta (Washington, USA) found beaver dams and lodges in the tidal shrub zone at densities equal or greater than in non-tidal rivers. Dams were typically flooded by a meter or more during high tide, but at low tide they impounded water, allowing beaver to swim freely while quadrupling pool habitat for fish compared to channels without dams. Seven fish species were caught in low-tide pools, including threatened juvenile Chinook Salmon (Oncorhynchus tshawytscha), whose densities (by volume) averaged 3.2 times higher in low-tide pools than shallows. Accounting for the total contribution of pools and shallows to juvenile Chinook abundance, beaver pools tripled shrub zone channel capacity for juvenile Chinook Salmon at low tide relative to herbaceous zone marsh without beaver pools. Current Chinook recovery efforts focus on restoring herbaceous zone tidal marsh for rearing juveniles, but this focus overlooks presently rare and poorly understood habitat, like tidal shrub marsh, that was historically common and likely important to beaver and small estuarine or anadromous fish.

Hood (2013) (Unique Identifier: 273)

Reference	Hood, W. G. 2013. Applying and testing a predictive vegetation model to management of the invasive cattail, Typha angustifolia L., in an oligohaline tidal marsh reveals priority effects caused by non-stationarity. Wetlands Ecology and Management 21:229-242.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Water Quality and Productivity:*** salinity. ***Modeling Tools:*** bathymetry, habitat. ***Land Use and Cover:*** floodplain. ***Fish and Habitat:*** Habitat: wetland, invasive species, estuary, restoration.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Effective tidal marsh restoration requires predictive models that can serve as planning and design tools to answer basic questions such as which, if any, plant species will colonize a proposed restoration site. To develop such a tool, a predictive model of oligohaline tidal marsh vegetation was developed from reference marshes in the Skagit River Delta (Washington, USA) and applied to a 1.1-ha restoration treatment site. Probability curves for the elevational distributions of common marsh species were generated from RTK-GPS point samples of reference tidal marshes. The probability curves were applied to a LIDAR-derived digital elevation model to generate maps predicting the occurrence probability of each species within treatment and control sites. The treatment and control sites, located within a recently restored area that had been diked but never completely drained, were covered by a mono-culture of non-native *Typha angustifolia L.* (narrow-leaf cattail) growing 40–60 cm lower in elevation than in the reference marsh. The T. angustifolia was mowed repeatedly in the treatment site to allow colonization by predicted native marsh species. Four years after mowing, *T. angustifolia* was replaced on 60 percent of the treatment site by native sedges (*Carex lyngbyei, Eleocharis palustris*), consistent with the predictive vegetation model; the control site remained covered by *T. angustifolia*. The mowing experiment confirmed that pre-emptive competition from *T. angustifolia* was preventing vegetation recovery in the restoration site following dike removal, and implied that some vegetation species may be refractory to environmental change, such as dike removal or sea-level rise, because of differences in recruitment and adult niches.

Hood (2014) (Unique Identifier: 062)

Reference	Hood, W. G. 2014. Differences in tidal channel network geometry between reference marshes and marshes restored by historical dike breaching. Ecological Engineering 71:563-573.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, estuarine habitats and landforms, sediment transport and supply. ***Land Use and Cover:*** floodplain, agriculture, urban. ***Fish and Habitat:*** Habitat: estuary, restoration, instream flows, riparian, connectivity; Fish: rearing; Monitoring: habitat, restoration.									
Species and Life Stages	***Chinook, Coho, Chum:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Tidal marsh restoration generally involves dike breaching rather than complete dike removal to restore tidal inundation. Dike removal more completely restores hydrodynamic processes, but dike breaching is more economical. Thus, without a clear demonstration of the ecological benefits of complete or extensive dike removal, economic considerations are likely to cause restoration planners and engineers to prefer dike breaching. To provide some insight into the relative benefit of dike breaching versus dike removal, tidal channel planform geometry was compared between historical dike breach sites (>15 years old) and reference tidal marsh. Tidal channel networks were examined because they mediate many hydrodynamic, sedimentary, and ecological processes. Dike breach sites were found to have fewer tidal channel outlets than reference sites, but greater total channel surface area and length. These differences were likely the result of remnant dikes constraining tidal prism entirely to channel networks rather than allowing a portion of the prism to transit site boundaries as sheet flow. Allometric analysis of GIS-calculated tidal channel drainage basin area relative to total marsh area indicated the proportion of tidal prism comprised of sheet flow was inversely related to total marsh area, with the smallest marsh islands having no tidal channels and all of their tidal prism consisting of sheet flow. This suggests dike removal to restore sheet flow is most important for small restoration projects. However, dike removal may still be important for large restoration sites depending on issues not examined in this paper, e.g., remnant dike effects on river flood hydrodynamics.

Hood (2015) (Unique Identifier: 064)

Reference	Hood, W. G. 2015. Predicting the number, orientation and spacing of dike breaches for tidal marsh restoration. Ecological Engineering 83:319-327.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, sediment transport and supply. ***Land Use and Cover:*** floodplain, agriculture, urban. ***Fish and Habitat:*** Fish: rearing; Habitat: estuary, restoration, connectivity; Monitoring: restoration, habitat.									
Species and Life Stages	***Chinook, Chum:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Tidal channels are structurally and functionally prominent features in tidal marshes, so their restoration is central to tidal marsh habitat restoration. Consequently, an important question in tidal marsh restoration is how many tidal channels can a restoration site support, and thus, how many dike breaches should be made to restore tidal inundation and tidal channels, if the dike is not to be removed entirely. Allometric analysis of reference tidal marshes in Puget Sound river deltas and the lower Columbia River estuary showed that channel outlet count scales with marsh area, and that completed and proposed tidal marsh restoration projects had 5-fold fewer channel outlets than reference marshes. This deficiency likely impacts fish access to the restoration sites. After addressing the question of tidal channel outlet count, or dike breach count, the next design questions are how should dike breaches be oriented in tidal marsh islands and how should they be spaced. GIS and statistical analysis of reference marsh islands indicated that outlets of the two largest tidal channels draining a marsh island are typically oriented downstream, in parallel with the nearest river channel. However, the outlets of smaller tidal channels are oriented randomly. Tidal channel outlet spacing is generally independent of site size and constant within a river delta. Geometric mean spacing ranged from 122 m in the Snohomish Delta to 280 m in the North Fork Skagit Delta. These results provide important guidance to improve tidal marsh restoration design, and illustrate a useful approach to restoration design evaluation.

Hood (2016) (Unique Identifier: 274)

Reference	Hood, W. G. 2016. Parallel scaling of tidal channel length and surface area with marsh area for 1st through Kth-ranked channels and their tributaries: application for tidal marsh restoration. Ecological Engineering 95:54-63.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, sediment transport and supply, change. ***Modeling Tools:*** habitat. ***Fish and Habitat:*** Habitat: restoration, estuary.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Scaling relationships in landforms are a signature of locally stable, self-organized critical states, which in tidal marshes result from the interaction of hydrodynamics, sediment dynamics, and biota. Empirical scaling relationships for tidal channel planform were developed for reference tidal marshes in four of the largest river deltas in Puget Sound to explore the potential underlying generative process of the observed patterns and to provide design guidance for restoration of estuarine rearing habitat for juvenile salmon. The length, surface area, and drainage basin area of the largest, 2nd-largest, 3rd-largest, etc., up to 15th largest tidal channels that drain a marsh island, as well as the lengths of the largest through 5th-largest tributaries to the largest and 2nd-largest channels scaled with marsh area. Additionally, regression of the scaling relationship y-intercepts against channel rank for each delta showed that the rate of channel size decrease from one rank to the next was well fit by a power function, with R2 values approaching 1. These relationships reveal predictable structure in many aspects of tidal channel planforms and allow engineers to design channel excavation in considerable detail. A simulation model of channel formation through recursive marsh island conglomeration in river deltas reproduced the scaling behavior of the empirically observed marsh channels, thereby linking observed patterns to the underlying generative process. Previous allometric modeling has provided predictions of the number of tidal channels a marsh restoration site should have; this study provides a method to predict the size distribution of those channels so that engineers, planners, and restoration scientists can better plan, design, and monitor marsh restoration.

Hood (2016) (Unique Identifier: 275)

Reference	Hood, W. G. 2016. Tidal channel monitoring in 2015 for the Port Susan Bay restoration project. Report prepared for The Nature Conservancy by Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, substrate and sediment, change, estuarine habitats and landforms, channel incision. ***Land Use and Cover:*** agriculture, floodplain. ***Fish and Habitat:*** <u>Habitat:</u> restoration, estuary; <u>Monitoring:</u> restoration, habitat.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound (Port Susan Bay).									
Linkages to Hydroelectric Operations	NA									

Abstract: The purpose of this report is to describe the condition of tidal channels on the newly restored Port Susan Bay tidal marsh restoration site, three years after dikes were removed to restore tidal inundation to the site. We anticipate that an extensive tidal channel network will develop on the site over the next decade to efficiently convey tidal waters to and from the site. The principal question is exactly how fast will this development occur.

Approximately 62 hectares of tidal marsh were restored through dike removal. In addition, two large channel outlets were excavated to connect an historically remnant tidal channel and the pre-existing agricultural drainage network to tidal channels seaward of the former dikes. No other channel excavation occurred. Further channel development on the site will occur through natural tidal processes.

The restoration site subsided while under agricultural management, especially the seaward portions of the site, which are now approximately one meter lower in elevation that the natural marsh adjacent to the site. As a result, the restoration site forms a topographic bowl. This will likely affect the nature of the tidal channel network that develops on the site. While dikes have been removed, facilitating sheet flow of tidal waters, the sharp elevation difference across the site boundary will likely constrain development of new tidal channel outlets across the boundary just as remnant dikes would. Thus, the two excavated channel network outlets are likely to remain the only two outlets from the site. This could change if Hat Slough migrates northward to erode the southern site boundary and breach the high topography on that side of the site. An additional consideration is that the Oso landslide occurred in March 2014, two years after dike removal on the site. This has become a major sediment source of sediment to Port Susan Bay and will likely remain so for the next several years. It is unclear what the effect of this new sediment supply will be on site elevations and channel development. We will examine channel cross-sections for any appreciable gains in elevation in either the marsh surface or the channel bottoms.

Johannessen and MacLennan (2007) (Unique Identifier: 277)

Reference	Johannessen, J., and A. MacLennan. 2007. March's Point geomorphic assessment & drift cell restoration prioritization. Report prepared for Skagit County Marine Resources Committee by Coastal Geologic Services, Bellingham, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, nearshore habitats and landforms, history, climate change. ***Fish and Habitat:*** Habitat: restoration; Monitoring: restoration. ***Land Use and Cover:*** banks and shoreline.									
Species and Life Stages	***Other Species (Pacific Herring, Surf Smelt, Dolly Varden, Cutthroat Trout), steelhead:*** not specified.									
Reaches and Spatial extent	Skagit Bay (Fidalgo Island), Padilla Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: The purpose of this study was to provide a coastal geomorphic assessment and restoration prioritization of the March's Point Peninsula of Fidalgo Island for the Skagit County Marine Resources Committee (MRC). The assessment entailed mapping the current and historic geomorphic character of the drift cells within the defined study area with attention focused on coastal processes and impairment of those processes. The results of the assessment were then applied to developing prioritized, coastal processes-based restoration opportunities aimed at restoration/ enhancement of the nearshore habitats found along the shores of the study area. This included actions that will restore or enhance physical processes throughout the study area with emphasis on the March's Point Cusp and Crandall Spit, and enhancing forage fish spawning habitat. In the future, specific project-level geomorphic assessment combined with historic shore change analysis from this report can be used for development of detailed designs for high-ranking restoration and/or enhancement opportunities.

Kagley (2007) (Unique Identifier: 278)

Reference	Kagley, A., J. Marcell, K. Fresh, and E. Beamer. 2007. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Harrington Lagoon, 2006. Report prepared for Island County Planning and Community Development, Coupeville, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: estuarine habitats and landforms, nearshore habitats and landforms. ***Fish and Habitat***: Habitat: nearshore, pocket estuary, connectivity; Fish: abundance, distribution, size structure, rearing, periodicity.								
Species and Life Stages	***Chinook, Pink, Chum:*** estuary rearing and emigration, nearshore rearing and emigration.								
Reaches and Spatial extent	Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: Studies of fish use in pocket estuaries throughout the Whidbey Basin began in 2002. At first, research was limited to understanding juvenile Chinook Salmon use of sites within Skagit Bay (Beamer et al. 2003). In 2004, studies were expanded to sites throughout the Whidbey Basin, Fidalgo Bay and Samish Bay via a cooperative effort that was partially funded by the Northwest Straits Commission1. The focus of the expanded research is to understand landscape scale patterns of fish usage including what species and life history types use these systems, how connectivity or position within the larger landscape affects this use, and how patterns of use can relate to protection and restoration of these systems. Use of Island County WSU Beach Watchers volunteers helped expand this research effort from 2005 through 2007 and included sampling in Harrington Lagoon. The focus of this report is on fish abundance and size in Harrington Lagoon during 2006, a similar report using 2005 data was published in June 2006 (Beamer et al. 2006). Although we primarily report only fish abundance and size in this one system, we will also briefly consider results within the context of the larger Whidbey Basin study of pocket estuaries. The results of this study can be used to inform local citizens about fish populations currently using the Harrington Lagoon area. The results are useful to Island County, and other agencies and groups interested in Puget Sound salmon recovery and nearshore ecology.

Kagley et al. (2007) (Unique Identifier: 279)

Reference	Kagley, A., T. Zackey, K. Fresh, and E. Beamer. 2007. Juvenile salmon and nearshore fish use in shoreline and lagoon habitat associated with Elger Bay, 2005-2007.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** large wood, substrate and sediment. ***Water Quality and Productivity:*** salinity, temperature, dissolved oxygen. ***Land Use and Cover:*** forestry, floodplain. ***Fish and Habitat:*** Habitat: pocket estuary, nearshore; Fish: abundance, distribution, growth, life history, size structure, periodicity, hatchery; Monitoring: abundance, water quality.									
Species and Life Stages	***Chum, Chinook, Pink, Coho:*** nearshore rearing and emigration. ***Other species (Shiner Perch, Pacific Staghorn Sculpin, Sandlance, etc.):*** not specified.									
Reaches and Spatial extent	Skagit Bay, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: Studies of fish use in Puget Sound pocket estuaries began in 2002. At first, research was limited to understanding juvenile Chinook Salmon use of sites within Skagit Bay (Beamer et al. 2003). In 2004, the study expanded to sites throughout the Whidbey Basin, Fidalgo Bay and Samish Bay via a cooperative effort that was partially funded by the Northwest Straits Commission. The focus of this expanded research is to understand landscape scale patterns of fish usage including what species and life history types use these systems, how connectivity or position within the larger landscape affects fish use, and how patterns of fish use relate to protection and restoration of these areas. This expanded research effort has continued throughout 2007 and included sampling in Elger Bay with the help of Island County WSU Beach Watchers. The focus of this report is on fish abundance and size in Elger Bay from 2005 through 2007. Although we primarily report only fish abundance and fish size in this one system, we also briefly consider results within the context of the larger study of pocket estuaries.

Kendell et al. (2020) (Unique Identifier: 068)

Reference	Kendall, N., M. Ramirez, and N. Hamel. Puget Sound Chinook salmon vital sign reporting. Prepared for the Puget Sound Partnership, Olympia, Washington.										
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No	
Topics and Keywords	***Fish and Habitat:*** Fish: status and trends, abundance.										
Species and Life Stages	***Chinook:*** not specified.										
Reaches and Spatial extent	Puget Sound.										
Linkages to Hydroelectric Operations	NA										

Summary: This proceedings document presents the results of an analysis of the status of the Puget Sound Chinook population as it relates to the Vital Sign study. The target of the project is to *"Stop the overall decline and start seeing improvements in wild Chinook abundance in 2-4 populations in each biogeographic region by 2020."* Data on natural-origin Puget Sound Chinook abundance from 1999-2019 was compiled and analyzed to determine the trend over time. Results showed that 11 of the 22 populations were increasing, and 11 of the populations were decreasing over time. Although there was a slight increasing trend, populations were still far from the recovery targets and were, therefore, given a progress conclusion of *"not improving, no change."*

Keystone Ecological (2009) (Unique Identifier: 281)

Reference	Keystone Ecological LLC. 2009. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Cornet Bay, 2009. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Land Use and Cover:*** land cover. ***Water Quality and Productivity:*** temperature, salinity, dissolved oxygen. ***Fish and Habitat:*** Habitat: nearshore; Fish: abundance, size structure, movement; Monitoring: abundance, water quality.									
Species and Life Stages	***Chinook, Chum:*** nearshore rearing and emigration. ***Other species (Sculpins, Flatfish, Gunnels):*** not specified.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Island County Beach Watchers are working collaboratively with the Island County Marine Resources Committee and Washington State Parks. Collecting data about juvenile salmonid use of the nearshore at Cornet Bay is a part of the characterization process of the bay prior to nearshore habitat enhancement projects that are planned at this location. The focus of this report is on fish abundance and size in Cornet Bay in 2009. This report is meant to inform local citizens and Cornet Bay project partners about fish populations currently using the Cornet Bay area. The use of beach seining techniques to understand juvenile salmon utilization of coastal lagoon habitats and adjacent beach sites started in Island County in 2002 with research focused on juvenile Chinook at sites in Skagit Bay (Beamer et al. 2003). Since then a number of studies have utilized this technique to assess nearshore fish use throughout Island County. The Beach Watchers have been a part of these research efforts since 2005.

Kiffney et al. (2006) (Unique Identifier: 070)

Reference	Kiffney, P. M., C. M. Greene, J. E. Hall, and J. R. Davies. 2006. Tributary streams create spatial discontinuities in habitat, biological productivity, and diversity in mainstem rivers. Canadian Journal of Fisheries and Aquatic Sciences 63:2518-2530.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, large wood. ***Water Quality and Productivity:*** primary productivity, secondary productivity, nutrients. ***Land Use and Cover:*** forestry. ***Modeling Tools:*** habitat. ***Fish and Habitat:*** Habitat: riparian, instream flow; Fish: abundance, size structure, density dependence; Monitoring: abundance.								
Species and Life Stages	***Salmonids, Bull Trout, Other Species (Sculpin):*** not specified.								
Reaches and Spatial extent	Finney Creek.								
Linkages to Hydroelectric Operations	NA								

Abstract: Lotic ecosystems are made up of numerous tributary streams forming a complex branching network. The point where smaller tributaries flow into larger rivers, or tributary junctions, may be sites in the network where spatial discontinuities or "hot spots" are created and maintained, because small streams funnel important materials captured from the surrounding landscape and carry them by gravity downstream. We hypothesized that habitat complexity, environmental productivity, and abundance of primary consumers and predators peak in mainstem rivers at or downstream of tributary junctions. We conducted surveys in three river basins and 13 reaches to examine interdependence between tributary streams and the larger rivers they enter. Wood abundance and volume, variability in median substrate size (i.e., substrate heterogeneity), concentrations of nitrogen and phosphorus in water, algal biomass, and abundance of consumers and predators peaked with a higher frequency at or downstream of tributary junctions. For several variables, the size of the tributary relative to the main stem contributed to the strength of tributary affect. These findings suggest that some tributary streams have fundamental effects on the larger rivers they enter. We argue that maintaining the integrity of connections among and between ecosystems is essential for promoting habitat complexity and community structure within river networks.

Kinsel et al. (2008) (Unique Identifier: 146)

Reference	Kinsel, C., M. Zimmerman, L. Kishimoto, and P. Topping. 2008. Annual report: 2007 Skagit River salmon production evaluation. Report prepared by Washington Department Fish and Wildlife, Olympia, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** turbidity, temperature. ***Fish and Habitat:*** Habitat: instream flow; Fish: abundance, density dependence, survival, life history, size structure, periodicity, status and trends, hatchery, movement, condition; Monitoring: abundance, biotelemetry.								
Species and Life Stages	***Chinook, Coho, Sockeye:*** incubation-outmigration, migration. ***steelhead:*** full life cycle. ***Pink, Chum:*** rearing-outmigration. ***Other species (Cutthroat, Trout, Dolly Varden/Bull Trout):*** full life cycle.								
Reaches and Spatial extent	Skagit Watershed.								
Linkages to Hydroelectric Operations	NA								

Abstract: The Skagit River juvenile salmon trapping project, initiated by the Washington Department of Fish and Wildlife in 1990, began with the goal of estimating natural Coho smolt production and was later expanded to estimate production of natural-origin juvenile Chinook and to enumerate other juvenile salmonid migrants. Results from this project contribute to the fishery management of Coho and provide information on the recovery status of Puget Sound Chinook and steelhead, both listed under the Endangered Species Act.

Scoop and screw traps operated on the Skagit River are located 17-miles upstream of the river mouth. Traps were operated from January 19 through July 25, 2007. The study objectives were to estimate migration abundance and associated confidence intervals for sub-yearling Chinook and yearling Coho, investigate the relationship between environmental variables and inter-annual variation in egg-to-migrant survival of sub-yearling Chinook, and document juveniles of additional salmonid species migrating from the Skagit River.

Chinook production estimates were made using a stratified mark-recapture approach. Coho production estimates were made using a pooled mark-recapture approach. For each time strata, juvenile migration and associated variance is based on a Petersen estimator calculated from the number of fish that were marked and released, the number of unmarked fish that were recaptured, and the number of marked fish that were recaptured. Catches of unmarked fish included estimated catch during trap outage periods.

An estimated 2.2 million ± 0.27 million (95 percent C.I.) natural-origin sub-yearling Chinook migrated during the trapping period, with an additional 4,661 Chinook estimated to have migrated prior to the start of trap operation. Egg-to-migrant survival of the 2006 brood of Skagit River Chinook was estimated to be 3.9 percent.

The 2007 outmigration of juvenile salmonids included 747,490 ±78,324 (95 percent C.I.) natural-origin Coho smolts as well as catches of 137,829 natural-origin Chum fry, 3 Pink fry, 925 natural-origin steelhead smolts, and 232 Dolly Varden/Bull Trout smolts. Catches also included Chinook yearlings, Coho fry, Sockeye fry and smolts, steelhead adults, Cutthroat smolts and adults, and trout fry and parr.

Egg-to-migrant survival of Chinook was among the three lowest survivals observed in eighteen years of data compiled from the Skagit River. This trend was attributed to high flows during vulnerable egg incubation periods in fall 2006.

Klochak et al. (1999) (Unique Identifier: 282)

Reference	Klochak, J., C. Tanner, and P. Cagney. 1999. Deepwater slough restoration project monitoring plan. Report prepared for Deepwater Slough Restoration Monitoring Team.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: barriers, restoration; Monitoring: restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: This plan presents all tasks required to adequately monitor the success of the Deepwater Slough Restoration Project. The plan is based on a conceptual model linking watershed processes to habitat conditions and functions, and biological responses to those functions. Thom and Wellman (1996) suggest using such an ecosystem model to identify linkages between controlling factors, structure and function when developing a restoration monitoring program. We use the general watershed model developed by the Skagit Watershed Council (1998) to link controls, processes, and habitat conditions and then focus the model on our project area.

We link the restoration of disrupted watershed processes to the restoration of habitat conditions, and then to ensuing biological responses. We describe processes and conditions as they historically existed and currently exist at the Deepwater Slough Restoration Project site. We develop a restoration goal and objectives, and describe restoration actions with which we hope to meet them. Finally, we monitor restored processes, habitat conditions, and biological responses in order to determine the success of the project and to recommend adaptive management measures.

Lautz et al. (2004) (Unique Identifier: 398)

Reference	Lautz, K., R. W. Schanz, and J. D. Park. 2004. Site and reach assessment evaluation of treatment alternatives SR 530/Sauk River chronic environmental deficiency site. Report prepared by Washington State Department of Transportation.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow, restoration. ***Geomorphology and Landforms***: history, substrate and sediment, scour. ***Land Use and Cover:*** roads.								
Species and Life Stages	NA (salmonids listed as threatened in the defined area).								
Reaches and Spatial extent	Sauk River.								
Linkages to Hydroelectric Operations	NA								

Abstract: This report presents a Preliminary Site and Reach Assessment conducted for a Chronic Environmental Deficiency (CED) site located along the right bank of the Sauk River on SR 530 between Darrington and Rockport. This Site and Reach Assessment is prepared as per Chapters 2-5 of the Integrated Streambank Protection Guidelines (ISPG), and to present technical design recommendations. The ISPG is published by the Washington State Aquatic Habitat Guidelines Program (2003). This is a consortium of public agencies including the Washington State Department of Fish and Wildlife, the Washington State Department of Ecology, the Washington State Department of Transportation, U.S. Army Corps of Engineers, and the U. S. Fish and Wildlife Service. The ISPG site/reach assessment is similar to the Level 1 geomorphic assessment described in Hydraulic Engineering Circular (HEC) 20 (Federal Highway Administration, 1995), and includes a much more in depth consideration of aquatic habitat impacts (chapter 4). This report includes both site and reach assessments with a focus on geomorphic and habitat implications.

Lawrence (2020) (Unique Identifier: 399)

Reference	Lawrence, E. J. 2020. Incorporating climate change predictions in ecological risk assessment: a bayesian network relative risk model for Chinook salmon in the Skagit River watershed. Master's thesis. Western Washington University, Bellingham.									
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Modeling tools:*** climate change***. Water Quality and Productivity:*** temperature, dissolved oxygen, contaminants. ***Fish and Habitat:*** Habitat: climate change; Fish: abundance. ***Land Use and Cover:*** land cover.									
Species and Life Stages	***Chinook:*** full life cycle.									
Reaches and Spatial extent	Skagit watershed (mostly the lower portions of the lower Skagit watershed) and Samish watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: Climate change is expected to have widespread impacts on future ecosystem services in the Puget Sound and around the world. It is important that climate change be included in ecological risk assessment so that changing climate variables and potential interactive effects with chemical stressors can be taken into account. In this research, I focused on the question of how water temperature changes generated by climate change interact with organophosphate pesticide toxicity to affect Chinook Salmon (Oncorhynchus tshawytscha) population size in the Skagit River, WA. To answer this question, I conducted an ecological risk assessment using the Bayesian network relative risk model (BN-RRM). It is a quantitative, probability-based approach that calculates complex relationships between ecological variables in a cause-and-effect framework to provide estimates of risk to valued receptors (endpoints). I used region and season specific measurement data for water temperature, dissolved oxygen, chlorpyrifos concentration, and diazinon concentration as the model input. Climate predictions were based on model output between the years 2071 and 2100 from an ensemble of global climate models (GCMs) selected from the Fifth Coupled Model Intercomparison Project (CMIP5). The probability of Chinook Salmon population decline, before climate change predictions were taken into account, ranged between 77.1 percent and 64.0 percent depending on region and season. I found climate change caused changes in water temperature influenced risk in different ways depending on the region and season. The probability of Chinook population decline increased by up to 4.2 percent in different regions and seasons. I used sensitivity analysis of the BN-RRM to analyze which stressors had the most influence on Chinook Salmon population size. I found that the environmental stressors of water temperature and dissolved oxygen had the most influence, which suggests habitat remediation may be an effective strategy for addressing risk to Chinook Salmon in the Skagit River. This research demonstrates that climate change scenarios can be successfully incorporated into ecological risk assessment using the BN-RRM. This approach can be easily adapted to other watersheds and allows for the inclusion of additional stressors and/or endpoints.

Legg and Olson (2015) (Unique Identifier: 363)

Reference	Legg, N. T., and P. L. Olson. 2015. Screening tools for identifying migrating stream channels in western Washington: geospatial data layers and visual assessments. Washington State Department of Ecology Publication 15-06-003.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** channel migration, scour, sinuosity. ***Fish and Habitat:*** Habitat: instream flow.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound, Western Washington.									
Linkages to Hydroelectric Operations	NA									

Abstract: Lateral movement, or *migration*, of stream channels can threaten infrastructure and communities, while at the same time sustain floodplain health. Both the costs to human communities and the ecological benefits of migrating streams call for the identification and incorporation of channel migration into management decisions. Yet, few tools exist to rapidly identify migrating streams at landscape scales where spatial variability in channel migration is great. The Washington State Department of Ecology (Ecology) has developed two complementary tools for quickly assessing channel migration potential.

The first tool is a geographical information systems (GIS) layer called the Channel Migration Potential (CHAMP) layer. It contains stream networks of Western Washington (and much of Western Oregon) with associated data and information important for assessing channel migration activity. It also features information on channel characteristics such as stream flow and physical dimensions. This data layer's main feature is a classification of channel migration potential based on channel confinement and erosion potential. The layer was derived from existing statewide geospatial datasets and classified according to channel migration measurements by the High Resolution Change Detection (HRCD) project for the Puget Sound Region (Washington Department of Fish and Wildlife (WDFW), 2014). While the layer identifies the potential for channel migration, it does not *predict* channel migration rates. Thus, this data layer should be used to screen and prioritize stream reaches for further channel migration evaluation.

The second tool describes channel features that are diagnostic of channel migration activity and readily observed in aerial photographs. Thus, visual assessment can help refine the initial broad-scale assessments of channel migration potential using the CHAMP data layer. Together, these tools help plan and prioritize floodplain management actions such as Channel Migration Zone mapping, erosion risk reduction, and floodplain restoration.

Lisi et al. (2022) (Unique Identifier: 494)

Reference	Lisi, P., J. Anderson, T. Zackey, M. Pouley, E. Seay, J. Keith, K. Nelson, J. Griffith, K. Konoski, C. Scofield, A. Voloshin, A. Berger, M. McHenry, M. Elofson, M. Liermann, G. Pess, P. Topping, C. Kinsel, M. Klungle, A. Lindquist, and J. Weinheimer. 2022. Synchrony of freshwater and marine survival among Chinook salmon populations in Puget Sound. Report submitted to Puget Sound Partnership.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: abundance, life history, status and trends. ***Modeling tools:*** adult returns, juvenile production.									
Species and Life Stages	***Chinook:*** outmigration, migration.									
Reaches and Spatial extent	Puget Sound (major rivers including Skagit, Stillaguamish, Snohomish, Nisqually, Cedar, Bear, Dungeness, Skykomish, Green, Puyallup rivers).									
Linkages to Hydroelectric Operations	NA									

Abstract: Juvenile salmon smolt outmigration projects provide useful information on population abundance, productivity, and life-history diversity relevant to salmon conservation and management. Juvenile salmon outmigration studies continue in most major Puget Sound rivers, but projects are often funded, evaluated, and described individually which undermines a regional level understanding of population status and coherence among populations. We reviewed methodology with project managers and compiled time-series of juvenile and adult Chinook abundance from eleven long-term (12-25 years) smolt outmigration projects from around Puget Sound. We calculated juveniles per spawner (JPS) as a measure of freshwater productivity and smolt to adult return rates (SAR) as a measure of marine productivity. Analysis revealed strong evidence for synchrony among populations at both life stages, as models including a single shared trend performed well for JPS and SAR. The dominant trend for JPS was a long term, gradual decline from brood years 2005 – 2019, bookending a sharp increase in brood years 2010 - 2014. The dominant trend for SAR was a long-term increase from brood years 2000 – 2015, with a marked increase from 2013 – 2015. Evidence for asynchronous trends were also found in both productivity measures and can be viewed an important part of sustaining the broader portfolio of Chinook Salmon survival in freshwater and marine environments. The results indicate some positive signs of resilience, as both JPS and SAR showed rapid increases for some populations, suggesting Chinook Salmon retain the ability to take advantage of favorable environmental conditions. From a monitoring standpoint, the temporal agreement in production metrics gives us confidence about the assumptions regarding different project trapping and expansion techniques for estimating juvenile and adult Chinook Salmon abundance. Individual juvenile monitoring projects in large Puget Sound rivers are not duplicative, but rather complementary. The shared trends help us understand large scale forces affecting Puget Sound Chinook Salmon, while also appreciating differences in how populations respond to them. The longevity of this monitoring effort could be appropriately used as a "vital sign" indicator of ecosystem health for marine and freshwater environments. Our results help define the range of contemporary survival values for Puget Sound Chinook Salmon; we suggest that management strategies robust to periods of both high and low survival will confer resilience in a changing climate. We recommend that maintaining and promoting habitat diversity enhances life-history diversity, allowing for interaction between

broad-scale and local effects, fostering regional stability and long-term sustainability of populations. Finally, as a result of unexplained fluctuations in key survival rates, we urge policy makers to acknowledge and embrace uncertainty, in some cases volatility, when managing hatcheries, harvest, habitat protection and restoration.

Lyons and Ramsey (2013) (Unique Identifier: 339)

Reference	Lyons, B., and M. Ramsey. 2013. Program report: summary and synthesis of comments on a study of the "Biological and Physical Effects of 'Fish-Friendly' Tide Gates." Washington Department of Fish and Wildlife, Estuary and Salmon Restoration Program. March 2013.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: barrier, connectivity, data gaps; Monitoring: restoration. ***Geomorphology and Landforms:*** estuarine habitats and landforms.									
Species and Life Stages	***Chinook:*** outmigration.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: This paper summarizes and translates, into less technical language, a scientific investigation of the biological and physical effects of 'fish-friendly' tide gates in the Pacific Northwest. This work was commissioned in 2009 by the Estuary and Salmon Restoration Program (ESRP) and was completed by NOAA's Fisheries Science Center through an Interagency Agreement (PRISM Contract 09-1777) with the Recreation and Conservation Office, acting as ESRP's fiscal sponsor. The final product of this agreement was a technical report which is provided in its entirety in Appendix B. This investigation was a first step toward a much needed comprehensive evaluation of the effectiveness of tide gates in providing benefits to fish. We expect the results of this study will be of interest to the broader restoration community.

During review and early circulation of this report a number of important questions were raised provoking a useful dialogue about the current state of knowledge and remaining data gaps. Much of this dialogue is preserved in Appendix A as a technical Question and Answer session between authors, reviewers and ESRP staff. We have provided this information to help answer common questions, to clarify some uncertainties presented in the report and to identify priority data gaps need to better inform policy and restoration practice.

MacLennan (2013) (Unique Identifier: 076)

Reference	MacLennan, A. J., J. W. Johannessen, S. A. Williams, W. J. Gerstel, J. F. Waggoner, and A. Bailey. 2013. Feeder bluff mapping of Puget Sound. Report prepared for Washington Department of Ecology and Washington Department of Fish and Wildlife.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: nearshore habitats and landforms, sediment transport and supply. ***Fish and Habitat***: Monitoring: habitat									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: The term "feeder bluff" is used in the Puget Sound region to describe bluffs that provide a significant volume of sediment to the beach. Beaches and spits, sustained by the ongoing supply of sand and gravel from feeder bluffs, are key elements in the Puget Sound nearshore ecosystem. The objective of this project was to produce comprehensive mapping of Puget Sound feeder bluffs and related coastal landforms suitable for guiding improved shoreline management. The project consisted of three major tasks:

- Develop a detailed Quality Assurance Project plan (QAPP)
- Compile and assess all existing feeder bluff mapping datasets
- Complete feeder bluff mapping Sound-wide and compile the Sound-wide data set

Feeder bluff mapping differs from coastal landform mapping, such as the shoreline classification scheme or typology (Shipman 2008) applied in the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) Change Analysis, in that feeder bluffs are definitively linked with a physical process—the delivery of new beach-quality sediment to the littoral system. Feeder bluff mapping follows some of the general geomorphic principles of net shore-drift (drift cell) mapping completed in Washington State (Schwartz et al. 1991, Johannessen 1993).

In recent years, different mapping efforts conducted in the region have attempted to integrate general principles and concepts of coastal geomorphology. Coastal Geologic Services (CGS) developed a mapping method, in collaboration with a technical advisory group consisting of local coastal processes experts, which had been applied across 11 counties and over 1,150 miles of Puget Sound shore (Johannessen and Chase 2005, Johannessen 2010). However, neither this method nor any other which sufficiently addressed these principles had been applied across Puget Sound. Several previous Sound-wide mapping efforts fell short either due to coarse resolution, frequent errors, or by being focused only on the mapping of coastal landforms rather than morphology and processes.

The CGS team compiled 26 data sets to characterize and evaluate how feeder bluffs or similar landforms were mapped (Table 1). Data sets had been produced to address various objectives by a wide range of authors. At least eleven data sets originally had been created by CGS, spanning a

total of 1,150 miles with individual mapping areas ranging from tens to hundreds of miles. Data sets by other authors covered a similar range of areas from tens of miles to the entire Puget Sound. Many of the data sets had been compiled for specific objectives that did not directly align with the objectives of feeder bluff mapping. The majority of the data sets had been created to improve aspects of shoreline management, such as habitat protection, or to aid in the Inventory and Characterization phase of local Shoreline Master Programs updates.

The objective of the data assessment portion of this study was to measure the relative quality of data, identify consistencies and differences among the data sets, and identify the best quality data for inclusion (with minor revisions if necessary) into the interim geodatabase of existing feeder bluff mapping. Assessment criteria were developed as part of the Quality Assurance Project Plan (QAPP) to aid in the screening process and to establish standards that all data included in the (GIS) geodatabase would meet (Figure 1). The assessment criteria were designed to function as filters so once a data set did not meet a fundamental criterion, it would no longer be eligible to be included in the geodatabase. Data sets were also evaluated for their potential utility in supporting new remote mapping of feeder bluffs and related shoreforms as ancillary or supporting data sets. Each data set was evaluated by review in ArcGIS and ArcCatalog and by referencing text reports when available. The characteristics of each data set associated with each assessment criterion were recorded in a spreadsheet and included data availability, format (digital or paper), feature type (point, line, or polygon), amount of adaptation required to incorporate the data into the project geodatabase, spatial coverage, feature classification (e.g., landslides or contiguous geomorphic shoreforms), mapping resolution (scale and minimum mapping unit), and methods (field or remote); as well as whether remote mapping efforts were verified on-the-ground (“ground-truthing”), and whether or not the data set would be useful for remote mapping. Once the spreadsheet was fully populated, each data set was systematically evaluated for inclusion using the criteria shown in Figure 1. The rationale behind each element included in the criteria is shown in Table 2.

Ten existing feeder bluff mapping data sets covering approximately 700 miles of shore met the assessment criteria for inclusion into the Sound-wide data set (Table 4, Figure 5). These data sets formed the foundation for the final feeder bluff mapping geodatabase. CGS had created each of the accepted data sets using mapping that was largely field-based with a consistent resolution and had applied consistent criteria that were also utilized in new data collection. Figure 5 shows the spatial extent of the existing data sets that were accepted for integration into the Sound-wide geodatabase of feeder bluff mapping.

After data were assessed and compiled into a single coverage, the data were loaded into a Geographic Information System (GIS) along with shores in which No Appreciable Drift occurs (commonly referred to as NAD shores, an element of the net shore-drift data set). The remaining unmapped shores determined the areas in which new mapping would focus. A review of conditions throughout the shore to be mapped helped classify areas in which remote mapping would be as accurate as field mapping and potentially cost effective. Most of the remaining portions of the study area within drift cells (575 miles) were mapped using the field-based approach. This is the same approach applied by CGS across approximately half of the Puget Sound region shore. Remote mapping was conducted along approximately 22 percent of the Puget Sound shore that remained to be mapped. The remote mapping methods adhered to the same mapping criteria as field mapping, following investigation which showed this to be possible based on the quality of aerial photography and available data. Detailed methods are described in the *Methods* section of the report.

All data were compiled and analyzed to enhance understanding of the occurrence of feeder bluffs and other geomorphic shoretypes throughout the Puget Sound region. Shoretype data were analyzed Sound-wide, within each drift cell, and within each county, to support county-wide shoreline management. A set of 1:100,000 scale maps of the final mapping product are in the attached map folio along with net shore-drift mapping which was corrected and updated in this study. The project geodatabase contains both all shoretype and net shore-drift data mapping reported in results.

Of Puget Sound's 2,459 miles of shoreline, sediment delivery and transport processes occur within the 1,383 miles in which net shore-drift cells are mapped. Feeder bluffs were mapped along more than 365 miles of shore (15 percent), with an additional 51 miles of feeder bluff exceptional shore (2 percent, Table 10, Figure 11). Feeder bluff exceptional units deliver greater quantities of sediment to the nearshore and deliver it more frequently than do typical feeder bluffs. In addition eighteen percent of shore was armored. Although mapping of historic conditions was not a primary objective of this project, at least 32 percent of the modified shores were likely to have been feeder bluffs prior to modification. Accretion shoreforms and transport zones were slightly less prevalent than feeder bluffs and represented comparable portions of the larger region.

Outside of net shore-drift cells, 1,076.5 miles of Puget Sound shoreline are mapped as areas with no appreciable drift (NAD). These shores account for 44 percent of the region's shore (Table 10, Figure 11). The net shore drift mapping was updated as part of this effort. Net shore-drift updates addressed the spatial extent of drift in several locations throughout the region (based on field observations) as well as additional attribution of why there is an absence of littoral drift, due to bedrock geology, low wave energy, being part of a large river delta or due to highly altered conditions (such as fill and armor).

Data assessment, compilation, and new data collection have resulted in a high-quality, comprehensive, geomorphic data set spanning the Puget Sound region. This data set documents regional variability in nearshore geomorphic conditions, forms a foundation for future coastal geomorphic research, and will enhance greater understanding of geomorphic processes in the region over time. Ideally, these data will aid in the preservation of feeder bluff functions in the Puget Sound, particularly in shoreline jurisdictions that mandate feeder bluff protection but that did not previously have spatially-explicit documentation of where feeder bluffs occur. These data can also be paired with habitat data to enhance nearshore ecosystem management and salmon recovery planning.

Mantua et al. (2009) (Unique Identifier: 077)

Reference	Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102:187–223.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: survival, climate change; Habitat: freshwater, instream flow, limiting factors, climate change. ***Water Quality and Productivity***: temperature. ***Modeling Tools***: hydrology, climate change.									
Species and Life Stages	***All anadromous species***: not specified.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: This study evaluates the sensitivity of Washington State's freshwater habitat of Pacific salmon (*Oncorhynchus* spp.) to climate change. Our analysis focuses on summertime stream temperatures, seasonal low flows, and changes in peak and base flows because these physical factors are likely to be key pressure points for many of Washington's salmon populations. Weekly summertime water temperatures and extreme daily high and low streamflows are evaluated under multimodel composites for A1B and B1 greenhouse gas emissions scenarios. Simulations predict rising water temperatures will thermally stress salmon throughout Washington's watersheds, becoming increasingly severe later in the twenty-first century. Streamflow simulations predict that basins strongly influenced by transient runoff (a mix of direct runoff from cool-season rainfall and springtime snowmelt) are most sensitive to climate change. By the 2080s, hydrologic simulations predict a complete loss of Washington's snowmelt dominant basins, and only about ten transient basins remaining in the north Cascades. Historically transient runoff watersheds will shift towards rainfall dominant behavior, undergoing more severe summer low flow periods and more frequent days with intense winter flooding. While cool-season stream temperature changes and impacts on salmon are not assessed in this study, it is possible that climate- induced warming in winter and spring will benefit parts of the freshwater life-cycle of some salmon populations enough to increase their reproductive success (or overall fitness). However, the combined effects of warming summertime stream temperatures and altered streamflows will likely reduce the reproductive success for many Washington salmon populations, with impacts varying for different life history types and watershed-types. Diminishing streamflows and higher stream temperatures in summer will be stressful for stream-type salmon populations that have freshwater rearing periods in summer. Increased winter flooding in transient runoff watersheds will likely reduce the egg-to-fry survival rates for ocean-type and stream-type salmon.

Marks et al. (2004) (Unique Identifier: 284)

Reference	Marks, D., M. Olis, and K. Wyman. 2004. An evaluation of the Skagit basin coho SSHIAP/LFA database and an assessment of the DNR last fish water type map. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** habitat, data gaps. ***Fish and Habitat:*** Habitat: barriers, data gaps; Fish: distribution; Monitoring: abundance.									
Species and Life Stages	***Coho:*** not specified.									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: Recent changes to Forest Practices Regulations (Forests and Fish Report 1997) spawned out of concerns of inadequate protections to fish resources and pending Endangered Species Act (ESA) listings of local salmon stocks have led to the development of a potential predictive fish habitat model for the purpose of identifying and classifying all fish-bearing and end of fish habitat waters in western Washington. The "model," a GIS-based logistic regression model, was to be developed using existing data (10m digital elevation network, precipitation, gradient, and basin size) coupled with survey-verified end of fish distribution points scattered throughout the western portion of the State. The model was given a performance target for accuracy of 95 percent with± 5 percent likelihood – "*that the line demarcating fish and non-fish habitat waters will be drawn so as to be equally likely to be over and under inclusive… .*" In preparation for an evaluation of the new fish habitat model, the Skagit River System Cooperative (SRSC) Forest and Fish program set out to determine the accuracy of the existing Coho Salmon upper extent distribution portion of the Salmon and steelhead Habitat Inventory and Assessment Program (SSHIAP) database for the Skagit basin and compare those results with the preliminary fish habitat model output maps.

The SSHIAP database is a spatial data system that characterizes salmonid habitat conditions and distribution of the salmonid stocks in Washington. SSHIAP is a co-management-based dataset operated jointly by the Washington Department of Fish and Wildlife (WDFW) and the Northwest Indian Fisheries Commission (NWIFC) that covers WRIAs (Water Resource Inventory Areas) 1-62. In WRIAs 3 and 4, the salmonid distribution portion of the SSHIAP database was primarily established through the efforts of a technical advisory group (TAG) that convened to provide input to the habitat limiting factors analysis (LFA) that affect the natural production of salmonids. Salmonid distribution is arguably one of the most important outcomes of the LFA.

The goal of our study was to verify and determine the accuracy (ground truth) of the LFA Coho distribution database and to further use the verified data as a base to expand and evaluate the preliminary fish habitat model maps. Our first concern with the proposed fish habitat model was to make certain that the output maps would be inclusive of known fish distribution and designate it as such (i.e., type F), in addition to designating potential or likely "fish habitat" that may or may not have fish present during our "snap-shot" sampling period. Protection of fish and fish habitat is a key goal of the Forests and Fish Report.

Coho Salmon LFA distribution points were used in this investigation for several reasons. It is a large data set in the Skagit basin with 519 points (562 points if you include the Baker River system; not included in our study). Coho typically utilize the furthest upstream reaches compared to the other salmon species; therefore, Coho protection should be inclusive for all salmon species and provide a "conservative" standard for what should be called fish habitat waters. We also have a better understanding of Coho distribution than we do for resident fish species (e.g., cutthroat and rainbow trout, native char, dace, lamprey, and sculpin). In addition, Indian Tribes in the Skagit drainage depend on salmon for both income and their cultural significance; therefore, they place a high priority on their protection and restoration.

Mastin and Kresch (2005) (Unique Identifier: 504)

Reference	Mastin, M. C., and D. L. Kresch. 2005. Verification of 1921 peak discharge at Skagit River near Concrete, Washington, using 2003 peak-discharge data. Scientific Investigations Report 2005-5029. Report prepared by United States Geologic Survey, Reston, Virginia.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow. ***Project operations:*** flow regulation, flood control.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed (particularly near Concrete, WA).									
Linkages to Hydroelectric Operations	***Project operations:*** flow regulation, flood control.									

Abstract: The 1921 peak discharge at Skagit River near Concrete, Washington (U.S. Geological Survey streamflow-gaging station 12194000), was verified using peak-discharge data from the flood of October 21, 2003, the largest flood since 1921. This peak discharge is critical to determining other high discharges at the gaging station and to reliably estimating the 100-year flood, the primary design flood being used in a current flood study of the Skagit River basin.

The four largest annual peak discharges used in the determination of the 100-year flood discharge at Skagit River near Concrete occurred in 1897, 1909, 1917, and 1921. The peak discharge on December 13, 1921, was determined by James E. Stewart of the U.S. Geological Survey using a slope-area measurement and a contracted-opening measurement. An extended stage-discharge rating curve based on the 1921 peak discharge was used to determine the peak discharges of the three other large floods. Any inaccuracy in the 1921 peak discharge also would affect the accuracies of the three other largest peak discharges.

The peak discharge of the 1921 flood was recalculated using the cross sections and high-water marks surveyed after the 1921 flood in conjunction with a new estimate of the channel roughness coefficient (*n* value) based on an *n*-verification analysis of the peak discharge of the October 21, 2003, flood. The *n* value used by Stewart for his slope-area measurement of the 1921 flood was 0.033, and the corresponding calculated peak discharge was 240,000 cubic feet per second (ft3/s). Determination of a single definitive water-surface profile for use in the *n*-verification analysis was precluded because of considerable variation in elevations of surveyed high-water marks from the flood on October 21, 2003. Therefore, *n* values were determined for two separate water-surface profiles thought to bracket a plausible range of water-surface slopes defined by high-water marks. The *n* value determined using the flattest plausible slope was 0.024 and the corresponding recalculated discharge of the 1921 slope-area measurement was 266,000 ft3/s. The *n* value determined using the steepest plausible slope was 0.032 and the corresponding recalculated discharge of the 1921 slope-area measurement was 215,000 ft3/s. The two recalculated discharges were 10.8 percent greater than (flattest slope) and 10.4 percent less than (steepest slope) the 1921 peak discharge of 240,000 ft3/s. The 1921 peak discharge was not revised because the average of the two recalculated discharges (240,500 ft3/s) is only 0.2 percent greater than the 1921 peak discharge.

McBride and Beamer (2010) (Unique Identifier: 285)

<table>
<tr><td>Reference</td><td colspan="9">McBride, A., and E. Beamer. 2010. Feasibility assessment for salt marsh restoration at Camano Island State Park, Whidbey basin. Report prepared for Skagit River System Cooperative, La Conner, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: sediment transport and supply, substrate and sediment, change, estuarine habitats and landforms. Water Quality and Productivity: salinity. Land Use and Cover: banks and shoreline. Modeling Tools: hydrology. Fish and Habitat: <u>Habitat:</u> restoration, pocket estuary, nearshore, connectivity, wetlands; <u>Fish:</u> distribution, movement, periodicity, predation, rearing, density dependence; <u>Monitoring:</u> sediment, genetics, abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum, Coho, Pink, Bull Trout: nearshore rearing and emigration. Other species (Pacific Staghorn Sculpin, Shiner Perch, Three-Spined Sticklebacks, Surf Smelt, Starry Flounder, Arrow Goby): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
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Abstract: The purpose of this Feasibility Assessment is to determine if landscape and land use conditions at Camano Island State Park could support the restoration of a small historic pocket estuary to saltwater and tidal influence while concurrently maintaining the existing land use. This feasibility assessment was initiated to direct Port of Everett mitigation funds toward nearshore restoration that would benefit ESA-listed Chinook Salmon (Oncorynchus tshawytscha) of mixed origin. Camano Island State Park (Camano ISP) is located along Saratoga Passage on Camano Island, Whidbey Basin (Figure 1). The Park was chosen as a potential restoration site because it:

- Is located within an area assumed to be used by mixed juvenile Chinook Salmon stocks;
- Is on a juvenile salmon migration corridor;
- Has likely had historic tidal channel marsh habitat; and
- Has landowners willing to explore the idea of habitat restoration (Washington State Parks).

Efforts are underway throughout Puget Sound to develop and implement actions in the nearshore that will benefit nearshore ecosystems and support salmon recovery efforts. Skagit Bay research since 2002 shows that wild fry migrant juvenile Chinook Salmon extensively use non-natal pocket estuaries (Beamer et al. 2003). Non-natal pocket estuaries are small estuaries within the landscape that are not associated with salmon-bearing watersheds. Chinook Salmon utilize pocket estuaries during the early period of nearshore rearing (Beamer et al. 2003 & 2006). This use of pocket estuaries allows them to grow faster and avoid predation by other fish (Beamer et al. 2003 Figure 1. Location map. 2 & 2005). Pocket estuaries are also important for maintaining the diversity of Chinook Salmon life history strategies and for partially relieving overcrowding at natal river estuaries (Beamer et al. 2005). Human impacts to these habitats region-wide have resulted in fewer, smaller, and moredispersed pocket estuaries than historically (Beamer et al. 2005 & 2006, McBride et al. 2009). Pocket estuary restoration is important for Puget Sound Chinook Salmon population recovery. This feasibility assessment is one part of the regional efforts to restore nearshore habitat for salmon recovery.

Restoration at Camano ISP means possibly excavating and then reconnecting the low marshy areas of the park to tidal inundation from Saratoga Passage. Restoration scenarios, project objectives, and constraints for implementing restoration at the Park were developed by the landowner (Washington State Parks) and Skagit River System Cooperative (SRSC). Successful restoration will:

- Restore landscape processes to the extent possible. This means maximizing tidal range and volume; restoring natural freshwater inflow, fluvial deposition and erosion, and estuarine mixing; and restoring or protecting wave erosion and deposition processes. Process-based restoration provides the greatest likelihood of naturally sustainable habitat restoration.
- Maximize benefits to juvenile Chinook Salmon and other fish.
- Protect existing eelgrass beds and existing forage fish spawning beaches.
- Conserve existing sediment and water quality.
- Maximize the potential for habitat function and sustainability through predicted sea level changes over the next 100 years.
- Preserve Park facilities and operations.
- Place no new long-term or permanent restrictions on boating or fishing.
- Minimize or prevent any new required long-term maintenance of Park facilities after restoration.

This is a technical document to provide landowners, restoration practitioners, and restoration funders with necessary information to make decisions about process-based restoration at Camano ISP. The feasibility assessment will include an assessment of potential fish use for a restored pocket estuary, a determination of how much pocket estuary habitat could be gained (restoration potential), and an analysis of the sustainability of a possible restoration scenario (inlet channel stability).

McBride and Beamer (2010) (Unique Identifier: 286)

Reference	McBride, A., and E. Beamer. 2010. Feasibility assessment for salt marsh restoration at Possession Park, Whidbey basin. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply, substrate and sediment, change, estuarine habitats and landforms. ***Land Use and Cover:*** banks and shoreline. ***Modeling Tools:*** hydrology. ***Fish and Habitat:*** Habitat: restoration, pocket estuary, nearshore, connectivity; Fish: distribution, movement, periodicity, predation, rearing; Monitoring: sediment, genetics, abundance.									
Species and Life Stages	***Chinook, Chum, Coho, Pink, Bull Trout:*** nearshore rearing and emigration. ***Other (Pacific Staghorn Sculpin, Shiner Perch, Three-Spined Sticklebacks, Surf Smelt, Starry Flounder, Arrow Goby):*** not specified.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: Introduction and Objectives: The purpose of this Feasibility Assessment is to determine if landscape and land use conditions at Possession Park could support the restoration of a small historic pocket estuary to saltwater and tidal influence while concurrently maintaining the existing land use. This feasibility assessment was initiated to direct Port of Everett mitigation funds toward nearshore restoration that would benefit ESA-listed Chinook Salmon (*Oncorynchus tshawytscha*) of mixed origin. Possession Park is located at the southern end of Whidbey Basin on south Whidbey Island (Figure 1). Possession Park was chosen as a potential restoration site because it:

- Is located within an area of assumed mixed juvenile Chinook Salmon stock use;
- Is on a juvenile salmon migration corridor;
- Is near the Snohomish River which has source populations of ESA-listed Chinook Salmon;
- Has intact, though isolated, tidal channel marsh habitat; and
- Has landowners willing to explore the idea of habitat restoration (Port of South Whidbey).

Efforts are underway throughout Puget Sound to develop and implement actions in the nearshore that will benefit nearshore ecosystems and support salmon recovery efforts. Skagit Bay research since 2002 shows that wild fry migrant juvenile Chinook Salmon extensively use non-natal pocket estuaries (Beamer et al. 2003). Non-natal pocket estuaries are small estuaries within the landscape that are not associated with salmon-bearing watersheds. Chinook Salmon utilize pocket estuaries during the early period of nearshore rearing (Beamer et al 2003 & 2006). This use of pocket estuaries allows them to grow faster and avoid predation by other fish (Beamer et al. 2003 & 2005). Pocket estuaries are also important for maintaining the diversity of Chinook Salmon life history strategies and Figure 1. The area under consideration for restoration is the wetlands within Possession Park and, as a separate restoration scenario, the wetlands north of and adjacent to the park. The adjacent area is not owned by the park. 1 for partially relieving overcrowding at natal river estuaries (Beamer et al. 2005). Human impacts to these habitats region-wide have resulted in

fewer, smaller, and more-dispersed pocket estuaries than historically (Beamer et al. 2005 & 2006, McBride et al. 2009). Pocket estuary restoration is important for Puget Sound Chinook Salmon population recovery. This feasibility assessment is one part of the regional efforts to restore nearshore habitat for salmon recovery.

Restoration at Possession Park means reconnecting the isolated marsh to tidal inundation from Possession Sound. We examine two scenarios for restoring tidal influence to the marsh: 1) reconnecting only the marsh area within Possession Park; and 2) reconnecting the marsh area within the Park and immediately adjacent to the Park (Figure 1). Restoration scenarios, project objectives, and constraints for implementing restoration at Possession Park were developed by the landowner (Port of South Whidbey) and Skagit River System Cooperative (SRSC). Successful restoration will:

- Restore landscape processes to the extent possible. This means maximizing tidal range and volume; restoring natural freshwater inflow, fluvial deposition and erosion, and estuarine mixing; and restoring or protecting wave erosion and deposition processes. Process-based restoration provides the greatest likelihood of naturally-sustainable habitat restoration.
- Maximize benefits to juvenile Chinook Salmon and other fish.
- Protect existing eelgrass beds and existing forage fish spawning beaches.
- Conserve existing sediment and water quality.
- Maximize the potential for habitat function and sustainability through predicted sea level changes over the next 100 years.
- Preserve Park facilities and operations.
- Place no long-term or permanent restrictions on boating or fishing (including shore casting) that do not already exist.
- Minimize or prevent any new required long-term maintenance of Park facilities after restoration.

This is a technical document to provide landowners, restoration practitioners, and restoration funders with necessary information to make decisions about process-based restoration at Possession Park. The feasibility assessment will include an assessment of potential fish use for a restored pocket estuary, a determination of how much pocket estuary habitat could be gained (restoration potential), and an analysis of the sustainability of the two possible restoration scenarios.

McBride et al. (2006) (Unique Identifier: 287)

Reference	McBride, A., and E. Beamer. 2010. Feasibility assessment for salt marsh restoration at Possession Park, Whidbey basin. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, estuarine habitats and landforms. ***Water Quality and Productivity:*** primary productivity. ***Land Use and Cover:*** banks and shoreline. ***Modeling Tools:*** habitat. ***Fish and Habitat:*** Habitat: nearshore; Fish: movement; Monitoring: habitat.								
Species and Life Stages	***Chinook:*** nearshore rearing and emigration.								
Reaches and Spatial extent	Skagit Bay, Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: Juvenile Chinook Salmon travel through and utilize nearshore habitats as part of their life cycle. An understanding of how Skagit Chinook Salmon utilize nearshore habitats, and how landscape processes and land uses determine and impact nearshore habitats, is necessary for the successful recovery of Skagit Chinook Salmon. A study (Greene et al. 2005) using environmental data and adult returns of wild Skagit Chinook Salmon has shown that factors present during the nearshore life stage (i.e., when juvenile Chinook are present in Skagit Bay and the Puget Sound fjord estuary) significantly influence adult recruitment, further supporting the need to understand the nearshore ecosystem and its role in the recovery of Puget Sound Chinook. Skagit River System Cooperative (SRSC) has begun an inventory and evaluation of nearshore habitats within Skagit Bay, Washington (Figure 1) as part of Skagit Basin wide efforts to protect threatened Skagit Chinook Salmon. This paper outlines nearshore habitat mapping methods to characterize substrate, vegetation, shoreline materials, and shoreline modifications. These data will be utilized to develop a landscape process based nearshore habitat model for estimating habitat potential and predicting the results of habitat and geomorphic process-based restoration efforts. These data will also be linked to fish distribution data to determine biotic response to habitat conditions.

Mickelson et al. (2015) (Unique Identifier: 288)

Reference	Mickelson, E., B. Clifton, N. Kammer, S. Hinton, E. Beamer, R. Henderson, and B. Brown. 2015. South Fork Skagit delta estuarine habitat assessment final report. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration, wetlands, connectivity, capacity, barriers; Monitoring: restoration; Fish: density dependence. ***Land Use and Cover:*** land cover. ***Water Quality and Productivity:*** temperature, salinity, dissolved oxygen. ***Modeling Tools:*** juvenile production. ***Geomorphology and Landforms:*** change, slope.									
Species and Life Stages	***Chinook, Pink, Chum, steelhead:*** outmigration. ***Other Species (Cutthroat Trout, Native Char, Whitefish, Stickleback, Perch, Sculpin, Flounder, Sunfish, Sucker, Lamprey, Peamouth chub):*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The South Fork Skagit River Estuarine Habitat Restoration Assessment is an ongoing habitat evaluation project designed to track and assess progress towards meeting restoration goals. Results from this assessment will be applied towards adaptive management of project sites and towards answering important questions regarding the application of restoration techniques in large river delta settings. Our intent is to utilize these lessons to deepen our understanding of natural process restoration in the South Fork Skagit River delta and similar estuarine environments.

Mickelson (2009) (Unique Identifier: 290)

Reference	Mickelson, E. 2009. Crescent Creek freshwater input analysis. Report prepared for Island County and Washington Department of Fish and Wildlife by Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** hydrology. ***Land Use and Cover:*** land cover. ***Fish and Habitat:*** Habitat: wetlands, data gaps.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit Bay (Crescent Harbor).								
Linkages to Hydroelectric Operations	NA								

Abstract: Urbanization of watersheds in the form of increasing impervious surface area has been shown to result in degradation of downstream aquatic ecosystems (Booth and Jackson 1997). Increases in impervious surface reduce the infiltration capacity of the soil, leading to overland flows more frequently and rapidly than in a system with lower amounts of impervious surface. In combination with the ditches and gutters and the straightening or deepening of natural channels that typically accompany such systems, impervious surfaces serve to increase the rate and volume of stormwater flows to downstream reaches. These changes to the hydrologic flow regime can increase erosion, sediment delivery, and overall rates of disturbance to stream habitat (Booth 2000). Additionally, stormwater flows over impervious surfaces entrain pollutants deposited on impervious surfaces and transport these pollutants to stream systems.

Analysis of existing and potential habitat conditions is an important step in planning habitat restoration projects. Changes to stream habitat and runoff conditions are an important component of this process. Therefore, this study assessed potential changes to runoff conditions resulting from urbanization of the Crescent Creek watershed. This work is intended to supplement and support work that has already taken place to develop the Crescent Harbor Salt Marsh Restoration Project. Located on NAS Whidbey Island property near Oak Harbor, the restoration project will restore tidal inundation and fish access to approximately 206 acres of salt marsh habitat on Whidbey Island. The Crescent Harbor Salt Marsh restoration project has been identified in the Skagit Chinook recovery plan, and will benefit all six stocks of wild Skagit Chinook Salmon as well as other native Puget Sound salmonids, forage fish, and wildlife species.

Once Crescent Harbor Salt Marsh has been reconnected to Crescent Bay, Crescent Creek may potentially offer suitable spawning habitat for Coho Salmon (based on field observations of the existing stream channel; no historic data are known to exist). The freshwater wetland buffering Crescent Creek just above the connection with the Crescent Harbor Salt Marsh has been identified as a possible site for future restoration work (personal communication, John Phillips, NAS Whidbey Environmental Affairs). In addition to the potential spawning habitat benefits, this wetland serves to modulate storm flows reaching the salt marsh and surrounding landscape. The ditching of Crescent Creek has likely reduced the ability of this wetland area to buffer flows.

For this project, Island Salmon Recovery Program Capital Project Development funds were used to conduct a GIS-based analysis of current and future impervious surface and freshwater volumes

reaching the Crescent Harbor Salt Marsh via Crescent Creek, a ditched seasonal stream that enters the salt marsh at its northwest edge (Figure 1). Estimates of current and future impervious surface and freshwater inputs from 10-, 50-, and 100- year storm events will serve as an initial step in assessing the feasibility of potential future restoration projects associated with the Crescent Harbor Salt Marsh/ Crescent Creek complex. Additionally, current freshwater contribution for storm events will be used as inputs into a regional hydrodynamic model that has been developed by the Battelle Memorial Institute/ Pacific Northwest National Laboratory (PNNL). This model will be used to assess the impacts of changes to the original Crescent Harbor Salt Marsh restoration project design (PWA 2003), and results will be presented to project stakeholders.

Mitchell et al. (2005) (Unique Identifier: 088)

Reference	Mitchell, T. A., K. J. R. Mitchell, R. LovellFord, and L. Klein. 2005. Fornsby Creek project: self-regulating tide gates and estuary restoration. Proceedings of the 2005 Puget Sound Georgia Basin Research Conference, La Conner, Washington.								
Source Information	***Type***	Proceedings	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Water Quality and Productivity:*** salinity, temperature, pH, dissolved oxygen, contaminants, secondary productivity. ***Land Use and Cover:*** agriculture, floodplain. ***Fish and Habitat:*** Habitat: instream flow, riparian, estuary, pocket estuary, limiting factors, restoration; Fish: distribution; Monitoring: restoration, habitat, water quality, flow, abundance.								
Species and Life Stages	***Chinook:*** estuary rearing and emigration. ***Other species (Sticklebacks, Staghorn Sculpin):*** not specified.								
Reaches and Spatial extent	Skagit Bay, Skagit estuary, Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: Estuarine habitat is increasingly recognized as critical and limiting to salmonid populations (Beamer, 2000). The Swinomish Indian Tribal Community has initiated a restoration project, the Fornsby Creek SRT Project, to accomplish restoration of former estuarine habitat adjacent to the Swinomish Channel on the Swinomish Indian Reservation. The project will re-open more than five miles of estuarine-riparian channel to fish and improve more than 70 acres of associated aquatic habitat by replacing existing impassible tidegates with self-regulating tidegates (SRTs), improving the channel quality behind the new tidegates, and installing vegetated buffers adjacent to the channels. An extensive monitoring program, documenting pre-, syn-, and post-project ecologic and hydrologic conditions, is included to facilitate evaluation of positive and negative impacts of the project to fish use and adjacent land uses.

Montgomery et al. (1999) (Unique Identifier: 081)

Reference	Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Science 56:377-387.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: scour, sediment supply and transport, slope, aquatic habitats and landforms. ***Fish and Habitat***: Habitat: limiting factors.									
Species and Life Stages	***Chinook, Coho***: spawning.									
Reaches and Spatial extent	Tributaries.									
Linkages to Hydroelectric Operations	NA									

Abstract: Consideration of fundamental channel processes, together with map-based and field investigations, indicates that stream channel type influences salmonid spawning distributions across entire channel networks and salmonid abundance within channel reaches. Our analysis suggests that salmonid spawning patterns in mountain drainage basins of the Pacific Northwest are adapted to, among other things, the timing and depth of channel bed mobility. We hypothesize that because the bed of pool–riffle and plane–bed reaches scours to a variable fraction of the thickness of alluvium, survival to emergence is favored by either burying eggs below the annual scour depth or avoiding egg burial during times of likely bed mobility. Conversely, annual mobility of all available spawning gravel in steeper step–pool and cascade channels favors either adaptations that avoid egg burial during times of likely bed mobility or selection of protected microhabitats. Consistent with these expectations, we find that salmonid spawning distributions track channel slope distributions in several west-slope Pacific Northwest watersheds, implying that spatial differences in channel processes influence community structure in these rainfall-dominated drainage basins. More detailed field surveys confirm that different channel types host differential use by spawning salmonids and reveal finer-scale influences of pool spacing on salmonid abundance.

Morely et al. (2005) (Unique Identifier: 083)

Reference	Morley, S. A., P. S. Garcia, T. R. Bennett, and P. Roni. 2005. Juvenile salmonid (*Oncorhynchus* spp.) use of constructed and natural side channels in Pacific Northwest rivers. Canadian Journal of Fisheries and Aquatic Sciences 62:2811-2821.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms***: side and off-channels. ***Fish and Habitat***: Habitat: freshwater, restoration. ***Water Quality and Productivity***: nutrients, temperature, secondary productivity.								
Species and Life Stages	***Coho***, ***steelhead***, ***Chinook:*** rearing.								
Reaches and Spatial extent	US of R7, Sauk River.								
Linkages to Hydroelectric Operations	NA								

Abstract: Off-channel habitats, critical components in the life histories of Pacific salmonids (*Oncorhynchus* spp.), have become increasingly rare in human-modified floodplains. The construction of groundwater fed side channels is one approach that has been used in the Pacific Northwest to recreate off-channel habitats. We evaluated the effectiveness of this technique by comparing 11 constructed side channels with paired reference sites (naturally occurring channels fed by mixed groundwater and surface water) in western Washington. While total salmonid densities were not significantly different between channel types, Coho Salmon (*Oncorhynchus kisutch*) densities were higher in constructed channels and trout densities were higher in reference channels during the winter. Constructed channels were deeper than reference channels and warmer in the winter and cooler in the summer but had lower physical habitat diversity, wood density, and canopy coverage. We did not detect significant differences in water chemistry or invertebrate parameters between channel types. Summer Coho density was inversely correlated with minimum daily temperature and with total nitrogen and total phosphorous concentrations. Relative to other stream habitats, both constructed and reference channels supported high densities of juvenile Coho Salmon during the summer and winter.

Mostovetsky (2017) (Unique Identifier: 292)

Reference	Mostovetsky, A. 2017. Pre and post harvest assessment of uppermost points of perennial flow in the lower Skagit watershed. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land Use and Cover:*** forestry. ***Fish and Habitat:*** Habitat: instream flow.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit watershed.								
Linkages to Hydroelectric Operations	NA								

Abstract: According to the Washington State Forest Practice Rules, perennial streams are defined as “flowing waters that do not go dry any time of a year of normal rainfall” (WAC-222-16-30 [3]). The uppermost point of perennial flow (UMPPF) is considered the upper extent of a perennial stream segment. UMPPF locations can either be found at transition points between Np (perennial streams) and Ns (non-perennial) streams or at the channel head of a stream. The latter possibility was a more common finding amongst studies in Washington State examining the question of UMPPF locale (Veldhuisen, 2003; Jaegar et al., 2007; Hunter et al., 2005). Though UMPPFs are more commonly concentrated at or near stream channel heads, identifying these points can still sometimes be challenging, as hydrologic and weather conditions can vary both inter-annually and intra-seasonally (Hunter et al., 2005).

Natural variation in perennial stream dynamics has been explored, but few studies in the state have looked at UMPPF dynamics as a result of a controlled disturbance, such as clearcut timber harvesting, which has been shown to affect hydrologic regimes and water yield (Rothacher, 1970). This study aims to compare differences in UMPPF dynamics and locations pre and post clearcut harvesting.

Naman et al. (2016) (Unique Identifier: 084)

Reference	Naman, S. M., C. M. Greene, C. A. Rice, J. Chamberlin, L. Conway-Cranos, J. R. Cordell, J. E. Hall, and L. D. Rhodes. 2016. Stable isotope-based trophic structure of pelagic fish and jellyfish across natural and anthropogenic landscape gradients in a fjord estuary. Ecology and Evolution 6:8159-8173.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: diet, distribution; Habitat: connectivity. ***Land Use and Cover***: urban, agriculture, banks and shoreline. ***Water Quality and Productivity***: temperature, nutrients, turbidity, salinity, primary productivity, secondary productivity.									
Species and Life Stages	***Chinook, Chum:*** nearshore rearing and emigration.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: Identifying causes of structural ecosystem shifts often requires understanding trophic structure, an important determinant of energy flow in ecological communities. In coastal pelagic ecosystems worldwide, increasing jellyfish (Cnidaria and Ctenophora) at the expense of small fish has been linked to anthropogenic alteration of basal trophic pathways. However, this hypothesis remains untested in part because baseline description of fish–jellyfish trophic dynamics, and the environmental features that influence them are lacking. Using stable isotopes of carbon (δ13C) and nitrogen (δ15N), we examined spatiotemporal patterns of fish and jellyfish trophic structure in greater Puget Sound, an urbanizing fjord estuary in the NW United States. We quantified niche positions of constituent species, niche widths and trophic overlap between fish and jellyfish assemblages, and several community-level trophic diversity metrics (resource diversity, trophic length, and niche widths) of fish and jellyfish combined. We then related assemblage- and community-level measures to landscape gradients of terrestrial–marine connectivity and anthropogenic influence in adjacent catchments. Relative niche positions among species varied considerably and displayed no clear pattern except that fish generally had higher δ15N and lower δ13C relative to jellyfish, which resulted in low assemblage-level trophic overlap. Fish assemblages had larger niche widths than jellyfish in most cases and, along with whole community trophic diversity, exhibited contrasting seasonal patterns across oceanographic basins, which was positively correlated to landscape variation in terrestrial connectivity. In contrast, jellyfish niche widths were unrelated to terrestrial connectivity, but weakly negatively correlated to urban land use in adjacent catchments. Our results indicate that fish–jellyfish trophic structure is highly heterogeneous and that disparate processes may underlie the trophic ecology of these taxa; consequently, they may respond divergently to environmental change. In addition, spatiotemporal variation in ecosystem connectivity, in this case through freshwater influence, may influence trophic structure across heterogeneous landscapes.

NMFS (2008) (Unique Identifier: 429)

<table>
<tr><td>Reference</td><td colspan="10">National Marine Fisheries Service (NMFS). 2008. Endangered Species Act – Section 7 Consultation Final Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation, Implementation of the National Flood Insurance Program in the State of Washington Phase One Document – Puget Sound Region. NMFS Tracking No.: 2006-00472.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Links</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Project operations: flow regulation. Land use and cover: land cover, floodplain. Fish and Habitat: <u>Habitat:</u> connectivity, status and trends, capacity, estuary, pocket estuary; <u>Fish:</u> status and trends, abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, steelhead: outmigration, estuary rearing and emigration. Bull Trout, Coho, Chum, Pink, Sockeye: not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit watershed, Puget Sound, and Olympic Peninsula.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Project Operations: flow regulation. Fish and Habitat: <u>Habitat:</u> connectivity.</td></tr>
</table>

Abstract: The enclosed document contains a biological opinion prepared by the National Marine Fisheries Service pursuant to section 7(a)(2) of the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.), on the effects of certain on-going elements of the National Flood Insurance Program throughout Puget Sound in Washington State. This biological opinion is provided to the Federal Emergency Management Agency in accordance with the judicial order in *NWF v. FEMA,* 345 F. Supp. 2d 1151 (W.D. Wash. 2004). This biological opinion is based on the information provided in the February 2006 Biological Evaluation, numerous meetings, and phone calls, emails, and letters exchanged on the program. A complete administrative record of this consultation is on file at the National Marine Fisheries Service's Washington State Habitat Office in Lacey, Washington.

The National Marine Fisheries Service provides this biological opinion following consultation with the Federal Emergency Management Agency on effects of the National Flood Insurance Program on listed species found within the Puget Sound region, which are Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*), Puget Sound steelhead (*O. mykiss*), Hood Canal summer-run Chum Salmon (*O. keta*), Lake Ozette Sockeye Salmon (*O. nerka)*, and Southern Resident killer whales (*Orcinus orca*). In the biological opinion, the National Marine Fisheries Service concludes that the proposed action is likely to jeopardize the continued existence of Puget Sound Chinook Salmon, Puget Sound steelhead, Hood Canal summer-run Chum Salmon, and Southern Resident killer whales, and is likely to adversely modify Puget Sound Chinook Salmon, Hood Canal summer-run Chum Salmon, and Southern Resident killer whale critical habitat (Puget Sound steelhead critical habitat is not designated at this time). The proposed action is not likely to jeopardize Lake Ozette Sockeye Salmon or adversely modify Lake Ozette Sockeye Salmon critical habitat.

As required under the Endangered Species Act for consultations concluding with Jeopardy and Adverse Modification determinations, the National Marine Fisheries Service discussed with the Federal Emergency Management Agency, the availability of a reasonable and prudent alternative that the Federal Emergency Management Agency can take to avoid violation of the Federal Emergency Management Agency's Endangered Species Act section 7(a)(2) responsibilities (50

CFR 402.14[g][5]). Reasonable and prudent alternatives refer to alternative actions identified during formal consultation that 1) can be implemented in a manner consistent with the intended purpose of the action, 2) that can be implemented consistent with the scope of the Federal agency's legal authority and jurisdiction, 3) that is economically and technologically feasible, and 4) that the Director believes would avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat (50 CFR 402.02) The biological opinion includes a reasonable and prudent alternative which can be implemented to avoid jeopardy and adverse modification of critical habitat, while meeting each of the other requirements listed above. Accordingly, the National Marine Fisheries Service prepared an Incidental Take Statement describing and exempting the extent of incidental take reasonably certain to occur under the reasonable and prudent alternative.

NMFS (2013) (Unique Identifier: 425)

<table>
<tr><td>Reference</td><td colspan="10">National Marine Fisheries Service (NMFS). 2013. Reinitiation of the Endangered Species Act Section 7 Formal Programmatic Conference and Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for Aquatic Restoration Activities in the States of Oregon and Washington (ARBO II). NMFS, NWR-2013-9664, Seattle, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> barriers, restoration, limiting factors, climate change; <u>Fish:</u> abundance.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">steelhead, Chinook: not specified (types of runs).</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit watershed, Puget Sound.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: This document contains a programmatic conference and biological opinion (opinion) on reinitiation of consultation on the effects of the U.S. Forest Service (USFS), Bureau of Land Management (BLM), and Bureau of Indian Affairs (BIA) (acting for the Coquille Indian Tribe) funding or carrying out aquatic restoration actions in the States of Oregon and Washington. Actions covered in this opinion are modified from those analyzed in the biological opinion, issued on April 28, 2007, as summarized in the consultation history section of the opinion.

During this consultation, NMFS concluded that the proposed action is not likely to adversely affect southern DPS green sturgeon *(Acipenser medirostris)* or Steller sea lion *(Eumetopias jubatus)*, or their designated critical habitat, or southern resident killer whales *(Orcinus orca)*, which does not have designated critical habitat within the action area. NMFS also concluded that proposed program is not likely to jeopardize the continued existence of the following fish species listed as threatened or endangered under the ESA, or result in the destruction or adverse modification of their proposed or designated critical habitats:

(1) Lower Columbia River (LCR) Chinook Salmon (*Oncorhynchus tshawytscha*)

(2) Upper Willamette River (UWR) spring-run Chinook Salmon

(3) Upper Columbia River (UCR) spring-run Chinook Salmon

(4) Snake River (SR) spring/summer-run Chinook Salmon

(5) SR fall-run Chinook Salmon

(6) Puget Sound (PS) Chinook Salmon

(7) Columbia River (CR) Chum Salmon (*O. keta*)

(8) Hood Canal Chum Salmon

(9) LCR Coho Salmon (*O. kisutch*)

(10) Oregon Coast (OC) Coho Salmon

(11) Southern Oregon/Northern California Coasts (SONCC) Coho Salmon

(12) Lake Ozette sockeye Salmon (*O. nerka*)

(13) SR sockeye Salmon

(14) LCR steelhead (*O. mykiss*)

(15) UWR steelhead,

(16) Middle Columbia River (MCR) steelhead

(17) UCR steelhead

(18) Snake River Basin (SRB) steelhead

(19) PS steelhead

(20) Southern distinct population segment eulachon *(Thaleichthys pacificus*)

As required by section 7 of the ESA, NMFS is providing an incidental take statement (ITS) with the opinion. The ITS describes reasonable and prudent measures NMFS considers necessary or appropriate to minimize the impact of incidental take associated with this program. The ITS also sets forth nondiscretionary terms and conditions, including reporting requirements, that the Federal action agency must comply with to carry out the reasonable and prudent measures. Incidental take from actions that meet these terms and conditions will be exempt from the ESA's prohibition against the take of the listed species considered in this opinion, except eulachon because NMFS has not yet promulgated an ESA section 4(d) rule prohibiting take of threatened eulachon. However, anticipating that such a rule is likely to be issued in the future, we have included terms and conditions to minimize take of eulachon. These terms and conditions are identical to the terms and conditions required to minimize take of listed salmon and steelhead. Therefore, we expect the action agencies would follow these terms and conditions regardless of whether take of eulachon is prohibited. The take exemption for eulachon will take effect on the effective date of any future 4(d) rule prohibiting take of eulachon.

The proposed action addressed in this consultation includes projects that will replace or relocate an existing irrigation diversion structure, or modify an existing irrigation diversion structure so that it will meet NMFS's fish screen criteria. However, the proposed action does not include the issuance of any easement, permit, or right-of-way that would authorize construction of a new diversion structure, or conveyance of water across Federal land. Those types of action require an individual consultation under section 7 of the ESA whenever they may affect an ESA-listed species or designated critical habitat. Moreover, any take that may be due to the use of an existing irrigation diversion structure to withdraw water, or to the use of a water system to convey water across Federal land, is not incidental to the proposed action, and is not exempted from the ESA's prohibition against take by the ITS of this document.

This document also includes the results of our analysis of the action's likely effects on essential fish habitat (EFH) pursuant to section 305(b) of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), and includes three conservation recommendations to avoid, minimize, or otherwise offset potential adverse effects on EFH. Section 305(b)(4)(B) of the MSA requires Federal agencies to provide a detailed written response to NMFS within 30 days after receiving these recommendations.

If the response is inconsistent with the EFH conservation recommendation, USFS, BLM, or BIA must explain why the recommendations will not be followed, including the scientific justification for any disagreements over the effects of the action and the recommendations. In response to increased oversight of overall EFH program effectiveness by the Office of Management and Budget, NMFS established a quarterly reporting requirement to determine how many conservation recommendations are provided as part of each EFH consultation and how many are adopted by the action agency. Therefore, in your statutory reply to the EFH portion of this consultation, we ask that you clearly identify the number of conservation recommendations accepted.

NMFS (2020) (Unique Identifier: 426)

<table>
<tr><td>Reference</td><td colspan="10">National Marine Fisheries Service (NMFS). 2020. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response for King County's Coal Creek Trunk Maintenance Hole 25B Protection Project, King County, Washington (COE Number: NWS-2020-605-WRD, HUC: 171100120400 – Lake Washington). NMFS, WCRO-2020-01678, Portland, Oregon.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Habitat:</u> limiting factors, climate change. Water Quality and Productivity: temperature, dissolved oxygen, turbidity, contaminants.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: not specified (run types). steelhead: not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound (Coal Creek tributary of Lake Washington).</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: This consultation was conducted in accordance with the 2019 revised regulations that implement section 7 of the ESA (50 CFR 402, 84 FR 45016). The enclosed document contains the biological opinion (Opinion) prepared by the NMFS pursuant to section 7 of the ESA on the effects of the proposed action. In this Opinion, the NMFS concludes that the proposed action would adversely affect but is not likely to jeopardize the continued existence of Puget Sound (PS) Chinook Salmon, and documents our conclusion that the proposed action is not likely to adversely affect PS steelhead. This Opinion does not consider designated critical habitat for either species because the action area has been excluded from designation as critical habitat for any species under our jurisdiction.

This Opinion includes an incidental take statement (ITS) that describes reasonable and prudent measures (RPMs) the NMFS considers necessary or appropriate to minimize the incidental take associated with this action, and sets forth nondiscretionary terms and conditions that the COE must comply with to meet those measures. Incidental take from actions that meet these terms and conditions will be exempt from the ESA's prohibition against the take of listed species. Section 3 of this document includes our analysis of the action's likely effects on EFH pursuant to Section 305(b) of the MSA. Based on that analysis, the NMFS concluded that the action would adversely affect designated EFH for Pacific Coast Salmon. Therefore, we have provided 1 conservation recommendations that can be taken by the COE to avoid, minimize, or otherwise offset potential adverse effects on EFH.

Section 305(b) (4) (B) of the MSA requires Federal agencies to provide a detailed written response to NMFS within 30 days after receiving this recommendation. If the response is inconsistent with the EFH conservation recommendations, the COE must explain why the recommendations will not be followed, including the scientific justification for any disagreements over the effects of the action and recommendations. In response to increased oversight of overall EFH program effectiveness by the Office of Management and Budget, NMFS established a quarterly reporting requirement to determine how many conservation recommendations are provided as part of each EFH consultation and how many are adopted by the action agency. Therefore, we request that in your statutory reply to the EFH portion of this consultation you clearly identify the number of conservation recommendations accepted.

Olis and Veldhuisen (2007) (Unique Identifier: 293)

Reference	Olis, M., and C. Veldhuisen. 2007. Suiattle forest road sediment reduction assessment phase 1 – northern Suiattle basin. Report prepared for Mount Baker-Snoqualmie National Forest by Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply. ***Land Use and Cover:*** forestry. ***Fish and Habitat:*** Habitat: barriers, instream flow.									
Species and Life Stages	***Chinook, Bull Trout:*** not specified.									
Reaches and Spatial extent	Other Sauk River tribs (Suiattle River basin).									
Linkages to Hydroelectric Operations	NA									

Abstract: The Suiattle Basin Forest Road Sediment Reduction Assessment is an ongoing cooperative project sponsored by the Skagit River System Cooperative (SRSC) and the Mt. Baker-Snoqualmie National Forest (MBSNF). The Skagit River System Cooperative is a fisheries management consortium for the Sauk-Suiattle Indian Tribe and Swinomish Indian Tribal Community. The project was designed to identify opportunities to reduce sediment-related impacts to fish and aquatic resources from federal forest roads within the Suiattle basin. USFS lands within the Suiattle basin are entirely within the Usual and Accustomed Fishing area of the SRSC member Tribes and are managed by USFS.

The objective of this project is to identify opportunities to reduce sediment from forest roads that can negatively affect aquatic resources. The project determined the present condition of forest roads, the scale of ongoing and future sediment impacts and the portions of each road that pose the greatest threat to fisheries resources. Other aspects of road management, such as fish passage barriers, wildlife effects, and access for timber harvest, recreation or Tribal cultural activities, were beyond the scope of this study, but should be considered before road treatments are chosen.

We collected information needed to estimate the effects of a range of possible road treatments, including: 1. Maintenance – e.g., grading, ditch clearing and brushing, 2. Upgrades – e.g. replacing culverts, fill removal, 3. Deactivation – i.e. making the road undrivable so it is less erodible and requires minimal maintenance, and/or 4. No action – i.e. probable consequences of non-treatment. This study stopped short of designing road treatments, in part because such decisions would require consideration of broader landowner and stakeholder concerns listed in the previous paragraph. However, this study does characterize possible aquatic damage considerations that will be useful for prioritizing which road segments pose the greatest threat to aquatic resources and provides detailed data that can be used to help develop specific road treatments. Although the focus of this report is at the road-segment scale to provide an overview, the site-scale notes can be consulted to help evaluate specific sites and treatments.

Further, we also hope that the methodologies developed for this study can provide a model for similar road sediment reduction projects in other watersheds.

Olson (1995) (Unique Identifier: 442)

Reference	Olson, P. L. 1995. Shallow subsurface flow systems in a montane terrace-floodplain landscape: Sauk River, North Cascades, Washington.									
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, slope, substrate and sediment, history. ***Water Quality and Productivity:*** temperature. ***Modeling Tools:*** hydrology. ***Fish and Habitat***: Habitat: instream flow.									
Species and Life Stages	NA									
Reaches and Spatial extent	Sauk River, Other Sauk River tribs (Constant Creek).									
Linkages to Hydroelectric Operations	NA									

Abstract: Constant Channel, a salmonid spawning and rearing channel in the Sauk River floodplain, provides an opportunity to study subsurface flow in a montane floodplain and terrace landscape. The conventional viewpoint on subsurface flow in riverine floodplains assumes an alluvial aquifer underlies the surface and aquifer water levels are controlled by river stage. This study emphasizes the groundwater system viewpoint. Three distinct sources of subsurface flow to Constant Channel are proposed: hillslope upper terrace, lower terrace, and Sauk River. The hypotheses are tested using time-series and discriminant analysis statistical techniques on: (1) hydrologic data, including surface and subsurface water levels, seepage quantities, and precipitation; (2) subsurface and surface temperatures of water, air, and soil; and, (3) dissolved chemical constituent data including cations, anions, and nutrients. The three data sets are treated as separate case studies to independently test the hypotheses.

A conceptual framework describing predicted flow routing and regimes to Constant Channel is developed. The framework is based on generally accepted subsurface flow theories and empirical constructs verified by other investigators through experimental studies, field observation, or numerical models. Although floodplain and terrace morphology are complex, the study's underlying premise is subsurface flow will behave in a predictable manner. Key factors of hydrologic routing and regimes are expected to vary predictably with source areas. Factors are: (1) location of recharge areas to discharge areas; (2) potential storage volume; (3) baseflow recession and duration; (4) specific discharge of subsurface flow to Constant Channel; (5) direction of flow; and, (6) storm response. Factors 1-3 define water availability and drainage capacity. Factors 4-6 describe the source area transport 'efficiency1. Three source groupings and three seasons are significant discriminators for explaining variance in hydrologic regimes of Constant Channel catchment. Primary and secondary topography, soil drainage characteristics, remnant fluvial features, and spatial continuity adequately delineate distinct sources of subsurface flow that supports the hypotheses. Valley side and floor relief were dominant controls on the intermediate flow systems' direction. Terrace and floodplain secondary topography influence the direction of shallow local flow. Seasonal climatic patterns determine the quantity and timing of flow to the channel.

O'Neill et al. (Year) (Unique Identifier: 372)

Reference	O'Neill, S. M., A. J. Carey, J. A. Lanksbury, L. A. Niewolny, G. Ylitalo, L. Johnson, and J. E. West. 2015. Toxic contaminants in juvenile Chinook salmon (Oncorhynchus tshawytscha) migrating through estuary, nearshore and offshore habitats of Puget Sound. Report prepared by Washington Department of Fish and Wildlife, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** contaminants. ***Fish and Habitat:*** Fish: condition, size structure.									
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration, nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit watershed, Puget Sound (Snohomish, Green/Duwamish, Hylebos/Puyallup, Nisqually, and other marine sub-basins)									
Linkages to Hydroelectric Operations	NA									

Abstract: Juvenile Chinook Salmon (*Oncorhynchus tshawytscha)* can encounter a wide range of water quality conditions, from relatively clean to highly contaminated, as they migrate from rivers into Puget Sound. During this life stage, as they transition into saltwater, they are particularly sensitive to stressors such as toxic contaminants. This study was designed to provide a synoptic assessment of contaminant exposure for major populations of juvenile Chinook Salmon from Puget Sound as the fish migrate from their freshwater to marine habitats. Overall, the study estimated exposure of salmon to toxics chemicals in 1) the estuary habitats of major river systems entering Puget Sound, 2) the nearshore marine habitats associated with those rivers systems, and 3) the offshore marine habitats of the major basins of Puget Sound. The study addresses the general hypothesis that chemicals released into Puget Sound from human activities and development reduces the health and productivity of salmon and their food supply. Specifically, we hypothesized that juvenile Chinook Salmon residing and feeding in the more urbanized and industrial estuary, nearshore marine, and offshore habitats of Puget Sound are exposed to higher concentrations of toxic contaminants than those in less developed habitats. In addition, we hypothesized that the elevated contaminant concentrations in the more urban areas are high enough to affect juvenile Chinook survival through reductions in growth, disease resistance, and altered hormone and protein levels.

Ostberg et al. (2018) (Unique Identifier: 422)

Reference	Ostberg, C. O., D. M. Chase, M. C. Hayes, and J. J. Duda. 2018. Distribution and seasonal differences in Pacific lamprey and *Lampetra* spp eDNA across 18 Puget Sound watersheds. PeerJ 6:e4496.
Source Information	***Type*** Journal; ***Status*** Final; ***Quantitative Data*** Yes; ***Spatial Data*** Yes; ***Project Related*** No
Topics and Keywords	***Fish and Habitat:*** Fish: genetics, abundance, life history.
Species and Life Stages	***Pacific Lamprey:*** not specified.
Reaches and Spatial extent	Puget Sound (Nooksack, Skagit, Stillaguamish, Snoqualmie, Bear, Cedar, Green, Puyallup, Nisqually, Deschutes, Skokomish, Tahuya, Dewatto, Hamma-Hamma, Duckabush, Little Quilcene, Salmon Dungeness).
Linkages to Hydroelectric Operations	NA

Abstract: Lampreys have a worldwide distribution, are functionally important to ecological communities and serve significant roles in many cultures. In Pacific coast drainages of North America, lamprey populations have suffered large declines. However, lamprey population status and trends within many areas of this region are unknown and such information is needed for advancing conservation goals. We developed two quantitative PCR-based, aquatic environmental DNA (eDNA) assays for detection of Pacific Lamprey (*Entosphenus tridentatus*) and *Lampetra* spp, using locked nucleic acids (LNAs) in the probe design. We used these assays to characterize the spatial distribution of lamprey in 18 watersheds of Puget Sound, Washington, by collecting water samples in spring and fall. Pacific Lamprey and *Lampetra* spp were each detected in 14 watersheds and co-occurred in 10 watersheds. Lamprey eDNA detection rates were much higher in spring compared to fall. Specifically, the Pacific Lamprey eDNA detection rate was 3.5 times higher in spring and the *Lampetra* spp eDNA detection rate was 1.5 times higher in spring even though larval lamprey are present in streams year-round. This significant finding highlights the importance of seasonality on eDNA detection. Higher stream discharge in the fall likely contributed to reduced eDNA detection rates, although seasonal life history events may have also contributed. These eDNA assays differentiate Pacific Lamprey and *Lampetra* spp across much of their range along the west coast of North America. Sequence analysis indicates the Pacific Lamprey assay also targets other *Entosphenus* spp and indicates the *Lampetra* spp assay may have limited or no capability of detecting *Lampetra* in some locations south of the Columbia River Basin. Nevertheless, these assays will serve as a valuable tool for resource managers and have direct application to lamprey conservation efforts, such as mapping species distributions, occupancy modeling, and monitoring translocations and reintroductions.

Philip Williams & Associates et al. (2004) (Unique Identifier: 122)

<table>
<tr><td>Reference</td><td colspan="10">Philip Williams & Associates, Ltd., S. R. Hinton, and W. G. Hood. 2004. An assessment of potential habitat restoration pathways for Fir Island, WA. Report prepared for Skagit Watershed Council, Mount Vernon, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: history, change, log jam, sediment transport and supply, substrate and sediment, side- and off-channels, sinuosity, slope. Land Use and Cover: land cover, banks and shoreline. Modeling Tools: bathymetry, sediment. Fish and Habitat: <u>Habitat:</u> estuary, wetlands, restoration.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: outmigration, estuary rearing and emigration, rearing.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit estuary, reach R15.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: In an effort to address the significant decline of salmonid populations in the Skagit River basin, the Skagit Watershed Council was formed in 1997 as a coalition of diverse interests who share a common goal to develop community-based, voluntary solutions to this problem. As part of this effort, the Council developed a series of documents to guide their actions including a "Habitat Restoration and Protection Strategy" (SWC 1998), the "Application of the Skagit Watershed Council Strategy" (SWC, 2000), and an annual "Strategic Approach" which identify the need to address the isolation, fragmentation, and sustainability of habitat in the delta and estuary as a high priority. Through a partnership with Seattle City Light, the Skagit System Cooperative, and the Washington Department of Fish and Wildlife, the SWC commissioned this study to evaluate the feasibility and potential of alternative pathways for salmon habitat restoration that focus on the Fir Island portion of the Skagit Delta.

The purpose of this document is to present a logical scientific methodology that can be applied in the development of feasible restoration alternatives and to illustrate how this methodology is applied in developing and assessing five potential restoration "pathways." This methodology is based on an understanding of the dynamic evolution of the morphology and physical processes inherent in all river and tidal systems that support and sustain key habitats and ecological functions. The study draws on scientific research conducted in the Skagit River delta and on the broader literature related to river delta morphology, and examines a range of potential habitat restoration pathways and the anticipated evolution of Fir Island conditions, both for salmon habitat and land use, over the next 30 years.

Phillips et al. (2009) (Unique Identifier: 296)

Reference	Phillips, J., C. Veldhuisen, and M. Olis. 2009. Using channel geometry to simplify the use of the sizing table for culverts on type N streams. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	**_Type_**	Report	**_Status_**	Final	**_Quantitative Data_**	Yes	**_Spatial Data_**	Yes	**_Project Related_**	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow, barriers. ***Geomorphology and Landforms:*** slope, substrate and sediment.									
Species and Life Stages	NA									
Reaches and Spatial extent	Other lower and upper Skagit tribs, other Sauk River tribs, other Samish river tribs.									
Linkages to Hydroelectric Operations	NA									

Abstract: Although forest roads can adversely impact watershed processes by adding sediment and constraining stream channels, adequately sized road crossing structures can reduce such impacts. According to Washington State Forest Practice Rules, Type N Water crossing structures must be sized to accommodate the "100 year flood event with consideration for the passage of debris" (WAC 222-24-040). The Forest Practices Board Manual describes three approved methods for determining culvert sizing: A) the Sizing Table Method; B) the Bankfull Width Method and C) the Hydraulic Design Method. In this paper, we address the Sizing Table Method (Table 1), which we observe to be commonly used in the Skagit Basin.

The Sizing Table Method requires a two-step process described in the Board Manual Section 3, Guidelines for Forest Roads. In short, once it is determined that the stream is Type N Water (i.e., non-fish-bearing), the method requires measuring the bankfull width and average bankfull depth. These measurements are then used in the sizing table to determine the diameter of the culvert to be installed.

This paper is not intended to explore the appropriateness of the sizing table method or the origins of the table but rather to simplify and improve the field implementation of the method. The objective of this paper is to use a local sample of field surveyed channel measurements to highlight the channel dimensions in the table that most commonly occur in the northwestern Cascades. This would, in effect, simplify the sizing table method by reducing the dependence on an accurate bankfull depth measurement which is the most difficult part of the culvert sizing process and likely contains the largest amount of error.

Phillips et al. (2012) (Unique Identifier: 298)

Reference	Phillips, J., M. Olis, and C. Veldhuisen. 2012. Channel and fish response to the East Fork Hooper Creek culvert removal. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: barriers, freshwater, capacity; Monitoring: restoration, abundance. ***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, channel migration, slope, large wood.									
Species and Life Stages	***Coho:*** spawning. ***Other species (cutthroat):*** incubation - rearing.									
Reaches and Spatial extent	Other upper Skagit Tribs (Hooper Creek).									
Linkages to Hydroelectric Operations	NA									

Abstract: Culverts on forest roads can impact movement of fish and sediment. They can block upstream access and limit the migration of anadromous and resident fish if they are not designed and installed to provide fish passage. This is often due to high flow velocities in the culvert and/or large outfall drops that limit upstream movement. In recent decades, there has been an ongoing effort by forest land managers in Washington to replace these barriers with road crossing structures that allow for fish passage as well as high flows, sediment and debris.

In October 2008, forest landowner Sierra Pacific Industries (SPI) elected to replace an undersized fish passage barrier culvert with a bridge on the East Fork of Hooper Creek (Figure 1). The road work was implemented as a part of their Road Maintenance and Abandonment Plans (RMAP) work for this area.

The culvert had been recognized as a fish passage barrier for a decade or more but was not prioritized for repair mainly for two reasons. First, there was skepticism that the Stowe Road crossing was within the zone of access to anadromous fish. Second, some observers cited the potential for negative impacts on downstream habitat quality due to the release of the large volume of sediment stored above the culvert.

The only road crossing of Hooper Creek downstream of Stowe Road is at the county owned Concrete-Sauk Valley Road (hereafter referred to as CSV Road). This crossing was made fish-passable in 1995 and spawning Coho Salmon had been observed both up and downstream of the improved crossing at the CSV Road. Making the CSV Road passable focused additional attention on Stowe Road as the remaining man-made limitation to upstream access in Hooper Creek.

A longitudinal channel profile completed before the culvert was removed validated that a significant quantity of sediment had accumulated upstream (Figure 2). The expectation of significant vertical channel adjustment was a primary reason that SPI chose to install a bridge that allows more vertical channel movement, rather than a larger culvert. The recently removed culvert was above the equilibrium grade as it had replaced a lower culvert that was discovered during removal (Keith Greenwood, forester, SPI, phone conversation).

During bridge installation, a channel was excavated through the road fill where the culvert had been and banks sloped and armored around the bridge footings. No grade control structures were

put in place and only a minimal amount of sediment was removed from upstream that an excavator could reach from the road grade. The intent was to allow the stream to redistribute the sediment and reestablish an equilibrium grade naturally.

Plumb and Blanchard (2021) (Unique Identifier: 519)

Reference	Plumb, M. and M. Blanchard. 2021. Pacific Lamprey 2021 regional implementation plan for the Washington coast/Puget Sound regional management units. Submitted to the Conservation Team, August 12, 2021.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Fish: genetics, status and trends, distribution, abundance, data gaps; Monitoring: restoration, abundance, climate change.								
Species and Life Stages	***Pacific Lamprey:*** not specified.								
Reaches and Spatial extent	Skagit watershed, Puget Sound, Washington coast watersheds.								
Linkages to Hydroelectric Operations	NA								

Summary: This report provides an overview of Pacific Lamprey distribution in hydrologic units (HU) within Puget Sound and on the Washington coast. For each HU, the historic estimate for Pacific Lamprey is given and a current estimate of the status. Lamprey distribution data was and is currently being gathered from eDNA, occupancy sampling and *"networking with partner agencies to fill data gaps."* The report also provides a general overview of different monitoring programs that often began as a monitoring program for salmon and steelhead recovery that are now also including Pacific Lamprey. The common threats for Pacific Lamprey in four HUs were *"lack of awareness, stream and floodplain degradation, dewatering and flow management, and climate change were identified as threats"* as well as poorly designed culverts impeded fish migration. The report recommends gathering more information for all HUCs in Washington to determine the HUCs greatest threat before ranking and prioritizing.

PMFC (2020) (Unique Identifier: 101)

<table>
<tr><td>Reference</td><td colspan="10">Pacific Fishery Management Council (PFMC). 2020. Review of 2019 ocean salmon fisheries: stock assessment and fishery evaluation document for the Pacific Coast salmon fishery management plan. Report prepared by Pacific Fishery Management Council Pacific Fishery Management Council, Portland, Oregon.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Fish and Habitat: <u>Fish</u>: status and trends, harvest; <u>Habitat</u>: ocean.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Coho, Pink: ocean.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: The Salmon Technical Team (STT) and staff of the Pacific Fishery Management Council (Council) have prepared this stock assessment and fishery evaluation (SAFE) document as a postseason review of the 2019 ocean salmon fisheries off the coasts of Washington, Oregon, and California to help assess Council salmon fishery management performance, the status of Council-area salmon stocks, and the socioeconomic impacts of salmon fisheries. The STT and Council staff will provide three additional reports prior to the beginning of the ocean salmon season to help guide the Council’s selection of annual fishery management measures: Preseason Report I, Preseason Report II, and Preseason Report III. These reports will provide forecasts of stock abundance, determine annual catch limits, and will analyze the biological and economic impacts of the Council's proposed alternatives and adopted fishery management recommendations.

This postseason report will also provide a detailed description of the salmon fishery portions of the affected environment to be incorporated by reference into an Environmental Assessment (EA) to comply with National Environmental Policy Act (NEPA) requirements for the 2020 ocean salmon management measures. Preseason Report I will constitute the first part of the EA for 2020 ocean salmon fishery management measures, and include a statement of the purpose and need, a description of the affected environment, and a description and analysis of the status quo (no action) alternative. Preseason Report II will constitute the second and final part of the EA and will include a description and analysis of the alternative management measures considered for 2020 ocean salmon fisheries. The alternatives analyzed in Preseason Report II will provide a reasonable range of environmental effects, which will bound those of the final fishery management measures included in Preseason Report III. Together, these two parts of the EA will provide the necessary components to determine if a finding of no significant impact (FONSI) is warranted.

West Coast fisheries in Council-managed waters (ocean fisheries between the U.S./Canada border and the U.S./Mexico border from 3 to 200 nautical miles offshore) are directed toward and harvest primarily Chinook or King Salmon, *Oncorhynchus tshawytscha,* and Coho or Silver Salmon, *Oncorhynchus kisutch*. Small numbers of Pink Salmon, *Oncorhynchus gorbuscha,* also are harvested, especially in odd numbered years. There are no directed fisheries for other Pacific salmon species, which are rarely caught in Council-managed fisheries.

The Council's annual review of ocean salmon fisheries provides a summary of important biological and socioeconomic data from which to assess the status of managed stocks, impacts of past management actions, to determine how well management objectives are being met, and to improve regulations for the future. The Council will formally review this SAFE document at its March meeting prior to the development of management alternatives for the approaching fishing season.

Chapter I summarizes ocean salmon fishery regulations and landings within the Council management area, and management actions and landings under the jurisdiction of the Pacific Salmon Commission (PSC). Appendix A provides historical effort and harvest data by state and by management area. Appendix C summarizes historical ocean fishery regulations. For Chinook and Coho Salmon, respectively, Chapters II and III assess, where possible, the achievement of pertinent management objectives by salmon stock (including those listed under the Endangered Species Act [ESA]), outline regulations used to achieve the objectives, and summarize inside fisheries catch and spawner escapement data. Appendix B provides detailed historical spawning escapement and inside fisheries catch information. Detailed information for other salmon species is not included since Council fisheries have minor impacts on Pink Salmon escapements and no measurable impacts on sockeye or Chum Salmon or steelhead trout; however, catch and escapement data and objectives for Puget Sound Pink Salmon are summarized in Appendix B, Table B-43.

In 2011, the Council also adopted status determination criteria (SDC) for overfishing, approaching an overfished condition, overfished, not overfished/rebuilding, and rebuilt under Salmon Fishery Management Plan (FMP) Amendment 16. These criteria, approved and implemented in December 2011, were:

- Overfishing occurs when a single year exploitation rate exceeds the maximum fishing mortality threshold (MFMT), which is based on the maximum sustainable yield exploitation rate (FMSY);
- Approaching an overfished condition occurs when the geometric mean of the two most recent postseason estimates of spawning escapement, and the current preseason forecast of spawning escapement, is less than the minimum stock size threshold (MSST);
- Overfished status occurs when the most recent 3-year geometric mean spawning escapement is less than the MSST;
- Not overfished/rebuilding status occurs when a stock has been classified as overfished and has not yet been rebuilt, and the most recent 3-year geometric mean spawning escapement is greater than the MSST but less than maximum sustainable yield (MSY) spawning escapement (SMSY); and
- A stock is rebuilt when the most recent 3-year geometric mean spawning escapement exceeds SMSY.

All SDC rely on the most recent estimates available, which in some cases may be a year or more in the past due to incomplete broods or data availability. The above criteria for rebuilt status are the default criteria provided in the FMP; however, alternative criteria may be developed through a rebuilding plan if warranted by stock specific circumstances. Pertinent stocks are evaluated relative to these SDC as required by the FMP. In addition, new conservation objectives were adopted in 2011 for some stocks based on revised estimates of SMSY and FMSY, which are the reference points used to establish stock specific SDC. Stock specific reference points, and recent year estimates for relevant stocks, are presented in Table II-6 and Table III-6.

Status determinations for overfishing, overfished, not overfished/rebuilding, and rebuilt are reported in this SAFE document; however, because approaching an overfished condition relies on a preseason forecast, that status determination is reported in Preseason Report III. In addition, some status determinations may be updated in Preseason Report I if more recent spawning escapement or exploitation rate estimates become available between the time this SAFE document and Preseason Report I are published.

Socioeconomic impacts of the fisheries are discussed in Chapter IV. Appendix D provides historical fishery-related socioeconomic data.

The annual review of ocean salmon fisheries is drafted as early as analyses of landings and escapement data are available. The most recent entries are noted as preliminary and later updated when the data become final. If updated information or error corrections that could substantially affect the development of management measures for the upcoming season are available, an errata sheet will be included as an appendix in one of the subsequent STT preseason planning documents.

Pratt (1974) (Unique Identifier: 261)

<table>
<tr><td>***Reference***</td><td colspan="10">Pratt, D. C. 1974. Age, sex, length, weight, and scarring of adult chum salmon (*Oncorhynchus keta*) Harvested by Puget Sound commercial net fisheries from 1954 through 1970: supplemental progress report. Washington Department of Fisheries, Management and Research Division, Olympia, Washington.</td></tr>
<tr><td>***Source Information***</td><td>***Type***</td><td>Report</td><td>***Status***</td><td>Final</td><td>***Quantitative Data***</td><td>Yes</td><td>***Spatial Data***</td><td>No</td><td>***Project Related***</td><td>No</td></tr>
<tr><td>***Topics and Keywords***</td><td colspan="10">***Fish and Habitat***: Fish: age structure, size structure, sex structure, harvest, condition, competition.</td></tr>
<tr><td>***Species and Life Stages***</td><td colspan="10">***Chum, Pink***: migration.</td></tr>
<tr><td>***Reaches and Spatial extent***</td><td colspan="10">Skagit Bay, Puget Sound.</td></tr>
<tr><td>***Linkages to Hydroelectric Operations***</td><td colspan="10">NA</td></tr>
</table>

Abstract: Biological data on adult Chum Salmon (*Oncorhynchus keta*) were collected from the Puget Sound commercial net harvest from 1954 through 1970. During the 17-year period, 21,868 Chum were aged, 18,830 sex determinations made, 7,817 measurements taken, 1,619 individual specimens weighed and 12,731 Chum examined for scars. In total, sufficient observations were obtained to establish most of the basic age compositions, sex ratios, size relationships and degree of scarring of adult Chum entering the Puget Sound commercial harvest in eight different harvest units. This report provides sampling results, both in detail and summary form from 1954 through 1970.

In general, 97 percent of all adult Chum sampled were in their 3rd or 4th year. While age composition varied between areas and between years within each area, 4-year olds were consistently more abundant, particularly in the northerly Puget Sound harvest units.

Sex ratios were fairly uniform from area to area and year to year. Generally, males were more abundant in the 3-year-old age class while females dominated the 4-year-old category. From an average brood year standpoint, females comprised 53.5 percent of the typical brood year harvest.

Considerable overlapping of length distributions between males and females from both the 3- and 4-year old age groups was apparent. In addition, females demonstrated a greater variation in weight for a given length than males. Geographical differences in size were clearly evident as well. Further, average Chum weights apparently deviated downward from over-all weight trends during Pink Salmon return years, suggesting possible Pink-Chum competition for food during Pink Salmon cycle years.

PSRITT (2013) (Unique Identifier: 091)

Reference	Puget Sound Recovery Implementation Technical Team (PSRITT). 2013. Puget Sound Chinook salmon recovery: a framework for the development of monitoring and adaptive management plans. NOAA Technical Memorandum Draft, Seattle.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** channel migration, floodplain, side and off-channels, floodplain connectivity, sediment transport and supply, substrate and sediment, large wood, estuarine habitats and landforms. ***Water Quality and Productivity:*** temperature, nutrients, dissolved oxygen, contaminants, primary productivity, secondary productivity, salinity. ***Modeling Tools:*** bioenergetics, life cycle. ***Land Use and Cover:*** floodplain. ***Fish and Habitat:*** Habitat: instream flow, riparian, wetlands, barriers, invasive species, freshwater, nearshore, ocean, connectivity, restoration, pocket estuary; Fish: abundance, distribution, competition, survival, growth, rearing, predation, life history, size structure, movement, condition, harvest, status and trends, diet.									
Species and Life Stages	***Chinook:*** full life cycle.									
Reaches and Spatial extent	Puget Sound, Skagit Bay, Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: This document was developed by the Puget Sound Recovery and Implementation Technical Team (PSRITT) to provide a formal monitoring and adaptive management framework (the framework) for assessing Puget Sound Chinook Salmon recovery. Monitoring and adaptive management have occurred at the watershed and regional scales as implementation of the Recovery Plan has proceeded. However, the lack of a formal framework has meant that there is no standardized vocabulary or shared common approach to articulate the key assumptions of the chapters in Volume II, to test assumptions across chapters, or to connect the local, watershed scale information in Volume II with the regional scale information in Volume I. This gap limits the collective ability of resource managers to assess the effectiveness of salmon recovery efforts across the region, to identify uncertainties, and to update priorities and actions in the Recovery Plan. Furthermore, the framework is intended to help salmon recovery managers formalize their local scale monitoring and adaptive management plans using a common approach.

We developed the framework using concepts taken from the Open Standards for the Practice of Conservation (Open Standards). Open Standards is a scalable, adaptable system widely used to design, manage, and monitor conservation projects. The framework builds on several interrelated categories of information, or “elements.” These elements are as follows:

- Ecosystem components - Species, ecological systems/habitats, or ecological processes that are chosen to represent and encompass the full suite of biodiversity in the project area for place-based conservation.
- Key ecological attributes (KEAs) - Patterns of biological structure and composition, ecological processes, environmental regimes, and other environmental constraints necessary for an ecosystem component to persist.
- Indicators - Measures of condition or status.
- Pressures - Factors delivering direct stresses to ecosystem components.

- Stresses - Altered or degraded key ecological attributes.
- Contributing factors - Factors affecting human-induced actions, events, or natural processes that are not drivers or direct pressures but that affect the condition of ecosystem components.
- Drivers - The ultimate human-induced actions, events, or natural processes that underlie or lead to one or more pressures.
- Strategies - A group of actions with a common focus designed to achieve specific objectives and goals.

These elements function as building blocks of conceptual models that describe the relationships between strategies, pressures on ecosystem components, and recovery goals and objectives in order to determine what kind and level of intervention is likely to be most effective. Open Standards includes companion software (Miradi) to create graphical depictions of these conceptual models. Miradi software is also used to develop “results chains,” which are diagrams derived from the conceptual models depicting assumptions or hypotheses that link short-, medium, and long-term actions and results in an “if…then” fashion. Development of a monitoring and adaptive management plan consistent with the framework is not contingent on the use of the Miradi software, as we recognize other data management tools may already be in use in some watersheds.

We used the scientific literature on Pacific salmon and salmonid ecosystems and also the Recovery Plan chapters to describe the elements above for Chinook Salmon in the Puget Sound region. We identify 14 ecosystem components and their associated KEAs. These ecosystem components are Chinook Salmon, the two ecosystems - freshwater habitats, and estuarine and marine habitats - used by Chinook Salmon, and finally, the species and food web processes upon which Chinook Salmon depend.

We provide example indicators of KEAs that can be tailored to the individual watershed recovery plans. The list of indicators presented in this document is provided as an example and is neither prescriptive nor all inclusive. However, we do recommend watershed managers work together to develop common indicators in order to attain a common region-wide measure of progress.

We identify linkages between major life cycle segments and events that represent the Chinook Salmon ecosystem component and the habitat ecosystem components. Each life cycle segment and event is associated with habitat types used by Chinook Salmon during particular life stages. This association is necessary to connect the habitat-related ecosystem components with the Chinook Salmon ecosystem component in the framework. The habitat-related ecosystem components are organized into a hierarchical watershed, reach, and habitat unit scale classification. These classifications are intended to include all habitats utilized by Chinook Salmon across their life history or contributing to the formation and maintenance of Chinook Salmon habitat. Our intent is that every habitat-forming ecosystem process should be incorporated in the framework regardless of whether the process occurs upstream, upslope, or otherwise outside of habitats accessible to Chinook Salmon.

PSRITT (2014) (Unique Identifier: 094)

Reference	Puget Sound Recovery Implementation Technical Team (PSRITT). 2014. Puget Sound Chinook salmon recovery: a framework for the development of monitoring and adaptive management plans. NOAA Technical Memorandum NMFS-NWFSC-__, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** channel migration, floodplain, side and off-channels, floodplain connectivity, sediment transport and supply, substrate and sediment, large wood, estuarine habitats and landforms. ***Water Quality and Productivity:*** temperature, nutrients, dissolved oxygen, contaminants, primary productivity, secondary productivity, salinity. ***Modeling Tools:*** bioenergetics, life cycle. ***Land Use and Cover:*** floodplain. ***Fish and Habitat:*** <u>Habitat:</u> instream flow, riparian, wetlands, barriers, invasive species, freshwater, nearshore, ocean, connectivity, restoration, pocket estuary; <u>Fish:</u> abundance, distribution, competition, survival, growth, rearing, predation, life history, size structure, movement, condition, harvest, status and trends, diet.									
Species and Life Stages	***Chinook:*** full life cycle.									
Reaches and Spatial extent	Puget Sound, Skagit Bay, Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: This document was developed by the Puget Sound Recovery and Implementation Technical Team (PSRITT) to provide a formal monitoring and adaptive management framework (the framework) for assessing Puget Sound Chinook Salmon recovery. Monitoring and adaptive management have occurred at the watershed and regional scales as implementation of the Recovery Plan has proceeded. However, the lack of a formal framework has meant that there is no standardized vocabulary or shared common approach to articulate the key assumptions of the chapters in Volume II, to test assumptions across chapters, or to connect the local, watershed scale information in Volume II with the regional scale information in Volume I. This gap limits the collective ability of resource managers to assess the effectiveness of salmon recovery efforts across the region, to identify uncertainties, and to update priorities and actions in the Recovery Plan. Furthermore, the framework is intended to help salmon recovery managers formalize their local scale monitoring and adaptive management plans using a common approach.

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Ecosystem components - Species, ecological systems/habitats, or ecological processes that are chosen to represent and encompass the full suite of biodiversity in the project area for place-based conservation.

- Key ecological attributes (KEAs) - Patterns of biological structure and composition, ecological processes, environmental regimes, and other environmental constraints necessary for an ecosystem component to persist.
- Indicators - Measures of condition or status.

- Pressures - Factors delivering direct stresses to ecosystem components.
- Stresses - Altered or degraded key ecological attributes.
- Contributing factors - Factors affecting human-induced actions, events, or natural processes that are not drivers or direct pressures but that affect the condition of ecosystem components.
- Drivers - The ultimate human-induced actions, events, or natural processes that underlie or lead to one or more pressures.
- Strategies - A group of actions with a common focus designed to achieve specific objectives and goals.

These elements function as building blocks of conceptual models that describe the relationships between strategies, pressures on ecosystem components, and recovery goals and objectives in order to determine what kind and level of intervention is likely to be most effective. Open Standards includes companion software (Miradi) to create graphical depictions of these conceptual models. Miradi software is also used to develop "results chains," which are diagrams derived from the conceptual models depicting assumptions or hypotheses that link short-, medium-, and long-term actions and results in an "if…then" fashion. Development of a monitoring and adaptive management plan consistent with the framework is not contingent on the use of the Miradi software, as we recognize other data management tools may already be in use in some watersheds.

We used the scientific literature on Pacific salmon and salmonid ecosystems and also the Recovery Plan chapters to describe the elements above for Chinook Salmon in the Puget Sound region. We identify 14 ecosystem components and their associated KEAs. These ecosystem components are Chinook Salmon, the two ecosystems - freshwater habitats, and estuarine and marine habitats - used by Chinook Salmon, and finally, the species and food web processes upon which Chinook Salmon depend.

We provide example indicators of KEAs that can be tailored to the individual watershed recovery plans. The list of indicators presented in this document is provided as an example and is neither prescriptive nor all inclusive. However, we do recommend watershed managers work together to develop common indicators in order to attain a common region-wide measure of progress.

We identify linkages between major life cycle segments and events that represent the Chinook Salmon ecosystem component and the habitat ecosystem components. Each life cycle segment and event is associated with habitat types used by Chinook Salmon during particular life stages. This association is necessary to connect the habitat-related ecosystem components with the Chinook Salmon ecosystem component in the framework. The habitat-related ecosystem components are organized into a hierarchical watershed, reach, and habitat unit scale classification. These classifications are intended to include all habitats utilized by Chinook Salmon across their life history or contributing to the formation and maintenance of Chinook Salmon habitat. Our intent is that every habitat-forming ecosystem process should be incorporated in the framework regardless of whether the process occurs upstream, upslope, or otherwise outside of habitats accessible to Chinook Salmon.

PSRITT (2015) (Unique Identifier: 092)

<table>
<tr><td>**_Reference_**</td><td colspan="10">Puget Sound Recovery Implementation Technical Team (PSRITT). 2015. Puget Sound Chinook salmon recovery: a framework for the development of monitoring and adaptive management plans. NOAA Technical Memorandum NMFS-NWFSC-130, Seattle.</td></tr>
<tr><td>**_Source Information_**</td><td>**_Type_**</td><td>Report</td><td>**_Status_**</td><td>Final</td><td>**_Quantitative Data_**</td><td>Yes</td><td>**_Spatial Data_**</td><td>Yes</td><td>**_Project Related_**</td><td>No</td></tr>
<tr><td>**_Topics and Keywords_**</td><td colspan="10">**_Geomorphology and Landforms:_** channel migration, floodplain, side and off-channels, floodplain connectivity, sediment transport and supply, substrate and sediment, large wood, estuarine habitats and landforms. **_Water Quality and Productivity:_** temperature, nutrients, dissolved oxygen, contaminants, primary productivity, secondary productivity, salinity. **_Modeling Tools:_** bioenergetics, life cycle. **_Land Use and Cover:_** floodplain. **_Fish and Habitat:_** Habitat: instream flow, riparian, wetlands, barriers, invasive species, freshwater, nearshore, ocean, connectivity, restoration, pocket estuary; Fish: abundance, distribution, competition, survival, growth, rearing, predation, life history, size structure, movement, condition, harvest, status and trends, diet.</td></tr>
<tr><td>**_Species and Life Stages_**</td><td colspan="10">**_Chinook:_** full life cycle.</td></tr>
<tr><td>**_Reaches and Spatial extent_**</td><td colspan="10">Puget Sound, Skagit Bay, Skagit watershed.</td></tr>
<tr><td>**_Linkages to Hydroelectric Operations_**</td><td colspan="10">NA</td></tr>
</table>

Abstract: This technical memorandum was developed by the Puget Sound Recovery Implementation Technical Team (PS RITT) to provide a formal monitoring and adaptive management framework (hereinafter called the framework) for assessing Puget Sound Chinook Salmon recovery. Monitoring and adaptive management have occurred at the watershed and regional scales as implementation of the Recovery Plan has proceeded. However, the lack of a formal framework has meant that there is no standardized vocabulary or shared common approach to articulate the key assumptions of the chapters in Volume II, test assumptions across chapters, or connect the local, watershed-scale information in Volume II with the regional-scale information in Volume I. This gap limits the collective ability of resource managers to assess the effectiveness of salmon recovery efforts across the region, identify uncertainties, and update priorities and actions in the Recovery Plan. Furthermore, the framework is intended to help salmon recovery managers formalize their local-scale monitoring and adaptive management plans using a common approach.

We developed the framework using concepts taken from the Open Standards for the Practice of Conservation (hereinafter called Open Standards). Open Standards is a scalable, adaptable system widely used to design, manage, and monitor conservation projects. The framework builds on several interrelated categories of information, or elements. These elements are as follows:

- Ecosystem components—Species, ecological systems/habitats, or ecological processes that are chosen to represent and encompass the full suite of biodiversity in the project area for place-based conservation.
- Key ecological attributes (KEAs)—Patterns of biological structure and composition, ecological processes, environmental regimes, and other environmental constraints necessary for an ecosystem component to persist.
- Indicators—Measures of condition or status.

- Pressures—Factors delivering direct stresses to ecosystem components.
- Stresses—Altered or degraded KEAs.
- Contributing factors—Factors affecting human-induced actions, events, or natural processes that are not drivers or direct pressures, but that affect the condition of ecosystem components.
- Drivers—The ultimate human-induced actions, events, or natural processes that underlie or lead to one or more pressures.
- Strategies—A group of actions with a common focus designed to achieve specific objectives and goals.

These elements function as building blocks of conceptual models that describe the relationships between strategies, pressures on ecosystem components, and recovery goals and objectives in order to determine what kind and level of intervention is likely to be most effective. Open Standards includes companion Miradi software to create graphical depictions of these conceptual models. Miradi software is also used to develop results chains, which are diagrams derived from the conceptual models depicting assumptions or hypotheses that link short-, medium-, and long-term actions and results in an “if…then” fashion. Development of a monitoring and adaptive management plan consistent with the framework is not contingent on the use of the Miradi software, as we recognize other data management tools may already be in use in some watersheds.

We used the scientific literature on Pacific salmon and salmonid ecosystems and also the Recovery Plan chapters to describe the elements above for Chinook Salmon in the Puget Sound region. We identify 14 ecosystem components and their associated KEAs. These ecosystem components are Chinook Salmon, the two ecosystems—freshwater habitats, and estuarine and marine habitats—used by Chinook Salmon, and finally, the species and food web processes upon which these salmon depend.

We provide example indicators of KEAs that can be tailored to the individual watershed recovery plans. The list of indicators presented in this document, provided as an example, is neither prescriptive nor all inclusive. However, we do recommend that watershed managers work together to develop common indicators in order to attain a common, region-wide measure of progress.

We identify linkages between major life cycle segments and events that represent the Chinook Salmon ecosystem component and the habitat ecosystem components. Each life cycle segment and event is associated with habitat types these salmon use during particular life stages. This association is necessary to connect the habitat-related ecosystem components with the Chinook Salmon ecosystem component in the framework. The habitat-related ecosystem components are organized into hierarchical watershed-, reach-, and habitat unit–scale classifications. These classifications are intended to include all habitats utilized by Chinook Salmon across their life history or contributing to the formation and maintenance of their habitat. Our intent is that every habitat-forming ecosystem process should be incorporated in the framework regardless of whether the process occurs upstream, upslope, or otherwise outside of habitats accessible to Chinook Salmon.

Pucci et al. (2017) (Unique Identifier: 093)

Reference	Pucci, D. S., J. Selleck, B. Boyer, and A. Kagley. 2017. Juvenile salmon and nearshore fish use in Cornet Bay, Deception Pass State Park in response to beach restoration, 2009-2016. Report prepared for Island County Marine Resources Committee, Coupeville, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** salinity, dissolved oxygen, temperature. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: nearshore, restoration; Fish: movement, abundance, size structure, periodicity; Monitoring: abundance, restoration, water quality.									
Species and Life Stages	***Chum, Pink, Chinook, Coho:*** nearshore rearing and emigration. ***Other species (Cutthroat, Sculpin, Flatfishes, Forage Fishes):*** not specified.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: This report summarizes the results of beach seine fish sampling conducted for the Cornet Bay nearshore habitat restoration project, from 2009 (pre-restoration) through 2016 (post-restoration), including comparisons with natural reference sites outside of the restoration area. The Cornet Bay Day Use Area of Deception Pass State Park in Island County, Washington underwent several phases of nearshore habitat restoration from 2012 through 2015. The project, initiated in 2009 by the Island County Marine Resources Committee (IC MRC) and conducted in collaboration with Washington State Parks and the Northwest Straits Marine Conservation Foundation and the Island County Sound Water Stewards (formerly Island County Beach Watchers), includes the restoration of approximately 1.24 acres of modified shoreline to natural habitat conditions.

Shoreline modifications and fill imported on-site in the 1970s converted the upper intertidal shoreline into a flat upland bench planted with grass. The area selected for restoration contains four boat launch ramps, a T-shaped public pier used for mooring boats and fishing, and a Washington State Parks' Marine Crew maintenance pier.

Monitoring questions addressed in this report are:

(1) How does local environment vary by year, season, and spatial strata within the Cornet Bay Restoration Project?

(2) What fish species are present within the restored area?

(3) How does juvenile Chinook, Chum and Pink Salmon density vary by year and site within the Cornet Bay Restoration Project?

(4) How does density in the Cornet Bay Restoration Project compare with nearby natural pocket estuaries and outmigration populations?

(5) Can variation in juvenile Chinook, Chum and Pink Salmon outmigration timing be attributed to other environmental factors such as temperature or precipitation changes?

(6) What relationship do environmental parameters and outmigration timing have in regards to fish size?

Ramirez and Simenstad (2018) (Unique Identifier: 095)

<table>
<tr><td>Reference</td><td colspan="10">Ramirez, M., and C. Simenstad. 2018. Protocol recommendations for tracking estuary extent and restoration in Puget Sound: designed for reporting on Chinook salmon recovery common indicators and Puget Sound vital sign indicators. Report prepared for Puget Sound Partnership, Olympia, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: change, sediment transport and supply, floodplain, estuarine habitats and landforms, climate change. Modeling Tools: hydrology, bathymetry. Land Use and Cover: banks and shoreline. Fish and Habitat: <u>Habitat:</u> restoration, connectivity, barriers, riparian; <u>Monitoring:</u> habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: The purpose of this document is to offer protocol recommendations to the Chinook Salmon Recovery Lead Entities and interested parties monitoring the extent and change in estuarine habitat over time in the Puget Sound region. This report outlines topics discussed at a workshop about tracking status and change in Puget Sound estuaries in June 2017, and provides a recommended approach, including suggested data sources, for estimating the spatial extent of Puget Sound estuaries. In addition, specific protocol recommendations for measuring status and estimating estuary restoration are provided in Appendix A.

Ramirez (2018) (Unique Identifier: 097)

Reference	Ramirez, M. 2018. Shoreline armoring in Puget Sound: reporting on the Chinook salmon recovery common indicators. Report prepared for Puget Sound Partnership, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** sediment transport and supply. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: nearshore, wetlands.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: Shoreline armoring, the practice of constructing seawalls and rock revetments to stabilize coastal shorelines, has the unintended consequence of disrupting the natural process of erosion and restricts the movement of sediments. Shoreline armoring may also be used to protect coastal communities at risk of storm surges and flooding associated with accelerated sea level rise, however, the presence of these structures exacerbates the loss of nearshore and tidal wetland habitat by preventing intertidal areas from moving inland and the natural deposition of sediment, both of which help wetlands keep pace with sea level rise. For more information on shoreline armoring, see the Shoreline Armoring Vital Sign.

Feeder bluffs are eroding coastal bluffs that deliver much of the sand and gravel that maintains Puget Sound's beaches and spits and helps shape shoreline ecosystems. Armoring of these bluffs to reduce erosion disrupts this natural supply of sediment and can lead to the loss of beaches and degradation of nearshore habitat (see the Armor on Feeder Bluffs Puget Sound Vital Sign Indicator).

Puget Sound Chinook Salmon Recovery watersheds have developed 5-year Recovery Plans with companion monitoring plans that include a common set of regional indicators, referred to as the Common Indicators. Common Indicators help track the recovery status of Chinook Salmon habitat to inform recovery planning within each watershed chapter area and at the Puget Sound regional scale. This report describes the extent and attributes of shoreline armor in Puget Sound by county and salmon recovery watershed following the protocol recommendations to the Chinook Salmon Recovery Lead Entities (Figure 1). Data presented in this report are derived from the Beach Strategies Geodatabase (CGS 2017) and reproduced from the MacLennan et al. (2017) summary report.

Shoreline Armor Common Indicators:

- Extent (length) of shoreline armor
- Percent sediment source intact by drift cell

Ramirez (2019) (Unique Identifier: 096)

Reference	Ramirez, M. 2019. Estuary extent in Puget Sound: reporting on the Chinook salmon recovery estuaries common indicator. Report prepared for Puget Sound Partnership, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms, climate change. ***Modeling Tools:*** bathymetry, hydrology. ***Land Use and Cover:*** floodplain, banks and shoreline, commercial. ***Fish and Habitat:*** Habitat: riparian, barriers, connectivity, wetlands; Fish: rearing.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration, outmigration.									
Reaches and Spatial extent	Skagit estuary, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: Puget Sound Chinook Salmon Recovery watersheds have developed 5-year Recovery Plans with companion monitoring plans that include a common set of regional indicators, referred to as the Common Indicators.

Common Indicators help track the recovery status of Chinook Salmon habitat to inform recovery planning within each watershed chapter area and at the Puget Sound regional scale. The Common Indicators span the marine, terrestrial, and nearshore habitats, including an indicator related to estuary extent. This report describes a GIS approach, consistently applied across the region, to define and map the current estuary extent in Puget Sound's large river deltas and to track change in extent through periodic updates to the spatial database.

Puget Sound river deltas are critical to the recovery of the region's wild Chinook Salmon populations. During outmigration, juvenile Chinook utilize the mosaic of tidal freshwater, estuarine, and nearshore delta habitats as areas of abundant foraging and growth opportunities with relatively low predation pressure, and a physiological transition zone from freshwater to marine saltwater (Simenstad et al. 1982, Simenstad and Cordell 2000). Pervasive change has been documented in Puget Sound estuaries associated with human land uses, especially the simplification of river delta shorelines and extensive loss of estuarine wetlands (Simenstad et al. 2011). Despite habitat loss and the associated risks to estuarine dependent Chinook Salmon, there has not been an adequate system to track estuary extent and change over time in Puget Sound's large river deltas.

Ramirez (2019) (Unique Identifier: 098)

Reference	Ramirez, M. 2019. Tracking estuarine wetland restoration in Puget Sound: reporting on the Puget Sound estuaries vital sign indicator. Report prepared for Puget Sound Partnership, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** estuarine habitats and landforms. ***Land Use and Cover:*** floodplain, banks and shoreline. ***Modeling Tools:*** bathymetry, hydrology. ***Fish and Habitat:*** Habitat: restoration, connectivity, wetlands, estuary.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration.									
Reaches and Spatial extent	Puget Sound, Skagit Watershed, Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Puget Sound Vital Signs represent the overarching measures for communicating the health of Puget Sound. The indicators for each Vital Sign serve as the specific and measurable metrics of this determination. The Puget Sound Partnership (Partnership) adopted an initial collection of indicators in 2010, followed by ecosystem recovery targets in 2011. Ecosystem recovery targets are policy statements that reflect the region's commitments to and expectations for recovering Puget Sound by the year 2020. The Partnership reports on the status and trends of indicators and progress toward the targets, in collaboration with agencies and organizations throughout Puget Sound who collect, analyze, and provide the data.

Under the Puget Sound Protected and Restored Habitat Estuaries Vital Sign, the Partnership tracks an indicator for estuary restoration, including a target for restoration. Currently, the indicator is reported annually on the Partnership's Vital Sign website (www.psp.wa.gov/vitalsigns). Data are compiled primarily based on reporting of project areas in the Washington State Recreation and Conservation Office's Project Information System (PRISM) database. Project documentation in the past has been scattered and inconsistent, and mapping and survey methods were not standardized. This report describes results from a GIS-based approach, consistently applied across the region, to standardize how river delta restoration efforts are measured and reported.

The Estuary Vital Sign indicator tracks the amount of land returned to full, natural tidal flooding in Puget Sound's 16 large river deltas: Elwha, Dungeness, Quilcene, Dosewallips, Duckabush, Hamma Hamma, Skokomish, Deschutes, Nisqually, Puyallup, Duwamish, Snohomish, Stillaguamish, Skagit, Samish, and Nooksack (Figure 1). Projects that restore the full exchange of natural tidal flows are reported here and count toward the annual assessment of restored estuarine wetlands for this Vital Sign. Projects that maintain structures to regulate water level (e.g. tide gates) do not count toward the Vital Sign's assessment of restored tidal inundation, but will be tracked in the database under the qualifier that the area remains a muted system. While the replacement of older tide gates with more "fish-friendly" structures will likely improve habitat function to some degree, such tide gates are still shown to have reduced connectivity and lower Chinook Salmon densities relative to reference sites (Greene et al. 2012). Similarly, enhancement projects that improve habitat function or connectivity, but do not change the area of natural tidal inundation, will also not count toward the change in functional estuary extent.

The 2020 target for this Vital Sign is to restore 7,380 acres of estuarine wetland basin-wide.

Ramsden and Smith (2010) (Unique Identifier: 099)

Reference	Ramsden, K., and D. Smith. 2010. Suiattle River channel mapping and Forest Road 26 erosion risk analysis. Report prepared for USFS Mt. Baker-Snoqualmie National Forest.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** channel migration, change, substrate and sediment, floodplain. ***Land Use and Cover:*** land cover. ***Modeling Tools:*** bathymetry. ***Fish and Habitat:*** Habitat: instream flow.								
Species and Life Stages	***Chinook, Chum, Coho, Pink, steelhead:*** not specified. ***Other species (Cutthroat, Char):*** not specified.								
Reaches and Spatial extent	NA								
Linkages to Hydroelectric Operations	NA								

Abstract: The Suiattle River is located within the Skagit River watershed and enters the right bank of the Sauk River, the largest tributary to the Skagit River, just downstream from the Town of Darrington, WA. The Suiattle River watershed drains approximately 343 square miles, the majority of which (94 percent) falls within the jurisdiction of the U.S. Forest Service (USFS) Mt. Baker-Snoqualmie National Forest (Mt. Baker-Snoqualmie National Forest 2004). The remainder of the land ownership is primarily private and state timber interests, along with a few recreational parcels, Tribal holdings, and parcels managed for conservation purposes. Designated by Congress as a National Wild and Scenic River, the Suiattle River supports runs of Chinook, Coho, Chum, and Pink Salmon, steelhead trout, Cutthroat Trout, and native char. It also supports a genetically distinct population of Spring Chinook (SRSC and WDFW 2005).

The Suiattle River watershed is largely undeveloped and long stretches of the river undergo active and dynamic river channel migration. The main road that accesses the Suiattle River watershed is Forest Road 26 (FR26), also known as the Suiattle River Road. FR26 runs parallel to the Suiattle River for approximately 23 miles from State Route 530 to about a half mile past Sulphur Creek. The road runs in close proximity to the river along the majority of its length, in some places along a high terrace above the river and in other places along the edge of the floodplain. Active channel migration has impacted FR26 in several locations in the past, creating a road maintenance and management problem for the USFS. In addition, emergency road repairs that include rip-rap bank protection can negatively impact fish habitat by reducing edge habitat complexity (Beamer and Henderson 1998) and limiting the natural process of channel migration that can create side channels, sloughs, and other important habitats (SRSC and WDFW 2005). Over the past several decades, the river has continually eroded road embankments and bridge approaches. Information provided by the USFS (Doyle 2005) show that from 1980-2003, eight sites along FR26 that were damaged during Suiattle River flood events were funded by the Western Federal Lands Emergency Relief for Federally Owned Roads (ERFO) Program, just one of the funding sources for road repairs. Most recently, several road washouts occurred during the floods of 2003 and 2006, and the road is currently closed near milepost 12.

The USFS contracted Skagit River System Cooperative (SRSC) to assess the impact of river channel movement on FR26. The purpose of this analysis is to evaluate historic river channel

movement and development in the Suiattle River in order to help identify potential future erosion risks to FR26. Eight sets of historic aerial photographs dating from 1942 to 2007 were collected and analyzed to determine rates of historic channel movement and historic areas of erosion.

Reum et al. (2011) (Unique Identifier: 441)

Reference	Reum, J. C. P., T. E. Essington, C. M. Greene, C. A. Rice, and K. L. Fresh. 2011. Multiscale influence of climate on estuarine populations of forage fish: the role of coastal upwelling, freshwater flow and temperature. Marine Ecology Progress Series 425:203-215.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Habitat: instream flow, ocean, estuary, climate change; Fish: abundance, distribution, climate change. ***Water Quality and Productivity***: temperature, salinity, climate change.									
Species and Life Stages	***Other species:*** not specified.									
Reaches and Spatial extent	Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Abstract: We examined how local- and regional-scale environmental drivers affect patterns of abundance and recruitment in 2 abundant and ecologically significant forage fishes (Pacific herring *Clupea pallasi* and surf smelt *Hypomesus pretiosus)* in the Skagit River estuary (Puget Sound, Washington, USA). We identified associations between survey catch rates and environmental conditions at 2 scales: within-season distributional shifts in response to local environmental conditions, and interannual patterns of relative year class strength related to both local- and regional-scale drivers. Using monthly data that spanned a 9 yr period, we found that a small proportion (<2 percent) of the total deviance in catch rates for both species was related to within-estuary variation in surface water temperature and salinity but that a larger fraction (7 and 12 percent for Pacific herring and surf smelt, respectively) was explained by interannual variation in recruitment strength. Annual abundance indices for both species were uncorrelated with cumulative river discharge and regional sea surface temperature but positively correlated with an index of cumulative coastal upwelling, suggesting a linkage between regional-scale environmental conditions and age-0 recruitment. Moreover, our annual age-0 Pacific herring time series was positively correlated with a similar time series from the Strait of Georgia (~100 km north), further suggesting that age-0 recruitment in these populations is synchronized by regional upwelling as opposed to estuary-specific environmental forcing related to river flows. The present study isolates a potential key process governing age-0 forage fish abundance in this system and highlights the importance of simultaneously evaluating patterns of variability across multiple spatiotemporal scales in order to identify the primary pathways through which climate may impact estuarine populations.

Rice et al (2012) (Unique Identifier: 103)

Reference	Rice, C. A., J. J. Duda, C. M. Greene, and J. R. Karr. 2012. Geographic patterns of fishes and jellyfish in Puget Sound surface waters. Marine and Coastal Fisheries 4(1):117-128.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality and Productivity:*** temperature, salinity, turbidity. ***Land Use and Cover:*** urban. ***Modeling Tools:*** bioenergetics. ***Fish and Habitat:*** Habitat: estuary; Fish: diet, predation, status and trends, hatchery, abundance, distribution, periodicity; Monitoring: abundance, water quality.									
Species and Life Stages	***Chinook, Chum, Coho, Sockeye, Pink, steelhead:*** estuary rearing and emigration. ***Other species:*** not specified.									
Reaches and Spatial extent	Skagit Bay, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: We explored patterns of small pelagic fish assemblages and biomass of gelatinous zooplankton (jellyfish) in surface waters across four oceanographic subbasins of greater Puget Sound. Our study is the first to collect data documenting biomass of small pelagic fishes and jellyfish throughout Puget Sound; sampling was conducted opportunistically as part of a juvenile salmon survey of daytime monthly surface trawls at 52 sites during May–August 2003. Biomass composition differed spatially and temporally, but spatial differences were more distinct. Fish dominated in the two northern basins of Puget Sound, whereas jellyfish dominated in the two southern basins. Absolute and relative abundance of jellyfish, hatchery Chinook Salmon *Oncorhynchus tshawytscha*, and Chum Salmon *O. keta* decreased with increasing latitude, whereas the absolute and relative abundance of most fish species and the average fish species richness increased with latitude. The abiotic factors with the strongest relationship to biomass composition were latitude, water clarity, and sampling date. Further study is needed to understand the spatial and temporal heterogeneity in the taxonomic composition we observed in Puget Sound surface waters, especially as they relate to natural and anthropogenic influences.

Rice (2007) (Unique Identifier: 102)

Reference	Rice, C. A. 2007. Evaluating the biological condition of Puget Sound. Doctoral dissertation. University of Washington, Seattle.								
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat*: **Fish: survival, distribution, periodicity, hatchery, size structure, climate change; Habitat: nearshore. ***Land Use and Cover*:** banks and shoreline, urban.								
Species and Life Stages	***Chinook, Chum:*** nearshore rearing and emigration.								
Reaches and Spatial extent	Puget Sound, Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: Puget Sound is a biologically rich and productive fjord-estuary of high ecological and socioeconomic significance. During the last two centuries, the Puget Sound region became a major population center, full of industrial, agricultural, and forestry activity, and subjected to intensive environmental manipulation and natural resource harvest. Today we see severe and expanding human influence throughout the Puget Sound landscape, and multiple, continuing signs of biological decline. At the same time, monitoring and research to understand, protect, and recover Puget Sound is a fragmented, uneven collection of efforts, surprisingly little of which considers Puget Sound in an ecosystem context or focuses specifically on the biological effects of human activity. As a result, we have no comprehensive, coherent narrative of how the Puget System ecosystem works, how it has been affected by human activity, and what can and should be done to restore the Sound or even halt or slow its decline.

This dissertation contributes to such a narrative by briefly summarizing our understanding of the Puget Sound ecosystem in the context of human activity; by providing new research that improves that understanding; and by suggesting future directions for monitoring and research. Chapter 1 reviews the basic ecological character of Puget Sound and the history of natural resource management and environmental assessment. The next four chapters present results from several distinct research projects: a site-level assessment of effects of anthropogenic shoreline modification on beach microclimate and egg mortality in an intertidally spawning fish (Chapter 2); seasonal, geographic, and size distributions of juvenile hatchery and wild Chinook Salmon in nearshore surface waters (Chapter 3); landscape-scale characterization of pelagic macrofauna assemblage composition in nearshore surface waters (Chapter 4); and the combination and reanalysis of data from historical and ongoing assessment and monitoring programs to explore relationships between marine bird and waterfowl assemblage composition and urbanization in the adjacent terrestrial landscape (Chapter 5). Finally, Chapter 6 uses the historical context and research results of the first five chapters to outline the primary challenges in developing more effective biological monitoring and assessment programs for Puget Sound.

Riedel et al. (2010) (Unique Identifier: 388)

Reference	Riedel, J. L., J. J. Clague, and B. C. Ward. 2010. Timing and extent of early marine oxygen isotope stage 2 alpine glaciation in Skagit Valley, Washington. Quaternary Research 73:313-323.								
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, history. ***Modeling Tools:*** bathymetry.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit watershed, Finney Creek, Other upper Skagit tribs.								
Linkages to Hydroelectric Operations	NA								

Abstract: Twenty-two new radiocarbon ages from Skagit valley provide a detailed chronology of alpine glaciation during the Evans Creek stade of the Fraser Glaciation (early marine oxygen isotope stage (MIS) 2) in the Cascade Range, Washington State. Sediments at sites near Concrete, Washington, record two advances of the Baker valley glacier between ca. 30.3 and 19.5 cal ka BP, with an intervening period of glacier recession about 24.9 cal ka BP. The Baker valley glacier dammed lower Skagit valley, creating glacial Lake Concrete, which discharged around the ice dam along Finney Creek, or south into the Sauk valley. Sediments along the shores of Ross Lake in upper Skagit valley accumulated in glacial Lake Skymo after ca. 28.7 cal ka BP behind a glacier flowing out of Big Beaver valley. Horizontally laminated silt and bedded sand and gravel up to 20 m thick record as much as 8000 yr of deposition in these glacially dammed lakes. The data indicate that alpine glaciers in Skagit valley were far less extensive than previously thought. Alpine glaciers remained in advanced positions for much of the Evans Creek stade, which may have ended as early as 20.8 cal ka BP.

Riedel (2007) (Unique Identifier: 156)

Reference	Riedel, J. L. 2007. Late Pleistocene glacial and environmental history of the Skagit Valley, Washington and British Columbia. Doctoral dissertation. Simon Fraser University, British Columbia, Canada.									
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** climate change, history, change, substrate and sediment, floodplain connectivity, sediment transport and supply. ***Modeling Tools:*** bathymetry. ***Water Quality and Productivity:*** primary productivity, secondary productivity.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed, Sauk River, Baker River, Jackman Creek, Finney Creek, Other upper Skagit tribs.									
Linkages to Hydroelectric Operations	NA									

Abstract: Drainage patterns established in the Tertiary in the North Cascades were recognized to accommodate southern drainage of Cordilleran Ice Sheet meltwater. Repeated continental glaciation rendered the Skagit an interconnected valley, with meltwater routes opening it to the Fraser and Okanogan watersheds, and linking it to a drainage system around the east margin of the Puget lobe of the ice sheet.

Alpine glaciers from two major tributaries blocked Skagit valley during the late Wisconsin Evans Creek stade, creating glacial lakes Concrete and Skymo. Organic material from lake sediments provides the first radiometric constraint on the beginning of the Evans Creek stade in the Cascades about 25,040 ^{14}C yr BP. Sediments and macrofossils at the Cedar Grove section define two advances of Baker alpine glaciers during this sade, separated by warmer and wetter climate at 20,310 ^{14}C yr BP. During colder parts of the Evans Creek stade macrofossils indicate treeline was as much as 1200 ± 150m lower than present, which corresponds to a mean July temperature depression of approximately 7± 1 ℃. Glacier equilibrium line altitudes (ELA) during the cold periods were depressed 730-970 m below the modern glaciation threshold.

Skagit valley alpine glaciers advanced several times to positions 5-10 km below valley heads between 12,200 and 9,975 ^{14}C yr BP. ELA depression during these advances vary from 340 ± 100 m to 590 ± 75 m with greater depression in maritime western tributaries. Skagit ELA depression values are about 200 m less than reported for the southern North Cascades during the Sumas stade. The effect of the Cordilleran Ice Sheet on precipitation likely caused ELAs to be higher in the Skagit valley than in the southern North Cascades.

Riedel (2017) (Unique Identifier: 389)

Reference	Riedel, J. L. 2017. Deglaciation of the North Cascade Range, Washington and British Columbia from the last glacial maximum to the Holocene. Cuadernos de Investigacion Geografica 43(2):467-496.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** history, change, sediment transport and supply, substrate and sediment, climate change.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: Glacial retreat from the North Cascade Range after the Last Glacial Maximum (LGM) at approximately 21 ka until the end of the Pleistocene at 11.6 ka was complex and included both continental and alpine glaciers. Alpine valley glaciers reached their maximum extent before 21.4 ka, then underwent a punctuated retreat to valley heads. In the south, beyond the reach of ice sheet glaciation, several end moraines were deposited after the LGM. Moraines markin a re-advance of alpine glaciers to <5 km below modern glaciers were deposited from 13.7 to 11.6 ka. The Cordilleran Ice Sheet flowed south from near 52° north latitude in British Columbia into the North Cascades. At its maximum size the ice sheet covered more than 500km² and had a surface elevation of 2200m in upper Skagit valley. Deglaciation commenced about 16 ka by frontal retreat of ice flanking the mountains. Surface lowering eventually exposed regional hydrologic divides and stranded ice masses more than 1000m thick in valleys. Isolated fragments of the ice sheet disintegrated rapidly from 14.5 to 13.5 ka, with the pattern of deglaciation in each valley controlled by valley orientation, topography, and climate. Like alpine glaciers to the south, retreat of the ice sheet remnants was slowed by millennial scale climate fluctuation that produced at least one large recessional moraine, and multiple lateral moraines and kame terraces from elevations of 200-1400m in most valleys. Large volumes of glacial meltwater flowed through the North Cascades and was concentrated in the Skagit and Methow rivers. Outburst floods from deep proglacial lakes spilled across divides and down steep canyons, depositing coarse gravel terraces and alluvial fans at valley junctions. Climate at the LGM was characterized by a means summer temperature 6 to 7° cooler than today, and 40 percent lower mean annual precipitation. Persistence of this climate for thousands of years before the LGM caused a 750-1000m decrease in alpine glacier equilibrium line altitudes (ELA). In the southern North Cascades at 16 ka, glacial ELAs were 500-700m lower than today, and during advances from 13.7 to 11.6 ka alpine glacier ELAs were 200-400m lower.

Rosenkotter (2007) (Unique Identifier: 106)

Reference	Rosenkotter, B., K. Peters, D. Osterman, D. Myers, A. Nelson, L. Vigue, T. Mitchell, M. Tyler, and Cascadia Consulting Group (editors). 2007. Puget Sound nearshore project priorities: assessing consistency between local and regional strategies of the Puget Sound salmon recovery plan. Report prepared for Washington Department Fish and Wildlife, Olympia, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, estuarine habitats and landforms, floodplain connectivity, log jam. ***Water Quality and Productivity:*** temperature, dissolved oxygen, salinity. ***Land Use and Cover:*** banks and shoreline. ***Fish and Habitat:*** Habitat: nearshore, estuary, connectivity, riparian, barriers, restoration, pocket estuary, invasive species, instream flow, limiting factors, data gaps; Fish: hatchery, predation, life history, movement, size structure, harvest, periodicity, distribution, survival, abundance, data gaps, rearing; Monitoring: habitat, water quality, abundance.									
Species and Life Stages	***Chinook, Chum, Bull Trout, Pink, Coho, steelhead, Sockeye:*** nearshore rearing and emigration, spawning-rearing, rearing- outmigration, migration. ***Other species (Cutthroat, Dolly Varden, Rainbow Trout, Char, Kokanee):*** not specified.									
Reaches and Spatial extent	Skagit watershed, Puget Sound, Skagit estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: In 2006 the Washington Department of Fish and Wildlife (WDFW) funded three Puget Sound Lead Entities (King County [WRIA 9], San Juan County, and Kitsap County [West Sound Watersheds Council] to form a work group to evaluate salmon recovery actions in the nearshore. Specifically, the group was asked to analyze consistency between nearshore recovery strategies developed at two different scales of analysis in the Puget Sound Salmon Recovery Plan: fine-scale actions developed at the watershed scale, and broad strategies developed at the regional scale. WDFW hopes that this analysis will lay the foundation for the ultimate goal of developing an interim work schedule for salmon recovery actions in the Puget Sound nearshore. This analysis will be vital for the new Puget Sound Partnership in developing the 2020 Action Agenda, which will provide a "roadmap to a healthy Puget Sound." This analysis will also aid future project and funding prioritization efforts undertaken by federal, Tribal, and state resource managers, funding entities, and local watershed restoration groups.

This project grew out of needs identified during recent nearshore project funding and prioritization efforts, and because of data obtained from ongoing research on restoration science of the nearshore. The Puget Sound Nearshore Partnership is currently engaged in a sound-wide nearshore ecosystem analysis known as the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), or General Investigation Study, which is scheduled for completion in 2009. However, there is a need for guidance on early action investments in the interim. Our analysis provides guidance to resource managers and lead entities to better illuminate how individual nearshore projects align with regional nearshore priorities. Currently, lead entities and resource managers are compiling a collection of potential nearshore projects that can be implemented through various funding programs such as the Estuary and Salmon Restoration Program (ESRP). Having interim guidance on how to develop an appropriate portfolio will ensure that projects funded by ESRP and other such programs have Sound-wide strategic significance. Overall, it is hoped that by viewing local

projects in the context of Sound-wide priorities and strategies we can begin to see beyond the boundaries of individual watersheds and work to restore the whole of Puget Sound.

Rubin et al. (2018) (Unique Identifier: 107)

Reference	Rubin, S.P., M.C. Hayes, and E. E. Grossman. 2018. Juvenile Chinook salmon and forage fish use of eelgrass habitats in a diked and channelized Puget Sound river delta. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 10: 435-451.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply, estuarine habitats and landforms, nearshore habitats and landforms. ***Land Use and Cover:*** banks and shoreline. ***Water Quality and Productivity:*** temperature, salinity, turbidity, primary productivity. ***Fish and Habitat:*** Habitat: estuary, nearshore, data gaps; Fish: abundance, distribution, diet, rearing, size structure, hatchery, movement, life history; Monitoring: abundance, water quality.									
Species and Life Stages	***Chinook:*** estuary rearing and emigration, nearshore rearing and emigration, outmigration. ***Pink:*** not specified***. Coho, Chum, Other species (*****Pacific Herring, Shiner Perch, Surf Smelt, River lamprey):** estuary rearing and emigration, nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit Bay, Skagit estuary.									
Linkages to Hydroelectric Operations	NA									

Summary: This study evaluated how the presence or absence of eelgrass in the Skagit River delta fan in Skagit Bay affected the distribution and abundance of different species of fish. They found that eelgrass meadows in the deltas have the capacity to provide critical rearing habitat for fish including out-migrating juvenile Chinook, and therefore that activities such as diking and channelization that negatively impact eelgrasses could also impact fish populations. The analyses for this study involved the capture of fish with lampara nets across four different sites throughout the delta to compare abundance and body size of the four most prevalent species (Chinook Salmon, Pacific Herring, Shiner Perch, and Surf Smelt) across the sites. Comparisons were made between sites containing eelgrass and unvegetated sites, and other oceanographic condition data including temperatures, salinity, depth, and turbidity were recorded and related sample area proximity to channelized or diked features. It was found that for the three species of foraging fish, and Chinook juveniles to a lesser extent, fish were more abundant in areas containing eelgrass than unvegetated areas, and that given these findings, it is possible that conservation and restoration of Puget Sound river delta habitats containing eelgrass could be beneficial to fish species, including juvenile Chinook**.**

Information Relevant to Skagit River Relicensing: This study provides information regarding eelgrass habitat associations with fish species in Skagit Bay and the Skagit River delta, including two target species, Chinook and Pink Salmon. Alterations to the river delta are explained in the context of their effects on eelgrass, which can inform development of conceptual life history models and identification of factors affecting resource conditions in the Skagit River Relicensing SY-01 Synthesis Study Area. The appendix provides quantitative data of the number of fish caught per species and in what habitat. This data demonstrates the assemblage of fish species in Skagit Bay by eelgrass and unvegetated sites, and includes catches of Chinook, Coho, Chum, Pink, and River Lamprey as well as other non-target fish species. However, most of the results discussed are focused on Chinook, Pacific Herring, Surf Smelt, and Shiner Perch.

Geomorphology and Landforms: The Skagit River delta has been altered in many ways including river channelization, shoreline diking, and a jetty. Although efforts have been made to remove these dikes and restore habitats in some areas, the estuary environment has already experienced changes from these alterations. Since the flow of water is altered by these features, so is the sediment supply and transport. Offshore sediments have coarsened while finer sediments are carried farther away causing a prograde front of 0.5 km in the delta since the late 1800s. There is also a deposition zone north of the jetty that is a result of the disruption of tidal currents and variable bed morphology. Degradation and fragmentation of eelgrass meadows located directly offshore of distributary mouths often occurs due to the increased sediment being delivered to the depth ranges in which they occupy. The eelgrass is often buried by and/or sustains abrasions from the increased focused discharge velocities of larger quantities of moving sediment. Differences in sediment are present in areas of eelgrass as well, with mud being the primary substrate to the north of the jetty and sand being more predominant south of the jetty. The habitats offshore of the North and South Fork Skagit River differ from each other, with the North Fork having higher levels of water and sediment discharge and farther distances between river outlet and eelgrass.

Water Quality and Productivity: Water quality monitoring included water temperature (surface and bottom), depth, salinity, and turbidity. They found that water quality covaried with the proximity to channelized distributary outlets, diked shorelines, and the jetty within Skagit Bay. Averages and ranges for each of these components are reported with temperatures ranging from 9.1 - 15.8℃ (10.6℃ average April-May, and 13.1℃ average August-September); depths of 0.6 - 5.9 m (2.5 m average), salinities of 3.1 - 29.6 ppt (16.7 ppt average June-July, 26.2 ppt average Aug.-Sept.), and turbidities of 0.3 – 4 m by Secchi disk (1.8 m average June-July, 2.4 m average Aug. Sept.).

Fish and Habitat: Linear models and negative binomial models were used to test hypotheses relating to abundance, nonparametric tests were used to test hypotheses relating to differences in body size (length) of fish, and species accumulation curves were used to compare species richness between habitats. Of the Chinook sampled, 22 percent were identified as hatchery fish through the presence of a wire tag or a clipped adipose fin, and the other 78 percent were of natural origin (unmarked). Pink Salmon were also present in the study but in much smaller quantities than other fish species (less than 4 percent of the samples). There were variations by date in the use of eelgrass, location within the delta, and life stage of individuals present across the Chinook Salmon sampled in this study. Subyearlings and yearlings were both found in May, but only yearlings were found after May, and almost no Chinook were caught in April.

There were four zones chosen for sampling that vary by proximity to river outlets, underlying sediment size, and meadow morphology. Temperatures increased form Zone 1 to Zone 4 (north to south), so Zone 1 contained the coldest water with the highest levels of turbidity. Zone 1 was located north of the jetty and navigation channel, and sampling was only conducted on eelgrass vegetated areas. Zones 2-4 were located south of the navigation channel and jetty, with Zone 2 being the closest to the features, and Zone 4 being the furthest away. Samples were taken in both eelgrass vegetated and unvegetated areas in Zones 2-4, and Zone 2 contained the least mean cover in eelgrass meadows and greatest variation in cover. Also of note, Zone 2 was closest to the entrance of the North Fork Skagit River to the delta, and Zone 4 was the closest zone to the South Fork Skagit River. Generally, the results showed that there was a higher abundance of Chinook in eelgrass habitats than unvegetated habitats in Zones 3 and 4, but equal in Zone 2. Larger body sizes were also reported in Chinook found in Zones 3 and 4 with higher fish abundance in eelgrass than Chinook found in the eelgrass habitats of Zone 2 with equal distribution. These trends are similar for the 3 resident foraging fish species most prevalent in the study, with results being more amplified than those for the juvenile Chinook. Results suggest that reducing channelization and diking could positively benefit eelgrass habitats, and subsequently Chinook Salmon populations, through the reduction of discharge velocities and more even and widespread disbursement of sediment. The distribution of Chinook juveniles over particular zones of eelgrass over others can also show the habitat types that should be the focus of habitat protection or restoration efforts.

Data gaps were identified in the study, and hypotheses for future studies were provided. The two proposed hypotheses made from the findings in this study are:

"*(1) Chinook Salmon were large in zones 3 and 4 because they had been residing and growing there for an extended time, whereas salmon were smaller in zone 2 because there were new arrivals, and (2) Chinook Salmon were more abundant in eelgrass than in unvegetated habitat in zones 3 and 4 because eelgrass provided suitable rearing habitat, whereas salmon were equally abundant in eelgrass and unvegetated habitat in zone 2 because they were passing through rather than rearing."*

Although this study does show that there is a benefit to utilizing eelgrass habitat through the greater abundance of fish in eelgrass habitat as opposed to unvegetated habitats, there are more questions that must be addressed to inform management. In particular, developing a better understanding of how eelgrass habitats contribute to the productivity of a population is needed to determine the potential population level benefits of eelgrass restoration or protection strategies.

Ruggerone and Goetz (2004) (Unique Identifier: 157)

Reference	Ruggergone, G. T., and F. A. Goetz. 2004. Survival of Puget Sound Chinook salmon (Oncorhynchus tshawytscha) in response to climate-induced competition with pink salmon (Oncorhynchus gorbuscha). Canadian Journal of Fisheries and Aquatic Sciences 61:1756-1770.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: abundance, survival, competition, rearing, hatchery, density dependence, age structure, size structure, growth, climate change, harvest.									
Species and Life Stages	***Chinook, Pink:*** rearing, nearshore rearing and emigration.									
Reaches and Spatial extent	Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: We tested for competition between Pink Salmon (*Oncorhynchus gorbuscha*) and Chinook Salmon (*Oncorhynchus tshawytscha*) originating from rivers in the Puget Sound area using coded-wire-tagged subyearling hatchery Chinook Salmon. Following a 2-year life cycle, many juvenile Pink Salmon enter Puget Sound in even-numbered years, whereas few migrate during odd-numbered years. During 1984-1997, juvenile Chinook Salmon released during even-numbered years experiences 59 percent lower survival than those released during odd-numbered years, a trend consistent among 13 Chinook Salmon stocks. Lower even-numbered-year survival of Chinook Salmon was associated with reduced first-year growth and survival and delayed maturation. In contrast, Chinook Salmon released into coastal streams, where few Pink Salmon occur, did not exhibit an alternating-year pattern of survival, suggesting that the interaction occurred within Puget Sound and the lower Strait of Georgia. Unexpectedly, the survival pattern of Puget Sound Chinook Salmon was reversed prior to the 1982-1983 El Niño: Chinook Salmon survival was higher when they migrated with juvenile Pink Salmon during 1972-1983. We hypothesize that Chinook Salmon survival changed as a result of a shift from predation- to competition-based mortality in response to recent declines in predator and prey abundances and increases in Pink Salmon abundance. Alternating-year mortality accounted for most of the 50 percent decline in marine survival of Chinook Salmon between 1972-1983 and 1984-1997.

Schmidt (2012) (Unique Identifier: 300)

Reference	Schmidt, S. 2012. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Cornet Bay, 2011. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Land cover and use:*** land cover. ***Geomorphology and landforms:*** nearshore habitats and landforms. ***Water Quality and Productivity:*** salinity, temperature, dissolved oxygen. ***Fish and Habitat:*** Fish: size structure, abundance, movement.								
Species and Life Stages	***Chinook, Chum, Other species (sculpin, flatfish, herring, smelt, gunnel, greenling, stickleback, prickleback, cutthroat, perch):*** not specified.								
Reaches and Spatial extent	Skagit Bay (Cornet Bay).								
Linkages to Hydroelectric Operations	NA								

Abstract: The WSU Island County Beach Watchers are working collaboratively with the Island County Marine Resources Committee and Washington State Parks. Collecting data about juvenile salmonid use of the nearshore at Cornet Bay is a part of the characterization process of the bay prior to nearshore habitat enhancement projects that are occurring at this location. The focus of this report is on fish abundance and size in Cornet Bay in 2011. This report is meant to inform local citizens and Cornet Bay project partners about fish populations currently using the Cornet Bay area.

Seixas et al. (2019) (Unique Identifier: 484)

Reference	Seixas, G., M. Olis, D. Marks, and A. Roorbach. 2019. Stream gradient and anadromous fish use analysis.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and landforms:*** slope. ***Fish and Habitat:*** Fish: distribution; Habitat: barriers. ***Modeling tools:*** bathymetry.								
Species and Life Stages	***Coho:*** not specified.								
Reaches and Spatial extent	Skagit watershed, Samish basin.								
Linkages to Hydroelectric Operations	NA								

Abstract: The westside Indian Tribes have proposed to the Washington Forest Practices Board the inclusion of a gradient-based threshold below which streams are presumed to contain fish (anadromous floor) as part of the current water typing rule-making effort. However, there are few studies that specifically inform the relationship between stream gradients and anadromous fish distributions in western Washington. This analysis demonstrates a potential way to empirically address that data gap.

Reach gradients in 30 meter fixed-length segments in Skagit and Samish river basins streams were measured downstream from 387 Coho distribution points for five kilometers to quantify the steepest slopes Coho traversed to reach those points.

For the 91 Coho points observed with natural barriers as the termination of distribution, the median of the steepest downstream gradient was 9.2 percent. We present a range of percentiles in the Results section.

These methods and analysis can be replicated in other watersheds to expand our understanding of the relationship between stream gradients and anadromous fish distributions.

Simenstad (1982) (Unique Identifier: 110)

<table>
<tr><td>Reference</td><td colspan="10">Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of pacific salmon: an unappreciated function. Pages 343-364 in V.S. Kennedy, editor. Estuarine comparisons: Proceedings of the sixth biennial international estuarine research conference, Gleneden Beach, Oregon.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Proceedings</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: history, change, sediment transport and supply, estuarine habitats and landforms. Water Quality and Productivity: temperature, turbidity. Land Use and Cover: forestry, floodplain. Fish and Habitat: <u>Habitat:</u> estuary, nearshore, instream flow;
<u>Fish:</u> movement, periodicity, life history, rearing, predation, survival, growth, diet, status and trends, hatchery, harvest, size structure, distribution, condition, competition; <u>Monitoring:</u> biotelemetry.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Pink, Chum, Coho, Sockeye, Chinook: rearing-outmigration, estuary rearing and emigration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound, Skagit estuary, Skagit Bay.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: Washington State has approximately 100 diverse estuaries, ranging from the more classic coastal estuaries to Puget Sound, a continuum of estuaries with transitional habitats. Of the five Pacific salmon species, Chum and Chinook utilize these estuaries most extensively. Estimated residence times of individual juvenile salmon range from 4 days (Chum Salmon) to 6 months (Chinook) while individual residence times of adults from 1-6 weeks. Some salmon populations may, however, remain within Puget Sound until maturity. Juveniles of all species utilize neritic habitats, but Chum and Chinook also use shallow, sublittoral habitats. Abundant, uniquely estuarine prey organisms are eaten by juveniles of all species, although less so by Pink, Sockeye, and Coho, and contribute to high growth rates in estuaries. Significant predation on juveniles in estuaries has yet to be documented. We hypothesize that Pacific salmon use Washington's estuaries for: 1) productive foraging, 2) physiological transition, and 3) refugia from predators. These functions have probably changed due to salmon culture practices and alterations of estuarine habitat, and it is possible these changes could adversely impact salmon growth and survival. The importance of estuaries to salmon production should be more carefully considered in estuary and salmon management.

Simenstad et al. (2011) (Unique Identifier: 383)

Reference	Simenstad, C.A., M. Ramirez, J. Burke, M. Logsdon, H. Shipman, C. Tanner, J. Toft, B. Craig, C. Davis, J. Fung, P. Bloch, K. Fresh, S. Campbell, D. Myers, E. Iverson, A. Bailey, P. Schlenger, C. Kiblinger, P. Myre, W. Gerstel, and A. MacLennan. 2011. Historical change of Puget Sound shorelines: Puget Sound nearshore ecosystem project change analysis. Puget Sound Nearshore Report No. 2011-01. Report prepared by Washington Department of Fish and Wildlife, Olympia, Washington, and U.S. Army Corps of Engineers, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** change, history, sediment transport and supply, nearshore habitats and landforms. ***Land Use and Cover***: land cover, banks and shoreline. ***Fish and Habitat:*** Habitat: restoration.									
Species and Life Stages	NA									
Reaches and Spatial extent	Puget Sound (Strait of Juan De Fuca, San Juan Islands-Strait of Georgia, Hood Canal, North Central Puget Sound, Whidbey, South Central Puget Sound, South Puget Sound sub-basins).									
Linkages to Hydroelectric Operations	NA									

Abstract: The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) has conducted a comprehensive, spatially-explicit analysis (Change Analysis) of net changes to nearshore ecosystems of Puget Sound—its beaches, estuaries, and deltas—since its earliest industrial development. These quantitative changes in the structure of Puget Sound's shorelines are indicators of qualitative change to nearshore ecosystem processes. Because historical documentation of nearshore ecosystem processes does not exist per se, and certainly not uniformly across the breadth of Puget Sound, we used the observed physical changes to the shoreline, PSNERP conceptual models, and other sources of understanding about the relationship among nearshore ecosystem processes, structures, and functions to interpret the levels and types of impairment of nearshore ecosystem processes. Our approach was to systematically quantify historical change in the physical structure of Puget Sound's shorelines over the past approximately150+ yr, between the earliest land surveys of the General Land Office and U.S. Coast and Geodetic Survey (1850s–1890s) and present conditions (2000–2006). We view historical condition as an important baseline or reference point for restoration and preservation, but caution that historical condition should not be made a restoration/preservation target without considering modern constraints.

To conduct this nearshore change analysis, PSNERP's Nearshore Science Team (NST) developed a geospatial template that allows us to interpret likely changes in ecosystem processes based on historic change in structure and in the amount and types of stressors in nearshore ecosystems. This approach is predicated on the distinctive spatial arrangements of the dominant ecosystem processes along Puget Sound's beaches, estuaries, and river deltas. We delineated the Puget Sound shoreline into geomorphic segments (shoreforms) based on the PSNERP (Shipman 2008) Geomorphic Classification, which provided us with the basis for independently classifying both historical and current shoreforms that reflect varying sedimentation processes (beaches) and freshwater inflow and tidal mixing (estuaries/deltas) as the dominant controlling factors. The Puget Sound geomorphic shoreforms became one of the primary units in a geospatial hierarchy of data organized into four geographic scale units: 1) shoreforms, 2) shoreline drainage (watershed) units,

3) nearshore process units (drift cell or delta hydrogeomorphic components), and 4) larger scales of shoreline-delta organization, such as seven sub-basins of Puget Sound, distinguished by oceanographic, ecological, and other physical/natural science characteristics.

Slater (2004) (Unique Identifier: 179)

Reference	Slater, G. L. 2004. Final report: waterbird abundance and habitat use in estuarine and agricultural habitats of the Skagit and Stillaguamish River deltas. Report prepared by Ecostudies Institute for U.S. Fish and Wildlife Service, Skagit System River Cooperative, and The Nature Conservancy.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain, estuarine habitats and landforms. ***Water Quality and Productivity:*** secondary productivity. ***Land Use and Cover:*** agriculture. ***Fish and Habitat:*** Habitat: wetlands, restoration, estuary, riparian; Monitoring: restoration.								
Species and Life Stages	***Chinook:*** estuary rearing and emigration.								
Reaches and Spatial extent	Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: Coastal estuarine wetlands, with their integrated complement of tidal, nontidal, and riverine wetland habitats, are reservoirs for significant amounts of biodiversity in North America. Driven mostly by hydrological forces, these connected heterogeneous wetlands perform many valuable ecosystem functions and services, such as filtration of pollutants, retention of nutrients, and critical nursery and rearing habitat for many wildlife species, including commercially important fish (Mitsch and Gosselink 2000). Yet, significant areas of coastal wetland across North America have been lost, and continue to face increasing threats from human development (Gosselink and Baumann 1980, Mitsch and Gosselink 2000).

Coastal estuarine wetlands in the Puget Sound Trough of the Pacific Northwest, with its extensive network of rivers, have not fared better, and this is particularly evident in the Greater Skagit River Delta (GSD; Skagit, Stillaguamish, and Samish River). The GSD's fertile wetlands and wide floodplain have mostly been converted to agriculture, resulting in the loss of most tidal wetlands and all of its freshwater wetlands by the early 1900's (Collins 2000).

The loss and degradation of wetlands in the GSD has had a significant negative impact to native biodiversity, including the decline of many important fisheries, most notably salmon (Simenstad and Cordell 2000). Large populations of waterfowl and shorebirds used the tidal flats and estuarine marshlands during the winter and migration periods prior to Euro-American settlement. Although little is known about the historic composition and extent of these nonbreeding communities, it is generally accepted that populations have declined significantly (Ball et al. 1989, Drut and Buchanan 2002).

With the increasing recognition of the ecological services and functions that wetland ecosystems provide in the GSD, the decline of many wetland-dependent species, and the recent federal listing of the economically and culturally-important Chinook Salmon, many organizations and agencies are working to design and implement wetland restoration and wildlife conservation plans. In particular, restoration of estuarine habitats, especially tidal marsh, for salmon has gained substantial political momentum. Yet, some managers are concerned about potential trade-offs that may exist between management for fisheries and waterbirds, especially waterfowl.

Agricultural lands of the GSD that historically were coastal marsh are used by and often managed for waterfowl and shorebirds. However, the role that agricultural habitats play in the maintenance of waterfowl and shorebird populations is unclear. In general, the relative value of managed agricultural lands versus natural habitat has been little studied and largely unquantified, creating a significant information gap in our knowledge of waterbird ecology.

To address this information gap, we investigated the abundance and habitat use of waterfowl and shorebirds in estuarine and agricultural habitats of the GSD during the period from the end of the hunting season through spring migration. Our primary objectives were to 1) quantify the abundance of waterbirds with respect to habitat and tide, and 2) examine the relationship between habitat characteristics and waterbird use. Because we included two restored marsh sites and potential future restoration sites in this study, we are also able to provide two other important pieces of information. First, we compare waterbird abundance between restored and natural marsh sites as a preliminary assessment of the success of the restoration with regards to waterbirds. Secondly, data collected from the suite of potential restoration sites provides baseline information that can be utilized in a more rigorous statistical design to assess the specific effect of restoration on waterbird abundance.

SRSC Research Program (2014) (Unique Identifier: 173)

Reference	Skagit River System Cooperative (SRSC) Research Program. 2014. Summary of fish catch results for Bowman Reach, Bowman Lagoon, and Little Bay. Prepared by Skagit River System Cooperative Research Program, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Water Quality and Productivity:*** salinity, temperature. ***Fish and Habitat:*** Fish: abundance.								
Species and Life Stages	***Chum, Chinook, Coho:*** outmigration. ***Other species (sculpins, Cutthroat, Native Char, Shiner Perch, sticklebacks, cod, gunnel, pricklebacks, Greenlings, flat fish):*** not specified.								
Reaches and Spatial extent	Skagit Bay (Bowman Bay).								
Linkages to Hydroelectric Operations	NA								

Abstract: Bowman Beach, Bowman Lagoon and Lottie Bay are located on the northwest side of Deception Pass along Rosario Strait (Figure 1). Large and small net beach seines were used at these sites after methods described in Skagit System Cooperative (2003). Bowman Beach and Bowman Lagoon were originally sampled on April 7, 2004 as part of SRSC's study of fish use in pocket estuaries throughout the Whidbey Basin and north Skagit County bays (Beamer et al. 2006). Three small net sets were made at two locations on Bowman Beach near the lagoon (a total of six sets) and three separate sites within Bowman Lagoon were sampled by small net with one set at each location. Two additional (random) sites in Bowman Bay were sampled using a large net beach seine on August 2, 2006 and August 20, 2007. Lottie Bay was sampled over a seven year period from April 2007 through October 2013. Sixteen large net beach seine sets were made at seven different locations within the bay as part of SRSC's long term monitoring of juvenile Chinook Salmon (Greene and Beamer 2011), part of implementing the Skagit Chinook Recovery Plan (SRSC and WDFW 2005).

SRSC (2014) (Unique Identifier: 172)

Reference	Skagit River System Cooperative (SRSC). 2014. Kukutali Preserve Tombolo and Lagoon restoration feasibility. Report prepared by Skagit River System Cooperative for Swinomish Department of Environmental Protection, La Conner, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration, estuary, pocket estuary. ***Land Use and Cover:*** land cover. ***Geomorphology and landforms:*** nearshore habitats and landforms, substrate and sediment.									
Species and Life Stages	***Chinook:*** outmigration, estuary rearing and emigration. ***Other species (Surf Smelt, Sand Lace):*** not specified.									
Reaches and Spatial extent	Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Kukutali Preserve, located within Skagit Bay in Skagit County, Washington, was purchased in 2010 and is co-owned and co-managed by the Washington State Parks and Recreation Commission (State Parks) and the Swinomish Indian Tribal Community (SITC). The preserve encompasses approximately 90 acres, including an island connected to Fidalgo Island (hereafter referred to as the mainland) via a natural tombolo, along with a natural coastal lagoon and associated upslope wetlands on the mainland (Figure 1). In addition, the preserve is surrounded by approximately 11 acres of Tribally owned tidelands. The acquisition of these unique habitat features presents the opportunity to identify potential restoration actions that would benefit juvenile Chinook and other salmon. This report outlines restoration opportunities in the areas surrounding the tombolo and the lagoon/wetland complex on the mainland portion of the Preserve. A range of alternatives, including no action, will be presented for both sites so that a full range of costs and benefits can be evaluated.

Staubitz et al. (1997) (Unique Identifier: 423)

<table>
<tr><td>Reference</td><td colspan="10">Staubitz, W. W., G. C. Bortleson, S. D. Semans, A. J. Tesoriero, and R. W. Black. 1997. Water-quality assessment of the Puget Sound basin, Washington -- environmental setting and its implications for water quality aquatic biota. U.S. Geological Survey, Water Investigations Report 97-4013, Tacoma, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Land use and Cover: land cover, urban, agriculture, forestry. Geomorphology and Landforms: history, change, substrate and sediment. Water Quality and Productivity: contaminants, bacteria, turbidity. Fish and Habitat: <u>Habitat:</u> instream flow.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook, Chum, Coho, Pink, Sockeye, steelhead: not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Puget Sound.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: The Puget Sound Basin in Washington is one of 60 study units selected for water-quality assessment as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program. The Puget Sound Basin study unit encompasses the fresh surface and ground waters in the 13,700 square-mile area that drains to Puget Sound but does not include the marine waters of Puget Sound. Defining the environmental setting of the study unit is the first step in designing and conducting a multidisciplinary regional water-quality assessment. This report describes the natural and human factors that affect water quality in the basin and includes an overview of the physiography, geology, soils, surface- and ground-water hydrology, land use, instream habitat, and the aquatic ecosystem. The report also provides an overview of existing water-quality conditions and summarizes the results of selected water-quality studies of the basin. This information indicates that the quality of fresh water in the Puget Sound Basin is generally good, although in agricultural and urban areas, surface water is degraded in places by fecal-coliform bacteria, and nitrate at undesirable levels is found in some aquifers. Toxic materials from terrestrial sources also discharge to Puget Sound and accumulate in bottom sediments, and the physical hydrology, water temperature, and biologic integrity of many streams have been degraded to varying degrees by logging in the upper forested watersheds and by agricultural and urban development in the lower watersheds.

Stober et al. (1973) (Unique Identifier: 269)

Reference	Stober, Q. J., S. J. Walden, and D. T. Griggs. 1973. Juvenile salmonid migration through north Skagit Bay. Pages 35-69 *in* Q. J. Stober and E. O. Salo, editors. Ecological studies of the proposed Kiket Island Nuclear Plant site. Final report to Snohomish County P.U.D. and Seattle City Light. Fisheries Research Institute, University of Washington, Seattle.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Water Quality:*** contaminants, temperature, salinity, dissolved oxygen, turbidity. ***Fish and Habitat:*** Fish: distribution, abundance, size structure, status and trends.								
Species and Life Stages	***Pink, Chum:*** outmigration, estuary rearing and outmigration. ***Chinook:*** outmigration. ***Coho, steelhead, Sockeye, Other species (Surf Smelt, Longfin smelt, Pacific Herring):*** not specified.								
Reaches and Spatial extent	Skagit Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: The fisheries and marine ecology in the vicinity of Kiket Island, located in northern Skagit Bay, Skagit County, Washington have been investigated by the Fisheries Research Institute since 1969. This is the first thermal power site in Puget Sound on which comprehensive investigations have been conducted. A 1,000 MW_e nuclear power plant was proposed with a once through cooling system which would require about 1,500 cfs of cooling water with an increase in temperature of about 10 C (18 F). A potential environmental impact may result generally from construction activities, intake operation, biofouling control methods, hydraulic effects and thermal effects. These studies were designed to assess and predict the ecological significance of these various potential impacts upon the fisheries and marine ecology of north Skagit Bay and to develop solutions to the most critical impact.

The studies of the great variety of marine organisms at the site were divided into functional groups of organisms by association as well as those groups which may be specifically vulnerable to a particular aspect of a once-through cooling system. Study priorities were established by attention to the “worst case” which might be detrimental to the most vulnerable species with recognized importance in the sport or commercial fishery. The critical stages in the life history, size and timing as well as the relative abundance in time and space were important objectives for the species with regeneration times of one year or longer. The community ecology of the marine fishes and invertebrates was investigated in detail in order to develop baseline information upon which future changes whether natural or man caused may be assessed.

This investigation has researched the following specific areas: the seasonal changes in water quality in north Skagit Bay, juvenile salmonid migration, pelagic eggs and larval fishes, intertidal and subtidal. community ecology, marine fish species diversity, thermal effects on fish and invertebrates, toxicity of chlorine and heat, marine fouling of artificial substrates, qualitative evaluation of marine zooplankton and the potential of heated water in salmonid mariculture. The development of a 1,000 MW nuclear power plant at this site will create some localized changes in the marine ecosystem; however, the only problem of ecological significance is posed by the potential entrainment of the economically important juvenile salmonids (i.e., Pink and Chum Salmon). These species alternate in annual dominance and occur in dense numbers around Kiket Island for about three months each spring during their migration to sea. Because of their small size

[mean length about 35mm (1.4 inch)] and delicate nature, passage through the cooling system may not only cause direct mortalities but also induce some behavioral alterations among the survivors making them highly vulnerable to the natural fish predators in the Bay. An intake screening system of small enough aperture to prevent the passage of these juvenile salmonids through the plant is essential, Due to the fineness of the mesh this may require an intake screening system of unique design to avoid impingement problems usually associated with screening.

There are at least two possible approaches to the design and placement of a once through cooling intake structure in this area which would minimize the entrainment of juvenile salmon. The surface orientation of about 90 percent of the juvenile Pink, Chum, and Chinook Salmon to the upper 10 ft of the water column would logically dictate the placement of an intake equipped with a low velocity design to draw cooling water from a horizontal direction at a depth of approximately 60 ft. However, it is likely that large numbers of juvenile resident pelagic marine species (i.e., smelt and herring) or demersal marine fishes may be entrained in a deep intake and thus a fish screening and return system would be required on shore. An alternative approach is to develop a positive solution to the entrainment and impingement of larval and juvenile fishes, a problem common to all water use industries. Associated with this project has been the on-site testing of a model rapid sand filter to determine the design parameters necessary in applying this concept as a positive solution to the entrainment of larval and juvenile fishes. This work is detailed in a separate report by Stober, Hanson, and Swierkowski (1973). An engineering design concept was developed from this study by Strandberg (1972) for a high capacity sand filter which would provide an effective solution to the entrainment and impingement of small fishes and thus solve the only problem of major significance to the marine ecosystem at this site.

The predicted increased temperatures expected to result in the Bay from this 1,000 MW_e plant compared to all the thermal effects studies conducted in the on-site laboratory during the past three years on invertebrates as well as fish indicate that the increased temperatures will not be a problem of ecological significance with proper discharge design and location.

SWC (1998) (Unique Identifier: 454)

Reference	Skagit Watershed Council (SWC). 1998. Habitat protection and restoration strategy. Report prepared by Habitat Restoration and Protection Committee of Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration; Monitoring: restoration. ***Land Use and Cover:*** land cover.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Summary: This report is a restoration strategy developed for the Skagit Watershed Council (SWC) to aid in assessing and choosing high success restoration projects that will benefit salmon populations in the Skagit and Samish basins. The report goes into detail about the SWC's criteria for evaluating a potential degraded habitat and the quantitative cutoffs for categorizing habitats. Some of the habitat characteristics used in assessing are hydrology, sediment, riparian, floodplain, isolated habitat, and water quality. This report also lists the cost-effectiveness prioritization method and how projects seeking SWC funding will be evaluated and monitored (if chosen). Examples are also provided for specific project types listing the problem, examples of specific actions, monitoring implementation, and a maintenance plan.

SWC (2015) (Unique Identifier: 489)

Reference	Skagit Watershed Council (SWC). 2015. Skagit Watershed Council Year 2015 strategic approach. Report prepared by SWC, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration, estuary, pocket estuary, freshwater, status and trends, limiting factors, climate change; Fish: rearing; Monitoring: restoration. ***Geomorphology and Landforms:*** substrate and sediment.									
Species and Life Stages	***Chinook:*** rearing, estuary rearing and emigration.									
Reaches and Spatial extent	Skagit estuary, Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Skagit Watershed Council's 2015 Strategic Approach is updated from the 2005 and 2010 Strategic Approaches to provide a more focused, proactive plan for meeting the goals of the Skagit Chinook Recovery Plan (2005). The Approach has evolved since its inception as a multispecies restoration Strategy in 1998, to a Chinook-focused Strategic Approach for habitat restoration in 2005. This latest revision is motivated largely by the need to clarify a few important aspects of the 2010 version as well as new information that has become available regarding the relative importance of tributary habitats for Chinook Salmon recovery in the Skagit Watershed. Our Strategic Approach is expected to be periodically revised as information improves, short-term objectives of the Council change, and long-term goals for salmon recovery in the Skagit and Samish evolve through Council discussion and regulatory mandates (e.g., 4(d) rules, ESA status, the Puget Sound Action Agenda, etc.).

Our Strategic Approach remains committed to restoring and protecting landscape processes that will produce the long-term, sustainable recovery of habitat conditions that benefit multiple species, but it also continues to evolve to better account for significant human constraints that prevent full restoration of processes in both the delta and floodplains and with the understanding that long-term watershed health is in part dependent on the community. The Skagit Watershed Council also recognizes that habitat restoration efforts will not fully restore all historical habitats in the Skagit River basin, and that Chinook Salmon recovery is balanced against a variety of other ecosystem goods and services derived from the watershed. Hence, expected outcomes of restoration efforts should be tempered by a realistic view of human constraints that are unlikely to be removed or modified in the near future (e.g., certain dams or levees). This leads to more realistic expectations of what is possible, and a clear recognition that restoration actions in heavily constrained areas such as the lower Skagit will likely be dominated by habitat creation efforts that strive to mimic habitats that would naturally occur. An important challenge for habitat restoration in the Skagit basin is to assure that the suite of actions eventually taken is sufficient to support Chinook Salmon populations that meet the recovery goals.

SWC (2016) (Unique Identifier: 453)

Reference	Skagit Watershed Council (SWC). 2016. Skagit Watershed Council 2016 interim steelhead strategy.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration; Monitoring: restoration.									
Species and Life Stages	***steelhead, Bull trout:*** not specified.									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Summary: This memorandum builds off of the Skagit Watershed Council's 2015 Strategic Approach (Unique Identifier: 489) to include bull trout and steelhead into the SWC's strategic habitat *"priorities for habitat planning, protection, and restoration, making those projects eligible for habitat grants and incorporating them into other planning and monitoring activities."* This brief strategy documents the goals of including steelhead and how steelhead projects will not take away from Chinook Salmon priorities but will augment restoration projections. A brief overview of steelhead populations in the Puget Sound, their life history strategies, and habitats used are provided.

SWC (2017) (Unique Identifier: 452)

Reference	Skagit Watershed Council (SWC). 2017. 2017 Skagit Watershed Council projection strategy update. Report prepared by Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: restoration; Monitoring: restoration.									
Species and Life Stages	***Chinook, steelhead:*** not specified.									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: This report is intended to update and improve the voluntary conservation acquisition components of the Skagit Watershed Council (SWC) Habitat Protection and Restoration Strategy (SWC 1998) and its Application (SWC 2000). This update was developed to meet a locally-identified need to evolve our local strategy to preserve the remaining high quality habitat in the Skagit Watershed as well as to meet the required outputs of a grant (#13-1425) from the Salmon Recovery Funding Board. It should be considered an addendum to the Strategy (SWC 1998). While this product meets these needs at this time, it is also intended to be a vehicle for continued improvement in coming months and years.

The Watershed Company (2011) (Unique Identifier: 440)

Reference	The Watershed Company. August 2011. DRAFT Shoreline Analysis Report for Shorelines in Skagit County and the Towns of Lyman and Hamilton. Prepared for the Skagit County Planning and Development Services Department, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Land Use and Cover:*** banks and shoreline, land cover. ***Fish and Habitat:*** Habitat: nearshore, restoration, barriers, connectivity; Monitoring: restoration. ***Geomorphology and Landforms:*** floodplain connectivity, floodplain. ***Water quality and productivity:*** contaminants. ***Project Operations:*** flow regulation.									
Species and Life Stages	***All anadromous species*** (salmonids in general): not specified.									
Reaches and Spatial extent	Skagit Bay, Padilla Bay, Skagit watershed and Stillaguamish, Nooksack watersheds.									
Linkages to Hydroelectric Operations	***Fish and Habitat:*** Habitat: connectivity. ***Project Operations:*** flow regulation.									

Abstract: Skagit County (County) obtained a grant from the Washington Department of Ecology (Ecology) in 2010 to complete a comprehensive update of its Shoreline Master Program (SMP). The Towns of Lyman and Hamilton (Towns) are working in partnership with Skagit County to update their SMPs prepared through a coordinated process. One of the first steps of the update process is to inventory and characterize the County's shorelines as defined by the state's Shoreline Management Act (SMA) (RCW 90.58). This analysis was conducted in accordance with the Shoreline Master Program Guidelines (Guidelines, Chapter 173-26 WAC) and project Scope of Work promulgated by Ecology, and includes all unincorporated areas within the County and the incorporated Towns of Lyman and Hamilton. Under these Guidelines, the County must identify and assemble the most current, applicable, accurate and complete scientific and technical information available.

This shoreline inventory and analysis will describe existing conditions and characterize ecological functions in the shoreline jurisdiction. This assessment of *current* conditions will serve as the baseline against which the impacts of future development actions in shoreline jurisdiction will be measured. The Guidelines require that the County demonstrates that its updated SMP yields "no net loss" in shoreline ecological functions relative to the baseline (current condition) due to its implementation. The no net loss requirement is a new standard in the Guidelines that is intended to be used by local jurisdictions to test whether the updated SMP will in fact accomplish the SMA objective of protecting ecological functions.

Collected information included Watershed Resource Inventory Area (WRIA) documents, Skagit County studies, Town documents, scientific literature, personal communications, aerial photographs, internet data, and a brief physical inventory of the County and Towns' shorelines.

Timm and Roni (2017) (Unique Identifier: 024)

Reference	Timm, R., and P. Roni. 2017. Literature review of juvenile Chinook salmon densities in Puget Sound floodplain habitats. Memorandum to the Puget Sound Partnership prepared by Cramer Fish Sciences.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** floodplain. ***Fish and Habitat:*** Habitat: freshwater, wetland, restoration; Fish: abundance, distribution; Monitoring: abundance, restoration, data gaps.								
Species and Life Stages	***Chinook, steelhead, Coho, Chum, Bull Trout:*** rearing. ***Other (Cutthroat Trout, Dolly Varden):*** not specified.								
Reaches and Spatial extent	Puget Sound.								
Linkages to Hydroelectric Operations	NA								

Summary: This report presents relevant literature pertaining to Chinook Salmon densities in floodplain habitats. The literature review resulted in a total of 156 potentially useful papers with 35 of those papers containing quantitative density data for Chinook, steelhead, or Coho. These 35 references are listed in Appendix A to the document, and a table summarizing reports of Chinook density is provided. The document provides the methods used to compile the sources which included searching their internal database on global restoration effectiveness, contacting Puget Sound researchers, and searching for relevant material using Google Scholar. The results section of the report provided a brief overview of some of the information and species covered by the literature and includes some qualitative data for species densities in different floodplain habitat types. Additionally, some recommendations were provided for improvements to the database and for potential monitoring needs to mitigate the lack of information on Chinook and steelhead response to floodplain habitat restoration and Chinook use of riverine and floodplain habitats.

Timm (2016) (Unique Identifier: 025)

Reference	Timm, R. 2016. Puget Sound marine nearshore salmon ecology literature review. Report to the Puget Sound Partnership prepared by Cramer Fish Sciences.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Habitat: nearshore, estuary, pocket estuary, climate change; Fish: survival, growth, rearing, abundance, distribution. ***Water Quality and Productivity***: temperature, climate change, primary productivity, secondary productivity, contaminants, data gaps. ***Land Use and Cover***: banks and shoreline.									
Species and Life Stages	***Chinook***: nearshore rearing and emigration.									
Reaches and Spatial extent	Skagit estuary, Skagit Bay, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Summary: The following pages present a comprehensive literature review summarizing published and unpublished works and information on nearshore salmon recovery in Puget Sound from 2005 to mid-2016. The results of this effort include a data gap assessment, a discussion of findings and implications, and finally an annotated bibliography (attached as Appendix A) that includes a complete citation of each work and a paragraph summarizing the study and results. The summary of data gaps presented in this section is based on the enumeration of records categorized by major topic areas in the bibliographic search results. Finally, the findings and implications section presents responses to specific questions that are critical to understanding the nearshore ecology of Puget Sound and the ways in which ESA-listed salmonids use and derive benefit from these habitats.

Timm (2017) (Unique Identifier: 026)

<table>
<tr><td>Reference</td><td colspan="10">Timm, R. 2017. WRIA 6 Marine nearshore literature review. Memorandum to the Salmon Recovery Lead Entity, Island County Department of Natural Resources prepared by Cramer Fish Sciences.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>No</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: estuarine habitats and landforms, substrate and sediment, sediment transport and supply. Water Quality and Productivity: primary productivity, temperature, salinity, dissolved oxygen. Fish and Habitat: <u>Habitat:</u> nearshore, pocket estuary, estuary, restoration, connectivity, limiting factors, barriers, ocean, climate change; <u>Fish:</u> rearing, distribution, abundance; <u>Monitoring:</u> abundance, habitat.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: estuary rearing and emigration, nearshore rearing and emigration, outmigration. Coho, Chum: estuary rearing and emigration, nearshore rearing and emigration, spawning, outmigration. Pink, Bull Trout, steelhead: estuary rearing and emigration, nearshore rearing and emigration. Other (Cutthroat Trout, Shiner Perch, Staghorn Sculpin, Starry Flounder, Stickleback): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit Bay, Skagit estuary.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">NA</td></tr>
</table>

Abstract: It is well known that during the lifetime of salmon, the highest mortality often occurs when they are juveniles. Of major concern is that period when they are transitioning from their home rivers and estuaries to feed and grow in the ocean (Quinn 2005). However, the watersheds of Watershed Resource Inventory Area (WRIA) 6 in Island County are comprised of small streams that are generally too small to support much salmon spawning. This means that the marine nearshore habitats, small stream pocket estuaries, and the small streams themselves provide vital transition habitat for outmigrating juveniles from the large rivers draining to the Whidbey Basin (Zackey et al. 2015). Because biotic and abiotic changes in the nearshore marine environment are implicated in the status of imperiled fish populations, the WRIA 6 salmon recovery strategies are centered on protecting the diverse marine nearshore and estuarine habitats near major rivers. This approach is consistent with larger salmon recovery efforts in Puget Sound. Since the publication of the Puget Sound Chinook Recovery Plan (Shared Strategy Development Committee 2007), three guiding questions have directed salmon recovery efforts in the nearshore marine environment:

(1) Are we protecting the right places?

(2) How do we know what is "enough" habitat to recover salmon in the marine environment?

(3) How do we develop and implement solutions that work for fish and people?

The purpose of this document is to evaluate the literature specific to the Whidbey Basin including WRIA 6 to determine if recent information on salmon ecology in the nearshore marine environment help answer the questions presented in the Recovery Plan. WRIA 6 staff provided a set of local studies relevant to the nearshore conditions of the WRIA and the value for salmonid fishes that use them. All of the studies provided are included referenced in the document. The full list of is provided in the References section at the end. This review is undertaken as a complimentary companion document to the literature review that was performed for the Puget

Sound Partnership on the marine nearshore ecology of Puget Sound. The intent is to determine if information contained in these studies can aid the WRIA in answering seven specific questions that are thought to be important for updating the WRIA 6 Salmon Recovery Plan. We first provide a general summary of literature and studies specific to the Whidbey Basin. We then provide answers to these questions following the literature review section.

Toft et al. (2021) (Unique Identifier: 515)

Reference	Toft, J. D., M. N. Dethier, E. R. Howe, E. V. Buckner, and J. R. Cordell. 2021. Effectiveness of Living Shorelines in the Salish Sea. Ecological Engineering 167:106255.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Habitat: nearshore, restoration. ***Land Use and Cover***: banks and shoreline.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay, Puget Sound.									
Linkages to Hydroelectric Operations	NA									

Abstract: In human-impacted coastal ecosystems, living shorelines are becoming a common restoration technique. However, we lack a comprehensive understanding of the ecological and physical benefits, and how they could inform management needs. To address this, we studied effectiveness of living shorelines at a broad spatial scale within the Washington State boundaries of the Salish Sea, USA, with restored site ages spanning 1–11 years. We surveyed 30 beaches at ten locations, each with three strata of: (1) living shoreline beaches with armor removed, (2) armored control beaches altered by seawalls or riprap, and (3) un-armored reference beaches with natural conditions. We sampled eight physical and biological attributes: beach wrack, wrack invertebrates, sediments, terrestrial insects, riparian vegetation, logs, beach profiles, and stable isotope signatures of talitrid amphipods – generating 27 metrics focusing on upper intertidal and supratidal elevations affected by armoring and targeted by living shoreline actions. These metrics spanned the functions of beach stability, ecological diversity, and food web support for juvenile salmon. Statistical tests showed that 19 of the 27 metrics had significant strata differences, indicating that some beach metrics restore quickly (e.g., wrack accumulation), while others take longer (e.g., log accumulation). Terrestrial-associated metrics were higher at reference beaches, but insect taxa richness and logs with plant growth increased at beaches restored for four or more years (the average age of the living shoreline sites). This implies that certain living shoreline functions increase through time, providing improved food web support. Globally, trajectories of restoration have shown a range of functional improvement with time, and will be important to monitor for nature-based solutions to coastal defense given the increasing rate of shoreline stressors from global change and sea level rise.

USFWS (2004) (Unique Identifier: 479)

Reference	U.S. Fish and Wildlife Service (USFWS). 2004. Draft recovery plan for the coastal-Puget Sound distinct population segment of bull trout (Salvelinus confluentus): Volume I (of II) Puget Sound Management Unit. Report prepared by U.S. Fish and Wildlife Service, Portland, Oregon.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: limiting factors, barriers; Monitoring: abundance, water quality, flow, data gaps; Fish: diet, distribution, abundance, life history, status and trends, data gaps. ***Project Operations:*** flow regulation, downramping, life stage flows. ***Geomorphology and Landforms:*** substrate and sediment, sediment transport and supply. ***Land Use and Cover:*** land cover, forestry, agriculture, urban, floodplain, roads.								
Species and Life Stages	***Bull Trout:*** full life cycle.								
Reaches and Spatial extent	Puget Sound (including Chilliwack, Nooksack, Lower Skagit, Upper Skagit, Stillaguamish, Snohomish-Skykomish, Chester Morse Lake, and Puyallup basins).								
Linkages to Hydroelectric Operations	***Project Operations:*** flow regulation. ***Fish and Habitat:*** Habitat: barriers.								

Abstract: The Puget Sound Management Unit is one of two management units comprising the Coastal-Puget Sound Distinct Population Segment of Bull Trout (*Salvelinus confluentus*). The overall recovery implementation strategy for the Coastal-Puget Sound Distinct Population Segment is to integrate with ongoing Tribal, state, local, and federal management and partnership efforts at the watershed or regional scales. This coordination will maximize the opportunity for complementary actions, eliminate redundancy, and make the best use of available resources for bull trout and salmon recovery.

USGS (1916) (Unique Identifier: 431)

Reference	U.S. Geological Survey (USGS). 1916. Profile surveys in 1915 in Skagit River Basin, WA. Water Supply Bulletin 419.								
Source Information	***Type***	Dataset	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: instream flow. ***Geomorphology and Landforms:*** slope, substrate and sediment.								
Species and Life Stages	NA								
Reaches and Spatial extent	Skagit watershed.								
Linkages to Hydroelectric Operations	NA								

Abstract: In order to determine the location of undeveloped water powers, the United States Geological Survey has from time to time, alone and in cooperation with State organizations, made surveys and profiles of some of the rivers of the United States that are adapted to the development of power by low or medium heads of 20 to 100 feet.

The surveys are made by means of plane table and stadia. Elevations are based on heights derived from primary or precise levels of the United States Geological Survey. The maps are made in the field and show not only the outlines of the riverbanks, the islands, the positions of rapids, falls, shoals, and existing dams, and the crossings of all ferries and roads, but the contours of banks to an elevation high enough to indicate the possibility of using the stream. The elevations of the benchmarks left are noted on the field sheets in their proper positions. The figures given with the gaging stations shown on the maps indicate the elevation of the zero of the gage.

Veldhuisen (2000) (Unique Identifier: 168)

Reference	Veldhuisen, C. 2000. Preliminary results and recommendations from the Northwest Cascades type 4/5 stream study. Report by Skagit System Cooperative, Sedro-Woolley, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Fish and Habitat:*** Habitat: instream flow, riparian.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: The following report presents selected study results that are relevant to regulatory water typing of non-fish-bearing streams in northwestern Washington. It was developed to make this information available prior to finalization of permanent Forest Practices Rules, expected to occur in winter 2000/'01. More specifically, results describe the distribution of perennial and seasonally flowing reaches, the key attribute distinguishing Type 4 waters, which require partial buffering during timber harvest, from Type 5 waters, which do not. A subsequent report that covers this and other issues related to the implementation of new rules governing protection along non-fish-bearing streams will be written and made available in early 2001.

Among the primary objectives of this study was evaluating the applicability of the Emergency Rule default criteria for defining the upper extent of Type 4 waters in the northwest Cascades. For all areas west of the Cascades (exclusive of the coastal spruce zone), the present Emergency Rules (March 20, 1999 version) define the Type 4/5 break as the most upstream point of perennial flow. Except in cases where a distinct "perennial initiation point" is apparent, perennial flow is assumed to occur where the contributing basin size exceeds 52-acres (see WAC 222-16-010 – "perennial initiation point" definition). Concerns regarding the widespread applicability of the 52-acre threshold arose primarily because the data supporting that threshold were collected within southwestern Washington only (Mike Liquori, geomorphologist, International Paper Company, personal communication). The need for local validation of the default acreages was recognized in the Forests and Fish Report, which indicates that basin size thresholds are "subject to review through adaptive management" (Appendix B. II- B.1 [e][iii]).

Veldhuisen (2004) (Unique Identifier: 165)

Reference	Veldhuisen, C. 2004. Summary of headwater perennial stream surveys in the Skagit and neighboring basins: 2001-2003. Report by Skagit River System Cooperative, Sedro-Woolley, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** substrate and sediment. ***Fish and Habitat:*** Habitat: instream flow.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: The location of perennial and seasonal reaches of non-fish-bearing streams in Washington timberlands has been of particular interest during and since the development of the Forest and Fish Report (FFR) in 1998. Under the current Washington Forest Practices Rules (WFPB 2001), modified to conform to the FFR in 2001, perennial reaches ("type Np waters") receive greater protection from forest practices than do seasonal reaches ("type Ns waters"). In the context of water typing, the Np type applies to any waters as downstream of the highest surface flow, regardless of whether or not all intervening reaches have year-around surface flow. The FFR provides cursory field criteria and basin area methods for field application of water types, though the scientific basis for default basin areas has been questioned.

An improved understanding of flow regimes and associated basin areas of headwater streams was the goal of previous studies by the Skagit System Cooperative (SSC) in northwest Washington (Veldhuisen 2000) and similar recent studies (e.g., Liquori 2001, MacCracken and Boyd 2002, Pleus et al. 2003, Jaeger 2004) elsewhere in Washington. SSC participated in the 2001 CMER perennial stream study (Palmquist 2003) and the findings from the 25 SSC sites were analyzed among 200+ sites visited by the many cooperators involved. This document summarizes the 2001 SSC results to provide more detailed analysis of the SSC data set and to provide context for subsequent observations at the same headwater sites in 2002 and 2003. Our objectives in 2002 and 2003 were to evaluate year-to-year differences in the spatial distribution of dry season surface flow. In particular, we were interested in relocating the highest surface water in each channel (AKA "Pd" in CMER study), which indicates the regulatory break between type Np and Ns waters.

Wang et al. (2020) (Unique Identifier: 424)

Reference	Wang, C. J., H. A. Schaller, K. C. Coates, M. C. Hayes, and R. K. Rose. 2020. Climate change vulnerability assessment for Pacific lamprey in rivers of the western United States. Journal of Freshwater Ecology 35(1): 29-55.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Fish: climate change; Habitat: instream flow, climate change, restoration. ***Modeling Tools***: climate change. ***Water Quality and Productivity***: temperature.									
Species and Life Stages	***Pacific Lamprey***: not specified.									
Reaches and Spatial extent	Skagit watershed.									
Linkages to Hydroelectric Operations	NA									

Abstract: Pacific Lamprey (*Entosphenus tridentatus*) are a native anadromous species that, like salmon, historically returned to spawn in large numbers in watersheds along the west coast of the United States (U.S.). Lamprey play a vital role in river ecosystems and are one of the oldest vertebrates that have persisted over time likely influencing the evolution of many aquatic species. Pacific Lamprey have declined in abundance and are restricted in distribution throughout Washington, Oregon, Idaho and California. A key uncertainty influencing Pacific Lamprey status is the impact of climate change. We modified the NatureServe Climate Change Vulnerability Index (CCVI) to accommodate climate predictions from the International Panel on Climate Change. Using downscaled information, we characterized changes in 15 rivers occupied by Pacific Lamprey in the western U.S. We evaluated this risk under Representative Concentration Pathways (RCP) 4.5 and 8.5 for two time periods (mid-century 2040–2069 and end-century 2070–2099). The CCVI scores generally increased when going from RCP 4.5 to RCP 8.5 in three Global Climate Models for both mid-century and end-century, which our analyses forecasts degraded stream temperature and hydrologic conditions under increasing greenhouse gas emissions. The geographically assessed results suggest that climate change impacts to Pacific Lamprey vulnerability are magnified in highly altered rivers. If we continue to observe greenhouse gas emission levels associated with the RCP 8.5, Pacific Lamprey will be at greater risk to climate change impacts. In order to mitigate the risk from climate change toward the end of the century, additional actions will need to be prioritized to rapidly reduce the impact of these threats such as increasing flow, creating backwater habitat, restoring riparian vegetation and reducing stream disturbances. The findings revealed the patterns of vulnerability for Pacific Lamprey across their U.S. range are informative for prioritizing river restoration actions when paired with regional implementation plans.

Weinerman et al. (2012) (Unique Identifier: 342)

Reference	Weinerman, M., M. Buckley, and S. Reich. 2012. Socioeconomic benefits of the Fisher Slough restoration project. Prepared by ECONorthwest for The Nature Conservancy and National Oceanic and Atmospheric Administration.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Fish and Habitat***: Habitat: estuary, wetlands. ***Land Use and Cover***: banks and shoreline.								
Species and Life Stages	***Chinook, Coho***, C***hum***: not specified.								
Reaches and Spatial extent	Skagit estuary.								
Linkages to Hydroelectric Operations	NA								

Abstract: The Fisher Slough Tidal Marsh Restoration Project (the Project), completed in the fall of 2011, restored tidal wetlands and improved flood storage capacity within the Skagit River Delta in northwestern Washington. The Project, made possible by a partnership between The Nature Conservancy (TNC), Skagit County, Western Washington Agricultural Association (WWAA), local dike and drainage districts, and neighboring farmers, restored about 60 acres of freshwater tidal marsh, improved fish passage to 15 miles of salmon spawning and rearing stream habitat, and improved flood storage capacity to reduce flood damage in the lowland reaches of the 23-square mile watershed. About $5.7 million of the Project's total cost of $7.7 million1 was funded from the National Oceanic and Atmospheric Administration (NOAA) through the American Recovery and Reinvestment Act.

The Project is expected to produce a wide range of benefits for fish and wildlife, farmers, and residents of communities in the Skagit River Delta. This is the first habitat restoration action to occur on private land within the Skagit Delta. In addition to restoring habitat for threatened salmon species, a goal of the project was to improve flood protection for the surrounding agricultural community, showing how farms and fish habitat can coexist on the landscape. As the Project neared completion, TNC and NOAA asked ECONorthwest (ECONW) to quantify the benefits that would accrue to the community, including farmers, local governments, and local residents. This report presents our findings. Other sources describe the benefits of the Project associated with salmon restoration, improved ecosystem function, and the number of jobs and amount of income the Project generated for workers and the local community.2 Our findings should be taken together with these other benefits and economic impacts to understand the full range of economic effects the Project will generate.

Our analysis focuses on the Project's socioeconomic benefits enjoyed by those who live and work within and upstream of the Project, including farmers, local governments, and residents.3 These benefits arise as investments in the Project and improve the types of capital that farmers and the communities rely on to produce goods and services. These types of capital include physical resources we often think of as inputs to the production of goods and services: infrastructure (human-built capital) and land and water (natural capital). The Project also may produce benefits by improving other types of capital, including the social relationships and institutional

arrangements needed to solve problems and accomplish broader community goals (social capital), and people's skills and knowledge (human capital).

With this broad understanding of the types of effects the Project may generate that would benefit farmers and the broader community, we use available data to quantify the effects over the next 50 years. A focus group of farmers, dike and drainage district managers, local government officials, and other stakeholders identified the major categories of benefits they would expect to see from the Project. Through the focus group and subsequent interviews, the following benefits were identified as likely outcomes of the Project:

- New drainage and irrigation infrastructure is likely to require less frequent and less expensive investments in annual operation and maintenance (O&M), reduced energy costs, and reduced dredging costs, reducing farmers' and other landowners' annual operating expenses.
- Reduced flooding decreases damage to crops from rot, washouts, and pests, increasing farmers' annual income.
- Reduced flooding may allow farmers to plant higher-valued crops, including vegetable seed, increasing farmers' annual income.
- Reduced risk of large flood events may allow farmers to invest in permanent structures, such as greenhouses, that could facilitate the production of higher valued crops, increasing farmers' annual income.
- Improved flood storage capacity likely reduces damage to transportation infrastructure, residential and commercial structures, and other property downstream and upstream.
- Restored tidal marsh habitat counts toward the obligations to create salmon habitat in the Skagit River Basin under the Skagit Delta Tidegates and Fish Initiative (TFI) Implementation Agreement, reducing the overall costs to provide habitat as farmers and other landowners maintain infrastructure and regulatory predictability.
- Newly forged productive working relationships among stakeholders enhance the social capital available to solve community problems in the future.
- Expanded expertise and knowledge of tidal wetland restoration in the Skagit River delta has the potential to reduce the costs and increase the success of future Projects in the region.

To quantify these benefits, we surveyed literature and data sources as well as interviewed many of the focus group participants to obtain sources of data related to the benefits described during the focus group. We also worked with a geotechnical and environmental expert to develop additional sources of data. Some of the benefits are not as readily quantifiable as others, so where data are not available, relying on our conversations with each stakeholder, we describe how and when the benefits would arise and to whom they would accrue.

West Coast Chinook Salmon Biological Review Team (1997) (Unique Identifier: 119)

<table>
<tr><td>Reference</td><td colspan="10">West Coast Chinook Salmon Biological Review Team. 1997. Review of the Status of Chinook Salmon (Oncorhynchus tshawytscha) from Washington, Oregon, California, and Idaho under the U.S. Endangered Species Act.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>Yes</td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology and Landforms: sediment transport and supply, history, change, substrate and sediment, large wood. Water Quality and Productivity: temperature, nutrients, contaminants, bacteria. Land Use and Cover: forestry, agriculture, floodplain, urban, commercial. Fish and Habitat: <u>Habitat:</u> barriers, instream flow, riparian, capacity, freshwater, estuary, ocean;
<u>Fish:</u> life history, size structure, movement, periodicity, status and trends, abundance, hatchery, competition, age structure, growth, rearing, survival, fecundity, condition, distribution, climate change; <u>Monitoring:</u> genetics, abundance, biotelemetry, scale or otoliths.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">Chinook: full life cycle. steelhead, Chum, Coho, Sockeye, Pink, Other species (Cutthroat, Masu): not specified.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Skagit watershed, Puget Sound.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="10">Geomorphology and Landforms: sediment transport and supply. Water Quality and Productivity: temperature. Fish and Habitat: <u>Habitat:</u> instream flow.</td></tr>
</table>

Abstract: In 1994, the National Marine Fisheries Service (NMFS) received a petition (PRO-salmon 1994) requesting the listing of four populations of Chinook Salmon (Oncorhynchus tshawytscha) in Puget Sound as threatened or endangered species under the federal Endangered Species Act (ESA). In response to this petition and the more general concerns for the status of Pacific salmon throughout the region, NMFS announced that it would initiate ESA status reviews for all species and populations of anadromous salmonids in the states of Washington, Idaho, Oregon, and California. Subsequently, NMFS received a petition (ONRC and Nawa 1995) to list all Chinook Salmon south of British Columbia under the ESA. The ESA allows the listing of “distinct population segments” of vertebrates as well as named species and subspecies. The policy of the NMFS on this issue for anadromous Pacific salmonids is that a population will be considered “distinct” for purposes of the ESA if it represents an evolutionarily significant unit (ESU) of the species as a whole. To be considered an ESU, a population or group of populations must 1) be substantially reproductively isolated from other populations, and 2) contribute substantially to the ecological or genetic diversity of the biological species. Once an ESU is identified, a variety of factors related to population abundance are considered in determining whether a listing is warranted.

West Coast Chinook Salmon ESUs: Previous status reviews conducted by the NMFS have identified three ESUs of Chinook Salmon in the Columbia River: Snake River fall-run (Waples et al. 1991), Snake River spring- and summer-run (Matthews and Waples 1991), and mid-Columbia River summer- and fall-run Chinook Salmon (Waknitz et al. 1995). In addition, prior to development of the ESU policy, the NMFS recognized Sacramento River winter Chinook Salmon as a "distinct population segment" under the ESA (NMFS 1987). In reviewing the biological and ecological information concerning west coast Chinook Salmon, the Biological Review Team (BRT) identified 11 additional ESUs for Chinook Salmon from Washington, Oregon, and California. Genetic data (from protein electrophoresis and DNA analysis) and tagging information were key factors considered for the reproductive isolation criterion, supplemented by inferences

about barriers to migration created by natural features. Life-history differences were another important consideration in the designation of ESUs. The BRT utilized the classification system developed by Healey (1983, 1991) to describe the two races of Chinook Salmon: 1) ocean-type populations which typically migrate to seawater in their first year of life and spend most of their oceanic life in coastal waters, and 2) stream-type populations which migrate to sea as yearlings and often make extensive oceanic migrations. Genetic differences, as measured by variation in allozymes, indicate that the ocean- and stream-type races represent two major (and presumably monophyletic) evolutionary lineages. A number of additional factors were considered to be important in evaluations of ecological/genetic diversity, with data on life-history characteristics (especially ocean distribution, time of freshwater entry, age at smoltification and at maturation) and geographic, hydrological, and environmental characteristics being particularly informative.

Assessment of Extinction Risk: The ESA (section 3) defines the term “endangered species” as “any species which is in danger of extinction throughout all or a significant portion of its range.” The term “threatened species” is defined as “any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.” According to the ESA, the determination as to whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. For the purposes of this review, the BRT did not evaluate likely or possible effects of conservation measures and therefore did not make recommendations as to whether identified ESUs should be listed as threatened or endangered species. The BRT did, however, draw scientific conclusions about the risk of extinction faced by ESUs under the assumption that present conditions will continue. With respect to the 11 newly-identified ESUs, the BRT concluded that two (Sacramento River Spring Run and Upper Columbia River Spring Run) are at risk of extinction, primarily due to seriously depressed abundance. Five ESUs (Central Valley Fall Run, Southern Oregon and California Coast, Puget Sound, Lower Columbia River, and Upper Willamette River) are at risk of becoming endangered, due to a variety of factors. Only four ESUs (Upper Klamath and Trinity xxi Rivers, Oregon Coast, Washington Coast, and Middle Columbia River Spring Run) are not at risk of extinction or endangerment.

Whidbey Basin (2004) (Unique Identifier: 158)

Reference	Whidbey Basin. 2004. DRAFT Sub-basin summary: regional nearshore and marine chapter of the Puget Sound salmon recovery plan. Report prepared for Shared Strategy for Puget Sound, Seattle, Washington.								
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	No	***Spatial Data***	No	***Project Related***	No
Topics and Keywords	***Geomorphology and Landforms:*** nearshore habitat and landforms. ***Land Use and Cover:*** land cover, banks and shoreline. ***Fish and Habitat:*** Habitat: restoration.								
Species and Life Stages	***Chinook:*** outmigration.								
Reaches and Spatial extent	Skagit Bay (Whidbey Basin), Padilla Bay.								
Linkages to Hydroelectric Operations	NA								

Abstract: This document summarizes discussions between the Puget Sound Technical Recovery Team (TRT), NOAA Fisheries scientists, the Puget Sound Action Team (PSAT) and Shared Strategy staff about salmon recovery in the Whidbey Basin. People with an interest in this areas should also review the recommendations provided to watershed planning groups in the Shared Strategy Feedback for Decision Makers (October 2004) and the Technical Feedback from the TRT (November 2004). The nearshore and marine chapter of the recovery plan which is under development will expand upon the information in this summary and will provide the scientific foundation for the following recommendations. This summary is intended to help regional and watershed planning groups synthesize the technical and policy information that has been compiled to date and stimulate policy discussions on the conditions that are necessary to implement actions that will support recovery in the nearshore and marine environments.

Whiting et al. (2017) (Unique Identifier: 509)

Reference	Whiting, J. M., T. Wang, T. P. Khangaonkar. 2017. Hydrodynamic model development and application for restoration alternatives assessment - Skagit Delta Hydrodynamic Modeling Project (SHDM). Report prepared for The Nature Conservancy by Pacific Northwest National Laboratory, Seattle, Washington.									
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Modeling Tools:*** hydrology, bathymetry, climate change. ***Land Use and Cover:*** land cover, banks and shoreline. ***Fish and Habitat:*** Habitat: instream flow, restoration. ***Water Quality and Productivity:*** salinity.									
Species and Life Stages	***Chinook:*** outmigration.									
Reaches and Spatial extent	R14-R13, Skagit Bay.									
Linkages to Hydroelectric Operations	NA									

Abstract: The Farm, Fish, and Flood Initiative (3FI) aims to create and advance mutually beneficial strategies that support the long-term viability of agriculture and salmon while reducing the risk of destructive floods. The Skagit Hydrodynamic Model Project (SHDM Project), which contributes to and is supported by 3FI, is a landscape-scale alternatives analysis design to help identify multiple-interest projects. The Nature Conservancy (TNC), The National Oceanic and Atmospheric Administration (NOAA), and the Washington Department of Fish and Wildlife (WDFW) are the project leads working with a larger SHDM team that comprised of representatives from conservation, agriculture, and flood risk reduction interests. The SHDM team has identified goals that further three interests, thereby creating a suite of objectives for providing juvenile Chinook habitat, reducing flood risk and reducing impacts to agriculture. Performing an advanced assessment of planned restoration projects can determine which projects have the potential to provide benefits to all parties while minimizing impacts. Projects were assessed with hydrodynamic modeling, geographic information system (GIS) analysis, and estimation of potential Chinook Salmon benefits through two mathematical models developed by the Skagit Rivers System Cooperative (SRSC). This report covers the development and application of the hydrodynamic model component of this analysis.

The SHDM team identified 23 potential projects within the Skagit River delta region. Three types of potential projects were assessed: (1) dike setbacks or removals that allow for tidal inundation and the construction of new dikes built to a higher standard, (2) hydraulic projects that change the flow pattern by excavating new channels to distribute flow across the landscape, and (3) backwater channels where an existing channel within existing dikes is altered to increase backwater flow. Most of these project concepts were identified and described in the Skagit River Chinook Recovery Plan (CRP), and many include further refinements from planning processes such as the Puget Sound Nearshore Estuary Restoration Project (PSNERP) and individual project sponsor actions. Additional project concepts were pulled from the Skagit River Flood General Investigation or developed by the SHDM team.

For this assessment, researchers at the Pacific Northwest National Laboratory (PNNL) developed a three-dimensional hydrodynamic model of the Skagit River delta region based on a prior version

of the model developed at PNNL. The model is based on the Finite Volume Community Ocean Model (FVCOM), which solves the three-dimensional momentum, continuity, temperature, salinity, and density equations in an integral form by computing fluxes between non-overlapping, horizontal, and triangular control volumes. The new unstructured grid is the highest resolution yet produced by the PNNL modeling group for the Skagit River delta; it consists of 131,471 elements that vary in size from 400 meters (1,312 feet) to less than 10 meters (33 feet). Bathymetry was updated with recent Lidar and boat-based surveys available from sources including the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE). Skagit River flow was determined by a USGS gauge near Mount Vernon and the flow distribution between North and South Forks of the river were calibrated with five short-term stage gauges maintained by WDFW. The model was forced with tides and resulting outputs were validated against the WDFW and SRSC monitoring stations. Simulations were conducted over a 7-month period from November 2014 through May 2015, which coincided with the WDFW and SRSC stream gauge deployment and encompassed several 2-year floods and a majority of the fish outmigration period.

A total of 7 model simulations were planned to assess 22 of the 23 potential projects in the Skagit River delta. Projects were grouped so that the effects of each project would be isolated and quantifiable. This allowed small projects to be grouped, while some very large projects were simulated as stand-alone cases. Each simulation generated a set of deliverables including inundation area calculations, cumulative frequency plots for water surface elevation, distribution of water depths across the project site, stage-discharge curves, and GIS plots for depth of inundation, change in water surface elevation, change in bed shear stress, and change in salinity.

Following this initial assessment, the SHDM Team identified a group of selected projects for a simulation to assess cumulative impacts. Cumulative effects are an important and often overlooked element in restoration planning, as restored area can alter the tidal prism or hydraulics in a way that changes the viability of other projects. Avon-Swinomish Bypass and NF Left Bank Levee Setback A were excluded because they had significantly high levels of impact when compared to other projects.

Two more simulations were then conducted to assess the response of restoration projects to future climate change. The modeled future conditions included 0.57 m (1.87 ft) of sea level rise and a 2080 Skagit River hydrograph corresponding to the moderate emissions scenario (A1B-IPCC). This addresses questions about the longevity of restoration projects.

The hydrodynamic analysis was a progressive application addressing landscape-wide interactions and the resiliency of projects under future conditions. Results objectively inform the potential of individual projects to provide multiple benefits while minimizing potential impacts. In the future, sub-models can be nested within the larger model to inform engineering design by detailing how hydraulics are expected to change. Ranking of potential projects and judging the viability of each project will be reserved for separate publications by TNC, NOAA, and WDFW. This report seeks to exclusively explain methods and results.

Yang and Khangaonkar (2006) (Unique Identifier: 455)

Reference	Yang, Z., and T. Khangaonkar. 2006. Hydrologic and hydrodynamic modeling of the Skagit River Estuary - Rawlins Road restoration feasibility study. Report prepared by Battle for Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	Links
Topics and Keywords	***Fish and Habitat:*** Habitat: estuary, connectivity, restoration. ***Modeling Tools:*** hydrology, bathymetry. ***Land Use and Cover:*** banks and shoreline, agriculture. ***Project Operations:*** flow regulation.									
Species and Life Stages	***Chinook:*** not specified.									
Reaches and Spatial extent	Skagit estuary, Skagit Bay.									
Linkages to Hydroelectric Operations	***Project Operations:*** flow regulation. ***Fish and Habitat:*** Habitat: connectivity.									

Abstract: The Skagit Watershed Council (SWC) initiated the *Rawlins Road Restoration Feasibility Study* to evaluate the potential for improving habitat for migrating salmonids along the bayfront region of the Skagit River delta. The bayfront region of interest includes the mudflats and marsh habitat located adjacent to the dike on the seaward side. Fir Island is the region of the Skagit River delta enclosed inside a long perimeter dike that was constructed nearly 150 years ago for agriculture and flood protection. Historically, the Skagit River delta has provided rich estuarine and freshwater habit for salmon and other fish and wildlife. However, construction of the perimeter dike around the delta isolated Fir Island between the North and South Forks of the Skagit River and eliminated the pathways of freshwater and natural sediment to the mudflats and tidal marsh areas.

In a collaborative effort between the affected parties represented by the Western Washington Agricultural Association and the project sponsors including the Washington Department of Fish and Wildlife, Seattle City Light, and Skagit River System Cooperative in a technical advisory role, SWC selected the northwest corner of Fir Island as the target of this feasibility study. The region north of Browns Slough and around Rawlins Road tide gate became the focus of the *Rawlins Road Restoration Feasibility Study*. The expectation was that restoration alternatives in this region would have minimum impact on the agricultural lands, allow repair of the leaking tide gates, and provide additional benefit of improved drainage along with restoration of habitat.

Battelle's Marine Sciences Laboratory (Battelle) conducted a hydrologic and hydrodynamic assessment in support of SWC's efforts to evaluate the feasibility of achieving restoration goals through modifications of the Fir Island dike near the Rawlins Road project site at the northwest corner of the delta. The study had four major goals that included restoring marsh habitat, improving salinity conditions in the nearshore habitat, increasing conveyance and passage, and minimizing impact on current land use. In addition, the project team saw this as an opportunity to improve drainage conditions in the farmland interior of the Fir Island dikes.

Battelle developed predictive numerical models for the Skagit River estuary, Skagit Bay and the Fir Island watershed associated with the Rawlins Road study area. The hydrodynamic model was constructed using the Finite Volume Coastal Ocean Model (FVCOM) developed by the University of Massachusetts. The hydrodynamic model was driven by a combination of tides, freshwater

discharge, and surface-wind stresses. The model was set up using observed tide, current, and salinity data collected for this study for a period of 14 days. The hydrologic models included the U.S Army Corps of Engineers HEC-HMS model to provide runoff from rainfall and the UNET model, which routed flows in the agricultural drainage canals interior to the Fir Island dikes. Both models were calibrated to data collected in the summer of 2005. The models were then applied for five different alternatives that looked at cross-island diversions, breaches, and dike removals near the Rawlins Road study area.

Specific restoration alternatives that were evaluated as part of this study are as follows.

- Alternative 1: Creating a diversion/channel at the northwest corner of Fir Island along the existing dike to connect the North Fork of the Skagit River to Skagit Bay.
- Alternative 2: Reconnecting the North Fork of the Skagit River through a diversion channel to Skagit Bay along the existing Hall Slough channel through a tide gate.
- Alternative 3: Constructing a dike setback at the northwest corner of Fir Island to provide more tidal marsh area for salmon habitat.
- Alternative 4: Constructing a natural opening of channel near the mouth of the North Fork of the Skagit River to investigate the effect of channel modification on nearshore salinity distribution.
- Alternative 5: Reconnecting the North Fork through a diversion to Skagit Bay along the existing Browns Slough Channel by breaching the existing dike at the North Fork end.

A complete relative comparison of the effectiveness of these alternatives has not been performed. Qualitative assessment of the results indicates that it is feasible to improve salinities and conveyance along the bayfront of the Fir Island dike by making modifications to the North Fork branch of the Skagit River. In its current state, the North Fork of the Skagit River is constrained on either side by dikes that direct the flow of freshwater away from the target habitat in the bayfront region. Diversions and dike modifications showed considerable potential for the water to be re-directed towards the bayfront for restoration of the marsh habitat.

Alternatives 1 and 4 address modifications outside the dike. While these alternatives would cause minimal impacts to landowners, their locations are at the northwest corner of Fir Island, and the beneficial effects would likely not reach the middle part of the Fir Island bayfront.

Alternatives 2 and 5 are based on the concept of constructing channels that would convey freshwater and nutrients from the North Fork to the bayfront region. The model simulations indicate very promising results with these for reducing salinity and providing conveyance for migrating fish. Also, these alternatives provide flexibility in the placement of the outlet along the bayfront dike.

Alternative 3 involves a dike setback and reducing the existing Fir Island dike section to grade. This would produce a significant change in the hydrodynamic behavior of the system. While it appears to provide the greatest restoration benefit in terms of volume of freshwater conveyed from the North Fork, it caused reduced velocities downstream of the dike set back. Flows in the South Fork were also reduced due to increased flow being drawn through the North Fork.

The study also showed that drainage issues currently faced by the Fir Island agricultural community could be addressed effectively as part of the restoration efforts through modifications, repair, maintenance of canals, and hydraulic structures that control the routing and distribution of flows in the system.

Yang and Wang (2015) (Unique Identifier: 510)

Reference	Yang, Z., and T. Wang. 2015. Responses of estuarine circulation and salinity to the loss of intertidal flats - a modeling study. Continental Shelf Research 111:159-173.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Related***	No
Topics and Keywords	***Fish and Habitat:*** Habitat: estuary. ***Water Quality and Productivity:*** salinity. ***Modeling tools:*** hydrology, bathymetry.									
Species and Life Stages	NA									
Reaches and Spatial extent	Skagit Bay, Skagit estuary (including the greater Whidbey basin).									
Linkages to Hydroelectric Operations	NA									

Abstract: Intertidal flats in estuaries are coastal wetlands that provide critical marine habitats to support wide ranges of marine species. Over the last century many estuarine systems have experienced significant loss of intertidal flats due to anthropogenic impacts. This paper presents a modeling study conducted to investigate the responses of estuarine hydrodynamics to the loss of intertidal flats in Whidbey Basin of Puget Sound on the northwest coast of North America. Changes in salinity intrusion limits in the estuaries, salinity stratification, and circulation in intertidal flats and estuaries were evaluated by comparing model results under the existing baseline condition and the no-flat condition. Model results showed that loss of intertidal flats results in an increase in salinity intrusion, stronger mixing, and a phase shift in salinity and velocity fields in the bay front areas. Model results also indicated that loss of intertidal flats enhances two-layer circulation, especially the bottom water intrusion. Loss of intertidal flats increases the mean salinity but reduces the salinity range in the subtidal flats over a tidal cycle because of increased mixing. Salinity intrusion limits extend upstream in all three major rivers discharging into Whidbey Basin when no intertidal flats are present. Changes in salinity intrusion and estuarine circulation patterns due to loss of intertidal flats affect the nearshore habitat and water quality in estuaries and potentially increase risk of coastal hazards, such as storm surge and coastal flooding. Lastly, model results suggested the importance of including intertidal flats and the wetting-and-drying process in hydrodynamic simulations when intertidal flats are present in the model domain.

Zimmerman (2012) (Unique Identifier: 432)

<table>
<tr><td>Reference</td><td colspan="8">Zimmerman, M. 2012. 2012 Wild coho forecasts for Puget Sound, Washington coast, and lower Columbia. Report prepared by Washington Department of Fish & Wildlife, Olympia, Washington.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td>Project Related</td><td>No</td></tr>
<tr><td>Topics and Keywords</td><td colspan="8">Fish and Habitat: <u>Fish:</u> abundance, survival, harvest; <u>Monitoring:</u> abundance, flow. Modeling Tools: data gaps, adult returns, juvenile production.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="8">Coho: outmigration, migration.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="8">Skagit watershed, as well as Stillaguamish, Snohomish, Green, Nisqually, Deschutes rivers, Lake Washington tributaries and Hood Canal, Puget Sound, Washington Coast, and Lower Columbia.</td></tr>
<tr><td>Linkages to Hydroelectric Operations</td><td colspan="8">NA</td></tr>
</table>

Abstract: Run size forecasts for wild Coho stocks are an important part of the pre-season planning process for Washington State salmon fisheries. Accurate forecasts at the level of management units are needed to ensure adequate spawning escapements, realize harvest benefits, and achieve harvest allocation goals.

Wild Coho run sizes (adult ocean recruits) have been predicted using various approaches across Washington's Coho producing systems. Methods that rely on the relationship between adult escapement and resulting run sizes are problematic due to inaccurate escapement estimates and difficulty allocating fishery catches by stock. In addition, escapement-based Coho forecasts often have no predictive value because watersheds become fully seeded at low spawner abundances (Bradford et al. 2000). Furthermore, different variables in the freshwater (Lawson et al. 2004; Sharma and Hilborn 2001) and marine environments (Logerwell et al. 2003; Nickelson 1986; Ryding and Skalski 1999) influence Coho survival and recruitment to the next life stage. Therefore, the accuracy of Coho run size forecasts should be improved by partitioning recruitment into freshwater production and marine survival. In this forecast, wild Coho run sizes (adult ocean recruits) are the product of smolt production and marine survival and are expressed in a matrix that combines these two components. This approach is similar to that used to predict hatchery returns where the starting population (number of smolts released) is known.

Freshwater production, or smolt abundance, is measured as the number of Coho smolts leaving freshwater at the conclusion of the freshwater life stage. The Washington Department of Fish and Wildlife (WDFW) and Tribal natural resource departments have made substantial investments in monitoring smolt populations in order to assess escapement goals and improve run size forecasts. Long-term studies on wild Coho populations have been used to identify environmental variables contributing to freshwater production (e.g., low summer flows, Pink Salmon escapement, watershed gradient). For stocks where smolt abundance is not measured, smolt production is estimated by using the identified correlated to extrapolate information from neighboring or comparable watersheds.

Marine survival is survival from saltwater entry through the ocean rearing phase to the point that harvest begins. Marine survival for a given stock is measured by summing Coho harvest and escapement and dividing by smolt production. Marine survival rates for wild Coho stocks have been measured at four stations in Puget Sound and at one station in the Grays Harbor system. Harvest of wild Coho produced by these watersheds is measured by releasing a known number of coded-wire tagged wild Coho smolts and compiling their recoveries in coastwide fisheries. Coastwide recoveries are compiled from the Regional Mark Processing Center database (www.rpmc.org). Tags in returning spawners are enumerated at upstream trapping structures. Results from these monitoring stations describe patterns in survival among years and watersheds. These patterns are used to predict marine survival of the wild Coho cohort that is currently recruiting into the fisheries. For stocks where marine survival is not measured, adult ocean recruits are predicted by extrapolating information from neighboring or comparable watersheds.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT H

OTHER SOURCES

1.0 OVERVIEW

This attachment provides sources that were identified and screened but not included in the annotated bibliographies. These references are provided to support future studies and are organized by sources that provide information not directly related to the Skagit River basin (**Out of Basin**) and those that provide information for the Skagit River basin but are not specific to the study area for the Synthesis Study (**Out of Study Area**). This attachment also provides sources that were screened but superseded by a more recent report on the same study (**Previous Reports**), citations for websites and data (**Websites and Data**), studies that are in progress that will be useful for future studies (**Future Studies**), and studies that were screened but deemed irrelevant to the Synthesis Study (**Not Relevant**).

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SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT I

IDENTIFIED DATA GAPS

1.0 OVERVIEW

This attachment provides information synthesized from the literature review that pertains to data gaps and monitoring needs identified in sources. Depending on the year of the study or publication, data gaps and monitoring needs may or may not have been addressed by more recent studies, and information is organized into topical areas that follow the topics of interest for the SY-01 Synthesis and Integration of Available Information on Resources in the Lower Skagit River (Synthesis Study) and life stage factors identified in Steps 2-3. This information is intended to support the identification of key uncertainties in Step 4 of the Synthesis Study.

2.0 INSTREAM FLOWS

Instream flows in the study area for the Synthesis Study are influenced by regulated flows from the upper Skagit River Project operations as well as dams on the Baker River, and unregulated flows from the Sauk River and many other tributary systems throughout the Skagit River basin. Many studies have looked at Project operations impacts on resource conditions in the upper Skagit River, where the effects of Project operations are thought to be most prevalent. However, few studies have directly evaluated or quantified the effects of Project operations on flows and resource condition in the lower Skagit River Synthesis study area (Reaches R7 – R15). Zimmerman (2012, ID432) identified that further research is needed in order to identify alternate metrics that would improve the precision for forecasting in flow-based modeling, and hydrodynamic models are a potential tool that could support evaluation of unregulated tributaries and Project operations in the lower Skagit River.

Connor and Pflug (2004, ID385) provides an analysis of how changes in flow associated with implementation of flow management measures in 1981 were related to patterns of abundance and distribution of Pink, Chum, and Chinook spawners in the upper Skagit River, but their study only extended to Reaches R8-R7. In addition, their analysis used flow metrics based on discharge at the U.S. Geological Survey (USGS) gaging station for the Skagit River at Newhalem (number 12178000), which is upstream of the study area for the Synthesis Study and does not account for the contribution of flow from the Sauk River or other tributaries that could attenuate flow effects from Project operations. Connor and Pflug (2004, ID385) found that the linkage between Project operations and patterns of abundance and distribution attenuated downstream within their study that extended to Reach R8, but it is unclear how these patterns change downstream of Reach R8 given that they identified a pattern of attenuating effects with increasing distance from the Project.

Multiple studies identified data gaps for instream flow monitoring in unregulated tributaries to the lower Skagit River. Herrera Environmental (2017, ID427) noted that limited-to-no hydrology data was available for Carey Creek to develop recurrence intervals because it is an ungaged tributary. Beamer et al. (2000, ID190) indicated that instream flows are identified as important landscape processes, and impervious surface cover is used as a proxy for identifying potential impairments to hydrology in lowland habitats, but the authors recommend incorporation of field-collected hydrologic records and field-verification of hydrological modeling to evaluate peak flow impairments more accurately. However, the authors recommend long-term monitoring of unregulated sub-basins in the Skagit River watershed to help evaluate peak flow impairments, and they provide a map of mountain basins with likely impairments to peak flows that could be used to help identify sub-basins for long-term monitoring, which includes tributaries to the lower Skagit River.

Beamer et al (2005, ID 305) also noted that data on the flood history for unregulated mountain sub-basins in the Skagit watershed limited analyses to identify changes in peak flow through gages with long periods of record. Multiple studies used models to estimate flows or flow impairments in tributaries to the lower Skagit River. Veldhuisen and Haight (2003, ID 164) developed regression models and recommended the development of regressions for additional tributaries that are outside a 59 inch to 125 inch range of precipitation zones.

Smith (2003, ID376) indicated that no information was found regarding low flow conditions or impacts of low flows, and the report identifies this as a significant data gap in the lower Skagit Rivera and its tributaries. Smith (2003, ID376) identified several data gaps related to water quantity that included: (1) monitor low flow conditions in the tributaries to the lower Skagit River; (2) assess surface water withdrawals associated with the lower Skagit River and tributaries; (3) analyze the impacts of high flow to salmonid production in the mainstem Skagit River and larger tributaries; and (4) assess effects of exchanges to and from hyporheic zones. Lawrence (2008, ID071) also indicated that actual water withdrawals at any given time from streams in the lower Skagit River are not known, and these limit our understanding of low flow conditions and the effects of low flow conditions on resources. Lee and Hamlet (2011, ID196) reported that no published studies existed that addressed the impacts of climate change on groundwater resources in the Skagit River basin. In addition, detailed estimates of SLR impacts on low lying areas of the Skagit River valley were not available.

Graybill et al. (1979, ID259) speculate that if rearing habitat is limited then fry remaining after stranding events due to flow fluctuations may have higher survival, but no studies could corroborate at the time. Stranding experiments in a semi-controlled study at Big Beef Creek experimental station indicated that older Chinook fry may strand at lower rates than younger fry, thus suggesting that fry “learn” to avoid stranding during flow events (Graybill et al. 1979, ID 259). However, inconclusive and contradictory results were obtained during the same study and point to a need for further research on this subject.

3.0 HABITAT EXTENT AND CONNECTIVITY

3.1 River habitats

Beamer et al. (2000, ID 191) reported that freshwater capacity will likely constrain production at some point, but habitat inventories and continued monitoring are needed to support evaluation of freshwater rearing habitat limitations on freshwater Chinook capacity and productivity. Freshwater limitations on outmigrant productivity and life history diversity were later confirmed by subsequent work (e.g., see Beamer et al. 2005, ID005; Beamer et al. 2005, ID004; Greene et al. 2021, ID056).

NWFSC (2003, ID 087) identified a general lack of understanding of what influences salmonid abundance across multiple spatial scales in river habitats. More understanding is needed on how landscape variables influence salmonid abundance at the reach scale. Connor et al. (2015, ID413) noted that gradients were calculated at a scale that was not biologically relevant to fish, resulting in a data limitation. . The use of more precise tools such as LiDAR or direct measures could be used to fill the data gaps. They also note the need for a complete dataset that identifies floodplains associated with tributaries. Bilby and Villarin (2009, ID392) stated that there was a lack of data on fish abundance particularly for juvenile abundance at the reach scale. In addition, there are few long records for smolt production at select locations, and the most consistent data is on migrating adult salmon that are difficult to compare to freshwater habitat conditions. Beechie et al (2001, ID 365) stated that there is insufficient data in the literature to quantify Coho Salmon use of habitats in large rivers. Mickelson (2009, ID290) suggests that further research is needed to determine the timing and volume of actual stream flows, substrate composition, and other factors that can influence the likelihood of occupation by spawning Coho once fish access is restored to stream channels. Beamer et al. (2005, ID004) identified a need to improve understanding of yearling movement patterns and habitat preferences in freshwater habitats.

Edge type and cover can significantly influence habitat use patterns for the target fish species. Beamer and Henderson (1998, ID181) identified several specific data gaps and monitoring needs relating to the influence of edge conditions on fish habitat use and preference including the following questions:

- How do wood cover types vary among hydromodified and natural bank edges, and how do these change over time in the context of wood recruitment and supply?
- Do wetted widths of edge units vary among natural and hydromodified bank edge units? This is based on the hypothesis that hydromodified bank edges are hydraulicly smoother and would therefore have a narrower low velocity edge that would reduce the area of the bank unit.
- Evaluation of Chum habitat use was limited due to sample sizes, and more sampling of boulder and aquatic cover types would improve our understanding of how fish use bank cover types.
- Recommend more studies of capture efficiency for electrofishing to improve estimates of abundance and reduce bias in estimates.

Beamer et al. (2000, ID190) indicated that SRSC has completed bank inventories for all large river main channel areas of the Skagit River, but no reference to mapping tributary channels or intervals for updating these data are provided.

In addition to edge habitats, Beechie et al. (2005, ID 014) identified a data gap for juvenile salmon use of large river midchannel habitat types due to the difficulties of sampling with traditional methods (electrofishing and snorkeling) due to depth and velocities. Smith (2003, ID376) indicated that a lack of large wood and pool habitat was a potential concern, but a general lack of instream tributary habitat data are noted in their report. Marks et al. (2004, ID084) recommended that the existing water type map to be updated by DNR through a system that adds accurate fish and water information as they are submitted, and a more accurate hydrology map for Washington be created to model fish distributions.

3.2 Floodplain and refuge habitats

ESA et al. (2019) suggested that data gaps are present through a lack of quality floodplain mapping data above anadromous fish barriers and on tributaries and through a lack of accurate connectivity data in many areas. Beamer et al. (2005, ID004) identified a need for improved estimates of floodplain habitat losses from historical reconstructions, and Timm and Roni (2017, ID024) identified a lack of information pertaining to the response of Chinook and steelhead to different floodplain restoration techniques as well as the use of data on seasonal chinook use of riverine and floodplain habitats. It is suggested that more data should be collected for both topics for both the Puget Sound and the West Coast.

Roni et al. (2006, ID104) identified the need for research into how different floodplain habitat types are used as refuge from high flows and how that might contribute to smolt production at multiple spatial scales. Connor et al. (2015, ID413) also noted that there were data limitations for floodplains associated with tributaries. Smith (2003, ID376) reported multiple data needs for floodplain habitats including: (1) identify and prioritize floodplain habitat for restoration and protection; (2) study fish habitat in the alluvial fans to determine the importance of this habitat to salmonid production in the Skagit River basin; (3) monitor the effectiveness of human created off-channel habitat; and (4) investigate the impacts of floodplain alterations (such as dikes) on hydrologic connections, such as the hyporheic zone.

3.3 Estuary habitats

Slater (2004, ID179) proposed that the existing non-tidal wetland and surrogate habitats within the greater Skagit delta be identified and described along with the factors related to their persistence. Beamer et al. (2015, ID008) indicated that the unvegetated Skagit tidal delta habitats need to be digitized because they are known to be changing. However, Lee and Hamlet (2011, ID196) reported that it is unknown whether SLR will result in marsh habitat accretion (due to coastal sediment erosion) or net marsh loss. Beamer et al. (2015, ID008) indicated that GIS layers need to be created for tidal delta habitat extent, distributary and blind channel extent, tidal delta progradation rate, and the tidal delta habitat connectivity/fragmentation. However, many of these layers have been addressed in recent mapping for ongoing habitat status and trends monitoring associated with the Skagit Intensively Monitored Watershed (IMW) project.

Beamer et al. (2019, ID 013) made recommendations for future directions for the Skagit IMW project including continued implementation of the study design that includes:

- Annual monitoring at local scale (restoration project) and population scale (Skagit estuary) of juvenile fish, including metrics for abundance, timing, and body size. Fish monitoring should include specifically designed elements for sub-system level treatment effects.
- Update estuary habitat conditions and connectivity as necessary. Restoration is ongoing in the Skagit estuary. Changes to habitat conditions should be measured post-restoration projects. Natural changes to the estuary should be updated approximately every five years.

Redman et al. (2005, ID 100) suggests that more study is needed on delta fry (fry that rear in the natal delta before migrating into marine zones),especially with respect to movement within and between habitats, and the effects of flow regimens, tidal cycles, and estuarine geomorphology on fry distribution. Later works published have addressed these data gaps to some extent through continued monitoring associated with the Skagit IMW (see Greene et al. 2021, ID056 for most recent discussion of this topic).

Greene (2018, ID045) also provided directions for future research to improve knowledge of delta habitat use by fry, testing GIS accuracy and fish habitat use assumptions through ground-truthing maps of habitat types, and incorporating variable survival by habitat type through the coupling of restoration with population experiments. Questions to address in future research were*: what habitats are being used by fry*, and w*hat structural and dynamic habitat features best predict presence, abundance, and extended use by fry*?

Redman et al. (2005, ID 100) indicated that off-channel habitats, such as tidal marshes, that are only accessible at high tide cause fish to redistribute every time the tide ebbs and flows. It is unknown what constitutes sufficient low tide refuge in these situations. Availability of suitable refuge habitats and the degree of connectivity with marsh channels may be an important understudied feature of estuary habitat use in juvenile salmon. Redman et al. (2005, ID 100) also indicated that it is unknown what prompts juvenile Chinook Salmon to eventually leave delta habitats. Two competing hypotheses attempt to explain the mechanism. One is that residence time and emigration are size dependent. Another hypothesis suggests that emigration is primarily driven by temperature changes within the estuary. Greene et al. (2021, ID056) also provide a hypothesis for density dependent processes controlling estuary residency patterns.

Greene et al. (2021, ID056) provided a series of nested hypotheses for landscape connectivity which are identified as needing further research. These hypotheses included: (1) distance of migration pathways best predicts fish density; (2) complexity of migration pathways best predicts fish density; (3) the combination of distance and complexity of migration pathways best predicts fish density; and (4) distance, complexity, and accumulation of rearing habitat best predicts fish density. In addition, uncertainties over the spatiotemporal dynamics of density dependent processes in estuaries are in need of additional study. Better understanding of these dynamics can help to determine the effects of hatchery releases and large outmigration cohorts on natural origin Chinook habitat use within estuaries.

Smith (2003, ID376) reported multiple data gaps and monitoring needs for WRIA 3 estuary habitat conditions that included:

- Analyze potential causes of water quality problems in slough habitat to determine the best course of action to restore functional water quality. This would include tidal flux, riparian conditions, sedimentation, flow, and inputs from agriculture and urban land use;
- Regularly monitor water quality conditions that pertain to salmonids in the South Fork and North Fork Skagit River distributaries;
- Develop a prioritization process for addressing fish blockages (tidegates) within the estuarine areas;
- Assess the effects of tidegates including historic and current habitat quality and quantity; and
- Identify areas for LWD restoration in the estuarine environment.

Redman et al. (2005, ID 100) indicate that it is not well understood how non-native submerged plants, such as Eurasian water milfoil and purple loosestrife affect salmon in estuaries, salt marshes, and in pocket estuaries. Hood et al. (2018, ID143) also identified a need to understand how juvenile salmon use marsh surface of cattail and shrub zones for foraging, how marsh surface diets vary seasonally, and how goose grazing negatively or positively affects salmon use of marsh surfaces. Beamer et al. (2005, ID175) also identified a data gap for understanding the role of beavers in the tidal delta, which was later addressed in Hood (2007, ID061) and Hood (2012, ID144).

Beamer et al. (2018, ID213) suggested future monitoring of estuary habitat conditions, fish population, and vegetation in previously restored sites over multiple years to better understand how fish respond to the changes over time. Two research questions were specifically proposed in the report:

(1) Will the magnitude of the effects of density dependent processes regulating habitat use by juvenile Chinook Salmon decline as the restored habitat becomes more naturally vegetated and (presumably) on-site prey production increases?

(2) Furthermore, will the productivity of juvenile Chinook using the site increase as the site's vegetation matures?

Lastly, it was suggested that the site differences of Fir Island Farms be compared to those of other monitored restoration sites in order to determine the site characteristics that are most beneficial to restoration projects over time.

Hood (204, ID140) stated that "greater aerial coverage is needed to monitor likely downstream progradation effects and other indirect effects on channel geometry, and it would also be useful to get such photos in early spring (at low tide) before shrubs and trees leaf-out and before cattail, sedge, and other herbaceous vegetation have gotten too thick so that smaller tidal channels can be better detected and mapped." Monitoring other parameters were also identified including sedimentation rates, neuston abundance, detritus decomposition rates, and various soil quality parameters. The report also suggested these planning measures should ideally be applied to a delta-scale instead of the site-scale approach that has historically been taken.

3.4 Nearshore habitats

Smith (2003, ID376) indicate that less is known about how alterations to nearshore habitats impact salmonids, and therefore there is more uncertainty regarding the benefits or restoration actions. A future study is designed to specifically address this (WCET 2022, ID518) and the Skagit IMW has attempted to address some of these questions (Beamer et al. 2019, ID013). CGS (2020) suggests the development of several datasets to support the restoration and protection of Puget Sound nearshore systems. The suggested datasets included comprehensive mapping of the bluff crest, linking shoreforms and elevations (bluffs and low-lying features), structure setback distances to inform feasibility assessment, and vertical land movement and relative sea level rise throughout the region.

Smith (2003, ID376) reported multiple data gaps and monitoring needs for WRIA 3 nearshore habitat conditions that included:

- Develop a process that will prioritize nearshore areas for protection or restoration of salmonid and forage fish habitat;
- Monitor potential sediment contamination in the sloughs that drain into Skagit and Padilla Bays;
- Analyze and identify impacts to salmonids from boat and marina pollution and the sediment contamination in the March Point area; and
- Determine the linkage of forage fish production to Skagit Basin salmonid productivity.

Redman et al. (2005, ID100) also identified several data gaps relating to processes that regulate nearshore marine habitats in Puget Sound that included:

- The role of marine riparian zones in contributing organic matter, nutrients, and food across the terrestrial-nearshore interface;
- Historic distribution of habitats in Puget Sound and the processes that create and maintain them;
- Functional state of fringing eelgrass beds and eelgrass meadows within Puget Sound;
- Need for improved understanding of ecosystem processes in bays (e.g., benthic-pelagic transfer of organic matter and nutrients and nutrient cycling moderated by filter feeders and tidal circulation); and
- Evaluation of the linkages between climate, climate change, and population dynamics.

Rubin et al. (2018, ID107) also indicated that developing a better understanding of how eelgrass habitats contribute to the productivity of a population is needed to determine the potential population level benefits of eelgrass restoration or protection strategies to guide restoration efforts.

In addition, Redman et al. (2005, ID 100) provided a list of data gaps is given for topics relating to threats and impairments to Salmon and Bull Trout in nearshore and marine environments in Puget Sound. These included:

- How natural and human perturbations affect nearshore ecosystems and salmon functions;
- Need to identify historic distribution of pocket estuaries across Puget Sound and how Chinook interact with them;
- Continued research into relationship with toxic chemicals in Puget Sound with Chinook Salmon;
- Studies on the effects of habitat alteration caused by invasive plants;
- Need for an aggregate ecological indicator scoring approach for nearshore zones; and
- Need for better understanding of current and historic patterns of nutrient loading into Puget Sound with respect to the role of salmon as a nutrient pathway for nearshore and marine habitats.

Redman et al. (2005, ID100) indicated that for Chinook fry that migrate straight from the redd to Puget Sound nearshore habitats (fry migrants or nearshore fry migrants), it is unknown how Chinook fry migrants are dispersed in the nearshore zones. It is hypothesized that oceanographic forces control their distribution. Redman et al. (2005, ID100) also indicate that it is not fully understood how pocket estuaries are used by migrant fry. Distance to natal estuary, size, freshwater input, vegetation, and tidal influence are all areas that need further research to understand how migrant fry are affected. Later works published that have addressed these data gaps to some extent through continued monitoring associated with the Skagit IMW (see Greene et al. 2021, ID056).

SWC (2022, ID451) noted that nearshore pocket estuary habitats *provide extended rearing and growth opportunities for these Chinook* and that *eight-six percent of the total historic pocket estuary area in close proximity to the Skagit delta was blocked to non-natal salmon use*. While this is a listed target area, they indicated that the full extent of how Chinook Salmon utilize all nearshore marine habitats such as vegetated tidal flats, subtidal flats, and rocky reefs is unknown. Beamer et al. (2006, ID006) suggested that for larger pocket estuaries, more random sampling sites are necessary to determine differences in fish densities between habitat types. It is also suggested that future work involve sampling for Chinook at a bi-weekly frequency from February-June in pocket estuary habitats to detect important fish use patterns. In the same respect, sampling for surf smelt should occur year-round.

3.5 Fish passage barriers

Multiple sources provide information on water crossing features or potential fish passage barriers within the study area for the Synthesis Study, but data gaps and monitoring needs are identified by many of these sources. Beamer et al. (2000, ID190) identified the need for evaluation of water crossing features for fish passage, including within the Skagit estuary and on tributaries to the lower Skagit River. They reported that approximately 70 percent of the barriers identified in their analysis were unconfirmed or there was low certainty for barrier classifications. This represents a data gap and monitoring need identified by the authors that will likely require field surveys to address. Distributions were also based on slopes from digital elevation models, and they indicate that field surveys or higher resolution remote sensing are needed to improve slope estimates for tributaries. Smith (2003, ID376) also reported on a need to evaluate salmonid access conditions including to collect field data to verify habitat quantity and quality as well as type of blockage for passage problems in WRIAs 3 and 4. Beamer et al. (2013, ID207) suggested better mapping of small streams, a predictive model for juvenile Chinook Salmon, and the analysis of a range of culvert conditions in future research are suggested in this report.

WDFW (2019, ID487) provides an online and regularly updated statewide spatial database of water crossing features and fish passage barriers that likely contains updates since the Beamer et al. (2000, ID190). The Fish Passage and Diversion Screening Inventory database provides information to support evaluating water crossing features for fish passage, which is a priority to identify restoration opportunities to improve fish distribution. However, protocols are in need of refinement to address evaluation of fish passage for tidally influenced features (e.g., see Hall et al. 2021, ID491).

Mickelson et al. (2020, ID289) represents the most recent and up-to-date inventory and source for fish passage barriers within the Synthesis Study Area, but significant data gaps remain and are identified in the report. In addition, Hall et al. (2021, ID491) provides the most up-to-date inventory of tidal restriction features for the Skagit estuary. Collectively, the spatial data from these projects can be used to identify water crossing features that need to be evaluated for fish passage barrier status to support identification and prioritization of restoration actions to support salmon recovery. However, Lyons and Ramsey (2013, ID339) indicate that more studies need to better understand how tide gate design and operation affect physical processes as well as habitat use by estuarine species. Additionally, the potential type and amount of habitat upstream of a tide gate replacement is needed *to gauge the value of the installation*. Greene et al. (2017, ID055) found many data gaps regarding water crossing features and how these structures impact fish populations because there is a lack of data on local movement dynamics.

4.0 SEDIMENT SUPPLY AND TRANSPORT

Veldhuisen (2018, ID166) indicated that extended monitoring of landslide frequencies is needed to provide greater certainty on the relative strengths of potential driving mechanisms and trends in landslide frequencies. In addition, more definitive analyses of temporal inventories that quantify buffer implementation are needed to explore the relationship between buffers and implementation of buffer management practices and landslide rates. They also indicate that additional analyses of potential impacts of hydropower dams (Baker River and upper Skagit River dams) and natural variations in terrain and dynamic river processes in head waters on sediment supply and transport, and consequently their effects on fish and downstream habitats are needed in the Skagit River watershed.

Beamer et al. (2000, ID190) indicated that improved road inventories, especially in state and private lands, are a data gap and monitoring need to support evaluation of sediment process impairments in the Skagit River watershed. Field-based sediment budgets are also identified as a data gap and monitoring need for the Skagit River watershed, with budgets having only been completed for 12 percent of the basin area as of the date of this report. Development of screening tools and data for surface erosion and sedimentation for low-slope areas are also identified as a data gap and monitoring need for evaluating sediment processes impairments by Beamer et al. (2000, ID190). USACE (2010, ID117) identified additional data gaps that include understanding sediment supply and transport in high flow events, updated riparian habitat surveys, and updated soil surveys. Beamer et al (2005, ID305) noted several data sets that were limited analyses including data to identify the flood history for unregulated mountain sub-basins in the Skagit watershed, the relationship between hydrologic/sediment regime changes and salmonid populations, data used to estimate sediment supply for individual sites, and data to identify changes in peak flow through gages with long periods of record.

Paulson (1997, ID354) describes suggestions for future research to improve understanding of sediment dynamics which included: (1) improvement of the sediment budget approach; (2) analysis of mature forested areas only; and (3) investigation of the relationship between structural aspects of the landscape and mass wasting. Some of these recommendations are tied to use of GIS mapping and other data that may now be available given the time that this study was completed.

Smith (2003, ID376) indicated that very few tributary drainages have been assessed to identify the sources of sedimentation. Where assessments have occurred, landslides associated with roads and clearcuts are identified as major sources of landslides. Smith (2003, ID376) reported multiple data gaps and monitoring needs for streambed and sediment conditions including:

- Identify and prioritize sediment sources in “poor” rated watersheds for possible future restoration projects, focusing primarily on roads. The watersheds with excess sedimentation include: Miller, Alder, Day, Grandy, Nookachamps, Hansen Finney, Loretta, Gilligan, Rinker, Dan, Sauk Prairie, Shannon West, Jordon/Boulder, Samish, and Friday creeks. A process to prioritize these watersheds based upon benefit to salmonids is recommended to apply a focused approach to improving sedimentation.
- Conduct assessments on stream stability, gravel quality, and instream LWD quantities in a prioritized manner (see above). Identify potential project areas.

- Assess sediment conditions in non-forested land use watersheds for impacts to salmonids. Examples of potential problems that should be examined are lack of crop cover, ditching, loss of riparian, and off road vehicle use.
- Monitor and evaluate the effectiveness of sediment reduction efforts on state and private lands.
- Examine the possibility of re-establishing sediment supply and transport downstream of dams.

Beamer and Wolf (2017, ID187) indicate that sediment routing and supply impacts from levees, dikes, and other modifications are impacting sediment routing and supply in the Skagit estuary, and this likely contributes to erosion and progradation processes observed in the Skagit estuary. Quantifications of these effects are limiting, and they also indicate that sea level, storm surge, and sediment routing should be incorporated into an updated recovery strategy for the Skagit estuary to address sources of (natural) habitat losses and improve habitat forming processes.

5.0 WATER QUALITY AND PRODUCTIVITY

Tributaries and other non-mainstem habitats (e.g., floodplain and side- or off-channel habitats) provide important habitats for life stages of target species, as well as inputs to the study areas for the lower Skagit River and Synthesis Study. Several studies identified in the Synthesis Study provide water quality data for non-mainstem channels, but temporal and spatial extents are generally limited, and several data gaps and monitoring needs were identified. For example, the Skagit County Water Quality Monitoring Program (Jackman et al. 2020, ID 109) is mostly focused on sites within the estuary and on agricultural lands, and water quality data are needed from upstream sites and additional years to understand water quality patterns. Thompson and Beauchamp (2016, ID 114) identify a need for continued/expanded water temperature monitoring throughout the Skagit River watershed to better understand potential growth limitations given the influence of temperatures on growth rates and potential. Smith (2003. ID376) also identified data gaps and monitoring needs for water quality that included:

- Analyze potential causes of water quality problems in the lower Skagit tributaries to determine the best course of action to restore functional water quality. This would include riparian conditions, sedimentation, flow, and inputs from agriculture, urban, and forestry land use.
- Monitor water temperatures in the Sauk River and tributaries. Spot checks have detected warm water temperatures in the mainstem Sauk River, making this action a high priority.
- Monitor water temperatures in the tributaries to the upper Skagit sub-basin.

Mostovetsky et al. (2015, ID 291) suggest that monitoring studies to address specific drivers and effects of stream temperatures are needed. These could include studies on land-use effects, monitoring in actively managed buffers and restoration sites, studies on thermal refugia (especially in Finney and Day Creeks), hyporheic exchange, thermally stratified pools, and in small tributaries (Mostovetsky et al. 2015, ID 291). Veldhuisen and Couvelier (2006, ID 162) indicated that further research is needed to determine the effects of temperature changes in headwater tributaries and how these changes and processes impact biological productivity as well as the extent of warmer water flowing downstream to potentially affecting salmonids. McMillan (2018, ID400) provides some quantitative data for spot measurements of water temperatures in Finney Creek, but spatially and temporally extensive monitoring data are not presented. Nevertheless, they recommend that more thorough water temperature recordings are necessary to determine how water temperatures have been altered in Finney Creek.

In the mainstem Skagit River, Austin et al. (2021, ID 446) indicated that more research is needed to "…determine the energetic consequences of juvenile salmonid emergence at different developmental states and times as climate change drives riverine thermal regime change," along with more long-term monitoring of temperatures at the sub-basin scale to support more detailed analysis of the linkages between spawn timing and temperature patterns. Austin et al. (2021, ID 446) found that, in August and September, the lowest temperatures were observed in the upper Skagit River mainstem closest to the Project, and the highest temperatures were observed in the lower Sauk River and lower Skagit River reaches. Differences in temperatures were explained primarily by elevation and position relative to hydroelectric dams, but they identify a need for more long-term temperature monitoring data at the sub-basin scale (including tributaries) to better understand temperature patterns and sources of variation at watershed and sub-basin scales.

Beamer et al. (2000, ID190) recommended including maps of known point and non-point sources that may contribute to water quality impairments to identify areas of potential concern, and support identification of sites to monitoring for water quality. ESA (2017, ID039) found that the West Fork Nookachamps had water body impairment listings due to Dioxin, Hexachlorobenzene, and PCBs, but they were unclear as to how these pollutants impact riparian restoration potential. Smith (2003, ID376) noted that instream habitat and water quality data are data gaps for Sauk River tributaries, and water quality monitoring is recommended for this drainage. Cichosz and Barber (2008, ID480) state that more sites are needed for water quality monitoring up and downstream of a particular land use area.

Beamer et al. (2020, ID 214) also recommends looking deeper into plausible predictors for various salinity metrics to link climate change predictions to changes in nearshore salinity in ways that are biologically relevant to fish species.

6.0 RIPARIAN CONDITION

Beamer et al. (2000, ID190) recommended continued field surveys of riparian condition and field inventories are recommended to improve identification or riparian impairments. Smith (2003, ID376) also reported the need to conduct a basin-wide analysis of riparian conditions that include shade hazards and LWD recruitment potential, incorporating previous assessments where possible. More recent work may have addressed these data gaps (ESA 2017, ID039; SWC 2021, ID430; SWC 2022, ID451). USACE (2010, ID117) and also identified additional data gaps that include understanding sediment supply and transport in high flow events, updated riparian habitat surveys, and updated soil surveys.

7.0 TARGET SPECIES AND LIFE STAGES

PSI and WDFW (2017, ID085) list some data gaps that need to be prioritized to understand the current Skagit River MUs population dynamics and to further refine the harvest management objectives. Some suggestions include adding genetic stock identifications to juvenile monitoring programs, estimating natural dispersal to understand connectivity between populations, and to continue assessing life stage survivals between habitats. Beamer et al. (2005, ID004) identified several important data gaps and monitoring needs including improving our understanding of yearling movement patterns and habitat preferences in freshwater habitats, understanding how straying of unmarked hatchery Chinook and flow management influences yearling productivity, yearling capture efficiencies at rotary screw traps used to monitoring juvenile production. Roni et al. (2006, ID104) also identified the need for research into how different floodplain habitat types are used as refuge from high flows and how that might contribute to smolt production at multiple spatial scales. Beamer et al. (2005, ID175) identified a data gap understanding the sources of sediments impacting egg to fry survival.

Smolt trap monitoring in the Skagit River basin is comparatively extensive compared to many systems in the Puget Sound region. Lisi et al. (2022, ID494) provides the most recent compilation of the state of knowledge and data for Puget Sound smolt trap monitoring efforts, which includes the Skagit River basin. However, some studies indicate that the spatial resolution of smolt tap monitoring limits the ability to estimate the relative contributions of sub-basins to outmigrant production (Woodward et al. 2017, ID121). In addition, Volkhardt et al. (2005, ID 404) identifies the need for extended seasonal monitoring for juvenile outmigrants in order to improve understanding of density dependence and other limiting factors on production in the Skagit River watershed. Kinsel et al. (2013, ID 147) found in 2012 that researchers were unable to estimate steelhead smolt production for the Skagit River basin because only one PIT-tagged steelhead smolt was recaptured in the trap on the mainstem Skagit River. They recommended increasing sample sizes of tagged steelhead in future years as well as monitoring using acoustic tags. Graybill et al. (1979, ID 259) indicated that there was a need for understanding the relative contribution of fry from the Suiattle River to understand Chinook life history production patterns from the Sauk River.

Several studies identified data gaps and monitoring needs specific to Bull Trout. USFWS (2004, ID479) recommends that further studies are needed to describe the genetic makeup of Bull Trout within MU core areas. More knowledge of the genetic makeup of Bull Trout will enable better identification of local populations within core areas. In addition, more research is needed for identifying key habitat features as well as limiting factors for Bull Trout in freshwater and marine habitats. Smith (2010, ID 352) also indicated that a study on the metapopulation dynamics of fluvial Bull Trout within the Skagit River is needed to help understand how best to manage Bull Trout within the system. USFWS (2004, ID432) also indicated that the marine and estuarine residency period for Bull Trout is not well understood which also includes the habitat preferences (e.g., depth, salinity, bottom types, foraging habitats, etc.). USFWS (2004, ID432) identified that Bull Trout migration timing, particularly along south Puget Sound shorelines and island shorelines is not well understood. Additionally, more research is needed to understand peak migration timing for Bull Trout's life stages and if they are similar for management unit core areas. USFWS (2004, ID432) also stated that additional research is needed to understand Bull Trout's *extent of incidental mortality* in recreational, Tribal, and commercial fisheries.

Several data gaps were also identified for steelhead, which include the need for better estimates of juvenile production as noted above from Kinsel et al. (2013, ID 147). Gayeski et al. (2011, ID137) suggested that steelhead production in Puget Sound has outpaced the loss of stream habitat, implying that other factors play a larger role in reduced productivity. Some of the factors/avenues for further research they suggested to address these questions include interactions with hatchery conspecifics, reductions in run sizes, and simplification of life history components (i.e., reduced iteroparity), and/or changes in marine survival patterns.

Multiple studies reported data gaps and monitoring needs for Chinook. Greene et al. (2021, ID056) noted that the spatiotemporal dynamics of density dependent processes for Chinook in estuaries are in need of additional study. Better understanding of these dynamics can help to determine the effects of hatchery releases and large outmigration cohorts on natural origin Chinook habitat use within estuaries. Greene et al. (2021, ID 056) found that a bioenergetics model of juvenile Chinook Salmon consumption in Puget Sound tidal deltas does not account for consumption from other estuarine fish. A community ecology approach to bioenergetics modeling would fill knowledge gaps in how energy is transferred within estuarine systems. Beamer et al (2005, ID175) also identified a data gap for understanding the ecology of forage fish as it relates to salmon during nearshore rearing, the role of predation by seals and birds in limiting Chinook productivity, and further refinement in understanding Chinook rearing and survival in nearshore habitats, including the impacts of specific land uses. Redman et al. (2005, ID 100) suggests that what causes some Chinook Salmon to remain as extended residents (i.e., Black Mouth Chinook) within the offshore waters of Puget Sound is unknown.

Gamble et al. (2018, ID044) suggested that more comparisons between natural and hatchery origin Chinook stocks that are genetically similar could be used to determine differences in growth rates, and that a relationship should be determined between interannual variation in early marine growth and size-selective mortality. Additionally, future studies should take place over a larger timespan to make stronger connections between factors and survival and reveal patterns in survival that could be due to other factors including oceanic conditions. Future studies were also suggested to compare the growth of Chinook stocks across different regions in order to identify key factors affecting marine survival in each region. SSC and USGS (1999, ID171) identified some atypical life history patterns in Chinook and indicated that future analyses will be conducted to correlate length, residence period, and timing of the atypical samples at various life stages with water flow and temperature factors to further understand these life history patterns. However, since this report was published in 1999, analyses may have already been done. Sobocinski (2004, ID176) indicated that increased sampling of otoliths in juvenile salmon would help refine growth estimates during estuary rearing and emigration life stages.

Pflug et al. (2013, ID154) noted that the effects of competitive interactions between wild and hatchery origin smolts are not well known. However, natural origin smolts were only captured in 2009 at upper Skagit River trap sites, and this limited their comparative analysis. The authors acknowledge the extent to which hatchery fish residualize and become residents in the Skagit is unclear based on the data they analyzed, and this is another possible source of hatchery and natural origin steelhead interaction. Beamer et al. (2005, ID 005) indicated that declines in yearling life history expression among Upper Skagit populations coincided with cessation of unmarked hatchery releases and changes in flow management associated with the City Light hydropower relicensing (in 1980 and 1991), but they identify this as a potential area of future study to evaluate how the correlation is related to Project operations, straying rates, and hatchery practices.

Campbell et al. (2017, ID023) suggests that juvenile Chinook in Puget Sound estuaries need to be sampled for toxins (such as PCB and PAH) and pathogens in order to test the hypothesis that fish with higher residency in the estuaries have reduced survival. Rosenkotter et al. (2007, ID106) suggested that studies should be conducted on the effects of crab harvest on juvenile Chinook food supply.

Large scale climatic and productivity conditions in the ocean, harvest pressures, and predation pressures contribute to the survival and maturation rates of target species. Understanding the sources and magnitude of factors influencing marine survival can greatly improve the ability to evaluate population status and trends and limiting factors to the recovery of target species. Thompson and Beauchamp (2014, ID054) indicated that recent studies have highlighted the importance of survival in marine environments for steelhead, but the locations and modes of mortality for steelhead populations in the Salish Sea have not been conclusively determined. Several studies specifically identify the need for improved estimates of harvest rates and continued monitoring of marine conditions to better understand the influence of marine survival on adult return rates in the Skagit River (Greene et al. 2005, ID050; Woodward et al. 2017, ID121). Rosenkotter et al. (2007, ID106) provides data gaps on risks facing species of salmon in marine environments. The following are areas in which data gaps have been identified: (1) permitting reverse osmosis systems; (2) affects (sic.) of mari-culture net pens in marine waters, (3) identification of areas at risk from oil spills and response plans, and (4) habitat issues around proposed tidal power turbines.

For Chum Salmon, Beamer et al. (2019, ID013) found that Skagit River Chum Salmon population trends are driven by marine survival rather than freshwater productivity, although they indicate that parsing estuary and marine survival is difficult with the available monitoring data, and they identify this as an area of potential future study.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT J

FUTURE AND ONGOING STUDIES

The following future and ongoing studies represent studies that were identified during the Synthesis Study and are not intended to represent a comprehensive list. For each future and ongoing study identified during Step 1: Data Compilation, a summary of the study and relevant citations is provided along with links to more information, if available. These studies may provide information relevant to the Synthesis Study or address key uncertainties within the study area for the Synthesis Study.

ESRP Beach Strategies: This is a two-phased project that is developing science-based strategies to guide future restoration and protection strategies for Puget Sound's beaches, including shorelines associated with the study area for the Synthesis Study. See Salish Sea Wiki (2021, ID322) for more information on this project (https://salishsearestoration.org/wiki/Beach_Strategies_for_Nearshore_Restoration_and_Protection_in_Puget_Sound), as well as Coastal Geologic Services (2017, ID027) and (2020, ID028). This project is developing spatial data that will integrate with regional habitat status and trends monitoring programs (e.g., Puget Sound Partnership Common Indicators and Vital Signs) and will likely provide additionally useful information on nearshore habitats in the study area for the Synthesis Study.

Skagit Estuary Habitat Status and Trends: Spatial data have been developed by the Skagit River System Cooperative to support evaluation of habitat status and trends related to natural changes and restoration in the Skagit River estuary. Data from previous monitoring are reported in multiple sources included in the Synthesis Study (e.g., Beamer and Wolf 2017, ID187; Beamer et al. 2015, ID008; SWC 2021, ID430). Continued monitoring will provide additional time steps to evaluate changes in habitat overtime, evaluation of progress towards recovery targets, and sources of changes in habitat extent (e.g., restoration, natural progradation or erosion, sea level rise). Additional information on previous and ongoing habitat status and trends monitoring can be found on the Skagit River System Cooperative's website: http://skagitcoop.org/documents/ (SRSC 2022, ID524).

Skagit IMW: The Skagit River is part of the Ecology's Intensively Monitored Watershed (IMW) Program, and multiple reports and publications have been produced from previous monitoring activities in the Skagit River watershed that were included in the Synthesis Study (e.g., Beamer et al. 2019, ID013; IMW Scientific Oversight Committee 2006, ID066; IMW Scientific Oversight Committee 2007, ID276; Greene et al. 2015, ID341; Greene et al. 2016, ID053; Greene and Beamer 2012, ID123; Greene and Beamer 2006, ID231). Information on the IMW program itself can be found here (https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Intensively-monitored-watersheds). Ongoing monitoring and analysis efforts, lead primarily by the Skagit River System Cooperative and the Northwest Fisheries Science Center will likely produce additional reports and data relevant to the Synthesis Study (NOAA 2022, ID525).

Salmon Habitat Status and Trends Monitoring Program: This ongoing habitat status and trends monitoring program provides data relevant to the study area for the Synthesis Study, including large river, floodplain, estuary, and nearshore habitats. Multiple products from previous efforts were included in the Synthesis Study (Beechie et al. 2017, ID018; Hall et al. 2018, ID058; Stefankiv et al. 2019, ID112). The Puget Sound Habitat Status and Trend Monitoring Program began in 2014 and 2015 as part of NOAA Fisheries' statutory responsibility to evaluate progress towards recovery of the Puget Sound Chinook, Hood Canal Summer Chum, and Puget Sound Steelhead. Due to its success, the project was expanded in 2018 to include the Oregon Coast Coho

Salmon ESU and renamed the Salmon Habitat Status and Trend Monitoring Program (SHSTMP). The SHSTMP is a long-term monitoring program with a hierarchical approach to monitoring large river, floodplain, delta, and nearshore habitats using primarily remote sensing approaches. A number of boundaries and habitat features have been identified and delineated with the use of Coastal Change Analysis Program (C-CAP) land cover data, National Elevation Dataset (NED) and regional surface elevation lidar data, as well as aerial and satellite imagery. More information on the SHSTMP and data products can be found here: https://www.fisheries.noaa.gov/resource/map/salmon-habitat-status-and-trend-monitoring-program-data (NOAA 2022, ID315).

Puget Sound Partnership Common Indicators and Vital Signs: The Puget Sound Partnership maintains a habitat status and trends monitoring and indicator reporting framework to support evaluation of progress towards recovery and identification of restoration opportunities in the Puget Sound region. The scope of these indicators includes the Skagit River, and many of the indicators used are developed in coordination with other regional and local monitoring programs. Indicators include freshwater, floodplain, riparian, estuary, and nearshore habitats within the study area for the Synthesis Study. See https://www.psp.wa.gov/evaluating-vital-signs.php and https://commonindicators-wa-psp.hub.arcgis.com/ for more information on the Common Indicators and Vital Signs (PSP 2022, ID330).

ESRP Tidal Restriction and Marine Riparian Mapping: Tidal restriction features (e.g., levees, dikes, roads, tide gates, culverts) were mapped for all of Puget Sound's large river deltas, including the Skagit River delta, see Hall et al. (2021, ID491). That mapping effort is currently being expanded to include mapping for the rest of the Puget Sound shoreline, which would include nearshore habitats of Skagit Bay and Padilla Bay, and mapping will also include marine riparian extent (Cramer Fish Sciences TBD, ID492; Cramer Fish Sciences TBD, ID493). See https://salishsearestoration.org/wiki/Puget_Sound_Marine_Riparian_Mapping and https://salishsearestoration.org/wiki/Puget_Sound_Tidal_Restriction_and_Wetland_Mapping for more information on this ongoing project. In addition, the spatial database of tidal restriction and wetland features will be updated and maintained as part of regional habitat status and trends monitoring efforts in coordination with the National Oceanic and Atmospheric Administration's (NOAA) Salmon Habitat Status and Trends Monitoring, Puget Sound Partnership's (PSP) Common Indicator and Vital Signs, Washington Department of Fish and Wildlife's (WDFW) Fish Passage Inventory, and Estuary and Salmon Restoration Program's (ESRP) Beach Strategies. Current data products can be found here: https://geodataservices.wdfw.wa.gov/hp/tidal-restrictions/.

Comprehensive Hydrologic Study of the Skagit Estuary: The Washington State Academy of Sciences (2022, ID116) developed a proposed scope for a future Comprehensive Hydrologic Study of the Skagit estuary. This proposal outlines a process for finding the best available science to inform policy decisions that have the potential to impact many stakeholders who depend on the Skagit River, highlighting the gaps in current data available and proposed research that needs to be completed, as well as identifying research for immediate needs and long-term research. Information and data products developed by this future study will be potentially relevant to the Synthesis Study.

Skagit Relicensing Studies: Numerous ongoing studies that are part of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021). These studies will potentially provide information relevant to the study area for the Synthesis Study and objectives and include but are not necessarily limited to:

Seattle City Light (City Light). 2021. Revised Study Plan (RSP) for the Skagit River Hydroelectric Project, FERC Project No. 553. April 2021.

_____. 2022. 2022. FA-08 Fish Entrainment Study, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2022.

_____. 2023. FA-01a Water Quality Monitoring Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Meridian Environmental, Inc. and Four Peaks Environmental, Inc. March 2023.

_____. 2023. FA-01b Water Quality Model Development Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Geosyntec Consultants, Inc. and Northwest Hydraulic Consultants, Inc. March 2023.

_____. 2023. FA-02 Instream Flow Model Development Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Northwest Hydraulic Consultants, Inc. and HDR Engineering, Inc. March 2023.

_____. 2023. FA-04 Fish Passage Technical Studies Program Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2023.

_____. 2023. FA-06 Reservoir Native Fish Genetics Baseline Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Cramer Fish Sciences, Inc. March 2023.

_____. 2023. FA-07 Reservoir Tributary Habitat Assessment Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Cramer Fish Sciences, Inc. March 2023.

_____. 2023. GE-04 Skagit River Geomorphology Between Gorge Dam and the Sauk River Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Natural Systems Design, Inc., Northwest Hydraulic Consultants, Inc. and Fain Environmental LLC. March 2023.

_____. 2023. OM-01 Operations Model Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2023.

_____. 2023. RA-05 Lower Skagit River Recreation Flow Study Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by River Science Institute, Inc. March 2023.

_____. 2023. TR-09 Beaver Habitat Assessment Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2023.

Tidal Channel Mapping in Barrier Embayments: A previous ESRP Learning Project seeks to develop tidal channel reference data to efficiently design restoration of barrier embayments in Puget Sound. As part of that project, Blue Coast Engineering will systematically inventory the tidal channel geometry of intact barrier embayments, collect field data from a subset of these barrier embayment systems, and conduct a regression analysis to determine the best predictor of channel geometry.

See https://secure.rco.wa.gov/prism/search/projectsnapshot.aspx?ProjectNumber=16-2283 for more information on this project. The project outcome will be guidelines for appropriately sizing tidal channels for restoration projects based on empirically derived models which describe the relationship between channel geometry, marsh area, and tidal prism (Washington State Recreation and Conservation Office TBD, ID326).

Designing Large Wood Placement in Tidal Marshes: This ESRP Learning project aims to analyze the effects of distributary size on LWD distribution and evaluate large woody debris recruitment rates using high resolution aerial photos of seven Puget Sound river deltas to identify logs as well as validate with ground truth surveys (Washington State Recreation and Conservation Office TBD, ID328). Statistical analysis of results to date show that marsh size, fetch, topography, and woody vegetation affect LWD distribution on the marsh surface and in tidal channels. Channel and log size also affect distribution within channels. More information on this project can be found here: https://secure.rco.wa.gov/prism/search/projectsnapshot.aspx?ProjectNumber=18-2253.

Chum Study: Beamer et al. (2019, ID013) indicated that the results of a preliminary Chum study were presented to City Light and will be available in a future report (Ruff et al. TBD, ID520). The authors indicated that additional research is needed to parse out the effects of estuary conditions on marine survival (which they identify as being more related to declining population trends than freshwater conditions). Beamer confirmed that the City Light committee has responded to the draft with comments, and a revised draft will be available in the Fall of 2022 (Beamer personal communication, September 19, 2022).

The cumulative effects of nearshore habitat recovery actions on juvenile salmonids in the Whidbey basin: WCET (2022, ID518) is a collaborative study that was recently initiated to analyze, evaluate, and synthesize data from multiple studies across broad spatial and temporal scales using an approach called cumulative effects for the Whidbey Basin, which includes the Skagit River estuary and nearshore habitats. Cumulative effects are defined as *the collective effects of human activities upon the environment, and can be additive, synergistic, antagonistic, or some combination thereof occurring over various spatial and temporal scales*. A study report has been developed detailing the planned methodologies and models, with more results anticipated in 2023-2024.

Skagit River Geomorphology Part 2: This study (Riedel et al. TBD, ID217) will build on Part 1 (Riedel et al. 2022, ID001). Updated reach breaks for the lower river were developed as part of this study, and these were used to update the reaches used in the study area for the Synthesis Study. The results of their analysis, including quantitative and spatial data, will be developed and can be used to update descriptions of resource conditions in the lower Skagit River and estuary.

SYNTHESIS AND INTEGRATION OF INFORMATION ON RESOURCES IN THE LOWER SKAGIT RIVER

ATTACHMENT K

SY-01 LOWER RIVER SYNTHESIS MEETING MATERIALS

Skagit Hydroelectric Project Relicensing:
SY-01 Lower River Synthesis Meeting
December 15, 2021
Meeting Summary

Attendance

Licensing Participants (LPs):
Brock Applegate, Washington Department of Fish & Wildlife (WDFW)
Curtis Clemet, Upper Skagit Indian Tribe (USIT)
Steve Copps, National Marine Fisheries Services (NMFS)
Matt Cutlip, Federal Energy Regulatory Committee (FERC)
Jeffrey Garnett, US Fish and Wildlife Service (USFWS)
Rick Hartson, USIT
Brian Lanouette, USIT
Jim Myers, National Marine Fisheries Services (NMFS)
Dudley Reiser, Swinomish Indian Tribal Community
Jon Riedel, National Park Service
Sharon Sarrantonio, National Park Service (NPS)
Devin Smith, Skagit River System Cooperative
Alison Studley, Skagit Fisheries Enhancement Group
Erik Young, Skagit Fisheries Enhancement Group
Stan Walsh, Skagit River System Cooperative (SRSC)

Seattle City Light (City Light):
Andrew Bearlin , City Light
Rory Denovan, City Light
Andrew Haas, City Light
Erin Lowery, City Light
Leska Fore, City Light
Matt Love, Cascadia Law

Consultant Team:
Jason Hall, Cramer Fish Sciences
Jenna Borovansky, HDR
Matt Wiggs, HDR
Melinda Carr, Cramer Fish Sciences

Facilitation Team:
Greer Maier, Triangle Associates
Lauren Schultz, Triangle Associates

Meeting Materials

Meeting materials sent in advance:

- NOA Commitment Tracking Matrix
- Handout #1: Draft Report Outline
- Handout #2: Data Source Attributes
- Handout #3: List of References
- Meeting Presentation

Action Items

Action	Responsibility	Deadline
Licensing Participants (LPs)		

LPs will submit additional resources from studies (past or present) that have not yet been identified or compiled in Handout #3. LPs can also submit relevant data or literature from other Skagit relicensing technical studies. **Suggested resources can be sent directly to Jason Hall (Consultant Team) at Jason.Hall@fishsciences.net and cc: Andrew Bearlin (City Light) andrew.bearlin@seattle.gov**	LPs	January 6, 2022
LPs will submit comments and feedback through track changes on the following materials (please identify your name/affiliation in your comment): • **Handout #1: Draft Report Outline** • **Handout #2: Data Source Attributes** • **Handout #3: List of References** **Comments or questions can also be sent directly to Jason Hall at Jason.Hall@fishsciences.net**	LPs	January 6, 2022
City Light/Consultant Team Action Items		
Jason Hall will provide LPs the SY-01 study geographic extent map for review ***(completed) – Linked here and attached*** Please send any comments or feedback on the study extent to **Jason Hall at Jason.Hall@fishsciences.net**.	Jason Hall (Consultant Team)	Done
Triangle Associates		
The Triangle Facilitation Team will schedule an SY-01 Lower River Synthesis meeting for early February 2022.	Triangle	In Process
Prepare draft meeting summary and send to participating LPs, City Light, and other attendees for review.	Triangle	As soon as possible
Discussion Items		
Sufficiency linking identified data/information and Project impacts through the current literature review process.		
Outcomes of SY-01 informing other Skagit Relicensing studies – study integration.		
SY-01 study area extent – specifically tributaries included, Skagit Bay, and delta boundaries.		

Summary of Issues Discussed, Action Items, and Decisions

Welcome, Introductions, Agenda Overview

The facilitator, Greer Maier, welcomed the group and led a roll call. She gave a brief overview of the agenda and shared the meeting purpose, which was to introduce the study lead to the Licensing Participants (LPs), provide an update on the status of the SY-01 study, and discuss the approach for data compilation and study implementation.

Andrew Bearlin, City Light, provided background on the SY-01 Lower River Synthesis (SY-01) study and introduced the study lead. The study was requested from LPs interested in extending technical studies into the lower Skagit River. Andrew explained the study's intent is to compile all relevant and available data below the Sauk River confluence to inform and address questions on downstream impacts. The technical lead for SY-01 is Jason Hall from Cramer Fish Sciences.

SY-01 Approach for Study Implementation

Jason Hall, Cramer Fish Sciences (Consultant Team), provided an overview of the SY-01 study plan and objectives outlined in the Revised Study Plan (RSP), which were to:

- Compile, analyze, and summarize available data and studies on anadromous fish resources in lower Skagit River
- Characterize factors affecting populations
- Develop conceptual life history models
- Develop hypotheses to understand potential Project impacts and other contributing factors

The geographic extent of the SY-01 study area extends from the Sauk River confluence to the Skagit River delta estuary. Jason identified the study's target species and life stages of anadromous salmon species that rely on the lower Skagit River (see slide 6). He also listed key questions outlined in the RSP that are guiding the SY-01 study:

- Condition of resources (fish and habitat) in the lower Skagit River?
- Contributing factors to conditions of resources?
- Project impacts and other contributing factors?
- Data gaps and research/monitoring needs?

Jason clarified that the SY-01 study is currently focused on **step one** of the four-step study plan. Step 1 is to compile information and data. Step 2 is to inform future data analysis. Step 3 is identifying life stage factors affecting target species. Step 4 is identifying key uncertainties and data gaps.

Jason outlined the proposed approach for compiling existing references in Step 1. The study team is collecting references from several sources relevant to the SY-01 study area to build an accessible, relational database. This database will provide the opportunity to screen for specific attributes, flag data, and define and filter source information (see slide 13).

Jason then displayed *Handout #2 - Data Attribution and Inventory*, which provides a list of source classifications, topics and keywords, and data flag values that can be used to attribute and categorize sources and data identified in Step 1. Collectively, these attributes are intended to support identification and filtering of sources that can support Steps 2-4 of the SY-01 Revised Study Plan. Data flags can identify target species, life stages, and reaches and distinguish between quantitative, spatial and Project impact data (see Handout #2). This preliminary list should capture most of the crucial elements for identifying data in the sources.

Questions and Discussion

- In response to a question from USIT regarding what is being asked of LPs, Jason clarified that this is an opportunity to ensure no gaps or elements are missing in the database classification system. LP comments and feedback are requested by January 6, 2021.
- In response to a question from NMFS about identifying data and sources related to Project impacts, Jason explained there is a data flag “Project Impacts” set up to indicate when a source provides information on Project impacts. The conceptual model stage of data analysis will likely use a lines-of-evidence approach to address other cumulative Project impacts. The first step is to identify clear linkages in the database.
- In response to a question from the Swinomish Indian Tribal Community regarding the end product of the study and whether it fits in with other studies, Andrew explained that the current agreement is to conduct Step 1 to identify focus areas. The ultimate application of this study is to inform a long-term monitoring program to understand the presence and magnitude of Project impacts, the effectiveness of mitigation to deal with those impacts, and the ongoing management of those mitigation measures.
- Andrew clarified a question from USIT about reference reaches downstream and explained the study is intended to help identify metrics to monitor and manage mitigation programs in the future. Andrew noted that reference reaches have specifically been identified in the SY-01 study and Geomorphology studies.
- A representative from the Skagit River System Cooperative requested further discussion around sedimentation impacts downstream. He also suggested using two types of “Project Impact” data categories, one for flagging the information and one to indicate whether the study was intended to evaluate Project impacts. He noted further discussion should be had on Project impacts and the literature’s ability to evaluate those impacts. *This was added as a discussion topic.*
- Rick emphasized the importance of this study in identifying and evaluating Project impacts, noting that additional studies may be needed to evaluate impacts.

The facilitator suggested LPs make comments or suggestions, noting their name and organization, in Handout #2 through track changes. *This was listed as an action item.*

SY-01 Preliminary Progress

Jason updated the group on the preliminary progress report of the study. There have been over 375 resources identified so far, and some screening and attributing have been done already. Jason estimated compiling between 400-500 resources when complete.

Jason then discussed *Handout #3 – List of References*, which includes a list of compiled references and identifies other references that have not yet been obtained by the study team. Jason noted that based on study objectives, SY-01 focuses on final or processed data instead of raw data. Jason asked LPs to submit additional resources from studies (past or present) that are not on the list currently. LPs should make comments or suggestions, noting their name and organization, in Handout #3 through track changes or can submit references directly to Jason. *This was listed as an action item.*

Jason explained *Handout #1 - Draft Progress Report Outline*, which includes proposed sections on purpose, approach, results, summary of key questions, approach for conceptual models, and an annotated bibliography (see Slide 19). He noted that the annotated bibliography will provide an overview of basic source information, a list of attributes, and brief summaries on the study and relevancy to study objectives. The preliminary progress report provides an opportunity for LPs to review and refine the proposed report to best meet the objectives of SY-01 in the RSP. Jason noted that this preliminary progress report will be submitted in the Initial Study Report (ISR).

Questions, Timeline, and Next Steps

Jason and the group discussed the study area extent and identified linkages between other ongoing Skagit technical studies and current Skagit studies, with overlaps to SY-01 and including FA-01 Water Quality Study, FA-02 Instream Flow Model, FA-04 Fish Passage study, GE-04 Geomorphology and sediment transport models. Jason requested LP feedback on other studies with overlapping information synthesis to SY-01.

Jason explained that the study area extends from the Sauk River confluence to the delta/estuary. The study plan specifically references geomorphic reaches that have been developed previously. Jason explained three additional proposals related to the study extent, which included:

1. Should the study area include the full extent of R7, which extends upstream and downstream of the confluence of the Sauk River?
2. Should the study area include parts of the Swinomish and Stillaguamish delta boundaries?
    - Note: The Skagit River System Cooperative uses parts of these deltas as a footprint for the Skagit River delta.
3. Should the study area include Skagit Bay?
    - Including Skagit Bay would allow work to be done on nursery and migration habitats for target species.

Finally, Jason outlined the next steps and timeline for the study. The study team will continue compiling, screening, and annotating sources and will integrate feedback on the report outline, attribute list, and reference list for submission into the ISR.

Questions/Discussion

- In response to a question from Swinomish Indian Tribal Community about an accessible database with key word searchability, Jason clarified that Handout #2 outlines the key words and data attributes. The ultimate goal is to create a searchable database.
- In response to a question from Swinomish Indian Tribal Community regarding the outcomes of SY-01 related to sediment modeling, Andrew explained that a proposal from the GE-04 study suggests an approach for modeling sediment downstream of the Sauk River. There are no specific models anticipated to be developed in the initial scope of SY-01, but the study will help construct an understanding of available information to inform future tools and mitigation programs.
- In response to a question from USIT about calling out Project impacts in the progress report, Jason proposed a solution of organizing and prioritizing information based on the relevancy to SY-01 and Project impacts.
- A representative from USIT suggested incorporating or flagging existing and future study information and data that may inform SY-01. Jason asked LPs to identify any planned future studies outside of the RSP. *This was added as an action item.*
- In response to a question from the Skagit River System Cooperative regarding the intent of SY-01 to make recommendations for future studies in the licensing process, Andrew clarified that while it’s not a specific objective of SY-01, if results indicate an impact or potential impact that was not previously known, it can be discussed. Jason also noted how the conceptual model may help identify potential factors influencing conditions and linkages to Project impacts.
- A representative from USIT suggested including the Sauk River and unregulated rivers in the study area to provide additional relevant information to inform future discussions and identify Project impacts. Andrew added that conceptualizing and understanding relevant study information and data will ensure that this study is as robust as possible. Then, based on this understanding, identify potential additions to the study area. USIT noted the tight timeline to identify Project impacts.

- Andy Haas, City Light, confirmed that several questions being raised by LPs are being addressed through the GE-04 sediment models. The analyses will help evaluate the sensitivity of channels, channel width, and material mobilization.
- Jason clarified a question about including the Samish and Stillaguamish delta areas, explaining that the Samish is not included, but the Swinomish and north portion of the Stillaguamish delta are consistent with the Skagit River System Cooperative study area. Andrew suggested that we cast a broad net and include the full extent of Reach 7 and the Sauk River.
- A representative from the Skagit River System Cooperative highlighted the need for further discussion on the study area extent since there is a bit of ambiguity around boundaries. *This was added as a discussion topic.*
- Jason Hall agreed to provide LPs the SY-01 study geographic extent map for review. *This was added as an action item.*

<u>Action Items, Next Steps</u>

The facilitator reviewed the action items and outlined the next steps from the meeting. She noted that Triangle will be reaching out to schedule the next SY-01 meeting, which is anticipated to be in early February 2022. Andrew thanked the group for the discussion and emphasized the need for LP assistance to identify resources that have not yet been identified or compiled in Handout #3.

Skagit Hydroelectric Project Relicensing:
SY-01 Lower River Synthesis Meeting
Thursday, April 28th
1:00 – 4:00 pm

Meeting Notes

Attendance

Licensing Participants (LPs):
Brock Applegate, WA Department of Fish & Wildlife (WDFW)
Richard Brocksmith, Skagit Watershed Council
Steve Copps, National Marine Fisheries Service
Jenna Friebel, Skagit Drainage and Irrigation District Consortium
Daryl Hamburg, Skagit County Dike District
Rick Hartson, Upper Skagit Indian Tribe (USIT)
William Honea, Skagit County
Devin Smith, Skagit River System Cooperative (SRSC)
Alison Studley, Skagit Fisheries Enhancement Group (SFEG)
Amy Trainer, Swinomish Tribal Community
Erik Young, Skagit Fisheries Enhancement Group

Seattle City Light (City Light):
Andrew Bearlin, City Light
Leska Fore, City Light
Andy Haas, City Light

Consultant Team:
Jenna Borovansky, HDR
Meghan Camp, Cramer Fish Sciences (CFS)
Melinda Carr, CFS
Jason Hall, CFS
Matt Wiggs, HDR

Facilitation Team:
Greer Maier, Facilitation Team
Alex Sweetser, Facilitation Team

Meeting Materials

Meeting materials sent in advance:

- Meeting Agenda
- Meeting Slide Deck
- December 2021 SY-01 Meeting Summary
- Skagit Work Group Discussion Tracker
- NOA Commitment Matrix

Summary of Issues Discussed, Action Items, and Decisions

Introduction

The facilitator, Greer Maier, welcomed participants to the meeting and led a roll call. She reviewed the meeting purpose, agenda, and action items, noting that there were no additional comments on the study geographic extent outside of the December 2021 Work Group meeting (see below).

SY-01 Review Status of Study Implementation

Jason Hall, CFS (Consultant Team), outlined the topics being discussed, which included objectives, timeline, and the status of data compilation efforts. He provided an overview of SY-01 study goals and objectives and updated the group on the status of study implementation (see slides 4-5). Jason explained that the Study Team is currently working through data compilation (step 1), which consists of screening and reviewing Tier 1 sources. He noted that the Study Team has integrated input from the December SY-01 meeting and has coordinated with the GE-04 Study Team to synthesize geomorphic literature for the lower Skagit River.

Jason provided an overview of the study area, which extends from Sauk River confluence downstream to the delta. The geomorphic delta area is consistent with the Skagit River System Cooperative and Puget Sound Partnerships boundaries for the Skagit delta (see slide 7). He explained that Pacific Lamprey have been added to the list of target species and added an adult out-migration for iteroparous species and an overwintering and fluvial life stage for species that have an extended freshwater rearing period (see slide 8). The Study Team is also working to better identify information that describes links between Project operations and resources and studies designed to answer questions related to Project operations (see slides 9-11). To that end, a Project related data flag has been added along with a Project Operations topic field and a Project Linkages topic field.

Questions and Discussion:

- In response to a suggestion from Richard Brocksmith, Skagit Watershed Council, to include all documentation from the Skagit Watershed Council's website, particularly the 1998 restoration habitat strategy, Jason clarified that all information from the Skagit Watershed Council's website was incorporated into the reference list and will be provided along with the draft annotated bibliography for Tier 1 Sources.

SY-01 Data Compilation & Review of Tier 1 Sources (Step 1)

Jason Hall, CFS, provided an update on data compilation efforts, noting that the current list includes 492 sources, some of which still need to be digitally copied. He showcased the source categories, explaining the relevant information each source category provides and explaining how annotated bibliographies and data inventories are being developed (see slide 15).

Jason showed an example annotated bibliography and discussed how the information compiled could be used in the Synthesis Study (see slide 16). He described the development of an RShiny database, which provides the ability to search and filter by keywords and data flags within compiled PDFs or the annotative bibliographies themselves. Jason presented an example of the RShiny database concept, noting that there will be further opportunity for LP review and feedback (see slides 17-22) .

Preliminary Concepts for Steps 2-4

Jason Hall, CFS, provided an overview of preliminary concepts for Step 2: data analysis; Step 3: life stage factors affecting target species; and Step 3: identification of key uncertainties of the SY-01 Study.

Step 2: Data Analysis

Jason explained that Step 2 (data analysis) will include the development of a data inventory, and conceptual life history models with linkages between target species and factors. Data analysis will consist of developing a set of high-level summaries to describe the information that's available (see slide 27). He then provided background information on the development of life history models, explaining the factors and stressors/drivers that influence life stages (see slide 28).

Jason walked through a generalized life cycle diagram, showing how conceptual models can be used to evaluate the life cycle transitions between life stages. He detailed a diagrammatic example of a conceptual framework for migration and spawning, noting the various drivers/stressors, factors, and biotic responses influencing that life stage (see slides 28-31).

Questions and Discussion:

- In response to a question regarding how conceptual frameworks will be developed for life stages without existing information, Jason Hall explained that the current process of developing conceptual frameworks will help identify those information gaps.
- In response to a question about using GIS to display results, Jason Hall explained that this is a question that may be discussed in future meetings. He noted that displaying results on a spatial scope may not be in the RSP. Andrew Bearlin, City Light, added that more information can be provided as it becomes available.
- In response to a question about Pacific Lamprey data, Jason Hall clarified that Lamprey data does exist, and once Tier 1 sources are reviewed and completed, any data gaps will become clearer.

Step 3: Life stage factors affecting target species

Jason provided an overview of life stage factors of importance, which could include potentially limiting factors that are relevant to the study area; factors that can be influenced by management actions; or factors that can be linked to project operations. He walked through an example for Chinook salmon in the incubation to emergence life stages (see slides 35-39).

Step 4: Key uncertainties

Jason explained that the goal of Step 4 is to identify key uncertainties based on information collected in Steps 1-3 and through work group meetings. The goal is to identify key uncertainties among key factors that will help inform management decisions and to identify studies to address key uncertainties. He reiterated that these uncertainties would be addressed in coordination with LPs at future meetings.

Questions and Discussion:

- In response to a question regarding factors related to Project impacts on species, Jason Hall explained that the Study Team cannot currently determine the exact amount of information, noting that most sources include few linkages to project operation. Andrew Bearlin, City Light, noted that it is too early to draw conclusions, and that the current exercise of identifying gaps is an element of the study itself.
- In response to a question about a third study season, Andrew clarified that a third study season is not expected, and that further discussion related to data gaps can be had at future meetings. Andrew noted that addressing potential data gaps could be incorporated into a PME.
- In response to a question about how life stages will be brought together into a life cycle framework, Jason Hall explained that the SY-01 study provides a first step to support the development of life cycle models and work with LPs to identify linkages and determine relative importance of various life stage factors.

Commented [A(1]: LPs hear different comments about a 3rd study season by SCL from "yes" to "no."

Commented [A(2]: SCL should make a hard effort to have this study address downstream effects for a Study Year 3, particularly since this study has fallen way behind. The SY-01 should have informed lower river issues in Study Year 2, according to the study plan.

<u>Summary of Next Steps: Preliminary Schedule</u>

Jason Hall, CFS, provided a summary of next steps for the SY-01 study, noting that annotated bibliographies for Tier 1 sources will be completed in May and provided to LPs for review and comment. He explained that the next meeting, slated for June 2022, will provide the opportunity for LPs to discuss comments or questions on the Tier 1 annotated bibliographies and review some of the data inventory results (see slide 44).

Questions and Discussion:

- In response to a question regarding sources linked to operations, Jason clarified that the screening was done to identify all potentially relevant information related to resource conditions in the study area, not specific to Project operations. He explained that Project related data can be flagged and attributed when drafting annotated bibliographies and data entries. LPs were welcomed to flag linkages as well.
- In response to a question regarding linking SY-01 screening to operations upstream, Andrew Bearlin clarified that the work done over the last 2-3 years was designed to identify linkages and demonstrable evidence indicating that there were project effects. He explained that there wasn't much evidence found. The intent of the Synthesis Study is to survey the literature that has been done. It is a bonus if the Study Team finds linkages to operations.
- In response to a question related to requests from tribal and resource agencies, Andrew Bearlin clarified that City Light conducted the SY-01 study based on an NOA agreement. He explained that City Light's approach to this work is focused on stewardship and understanding where the biggest impact can be made.
- Brock Applegate noted that FERC also required the SY-01 Study. It has been further clarified that based on Scoping Document 2 and the Study Plan Determination, FERC approved the study for implementation as proposed in the Notice of Agreements, and as such City Light is treating the Study as a required element of the Study Program.
- In response to a question regarding the integration of other Skagit Relicensing studies, Andrew Bearlin clarified that at some point there is going to be an opportunity to look at the results of other studies to better understand project operations and potential impacts.
- Rick Hartson, USIT, suggested increased coordination to develop a clearer understanding of study integration and when results will be ready. Andrew Bearlin explained that there will be an opportunity to bring actionable information around the Skagit Relicensing studies together and identify data gaps.
- Rick Hartson, USIT and Steve Copps, NMFS, noted their concern about the timeline of available information and its ability to inform a draft license. Jason noted that the Study schedule assumes status check-ins and opportunities for LPs to engage.
- In response to a question about adding references, Jason Hall explained that the Study Team can continue to add references, but a cut off will be established.
- In response to a question regarding future public meeting opportunities and involvement of local communities, Andrew Bearlin clarified that there have been no barriers to participation in the relicensing process thus far, and that if there are additional parties missing to let City Light know. He also noted that due to the COVID-19 pandemic, public meeting opportunities were not possible in the way they were envisioned. He also explained that City Light is planning to host site visits as part of the settlement process.

Commented [A(3]: I think any study approved by FERC in the Study Plan Determination becomes required for implementation by the steps in the RSP and updated RSP.

Action Items and Next Steps

Greer Maier, facilitator, explained that the draft annotated bibliographies for Tier 1 sources will be provided to LPs for review and comment ahead of the June SY-01 meeting. She also shared the proposed calendar for anticipated technical work group meetings through the remainder of the Study Plan Implementation phase. The SY-01 Lower River Synthesis study anticipates meetings in June, August, October, and December of 2022.

The meeting adjourned at 3:00 pm.

Skagit Hydroelectric Project Relicensing:
SY-01 Lower River Synthesis Meeting
July 14, 2022
Meeting Summary

Attendance

Licensing Participants (LPs):
Brock Applegate, Washington Department of Fish & Wildlife (WDFW)
Joe Benjamin, United States Geological Survey (USGS)
Richard Brocksmith, Skagit Watershed Council
Jason Dunham, USGS
Jenna Friebel, Skagit Drainage and Irrigation District Consortium
Jeffrey Garnett, US Fish and Wildlife Service (USFWS)
Will Honea, Skagit County
Brian Lanouette, USIT
Jim Myers, National Marine Fisheries Services (NMFS)
Dave Price, NMFS
Devin Smith, Skagit River System Cooperative (SRSC)
Amy Trainer, Swinomish Indian Tribal Community
Erik Young, Skagit Fisheries Enhancement Group

Seattle City Light (City Light):
Andrew Bearlin , City Light
Leska Fore, City Light
Andrew Haas, City Light
Erin Lowery, City Light

Consultant Team:
Jenna Borovansky, HDR
Meghan Camp, CFS
Jason Hall, Cramer Fish Sciences (CFS)
Jake Kvistad., CFS
Matt Wiggs, HDR

Facilitation Team:
Greer Maier, Triangle Associates
Lauren Schultz, Triangle Associates

Meeting Materials

Meeting materials sent in advance:

- Proposed Agenda
- Meeting Slide Deck
- Annotated Bibliographies for Tier 1 Sources: For each identified source, a brief summary of the source and a narrative of how the information supports the Skagit River Relicensing SY-01 Synthesis Study objectives are provided.
- Data Source Attributes: Provides supporting information for each annotated bibliography (description of the fields and values used in the data inventory and to categorize sources and source information).
- SY-01 Sythesis Study GE-04 Annotated Bibliographies 20220718.pdf
- SY-01 Life Cycle and Conceptual Life History Models V2.pdf

Action Items

Action	Responsibility	Deadline
Licensing Participants (LPs)		

LPs will submit additional resources from studies (past or present) that have not yet been identified or compiled. **Suggested resources can be sent directly to Jason Hall (Consultant Team) at Jason.Hall@fishsciences.net and cc: Andrew Bearlin (City Light) andrew.bearlin@seattle.gov**	LPs	Ongoing
LPs will explore the working version of the R-Shiny tool for resources (https://fishsciences.shinyapps.io/HDR_Skagit_APP_V1/) and send suggested changes and additions **to Jason Hall (Consultant Team) at Jason.Hall@fishsciences.net.**	LPs	Ongoing
LPs will review the conceptual Life Cycle Model framework for salmon, trout, and lamprey and send suggested changes and additions **to Jason Hall (Consultant Team) at Jason.Hall@fishsciences.net**	LPs	Ongoing
City Light/Consultant Team Action Items		
Jason Hall will create a version of the Life Cycle Model frameworks for review and comment,	Jason Hall (Consultant Team)	Complete - SY-01 Life Cycle and Conceptual Life History Models V2.pdf
Triangle Associates		
The Triangle Facilitation Team will schedule the next SY-01 Lower River Synthesis meeting.	Triangle	In Process
Prepare draft meeting summary and send to participating LPs, City Light, and other attendees for review.	Triangle	Complete

Summary of Issues Discussed, Action Items, and Decisions

Welcome, Introductions, Agenda Overview

The facilitator, Lauren Schultz, welcomed the group and led a roll call. She gave a brief overview of the agenda and shared the meeting purpose, which was to

- Review status and timeline for SY-01 study implementation
- Review and discuss annotated bibliographies of Tier 1 sources and data inventory results
- Review and discuss preliminary conceptual life history models
- Discuss LP input on key questions and associated data gaps

SY-01 Status Update and Timeline for Study Implementation

Jason Hall, Cramer Fish Sciences (Consultant Team) began the meeting with an overview of objectives, timeline, and status of the study. He summarized the stepwise process being implemented and gave a summary of the timeline for implementation. Step 1 is data compilation (Tier 1 complete); Step 2 is data analysis with both data inventory (Tier 1 complete) and conceptual life history model development as subtasks; Step 3 is life stage factors affecting target species; and Step 4 is identification of key uncertainties and identification of key data gaps and monitoring needs. The SY-01 Work Group will be meeting in August, October and December (see slides 4-6).

Updates on Step 1 Data Compilation

Jason Hall provided an update on the compilation of data and information (Step 1). He has identified 495 sources and archived pdfs and screened and categorized these sources. Tier 1 sources are sources directly relevant to the study area and focused on the Skagit system. Tier 2 sources are more site specific and/or are regional in scope and the Skagit is just part the larger study. This tiering helped the team prioritize their work. They have finished their review of Tier 1 and are now working on Tier 2 studies; focusing on the most recent reports in their review (slide 8).

The annotated bibliographies that have been provided to the Work Group were develop so that they could easily access the information in the study. They were designed to give a quick view of the information from the study. Jason noted that that although the annotated bibliographies are extensive, they summarize over 8,000 pages of material and are meant to be a tool to support steps 2-4. Tier 2 sources will be added to the annotated bibliographies as completed.

Along with the annotated bibliographies, Jason and his team have developed an R-shiny application to allow for easy access and exploration of sources (see working version here https://fishsciences.shinyapps.io/HDR_Skagit_APP_V1/). The application allows users to search and filter by keywords and data flags. Jake Kvistad, Cramer Fish Sciences (Consultant Team) provided a demonstration of the application to the Work Group. He noted that Cramer is still looking for input from users to further develop the application. *This was added as an action item.*

Questions and Discussion

- Dave Price, NMFS, asked a specific question about whether a specific source (linked here) had been included in Step 1: Jason looked into this during the meeting and the citation was generated from the GE-04 sources and is included now.
- Dave Price, NMFS, asked a question about the focus of the topics in the tool. Jason responded that the focus was target species and key resources, but his team didn't narrow the search in any way.

<u>Preliminary Data Inventory Results</u>

Jason Hall presented an overview of the data inventory that has been completed from Tier 1 sources (see slides 14-22). He noted that this data inventory is meant to inform Steps 2-4 but is NOT intended to identify data gaps. Based on the data inventory, the main topic and keywork in Tier 1 sources were fish and habitat, followed by geomorphology and landforms, modeling tools, land use and cover, water quality and productivity and hydroelectric operations. Several subtopics and keywords were identified under these larger topics and Jason showed information on the number of sources compiled for different topics. He also showed the number of information sources by species and life stage. He noted that SY-01 study is not restricted to the study area, but he did compile data available for each reach and geographic area within the study area. Lastly, Jason presented the number of sources that address different data flags (yes/no for quantitative data, spatial data, and project linkages). This evaluation will be updated as Tier 2 sources are compiled.

Questions and Discussion

- Dave Price, NMFS, asked the question of whether sources that address multiple topics were counted multiple times in the graphs. Jason responded that sources that addressed multiple topics/areas/etc. could be counted multiple times and therefore the sum does not equal the total number of sources.

<u>Preliminary Conceptual Life History Models</u>

Next, Jason Hall presented information on preliminary conceptual life cycle models (LCMs) which are intended to identify drivers and stressors, which produce factors and processes, and in turn lead to biological responses in target species and life stages (slide 25-44). The intent was to help identify key factors from LPs and integrate that with data compilation to help focus model development. The next step (Step 3) will be to develop a table of key factors with ratings of importance and citations. The target species groups are salmon (Chinook, Coho, Sockeye, Chum, and Pink), trout (Bull Trout and Steelhead), and Lamprey.

During his presentation, Jason provided an overview of the modeling framework and outputs. He presented a slide on each of the species' groups, showing the species, life stages, and spatial bins (e.g., salmon include ocean rearing and river maturation and holding). Unique variations in specific life stages were called out by species (e.g., Chinook estuary rearing). Jason identified key life stages for SY-01 for each species group based on whether those life stages were within the study area and tied to project impacts.

Lastly, Jason led the group through a review of the model framework for each species group, focusing the discussion on confirmation on prioritization and identifying missing information. He noted that he is welcoming feedback at any time. Jason live edited the slide deck during the meeting and agreed to send out a reviewable product. Jason asked Work Group member to look at the slides between now and August and provide comments (particularly on lamprey) by email. *This was added as an action item.* Comments during the meeting are summarized below.

Questions and Discussion

Salmon LCM:

- Brian Lanouette, USIT, suggested including temperature minimums that may disrupt spawning cues.
- Dave Price, NMFS, asked where reproductive success or productivity lie in the diagram. He was specifically interested in female fecundity or fitness and biotic and demographic response. He suggested adding pertinent demographics such as hatchery influence.
- Dave Price, NMFS, did not want to exclude nearshore and ocean rearing because of density dependence which influence relative mortality. Jason Hall responded that he is still including nearshore life stage but areas outside Puget sound will not be included.
- Jim Meyers, NMFS, suggested for ocean condition and maturation to consider the potential effect on age at maturation (therefore: fecundity, reproductive success, redd depth, etc). He suggested adding it to spawning/incubation and tie it to ocean growth. Other LPs added ocean rearing because there is a known differential mortality associated these fishes and consider density dependence as a factor in the early exit of these fish from estuary/delta habitats where productivity is relatively high.
- Jenna Friebel, Skagit Drainage and Irrigation District Consortium, raised a question about the outcome of this process. Jason Hall responded that the ultimate outcome is a set of conceptual models with linkage defined as derived initially from the Tier 1 sources and updated based on LP input. Jenna noted a concern that there might be overlap with what the Washington Water Research Center's Water Task Force work is doing. She suggested there could be benefits to coordinating efforts to ensure the studies are complimentary and not diverging. Andrew Bearlin, City Light, voiced support of such an approach and agreed to follow up with Jenna. Jason Hall indicated he could also help make those connections.

- Jenna Friebel asked a clarifying question about linkages between dam operations and life cycle model identified impacts? Andrew Bearlin indicated that there is a connection between which levers can be pulled and in which context, with some more readily available than others.
- Jim Meyers suggested age structure would fit into the migration, holding, and spawning, however, he noted a concern that you lose the link to ocean conditions. He reiterated that they should not lose sight of ocean impacts.
- Dave Price suggested that inundation frequency and duration should apply to estuary and floodplain habitat as well and rearing and outmigration would apply (habitat availability). Brian Lanouette noted that inundation frequency should be added to migration, holding, and spawning as well for fish looking to enter off-channel areas to spawn or stage or for fish trying to go into off-cannel side channels for spawning.

Jason Hall concluded the discussion with an overview of next steps. He compared the exercise to “organizing a laundry list and identifying what you don’t want to forget.” He clarified with the group that the purpose is to think about things in an LCM context and consider the literature available to help answer questions. Jason Dunham, USGS indicated he could potentially work on the lamprey life cycle with Ben Clemens.

Preliminary Discussion on Key Questions

Jason Hall began the discussion by giving the context for the discussion. Step 4 will directly address data gaps based on the literature review and LP feedback. He posed questions to the group about what questions need to be answered and what do the LPs see as key data gaps or information needs. Lauren Schultz reminded the group that this discussion is also a follow-up from a Technical Steering Committee conversation about timing and priorities for SY-01.

Questions and Discussion

- Devin Smith, SRSC, mentioned that he hadn’t had a chance to frame his question because he hadn’t reviewed the material provided. He noted he had a lot of questions, but he doesn’t know how to ask them. Hypothetically it would be helpful to know if project operations have an effect in the lower river.
- Brian Lanouette, USIT, noted that he was generally interested in productivity and habitat conditions, but he will need to revisit past input and refocus it on the lower river for more specificity.
- Devin Smith stated that he would like to understand if project operations influence woody debris supply in the lower river and whether flow regulation affects floodplain habitat connectivity or geomorphology in a way that affects habitat for salmon in the lower river. He mentioned he did not know if the literature review will shed light on those questions or not. He stated that he believes sediment supply would be on the list of questions too, but there will be some new quantitative information about sediment supply from another relicensing study.
- Dave Price, NMFS, noted that the obvious question is what the dam effects are on the lower river. He said the conceptual model helps us answer question but what is missing is dam effects on physical processes, (e.g. sediment effects on salmon and dam effects on sediment).
- Devin Smith stated that USIT or others might want to add water quality concerns to the list of questions. Brian Lanouette followed up with a question about what the hydropower effects are to water quality conditions (temperature, nutrients).
- Jim Meyers, NMFS, asked the group to consider a bigger question: “what is a data gap?” and “when is information sufficient to provide a conclusion with some level of certainty?” and “when

are there sufficient sources to look at a question from multiple angles?" He noted that formally, this might be outside the scope of SY-01 and the questions it is asking, but that lens could be worked into task 4 and the SY-01 LP feedback on key data gaps.

- Brian Lanouette noted there are data gaps related to processes and gave an example of nutrients tied to process that flush out side-channels. He suggested that data gaps do have layers and interconnect with each other in various ways.
- Devin Smith suggested that for anything noted as important habitat, the question would be what role project operations play in associated factors and life stages, asking what the literature tells us.
- Jason Dunham, USGS, noted in the chat that a data gap relates to bias or uncertainty in the structure of models or parameters. They influence assessments of outcomes or consequences of different decisions, scenarios, etc. and therefore you must look at this first and see what emerges. He noted that this is a very model-centric perspective and not the only one that matters. He said that in other words there's always something we would like to know more about but we need to ask whether they influence how we think about decisions.

Action Items, Next Steps

Jason Hall summarized next steps for the study as follows:

- **Step 1 Data Compilation (April – June 2022):** Complete ABs for Tier 1 Sources and provide drafts to LPs for review. Begin ABs for Tier 2
- **Work Group Meeting #3 (July 2022):** Discuss/review draft Tier 1 ABs and data inventory results, work session on preliminary life history models.
- **Work Group Meeting #4 (August 2022):** Continue developing preliminary conceptual life history models
- **Work Group Meeting #5 (October 2022):** Develop/review preliminary factors tables.
- **Work Group Meeting #6 (December 2022):** Develop/review key uncertainties.
- **USR Report and Reference Database (January - March 2023):** Integrate LP comments and Tier 2 Sources into conceptual models, factors tables, and key uncertainties. Draft USR and Reference Database.

The facilitator alluded to an August 11th meeting as the next time the group would meet.

Skagit River Hydroelectric Project Relicensing
SY-01 Lower River Synthesis Meeting
August 11, 2022
1:00 – 3:00 pm
Meeting Summary

Attendance

Licensing Participants (LPs)
Brock Applegate, Washington Department of Fish and Wildlife
Richard Brocksmith, Skagit Watershed Council
Curtis Clement, Upper Skagit Indian Tribe (USIT)
Rick Hartson, USIT
Brian Lanouette, USIT
Dave Price, National Marine Fisheries Service
Devin Smith, Skagit River System Cooperative (SRSC)
Amy Trainer, Swinomish Indian Tribal Community
Stan Walsh, SRSC
Erik Young, Skagit Fisheries Enhancement Group

Seattle City Light (City Light)
Andrew Bearlin, City Light
Leska Fore, City Light
Andy Haas, City Light
Erin Lowery, City Light

Consultant Team
Jenna Borovansky, HDR, Inc. (HDR)
Meghan Camp, Cramer Fish Sciences
Jason Hall, Cramer Fish Sciences
Matt Wiggs, HDR

Facilitation Team
Jacob Hibbeln, Triangle Associates (Triangle)
Lauren Schultz, Triangle

Meeting Materials

- SY-01 Work Session Slide Deck
- July 2022 SY-01 Meeting Summary
- SY-01 Life Cycle and Conceptual Life History Models
- ISR Meeting Summary
- City Light ISR Response to Comments
- NOA Commitments
- Draft Skagit Anticipated Work Group Calendar

Action Items

Action Item	Responsibility	Deadline
LPs		
Review the ***updated*** conceptual Life Cycle Model framework for salmon, trout, and lamprey, linked **here**. **As before, the PDF can be downloaded, marked up with Adobe Acrobat tools, and sent as an attachment via email, or you can provide comments/edits in list form via email – please send comments via email to Jason Hall (Consultant Team) (Jason.Hall@fishsciences.net).**	LPs	**Ongoing**
Continue to explore the working version of the R-Shiny tool for resources (https://fishsciences.shinyapps.io/HDR_Skagit_APP_V1/) and send suggested changes and additions **to Jason Hall at Jason.Hall@fishsciences.net**	LPs	Ongoing

Triangle		
Schedule the next SY-01 Lower River Synthesis meeting (anticipated in October).	Triangle	**Anticipated October 2022**

Summary of Issues Discussed, Action Items, and Decisions

<u>Introductions</u>

Lauren Schultz, facilitator, welcomed the group and led a roll call. She reviewed the agenda and meeting purpose, which was to review and discuss the SY-01 Life Cycle and Conceptual Life History Models for salmon (Chinook, Coho, Sockeye, Chum, and Pink), trout (bull trout and steelhead), and lamprey. The facilitator indicated that the R-Shiny tool contained new annotations and that the Consultant Team welcomes feedback from LPs.

<u>Overview of SY-01 Study Updates and Timelines (I)</u>

Jason Hall, Consultant Team, reviewed the SY-01 Lower River Synthesis study goals and objectives and reviewed all four steps of the study and the status of each. Jason also reviewed the timeline and study updates and indicated that the next meeting would focus on reviewing preliminary factor tables and identify key uncertainties in the study.

<u>Review SY-01 Life Cycle and Conceptual Life History Models (I and A)</u>

Jason reviewed the progress of the models and indicated that any requested changes would be captured in notes as opposed to live edits. Jason then reviewed a summary of updates which are on slide 9 of the meeting presentation as well as the review questions on slide 10.

Jason reviewed information on preliminary conceptual life cycle models (LCMs) for salmon, trout, and lamprey, and led the group through a discussion on drivers and stressors, factors and processes, and biological responses for each species various life stages.

Salmon Life Cycle Model

Jason reviewed the salmon life cycle model and the updates made by the Study Team. Key updates included edits to fish passage barriers and tributary confluence. Jason indicated that there were potential redundancies in this life cycle model and that there were opportunities to simplify information. Jason also acknowledged that there were conflicting comments regarding the anthropogenic aspects of the diagram but that he left those in the diagram intentionally to be inclusive.

In response to a question regarding whether TDG would be applicable to migration and holding, Jason indicated that it could be, and noted the addition of "Water Quality: cold water releases, nutrient sequestration, TDG" to the instream flows section of the Salmon life history stage. The group discussed sediment supply and transport, and Jason indicated that sediment supply and transport was mostly captured under predation and competition in the diagram. Rick Hartson, USIT, indicated that timing and duration of delivery seems important and should be captured. Jason affirmed Rick's addition, and suggested adding "harboring, straightening, and dredging" to the sediment supply and transport section of the estuary/nearshore rearing and emigration Salmon life stage.

Trout Species Group Life Cycle Model

Jason reviewed the trout life cycle model on slide 16 of the meeting presentation, noting that it was more complicated than the salmon life cycle model and meeting participants confirmed that he had captured the most important aspects of the trout life cycle.

Lamprey Life Cycle Model

Jason reviewed the lamprey life cycle model on slide 21 of the meeting presentation, and then reviewed the main differences between this and the other life cycle models. Jason indicated that fine sediments affect habitat and that he needed to add instream minimum and maximum temperatures to the incubation, emergence, and larval rearing life cycle stage for lamprey. The group discussed the impacts of anchor ice and Jason indicated that this affects steelhead more than lamprey.

The facilitator indicated that an updated PDF of the conceptual life cycle and life history models would be provided to LPs for further review following the meeting.

Action Items, Next Steps

Jason confirmed that the Consultant team would incorporate comments on all life cycle models by the next meeting in October and then reviewed the timeline on slide 26 of the meeting presentation, noting that submitting comments would help the Consultant Team complete the life cycle models.

The facilitator reviewed action items and noted that the facilitation team would coordinate with LPs on the next meeting.

Action Item: Review the ***updated*** conceptual Life Cycle Model framework for salmon, trout, and lamprey, linked **here.**

As before, the PDF can be downloaded, marked up with Adobe Acrobat tools, and sent as an attachment via email, or you can provide comments/edits in list form via email – please send comments via email to Jason Hall (Consultant Team) (Jason.Hall@fishsciences.net).

Action Item: LPs will continue to explore the working version of the R-Shiny tool for resources (https://fishsciences.shinyapps.io/HDR_Skagit_APP_V1/) and send suggested changes and additions **to Jason Hall at Jason.Hall@fishsciences.net**

Action Item: Triangle will schedule the next SY-01 Lower River Synthesis meeting (anticipated for October 2022).

Skagit River Hydroelectric Project Relicensing
SY-01 Lower River Synthesis Meeting
October 6, 2022
1:00 – 4:00 pm
Meeting Summary

Attendance

Licensing Participants (LPs)
Brock Applegate, Washington Department of Fish and Wildlife
Joe Benjamin, U.S. Geological Survey (USGS)
Richard Brocksmith, Skagit Environmental Endowment Commission
Jason Dunham, USGS
Jeff Garnett, U.S. Fish and Wildlife Service
Rick Hartson, Upper Skagit Indian Tribe
Shauna Hee, U.S. Forest Service
Jim Myers, National Marine Fisheries Service
Sharon Sarrantonio, National Park Service
Devin Smith, Skagit River System Cooperative (SRSC)
Stan Walsh, SRSC
Erik Young, Skagit Fisheries Enhancement Group

Seattle City Light (City Light)
Andrew Bearlin, City Light
Leska Fore, City Light
Andy Haas, City Light
Erin Lowery, City Light

Consultant Team
Jenna Borovansky, HDR, Inc. (HDR)
Meghan Camp, Cramer Fish Sciences
Jason Hall, Cramer Fish Sciences
Caitie Sheban, Cramer Fish Sciences
Matt Wiggs, HDR

Facilitation Team
Lauren Schultz, Triangle Associates (Triangle)
Alex Sweetser, Triangle

Meeting Materials

- SY-01 WS 5 SlideDeck.pdf
- SY01 Presentation_NPS.pdf
- August 11 Meeting Summary
- SY-01 Life Cycle and Conceptual Life History Models
- SY-01 Literature Database
- SY-01 Tier 1 Annotated Bibliographies
- SY-01 Synthesis Study GE-04 Annotated Bibliographies
- Data Source Attributes
- NOA Commitments
- Draft Skagit Anticipated Work Group Calendar

Action Items

Action Items – *10/6/22 SY-01 Lower River Synthesis Work Session*	**Responsibility**	**Deadline**
Licensing Participants (LPs)		
LPs will review the ***updated*** trout life cycle diagram in the conceptual life history model slide deck **linked here and attached.**	LPs	October 19

Please send any questions or comments via email to Jason Hall, Consultant Team (Jason.Hall@fishsciences.net).		
Consultant Team		
Jason Hall, Consultant Team, and Jason Dunham, USGS, to coordinate on presenting an overview of the SY-01 study framework and how the process will tie-in with other complex processes (i.e., structured decision making).	Jason Hall & Jason Dunham	Next Meeting
Triangle Associates		
The Triangle Facilitation Team will schedule the next SY-01 Lower River Synthesis meeting (anticipated for November).	Triangle Associates	November 2022
Prepare draft meeting summary and send to participating LPs, City Light, and other attendees for review.	Triangle Associates	In-process

Summary of Issues Discussed, Action Items, and Decisions

Introductions

Lauren Schultz, facilitator, welcomed the group and led a roll call. She reviewed the agenda and meeting purpose, which was to update Licensing Participants (LPs) on the develop of Tier 2 Sources and the SY-01 Literature Database, review the updated SY-01 Life Cycle and Conceptual Life History Models for salmon (Chinook, Coho, Sockeye, Chum, and Pink), trout (Bull Trout and Steelhead) and lamprey, update LPs on geomorphic mapping from the National Park Service (NPS), and to review and discuss the preliminary factors table and develop the ratings of importance.

Overview of SY-01 Study Updates and Timelines (I)

Jason Hall, Consultant Team, reviewed the SY-01 Lower River Synthesis study timeline and updates, including the study goals and objectives. Jason updated the group on the development of Tier 2 sources and the SY-01 Literature Database as well as updates to the Life Cycle and Conceptual Life History Models. Jason noted that an updated trout life cycle diagram is included in the conceptual life history model slide deck linked here .

Jason reviewed the SY-01 study timeline and added that there would be an additional SY-01 workshop in November to continue review of the factors tables, after which there would be one more meeting in December (see slides 5-9).

Sharon Sarrantonio, NPS, presented information from the Geomorphology Inventory Report. In response to a question about the Sauk mainstem above the Skagit River, Sharon indicated that slides 7 and 8 of the meeting presentation show how far up the Sauk River the analysis covered. Andrew Bearlin, Seattle City Light (City Light), indicated that City Light recently received the draft Geomorphology Inventory Report and that they would send the finalized version to LPs when possible. Sharon indicated that this report would include the rest of the watershed downstream and a full summary of the upper reaches. Erin indicated that the study broke the Skagit River into specific reaches to better integrate with Geomorphology work in the upper watershed.

Review and Discuss Preliminary Factors Tables
Jason presented on the life stage factors tables, starting with an overview of the approach and organization structure of the information synthesis (see slides 12-17). He then walked through each Life Stage Factor (LSF) Category and detailed the corresponding primary factors for each category (see slides 18-26). Following this overview, Jason provided an example of a LSF Summary Table using Instream Flow as an example (see slides 27-34).

In response to a question about the life stage factors narrative, Jason indicated that the Consultant Team is in the drafting process and that they will be reviewed by City Light, after which the Facilitation Team would send them to LPs.

Jason reviewed the criteria for identifying key life stage factors, emphasizing that the goal was to objectively evaluate and identify key factors to inform the identification of key uncertainties. Full details are described slide 35 of the meeting presentation. The group discussed how different factors are weighted due to water years, Jason indicated that the Consultant Team has not yet analyzed how flow management actions relate to water year type. Jim Myers, National Marine Fisheries Service, indicated that some factors may have a greater impact under a certain water type and that climate change could significantly impact the water year type.

The group discussed how ratings, questions, and criteria would be matched, and Jason clarified that relative ratings would be within the criteria and not necessarily across. This would be a way to account for factors that have an influence on a greater range of habitats and life species.

In response to a question about the next meeting, Jason indicated that the Consultant Team will provide life stage factor tables and an initial assessment of relative importance. Jason noted that this could be adjusted based on feedback and that the Facilitation Team would send this information to LPs ahead of the next meeting for review.

In response to a question about translating information from the SY-01 Literature Database into the life cycle model, Jason indicated that the length of time this would take depends partially on the objective. Jason indicated that the Consultant Team could present a roadmap to help one find information and would not be directly quantitative. Jason then reviewed the high-level steps for translating information from the database into the life cycle model, emphasizing that the goal was to make it easier to find information for the lower river.

Jason Dunham, U.S. Geological Survey, indicated that the plan is to provide an overview of how everything together within the context of Structured Decision-Making (SDM). In response to a question about how the outcome of SDM would fit into the Focus Table process, Jason Dunham indicated that integrating SDM principles into the Focus Table process for reviewing Life Cycle Models should be complementary. He also indicated that USGS could take Jason's product and build models for the group to evaluate. Jason Dunham then explained the process for using the SDM approach to evaluate Life Cycle Models, emphasizing that it would likely be an iterative process.

Action Item: Jason Hall, Consultant Team, and Jason Dunham, USGS, to coordinate on presenting an overview of the SY-01 study framework and how the process will tie-in with other complex processes (i.e., structured decision making).

Next Steps
Jason indicated that the next meeting (5.5) would occur in November and that the Consultant Team would prepare the necessary materials ahead of time. The facilitator reviewed action items and the meeting concluded at 3:15 p.m.

Action Item: The Triangle Facilitation Team will schedule the next SY-01 Lower River Synthesis meeting (anticipated for November).

Skagit River Hydroelectric Project Relicensing
SY-01 Lower River Synthesis Meeting
November 23, 2022
1:00 to 4:00 p.m.
Meeting Summary

Attendance

Licensing Participants (LPs)
Richard Brocksmith, Skagit Environmental Endowment Commission
Jeff Garnett, U.S. Fish and Wildlife Service
Rick Hartson, Upper Skagit Indian Tribe
Jim Meyers, National Marine Fisheries Service
John Riedel, National Park Service
Dudley Reiser, Consultant for the Swinomish Indian Tribal Community
Erik Young, Skagit Fisheries Enhancement Group

Consultant Team
Jenna Borovansky, HDR, Inc. (HDR)
Meghan Camp, Cramer Fish Sciences
Jason Hall, Cramer Fish Sciences
Matt Wiggs, HDR

Seattle City Light (City Light)
Andrew Bearlin, City Light
Erin Lowery, City Light

Facilitation Team
Jacob Hibbeln, Triangle Associates (Triangle)
Lauren Schultz, Triangle

Meeting Materials

- SY-01 Draft Life Stage History Factors Tables
- SY-01 Literature Database
- SY-01 Life Cycle and Conceptual Life History Models
- Data Source Attributes
- NOA Commitments
- Draft Skagit Anticipated Work Group Calendar

Action Items

Action Items – *11/23/22 SY-01 Lower River Synthesis Work Session*	**Responsibility**	**Deadline**
LPs		
Review the **SY-01 Synthesis Study Life Stage Factors Narrative** [***linked here and attached***] and send any comments or questions to Jason Hall, Consultant Team (jason.hall@fishsciences.net) and copy Lauren Schultz, Triangle Associates (lschultz@triangleassociates.com).	LPs	December 9th [*2 weeks*]
Consultant Team		
Consultant Team to send draft Life Stage Factors Tables to LPs for review and feedback.	Jason Hall, Consultant Team	Complete – Linked Here
Triangle Associates		

Send the updated 11/23 meeting presentation to meeting participants for reference.	Triangle Associates	***Complete*** – linked here
Schedule the next SY-01 Lower River Synthesis meeting (December).	Triangle Associates	As soon as possible – ***Doodle Poll here***
Prepare a draft meeting summary and send to participating LPs, City Light, and other meeting attendees for review.	Triangle Associates	December 9th [*2 weeks*]

Summary of Issues Discussed, Action Items, and Decisions

Welcome and Introductions

Lauren Schultz, facilitator, welcomed the group and led a roll call. She reviewed the agenda and meeting purpose, which was to review the SY-01 Lower River Synthesis Study timeline and discuss updates on the development of Tier 2 Sources and the SY-01 Literature Database, present on the SY-01 Lower River Synthesis Study Framework, and to continue discussion and review of primary factors that develop ratings of importance.

Overview of SY-01 Study Updates and Timelines

Jason Hall, Consultant Team, reviewed the SY-01 Lower River Synthesis timeline, emphasizing that Study's final meeting was set to occur in December 2022 and that the Updated Study Report was set to be completed in March 2023. Jason reviewed updates to the SY-01 Lower River Synthesis Study, emphasizing how information from steps one and two were synthesized. This is shown on slides 7 – 8 of the meeting presentation.

Overview of SY-01 Study Framework

Jason reviewed step three of the Life Stage Factors (LSF), details of which are shown on slides 13 – 14 of the meeting presentation. Jason then reviewed the LSF narratives, explaining how they were organized and its purpose. This is fully explained on slides 16 – 19 of the meeting presentation.

Jason then explained how the LSF tables were developed and the initial assessment of importance using criteria to identify key factors. All steps for this are outlined on slide 22 of the meeting presentation. Jason also reviewed scoring considerations, emphasizing that there are several scoring methods and the goal was to keep the review as objective as possible. Jason reviewed key factor criteria which are explained in detail on slides 25 – 26 of the meeting presentation. In response to a question about whether specific species (i.e., type of salmon) categories are being used, Jason explained that the Consultant Team considered grouping species this specifically but that it was too complex. After reviewing the scoring approach and criteria, Jason explained the biological, management, and climate scoring components, noting that an aggregate score was calculated by integrating all three of the components and that each can be weighted individually.

In response to a question about flow regulation, Jason clarified that regulations could be used in the Baker or Skagit Rivers and that the Project operations field is specifically related to Skagit operations. The group discussed the relationship between limiting factors and the aggregate score as well as where the scores play into the decision-making process. Jason clarified that the group could discuss limiting factors that are most relevant at a later meeting. Erin Lowery, City Light, indicated that although the geographic scope of the SY-01 Lower River Synthesis study is limited to the lower Skagit River, there could be information from the upper Skagit River that is relevant but not included. In response to a question about how limiting factors might be linked and if a later model could be used to weigh each factor's relative importance, Jason indicated that Structured Decision-Making could help determine this.

Continued Review and Discussion on Preliminary Factors Tables

Jason reviewed the LSF tables and their purpose, emphasizing that they are based on conceptual ideas presented in previous work and they have been adapted to include specific information on species groups, life stages, and spatial extent. Jason summarized factors and the key values in the LSF tables (slides 41 – 46 of the meeting presentation) The group discussed the draft preliminary results and Jason encouraged LPs to point out any inconsistencies or errors. In response to a question about what factors might be influenced by Project operations, Jason indicated that the definition for direct and indirect influence is subjective. The group also discussed how connectivity was not included in preliminary results. Erin indicated that the Consultant Team is developing a framework for City Light to make management decisions. In response to a question about incremental benefits downstream of the Sauk River, Jason pointed to the LSF narratives and indicated that there is information on how to understand where low-flow period occurs.

Wrap-up and Next Steps

Jason indicated that the Consultant would update the presentation and LFS tables based on discussion at the meeting and that the facilitation team would distribute to LPs. Jason also requested that LPs provide comments on key factors before the next meeting in December.

Action Item: LPs will review the **SY-01 Synthesis Study Life Stage Factors Narrative** [***linked here***] and send any comments or questions to Jason Hall, Consultant Team (jason.hall@fishsciences.net) and copy Lauren Schultz, Triangle Associates (lschultz@triangleassociates.com) by December 9, 2022.

Action Item: The Consultant Team will send draft Life Stage Factors Tables to LPs for review and feedback as soon as possible.

Action Item: Triangle will send the updated 11/23 meeting presentation to meeting participants for reference as soon as possible.

Action Item: Triangle will schedule the next SY-01 Lower River Synthesis meeting (December) as soon as possible.

Action Item: Triangle will prepare a draft meeting summary and send to participating LPs, City Light, and other meeting attendees for review by December 9, 2022.