Recolonization of the Cedar River above Landsburg by anadromous fish: ecological patterns and effects

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Executive Summary

As part of the City of Seattle's Habitat Conservation Plan, a fish ladder was constructed at Landsburg Diversion to provide passage of salmon to ~33 km of available habitat. Adult salmon were passed above Landsburg beginning in September 2003 for the first time since 1900. This report compares fish communities and ecosystem attributes in the Cedar River above the diversion before (2000 and 2001) and after (2004-2006) installation of the Landsburg Fish Passage Facility.

In August and September 2005 and 2006 we surveyed approximately 10 km of river habitat from above the diversion pool (reach 1) to Cedar Falls (reach 10). During these two summers, physical habitat was quantified, and fish identified and counted in 8-10, 800-m long reaches established in 2000. Within each reach, we measured physical variables known to correlate with fish density and diversity such as channel gradient, habitat area, depth, velocity and substrate composition. Following habitat surveys, reaches were snorkeled to describe the fish community including identifying to species when possible and size class. We also used seasonal (spring, summer, fall) snorkel surveys of multiple pools to monitor colonization of Rock Creek by juvenile coho. Lastly, in 2005-2006 we tagged and recaptured coho and trout in Rock Creek and the main stem Cedar above Landsburg to monitor fish movement, growth, and survival.

Water samples (311 samples) were collected from historic sites throughout the Cedar River and Steele, Williams, Taylor and Rock creeks between September 2004 and October 2005. Samples were also collected from riparian vegetation and the stream food web (periphyton, invertebrates, sculpin, trout and coho) in September 2004 to measure concentrations of carbon and nitrogen isotopes. We collected and processed a total of 368

isotope samples. Carbon isotopes can be used as tracers to describe energy flow in the food web, while nitrogen isotopes can quantify the relative contribution of salmon-derived nitrogen in resident fish and other organisms. Similar samples were collected in 2000 and 2001 before arrival of salmon.

The objectives of these collective studies were to determine a) the efficacy of the fish passage facility in restoring anadromous salmon above Landsburg, b) whether salmon have measurable ecological effects on water chemistry, food webs or resident fish species, and c) habitat-fish associations in order to inform managers and conservation groups on potential strategies to improve or protect critical fish habitat in the Cedar River.

Juvenile salmon have rapidly dispersed and colonized multiple habitats within the main stem and Rock Creek. This recolonization has potentially led to large-scale shifts in the distribution and abundance of resident trout in the main stem and Rock Creek. Before the ladder was installed, trout density increased from reach 1 to 10, peaking in 9 and 10 (~0.10 fish/m^2), which were the furthest from Landsburg. In contrast, after installation of the ladder peak densities occurred in reach 1 and 2 (~0.12 fish/m^2), ~0.5-5 km above Landsburg diversion. Overall, fish densities have increased by three-fold in reaches 1-3 since installation of the ladder. This increase was largely due to juvenile coho salmon and trout >80 mm. We speculate that higher densities of large trout in reaches 1-3 may be partially a result of increased prey resources (salmon eggs, juvenile salmon, and salmon carcasses) or influx of trout from below Landsburg. Diet analysis of trout > 40 cm collected in 2000 and 2001 showed that these fish obtained approximately 35% of their diet from fish.

Juvenile coho densities in the Cedar River during 2005 and 2006 (~0.03 fish/m^2) were about two-fold higher than 2004. While coho were more abundant in 2005 and 2006 than 2004, the opposite was the case for juvenile Chinook. Although juvenile Chinook densities have declined since 2004, our summer surveys occurred after most Chinook have migrated to Puget Sound. The spatial extent of coho distribution also increased from primarily reach 1 and 2 in 2004 to reaches 1-7 in 2005 and 1-6 in 2006. The relative proportion of coho in reach 6 was about 5% in 2005 and 40% in 2006. At the habitat unit scale, juvenile coho, Chinook, and trout densities were highest in side channels, while densities of trout >80 mm were highest in pool and step pool habitat.

Juvenile coho have rapidly colonized lower Rock Creek, which has also contributed to major shifts in trout populations and size structure. Since summer 2004, the first year that juvenile coho and Chinook were present above Landsburg, the relative proportion of trout <80 mm in reach 1 of Rock Creek has declined, whereas the proportion of juvenile coho has doubled. Similar, but less pronounced, patterns were observed in reach 3 about 2 km away from the mouth of Rock Creek. Seasonal surveys of Williams, Steele and Taylor creeks have shown that salmon periodically occupy lower sections of these streams, but there is no indication of colonization.

We found evidence that reach-scale variation in fish density was correlated with water temperature, maximum pool depth and wood abundance. For example, reach-scale patterns of salmonid densities in main stem and tributaries were positively associated with mean annual water temperature. Maximum pool depth in Rock Creek was also positively associated with species diversity and juvenile coho density in 2004. Coho density showed a similar pattern in 2006.

To date, 1881 juvenile coho and trout received PIT tags in Rock Creek and the Cedar River at or above Landsburg. Recapture rates were relatively high, with the PIT tag reader at the mouth of Rock Creek recapturing approximately 25% of tagged fish. Recapture rates were highest for cutthroat (19%) followed by rainbow trout (13%) and juvenile coho (7%). Fish moved primarily during fall and spring, with downstream movements predominating. Survival of PIT-tagged coho was high: of 177 coho tagged in 2005, 32 were detected at the Ballard Locks. Given the reader at the Locks has a recapture efficiency of approximately 50%, smolt survival estimates from Rock Creek ranged from 18-36%. In addition, our tagging effort documented the first case of anadromy in *Oncorhynchus mykiss* above Landsburg diversion.

To date (2003-2006 Landsburg counts), about 1700 kg of salmon biomass has been imported into the Cedar River ecosystem upstream of Landsburg. These levels, however, have shown no measurable effect on nitrogen or phosphorus levels in surface waters. The low inputs of salmon biomass into the large Cedar River, high temporal and spatial variation in nutrient chemistry, the timing of spawning (September-February), and abundant scavengers likely limit carcass effects on water chemistry.

We used the distribution of known Chinook and coho redds as a means to quantify salmon input. Although this approach is likely conservative as more salmon were passed above the dam than identified redds, we have no way of knowing the fate of salmon that did not spawn. Based on surveys, reaches 1 and 2 have received the greatest amount of salmon input averaging about 103 and 89 kg of total salmon biomass per year, respectively. This translates into about 31 kg N and 4 kg of P into reach 1. The next highest input occurred in reach 4 (~19 kg), with very few salmon spawning in reach 3.

Correcting salmon input by reach area shows that mean annual inputs (~0.0004 – 0.0006 kg/m^2) were similar among reach 1, 2 and 4, and approximately 250 – 375× lower than inputs (0.15 kg/m^2) shown to affect N^{15} levels in trout (Bilby et al. 2001). Although salmon input into the Cedar River was orders of magnitude lower than earlier studies documenting carcass effects, these relatively energy-rich inputs may produce a local (i.e., habitat unit scale) increase in primary and secondary productivity which benefit higher trophic levels (fish and birds). To test this hypothesis, we recently added salmon carcasses to experimental streams, with inputs ranging from values observed in reaches 1 and 2 (~0.0001 kg/m^2), to levels found to affect productivity (0.5 - 1 kg/m^2), to very high levels (4 kg/m^2). Preliminary results indicate the total nitrogen and phosphorus concentrations increased as carcass loading increased as did total abundance of aquatic invertebrates.

In contrast to lack of ecosystem effects, our results show significant shifts in fish populations and communities in the Cedar River and Rock Creek as a result of both adult and juvenile salmon dispersal. Remarkably, these changes have occurred in three years. The rapid colonization by salmon of the Cedar River above Landsburg emphasizes their innate ability to colonize newly available habitat. Our results also suggest that juvenile fish preferentially select side-channel habitat; these patterns are consistent to those observed below Landsburg (Dr. R. Peters, personal communication). In addition, coho survival to the Ballard Locks from Rock Creek was relatively high compared to other Puget Sound systems. Finally, we have documented anadromy in rainbow trout, which has implications for conservation of depressed steelhead populations in the basin.

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1.0 Introduction

Fishing, habitat loss and degradation, poor hatchery practices, climate change, and non-native species are the main causes of Atlantic (*Salmo salar*) and Pacific (*Oncorhynchus spp*.) salmon population declines (NRC 1996, Montgomery 2003). Some of the primary culprits in habitat loss are barriers to fish migration such as road crossings, levees, and dams blocking access to upstream and floodplain habitats. Lack of fish passage is a problem that has been documented throughout North America (e.g., USGAO 2001, Langill and Zomora 2002) and Europe (Yanes et al. 1995, Glen 2002). In Washington State over 7,700 km of historical salmon habitat are inaccessible to migratory fishes because of impassable culverts or road crossings, despite state regulations requiring fish passage (Roni et al. 2002).

In the United States, many salmon occupying truncated river systems have precipitously low population levels and have recently been listed as either threatened or endangered under the United States Endangered Species Act (ESA) (NRC 1996, Montgomery 2003). Removal of a blockage, whether it is a small culvert or a series of dams in a large watershed, is considered a key restoration action to aid in the recovery of listed salmon. These actions are currently being implemented across North America and will likely become more prevalent in the next 5–10 years (Roni et al., 2002). Although much effort has been made to remove blockages to salmon passage, surprisingly little is known about why salmon colonize new habitats and what occurs after a barrier is removed. For example, what are the key environmental factors that determine salmon colonization success? and What restoration actions might promote colonization success?

As part of the city of Seattle's Habitat Conservation Plan (HCP) for the Cedar River Watershed, a fish ladder was opened at the Landsburg Diversion Dam located on the Cedar River main stem in September 2003. This diversion blocked anadromous fish migration too approximately 33 km of main stem and tributary habitat for over 100 years potentially contributing to population declines of a number of fish species as well as resulting in losses of important food resources for a variety of species. It has been shown in other studies that salmon carcasses provide important nutrient subsidies to their natal streams and the surrounding terrestrial ecosystem (Bilby et al. 1996, Willson et al. 1998, Chaloner et al. 2002). In addition, resident fishes above Landsburg have been isolated from anadromous salmon for a number of generations; there are likely to be ecological effects (e.g., competition, predation) on these resident fishes resulting from the return of anadromous forms above Landsburg. We initiated a long-term monitoring study to evaluate recolonization success of anadromous fish above Landsburg Diversion in 2000, to describe the ecological effects of these colonizing salmon, and determine potential restoration actions to promote colonization success. As far as we know, this is one of the first studies to document the natural colonization process of Pacific salmon into native habitat. Most other published studies have relied on stocking fish (Bryant 1999) or were in Alaska where salmon colonized fishless streams after glacial recession (Milner et al. 2000). Therefore, this project presents a unique opportunity to understand the colonization process of Pacific salmon under natural conditions when a barrier is removed or altered to allow fish passage.

The objectives of the 2005 Scope of Work were to (1) quantify spatial characteristics of physical habitat of the lower Cedar River between Landsburg Diversion and Cedar Falls; (2) determine spatial and temporal patterns of nutrients and algal biomass, and whether these change with number of returning adults; (3) quantify spatial and temporal patterns of fish diversity and community structure in the lower Cedar River, and whether these attributes correlate with environmental conditions (e.g., wood abundance, nutrient concentrations, algal biomass); and (4) estimate movement, growth and survival of resident trout and coho salmon, and how these measures correlate with environmental data such as channel gradient, abundance of large woody debris, and nutrient concentrations. Results from this study will inform managers and policy makers on the effectiveness of the Landsburg passage facility in restoring populations of anadromous fish in the Cedar River above Landsburg, and provide insights into the ecological effects of salmon on the Cedar River ecosystem, as well as potential restoration or conservation measures that will benefit resident and anadromous fish.

To address these questions, we collected data on water chemistry (nitrogen, phosphorus, water temperature); stable isotopes of C and N in algae, insects, fish and riparian vegetation; habitat characteristics (wood abundance and distribution, habitat composition, etc.), and fish population from above Landsburg to Cedar Falls during 2000 and 2001 (Figure 1). Adult salmon were passed above Landsburg beginning in September 2003. In this report, we present the following results:

(1) size, growth and movement data from trout and coho marked in Rock Creek;
(2) the colonization of Rock Creek by juvenile coho from 2004 to 2006;
(3) a comparison of fish populations before vs. after the ladder;
(4) a simple model describing the potential ecosystem effects of salmon on a reach-scale.

2.0 Accomplishments

We have made considerable progress with support from the Seattle Public Utilities and the Anadromous Fish Commission (Table 1). These include:

1) documenting coho and Chinook colonization of Rock Creek and main stem Cedar River at the habitat unit and reach scale;
2) documenting anadromy in *O. mykiss*;
3) installing PIT tag antennae in Rock Creek above and below Landsburg and on the main stem Cedar;
4) the completion of one M.S. thesis and partially supporting three M.S. theses and one Ph.D. dissertation;
5) publishing one paper (Kiffney et al. 2006), submitting one manuscript describing coho colonization in Rock Creek to a peer-reviewed journal (Anderson et al. submitted) and completing analysis for another manuscript describing pre- and post-salmon fish communities in the Cedar River and Rock Creek (Kiffney et al. in preparation); and
6) presenting numerous talks at local and national meetings on the recolonization study.

3.0 Materials and Methods

3.1 Water chemistry

See Kiffney et al. (2006) for methods.

3.2 Stable isotopes

See Kiffney et al. (2006) for methods.

3.3 Invertebrate drift

To assess whether variation in invertebrate drift was correlated with reach-scale fish densities, drift samples were collected from a suite of sites on the main stem and Rock, Williams, Steele and Taylor tributaries in August and September 2005. Four drift nets, with a mesh opening of 250 µm, were placed in parallel at each site for 1-2 hours during two one-week periods. Two to three sites were sampled per day. Water velocity was measured at the net opening to determine discharge through the net during the sample interval. Drift samples are currently being processed. Aquatic invertebrates will be identified to family, and terrestrial insects to order. After identification, drift samples will be dried and ashed to determine drift biomass. This project is the master's thesis of Seth Amhrein in the College of Forest Resources at the University of Washington, co-supervised by Drs. P. Kiffney and D. Vogt.

3.4 Habitat

We categorized low-flow habitat types based on a modification of methods established and described in detail in 2000 (Riley et al. 2001). We modified this method in 2005 to allow for further classification of habitat types within main channel units (pool, riffle, run, cascade, step pool, side channel) used in previous years. Our habitat and survey protocols are now similar to those used by Dr. Roger Peters (USFWS) in the Cedar River below Landsburg Diversion. Specifically, we described habitats within each reach using a hierarchical classification scheme (Hawkins et al. 1993). The first level classified channel type as main or side channel. Level two classified main geomorphic units as fast (riffle) or slow (pool). The third level classifies fast water as cascades, riffles, step pools, or high gradient riffles, and slow water as scour or lateral pools. The fourth level describes secondary habitat types within level 3 units using the same terminology. These level four units must equal at least 20% of the wetted area within level 3 units.

We measured habitat length, width, current velocity, maximum and average depth, percent riparian cover, vegetation overhang, undercut banks, and length and width of available cover for each level four habitat class. Flow was measured with a Swoffer model 2000 current meter at 60% of total depth. Depth was measured using a stadia rod and recorded to the nearest 0.1 m. Percent overhead riparian and vegetation overhang were estimated and included only vegetation within 30 cm (1 ft) of the water surface. Each cover component (Table 2) was measured for length and width using a stadia rod to the nearest 0.5 m. We also estimated dominant and subdominant substrate composition (Riley et al. 2001). Bankfull width and a GPS coordinate were taken every fifth unit.

3.5 Fish

3.5.1 Mark-recapture

To examine juvenile salmon performance (defined as growth, movement and survival) colonizing the Cedar River, we initiated a mark-recapture study in the fall of 2005. One aspect of this study is to compare fish performance in two tributaries of the Cedar River, one above and one below Landsburg. This contrast will allow us to describe fish performance in relation to history of anadromy (Figure 2). “Upper” Rock Creek (above Landsburg Diversion) has a relatively recent and truncated history of anadromy, whereas “lower” Rock Creek (below Landsburg Diversion) has a longer and more continuous exposure to anadromy.

For this study, we have completed the following:

- Tagged over 1,500 fish in upper Rock Creek
- Monitored seasonal movement and growth using mark-recapture techniques

- Monitored outmigration and estimated survival with permanent PIT tag readers
- Compared differences in growth, movement, and survival among species and life stages within upper Rock Creek.

To estimate fish abundance and biomass, we used three-pass electrofishing during summer, fall, winter, and spring in 30 to 50 pools in upper Rock Creek (Carle and Strub 1978). All vertebrates captured were identified to species, anesthetized, weighed and measured. All coho or trout greater than 55 mm were tagged using a Passive Integrated Transponder (PIT) tag. The PIT tag is a unique identifier for each fish that is detected in recapture events when pools are sampled again, or at stationary locations. Tagged fish were released into the same habitat unit they were captured.

Habitat surveys were conducted at the same time or prior to electrofishing to quantify habitat characteristics. During surveys we measured wetted length and width, maximum depth, tail out depth, wood abundance, and dominant and subdominant substrate size (e.g., sand/silt, gravel, cobble, or boulder) of each pool. A GPS coordinate was also recorded at each pool sampled.

To continually monitor fish movement, we installed multiplex transceiver units (MUX) and six antennas at the mouth of upper Rock Creek, which has been operational since October 2005. Recently, we completed installation of a PIT tag reader in lower Rock Creek, with an additional reader installed in the main stem in February 2007 (Figure 3). With a PIT tag reader at the Ballard Locks, we can now recapture fish at a number of locations, including the Landsburg diversion, as they move through the Lake

Washington system. This infrastructure will be invaluable in documenting life history, growth, movement and survival of multiple species.

Movement data were downloaded on a weekly basis. Additional data on downstream migration of marked fish were collected at the Ballard Locks. In addition, a mobile PIT tag reader is used at the screw trap near the mouth of the Cedar. The screw trap is typically deployed during the spring/early summer outmigration period (April to July). Trap efficiency is low (2%, personal communication, Greg Volkhardt, Washington Department of Fish and Wildlife, Olympia, WA), so it is not known if these data will be used in forthcoming analysis. Stationary PIT tag readers will be operated until 2008 and perhaps past that point if funding is available.

3.5.2 Snorkel surveys

Summer (July) to late summer (August-September) snorkel counts of fish in the Cedar River were conducted on habitat types and reaches surveyed in 2000 - 2001 and 2004 - 2006 or before and after ladder installation, respectively. In 2000 and 2001 all 10 reaches were snorkeled, while in 2004 reaches 1-6 were surveyed; in 2005 and 2006 seven to nine reaches were snorkeled. The number of habitat units snorkeled within a reach increased with the number of total units within that reach. In 2005, the number of units per reach ranged from 11-43 (mean ± [1SD], 26 [8]), while in 2006 the range was 15-48. We snorkeled various habitat unit types (pools, riffles, glides, depositional and side channels) in proportion to their abundance within each reach, and at a minimum, attempted to snorkel at least three replicates of each habitat type.

To determine seasonal variation in fish distribution and abundance, snorkel surveys were also conducted in tributary and main stem pools. Snorkel counts were conducted three times on the main stem during 2005-2006, and eight to 10 times on Williams and Rock creeks. At least three main stem pools were snorkeled in reaches 1-6, while 1-2 pools were snorkeled in reaches 7-10. Replicate pools (n=5) were surveyed in reach 1 and 3 of Rock Creek and reach 3 of Williams Creek during 2004 - 2006. Pools were snorkeled during daylight hours except when water temperature was below 8°C; night snorkels were conducted below this temperature, because juveniles exhibit nocturnal behavior. We measured pool surface area, maximum and residual depth, wood abundance and wood volume. A GPS coordinate was also recorded.

The entire unit was snorkeled unless it was large or dangerous, and was therefore sub-sampled. One to five observers (depending on stream width) entered the habitat unit at the downstream end and proceeded upstream through each site, counting and recording species and size classes of all fish encountered. Resident fish (rainbow and cutthroat trout, and whitefish) and juvenile salmon were divided into five size classes. For the sake of brevity, we summarized size classes into two (fish $\leq$ 80 mm and fish >80 mm in total length) for this report. Sculpin (*Cottus* sp.) were also counted but these data were not presented because a snorkel count underestimates density compared to electrofishing (Kiffney et al. 2001).

4.0 Data analysis

A two-way ANOVA was used to test whether fish density differed by time (before vs. after ladder), reach, or the interaction of time and reach. Our unit of replication for this analysis was determined by pooling data across habitat units within a reach for before (2000 and 2001) vs. after (2004-2006) the ladder was installed. We used a one-way ANOVA to test whether fish density or species diversity varied by habitat type in summer 2005 and 2006. Our unit of replication for this analysis was calculated by pooling across reaches for each habitat type. Although the number of fish species in this system is low, the number of size classes within a species is relatively high as a result of complex life histories within Salmonidae. For example, a large pool may contain two species of salmon or trout, but support three to four size classes of each species. For purposes of analysis, we considered species/size class diversity as analogous to species diversity, especially within a stream (Kiffney et al. 2006). If the ANOVA model was significant ($p<0.05$), we used Tukey's multiple comparison procedure to distinguish among habitat types.

We used linear regression to examine relationships between several response variables (e.g., periphyton biomass, fish density, fish community diversity) and several habitat and reach-scale variables (mean, maximum, and minimum temperature, wood abundance, pool depth) to explore how habitat variability might influence biological patterns during recolonization. We also used linear or quadratic regression to calculate changes salmon input over time.

5.0 Results

5.1 Fish populations

5.1.1 Mark-recapture

<u>Tagging events and salmonid composition</u>

From summer 2005 to fall 2006, we have conducted six different tagging events, which are defined as one or several consecutive days where fish were collected for PIT tag insertion. Five of the six tagging events occurred in the lower 2.0 km of upper Rock Creek. One of these five events included a pilot exercise of tagging juvenile coho in the main stem Cedar River. The sixth event occurred at Landsburg diversion during spring 2006. Over 3,500 fish and amphibians have been captured during these events; the majority of vertebrates caught were cutthroat trout followed by sculpin, coho, trout < 80 mm (too small to classify to species), dace, rainbow trout, lamprey, and coastal Giant salamander.

To date we have captured 2709 salmonids and non-salmonids in upper Rock creek. Mortality combined from both electroshocking and/or PIT tag insertion is 1.4% (39 out of 2709). Of the 39 fish that have died 13 were trout, 11 coho, 7 cutthroat, 7 sculpin, and 1 dace. All the fish mortality was related to electroshocking and not related to PIT tagging. The majority of mortality occurred in the summer (35 out of 39), followed by fall (3 out of 39) and winter (1 out of 39). This reflects the fact that the number of fish caught during the summer is greatest.

We tagged a total of 1881 fish (Table 3). Almost half were coho (46%), followed by cutthroat (35%) and rainbow (9%) trout. A portion of tagged fish was classified as trout (10%) because their size precluded identification to species. If the spring 2006 tagging event is excluded due to its unique nature and focus on outgoing coho smolts, proportions change to cutthroat (43%), followed by coho (38%), unidentified trout (10%) and rainbow (6%).

Fish length and weight varied according to species and season (Figures 4a and b). Cutthroat and rainbow trout had the largest mean length, followed by coho, Chinook, sculpin, dace, and unidentified trout. Cutthroat and rainbow trout exhibited the greatest variation in mean size. Sample size was large for all species with the exception of Chinook salmon.

Recapture

We defined recapture as a salmonid re-encountered at a later time whether through physical means or remotely sensed. Two different recapture techniques, electroshocking and a PIT tag reader array, were used to enumerate growth, movement, and survival of salmonids in Rock Creek. Electroshocking resulted in 204 recaptures (13%) out of the 1513 tagged salmonids, excluding the Landsburg diversion effort. The PIT tag reader array resulted in 379 unique tag numbers (25%) over the course of one year. The amount of overlap between fish that were recaptured with electroshocking and the permanent PIT tag reader was 11% (63 out of 583).

Overall recapture rate (defined as the total number of re-captured fish/the total number of captures in a sampling event for a given brood year in upper Rock Creek by electroshocking) varied according to season and species (Table 4). Winter recapture rates were highest (20%), followed by fall (10% to 16%), and summer (2% to 9%). Recapture rates for cutthroat trout were highest (mean [range], 19% [1 to 35%]), followed by rainbow (13% [0 to 33%]), and coho (7% [0 to 15%]). Recapture rates were consistent with the different species dominant life history form, as rates were higher for resident trout species than coho, which emigrate during fall and spring (Figure 5).

Total salmonids recaptured were greater for the PIT tag array than for electroshocking (Tables 4 and 5). The majority of PIT tag “hits” occurred during winter 2006, while recaptures were relatively consistent across spring, summer, and fall. More than two-thirds of all PIT tag reader recaptures were cutthroat and coho. The total number of cutthroat recaptures peaked during winter; however the highest relative proportion of downstream movement events for cutthroat occurred in summer and fall.

Coho downstream movements peaked during fall and spring in accordance with migration patterns typical for the species (Figure 5). Rainbow trout downstream movement peaked during winter, while downstream movements of unidentified trout, which were small at tagging, peaked during summer.

Growth

We developed fish growth rate estimates based on recaptures during electroshocking and PIT tag detections. Individual length (mm) and weight (g) differences between tagging periods were used to quantify species specific instantaneous growth rate (log[initial weight] – log[recapture weight]/number of days) (Figures 6a and 6b). Individual growth estimates suggest several patterns. Coho and young of the year (YOY) trout had some of the highest instantaneous growth rates exceeding 0.010 g/day (Figure 6b and Figure 7a). Cutthroat and rainbow trout had growth rates typically less than 0.005 g/day; however, sample size for rainbow trout was small (n=3) (Figure 7b and c). Both coho and trout exhibited a slight bimodal distribution. Negative growth rates occurred on occasion for coho, cutthroat, and trout.

Highest individual growth rates (~ 0.012 g/day) occurred during the summer to fall period; however, average seasonal growth during this period was similar to average growth between fall and winter (0.005 vs. 0.006 g/day). Almost 20% of recaptures between summer and fall had negative growth rates, resulting in a decrease in overall average growth rate, which coincided when overall fish densities where highest.

Variance in growth rate increased with size at tagging resulting in significant differences in the coefficient of variation of growth rate between smaller (55 to 120 mm) and larger (>120 mm) salmonids ($p < 0.001$) but mean growth rates were not positively correlated with initial size at tagging.

Movement

Movement varied according to season, species, and direction. Coho outmigration from upper Rock creek peaked in November (~9% of all outmigrants) and May (~14% of all outmigrants), however downstream movement occurred throughout the year (Figure 5).Cutthroat consistently moved throughout the year with peaks in November and December (Figure 8a). The majority of fish moved downstream; however there was a substantial amount of within reach movement, defined as the detection of a tagged fish moving in both directions within a specific time period (e.g., hours or days) (Figure 8b). The majority of detections came from fish tagged near the reader; however, the proportion of unique tag hits based upon the number of fish tagged in each sampling reach was similar (Figures 9a and b).

Survival

Overall, coho survival in Rock Creek was high from tagging to smolt emigration, with 76 out of 154 coho detected moving downstream at the PIT tag array (Table 6). Of these 76, 32 were detected at the Ballard Locks. Detection rate of Cedar River natural coho smolts passing through the Ballard Locks in 2005 ranged between 25% and 65% and averaged approximately 50% for the time period that coho from Rock Creek were moving through the Locks (Devries 2007). Coho smolt survival estimates range between 21% and 42% for fish tagged in Rock Creek and 11% for coho tagged at the Landsburg diversion. Survival estimates were also made at the habitat unit scale, which we defined as the total number of coho emigrating past the PIT tag array in Rock Creek divided by the total number of coho tagged in a habitat unit for a given brood year. We focused on coho survival estimates since they were the only salmonid with a purely anadromous life form that could be tagged safely and in large numbers. Survival varied considerably among pools (0% to 100%) (Figure 10). Coho survival was highest in sampling reach 1 (mean [± 1SD], 46% [30%]), followed by sampling reach 3 (36% [47%]), and sampling reach 2 (27% [36%]). The proportion of total coho that survived to outmigrant stage increased with total number of tagged fish within a habitat unit (Figure 11).

<u>Growth, survival, density, and habitat characteristics</u>

Instantaneous growth rate was negatively related to the initial fish density from which habitat unit they were captured (Figure 12, R^2 = 0.13, p = 0.026) and initial biomass density (R^2 = 0.11, p = 0.058). None of the pool habitat characteristics (e.g., depth, cover, wood loading, etc) were statistically related to salmonid instantaneous growth rate. Individual coho survival rate was also not correlated to any habitat variables, nor were there statistically significant relationships between coho density and coho survival (p = 0.34), trout density and coho survival (p = 0.88), salmonid density and coho survival (p = 0.85), or total fish density and coho survival (p = 0.31) at the habitat unit scale.

There was a positive relationship between both density and habitat characteristics and the proportion of total coho survival from each habitat unit. The proportion of total coho survival increased with an increase in coho density (Figure 13, R^2 = 0.44, $p <$ 0.001), residual pool depth (Figure 14, R^2 = 0.11, p = 0.06) and instantaneous growth rate (Figure 15, R^2= 0.10, p = 0.10). Coho density (R^2 = 0.15, p = 0.002) and the proportion of coho was also positively correlated to residual pool depth (Figure 16, R^2=0.27, p =

0.002). There were differences in coho and trout density among sampling reaches ($p<0.05$) with coho decreasing in the upstream direction and trout increasing, however this did not correlate with differences in coho survival.

Patterns of habitat use by coho

Coho residency time in Rock Creek varied considerably (90 [76] days), with tagged fish leaving upper Rock Creek and heading into other habitats (e.g., main stem, tributary, lake) in fall, winter, early spring, and late spring immediately before smolt outmigration (Figure 17a). Tagged coho which moved out of Rock Creek in fall resided in these other habitats for over 200 days before detection at the Ballard Locks. Coho that migrated in late spring resided in Rock Creek for over 90% of their total freshwater residence time. These patterns of habitat use occurred regardless of when fish were tagged. Pool location or distance from the tributary junction between upper Rock creek and the main stem Cedar did not have a significant effect on outmigration date past the Ballard locks (Figure 17b).

5.1.2 Snorkel surveys

Reach-scale patterns

There were large-scale changes in reach-scale fish (salmon plus trout) density in the Cedar River main stem between time periods (before[2000-2001] vs. after[2004-2006] ladder), (Figure 18). Specifically, fish density in reaches 1, 2, and 3 were about 3× higher after the ladder compared to before. Although the interaction between time and reach was not statistically significant, trout density increased from reach 1-10 in 2000 and 2001 (Figure 19a), with this pattern, except for reaches 1, 9 and 10, reversed through 2004-2006 (Figure 19b). Specifically, in 2000 and 2001, large trout density was positively related to distance from Landsburg (large trout density = 0.00017 + 0.006*(reach), R^2 = 0.57, p = 0.01). Averaging across 2004-2006, this pattern was reversed following salmon passage except for the two most upstream reaches. If these reaches are omitted, large trout density declined with distance from Landsburg (large trout density = 0.03 – 0.003*(reach), R^2 = 0.40, p = 0.09). Also contributing to this change in fish distribution was the addition of juvenile salmon to the community, which peaked near Landsburg and declined with upstream distance Figure 19c). The positive relationship between coho redds and changes in reach-scale fish density before vs. after the ladder provides evidence that the passage of salmon above Landsburg has contributed to changes in fish distribution (Figure 20).

In 2005, coho density was highest in reach 2, and was 1.4 to 2.5× greater than reaches 1, 3 and 4 (Figure 21a). Coho density in 2006 peaked in reach 1 at 0.1 fish/m^2 and was about two-fold higher than reach 2. Coho density increased sharply in reach 6 in 2006 compared to 2005. Of reaches where coho were observed, densities were lowest in reach 6 and 7 (0.003 - 0.0006 fish/m^2) in 2005 and reach 6 in 2006 (0.04 fish/m^2). Summer juvenile Chinook density was orders of magnitude lower than other juvenile fish. Chinook density in summer ranged from 0.0001 to 0.004 fish/m^2, and was lower in 2005 and 2006 compared to 2004 (Figure 21b). While the spatial extent of juvenile coho distribution expanded in 2005 compared to 2004, Chinook distribution in summer contracted. These patterns should be treated with caution as most juvenile Chinook have migrated downstream at this time. Overall, juvenile coho density made up about 5 to 70% of total reach-scale abundance in 2005 and 35% to 80% in 2006 (Figure 22).

Averaging across reaches, juvenile trout (<80 mm) density showed little variation among years averaging about 0.03-0.04 fish/m^2 (Figure 23a), whereas density of trout > 80 mm has declined from a high of 0.04 fish/m^2 in 2000 to 0.02 fish/m^2 in 2006 (Figure 23b). Juvenile salmon (coho+Chinook) has approximately doubled from 0.015 fish/m^2 in 2004 to 0.03 fish/m^2 in 2006 (Figure 23c). Overall, although total fish density declined from 2000 to 2001, it has increased almost two-fold since 2001 (Figure 23d). From 2001 to 2006 total fish density has increased by 0.008 fish/m^2 per year (total fish density = -15.8 + 0.008*(year), $R^2 = 0.9$, $p = 0.07$).

Temporal patterns of fish density in lower Rock Creek (reach 1) provide further evidence that juvenile salmon have significantly altered the fish community. The proportion of total fish density comprised of juvenile trout has decreased steadily since installation of the fish ladder from 60% to 20% of total density (Figure 24a), whereas juvenile coho have increased from about 20% in 2004 to 60% of total density in 2006 (Figure 24c). In contrast, there has been little change in the density of trout > 80 mm in Rock Creek (Figure 24b). A similar pattern was observed in reach 3, which was about 2 km from the confluence with the Cedar River.

<u>Habitat-scale patterns</u>

Patterns of fish density at the habitat unit scale in the main stem (e.g., pool, riffle) in 2005 and 2006 were similar to those observed in 2004 (Kiffney et al. 2004). Juvenile trout, coho and Chinook densities were higher in side-channels compared to other habitat types (Figure 25a-d [showing 2005 data only as 2006 data showed similar patterns]). Juvenile coho density in side-channels (0.40 fish/m^2) was about five-fold higher than depositional habitat (0.08 fish/m^2), while juvenile Chinook density was about 27× higher in side-channels (0.008 fish/m^2) than riffles, pools or depositional areas (~0.0003 fish/m^2). Large trout (>80 mm) density was about four-fold higher in step-pool and pool habitat compared to riffles, runs or depositional areas.

Side-channels also had the highest fish density, which was 4-29× greater than other habitat types followed by depositional, pool, step-pool, run and riffle habitat (Figure 26a). Species×size class diversity was 1.6 to 3.1× higher in step-pool habitat compared to run, riffle and depositional areas; size class diversity was also higher in pool habitat compared to depositional areas (Figure 26b).

Habitat and reach-scale associations

In 2005 (2006 data not yet analyzed), periphyton biomass (µg/cm^2) increased with maximum temperature in main stem and tributaries (Figure 27), while fish density was positively correlated with mean annual temperature in the main stem and tributaries (Figure 28). There was also evidence that reach-scale coho and trout density were positively associated with reach-scale wood abundance (Figure 29a and b). Although peak trout density in tributaries was associated with peak wood abundance, there was no obvious relationship (Figure 29c). Depth, along with cover, may be one habitat feature attracting fish to pools in summer. In 2004, maximum pool depth was positively correlated with size-class diversity and juvenile coho density in Rock Creek (Figure 30a and b). Coho in Rock Creek showed a similar pattern in 2006 (Figure 31a). In contrast to coho, juvenile trout in Rock Creek were negatively correlated with maximum depth (Figure 31b). Species x size-class diversity exhibited a unimodal pattern with maximum depth in the main stem peaking at approximately 1.8 m (Figure 32).

5.2 Ecosystem effects

Adult coho returns have increased linearly since 2003 (Figure 33). Adult Chinook returns were lower in 2004 and 2005 than 2003, but increased substantially in 2006. Because adult returns have increased linearly over time, we can use this rate to calculate when carcass inputs reach a level where they could affect ecosystem productivity. We acknowledge this approach makes a number of assumptions and is likely conservative as adult returns should increased at a higher rate as offspring from initial colonists augment the population, but the model provides a heuristic tool for examining temporal patterns of salmon input. Assuming that the rate of adult returns increases by 53 adults per year, it will take about 600 years for salmon biomass in reach 1 to achieve a level (0.15 kg/m^2) where it might be detected in resident fish as measured by N^{15} (Bilby et al. 2000) (Figure 34).

6.0 Discussion

The implementation of the PIT tag reader system in the Cedar River watershed has created an opportunity to develop a more mechanistic understanding of how juvenile coho and trout, and adult trout grow, move, and ultimately survive in newly opened habitats. For example, tag to smolt survival estimates range between 18 and 36% for tagged coho from upper Rock Creek and overlaps with other overwinter survival rates for Washington and British Columbia (25–42%; e.g., Bustard and Narver 1975, Quinn and Peterson 1996). We have also observed major changes in fish density, distribution and community structure since installation of the fish ladder. These changes were a result of two factors: recolonization of the Cedar River above Landsburg by coho salmon and increase in the density of trout >80 mm in total length in reaches closest to Landsburg. Although we have no evidence to date to suggest that salmon carcasses have affected ecosystem properties, we speculate that some increase in productivity has occurred at the habitat unit scale primarily in main stem reaches where salmon redds were most abundant. Overall, these data suggest that installation of the fish passage facility at Landsburg has allowed the establishment of a juvenile coho population, led to shifts in distribution of trout, and resulted in the observation of anadromy in *O. mykiss*.

6.1 Individual to population-level effects

Juvenile trout and anadromous salmon growth was a function of initial fish density and biomass in the habitat unit where fish were tagged and season. Initial fish density and biomass were negatively related to instantaneous growth rate. Density dependent growth in trout and coho due to initial fish density and biomass conditions has been previously documented in small streams at the habitat unit scale (Keeley 2001, Harvey et al. 2005, Rosenfeld et al. 2005). Negative growth rates suggest that density dependence may limit growth rates at the habitat unit scale in Rock Creek. Comparable growth rates between summer and fall, and fall through winter indicate that tributary habitats in the Cedar River allow for continued growth of juvenile trout and salmon, particularly coho. Winter growth suggests that fish were actively foraging despite relatively cool water temperatures (~4° C); therefore, winter growth may be an important component of overall survival for both coho and trout (Petersen and Quinn 1996, Ebersole et al. 2006).

Tributary habitat is generally not considered as important over-winter habitat for juvenile salmon or trout compared to slow water environments such as floodplain channels (Petersen 1982, Solazzi et al. 2000). Recent studies have showed that tributary habitat was important for spawning and summer rearing for coho salmon (Pess et al. 2002, Ebersole et al. 2006). The relative importance of tributary habitat for juvenile trout and salmon during winter increases if there is a lack of main stem off-channel habitat (Ebersole et al. 2006), and this may be the case with the Cedar River above Landsburg. This section of the river is relatively confined with little side-channel or floodplain habitat (Riley et al. 2001, Kiffney et al. 2006).

The majority of outmigration from Rock Creek occurred during November and May, and was dominated by coho and cutthroat. Coho outmigration during November from tributary habitats is similar to other studies throughout the Pacific Northwest (Bustard and Narver 1975, Quinn and Peterson 1996, Ebersole et al. 2006). May outmigration from upper Rock Creek was just prior to smolt outmigration through the Ballard Locks. There was also considerable fish movement in and out of Rock Creek throughout the year, particularly by cutthroat trout. The immigration of adult cutthroat for spawning, and movement associated with flood events has previously been documented (Harvey et al. 1998, Hilderbrand and Kershner 2000); however, movement during fall and winter months is not as well described

Tag to smolt survival estimates ranged between 21 and 42% for coho from Rock Creek and were similar to overwinter survival rates for Washington and British Columbia (25–42%; e.g., Bustard and Narver 1975, Quinn and Peterson 1996). Survival estimates varied considerably at the habitat unit scale and we found no relationship between coho, trout, or total fish density and the survival of individual coho at the habitat unit or reach scale. However, there was a significant, positive relationship between the proportion of total coho survival and mean coho density per habitat unit. This positive relationship is suggests an allee effect, which is the positive relationship between population density of an individual species and the reproduction and survival of those individuals (Allee et al.

1949). Thus, as the density of a specific population increases, the survival of those individuals increase due to behavioral strategies, such as schooling, that are thought to be more effective for larger populations (Allee et al. 1949). This effect typically saturates or disappears at a threshold density; however, it has been documented in other coho salmon populations that are relatively small (Chen et al. 2002)

There was a positive relationship between residual pool depth and coho density, and residual pool depth and the proportion of total coho that survived in a habitat unit. Water depth has been shown to be a positively related to salmonid density and distribution, and has been identified as a source of cover from wading and diving predators (Power 1984, Harvey et al. 2005). Deeper environments can result in more energetically favorable habitats and allow for greater food acquisition (Rosenfeld et al. 2005). This can ultimately result in enhanced survival (Lonzarich and Quinn 1995). Other habitat variables that are typically identified as important to growth and survival such as cover, substrate size, and wood loading were not statistically significant.

Implementing the PIT tag technology in the Cedar River has allowed us to document several key findings. Perhaps the most important are habitat use, movement, growth and survival of juvenile coho and trout. While no spawning has been documented in upper Rock Creek, it is apparent juvenile coho rapidly colonized this tributary, use the habitat for a prolonged period of time, and survive at a relatively high rate to outmigrate as smolts. The use and contribution of newly opened habitats is important to understanding how salmon populations respond to restoration actions. Another important finding as a result of the PIT tag system was the documentation of anadromy in rainbow trout from Rock Creek. This is important because the contribution of the resident population to the anadromous population of any salmonid is relatively unknown (Olsen et al. 2006). Further development of the PIT tag readers across the watershed will allow us to gain critical information in the future on specific variables associated with growth, movement, and survival of all salmonids, and will allow us to better understand how populations respond to this large-scale restoration action.

6.2 Population and community-level effects

Installation of the fish passage facility in 2003 has led to major changes in the fish community above Landsburg. Fish density in the lower four reaches increased by approximately 3× after the ladder was installed compared to before; these changes were primarily a result of juvenile coho and an increase in resident trout >80 mm. The increase in coho densities in these reaches mainly reflects spawning locations of adult coho in the previous year. The increase in trout density could be a result of a number of factors. Trout could be migrating from below Landsburg during spawning, from upstream reaches or some combination of the two. The fish passage facility is equipped with a camera that documents upstream fish passage from February-August, and data from 2005 indicate that upstream trout movement peaks in May. The relatively high density of adult salmon spawning in these lower reaches may be attracting large trout because of the opportunity to feed on energy-rich resources such as eggs or emerging fry. Trout were found to consume approximately 27% of the natural Chinook production in the Cedar River below Landsburg (Tabor et al. 2004). Once trout above Landsburg reach a fork length of 40 cm about 35% of their diet comes from fish (P. Kiffney, unpublished data). Predator-prey studies and marking of trout planned for 2007-2008 below and above Landsburg will provide insights into factors explaining these patterns.

Coho density in the lower four reaches of the main stem and Rock Creek (~0.05 – 0.6 fish/m^2) were within the range of values estimated in other west coast streams (Burns 1971, Murphy et al. 1986, Rosenfeld et al. 2000, Burnett 2001, Roni 2002). For example, juvenile coho densities were 0.003 fish/m^2 in the Elk River, Oregon (Burnett 2001), 0.06 fish/m^2 in streams of northern California (Burns 1971), and 0.4 fish/m^2 in streams of Vancouver Island (Rosenfeld et al. 2000). Juvenile Chinook densities were towards the low end of values reported by Burnett (2001) (range 0.007 – 0.15 fish/m^2) in the Elk River, Oregon. Similarly, total trout densities in the main stem (~95% rainbow trout) were towards the low end reported in other studies. Platts and McHenry (1988) estimated that the mean trout density in small streams in the Pacific Ecoregion was 0.29 fish/m^2; mean densities of cutthroat trout ranged from 0-2.5 fish/m^2. Rosenfeld et al (2000) reported densities of cutthroat trout of 0.05 to 0.8 fish/m^2 in coastal streams of Vancouver Island, and Burns (1971) reported combined rainbow/cutthroat densities ranging from 0.1 - 1.6 fish/m^2 in northern California streams. We have reported on these low trout densities in earlier reports and there are a number of possibilities that may explain these values including: (1) low wood abundance in the main stem, (2) high density of large trout that potentially consume trout fry, (3) high density of bird predators also consuming trout fry, (4) lack of anadromous rainbow and cutthroat life history forms and (5) low productivity due to loss of salmon inputs.

Juvenile coho, Chinook and trout appeared to select side-channel, depositional and pool habitat in the main stem during summer. Other studies have show that coho were more abundant in pool habitat and small streams during summer (e.g., Rosenfeld et al. 2000), and prefer side-channel habitat during winter because of the more favorable rearing environment relative to main channel habitat (Gianicco and Hinch 2003). Our data suggest a similar pattern for summer rearing conditions for coho, possibly due to the high stream power of the main stem. Use by an organism of habitat at any spatial scale may reflect availability of, rather than selection for, a particular habitat type. Burnett (2001) observed that selection of side-channel habitat by coho was variable across years, with coho selecting this habitat during one year and using it according to availability in two other years.

We also found that juvenile Chinook and coho were more abundant in main stem pools, especially pools with abundant brush (P. M. Kiffney, personal observation). Burnett (2001) observed that juvenile Chinook preferred pools relative to fast water habitat. Taken together, these results suggest to improve summer rearing conditions in the main stem Cedar River the following restoration actions should be considered a high priority: (1) increase abundance of main stem side-channel habitat (juvenile coho, Chinook and trout) and (2) increase the abundance and complexity of pool habitat (trout, coho and Chinook). These actions might be most successful in the lower gradient reaches of the main stem (e.g., 1, 2 and 4), where wood additions are more likely to withstand high flow events because they are less confined with lower stream power than upstream reaches.

The rapid dispersal and colonization of Rock Creek by juvenile coho was expected given that this tributary is relatively low gradient and has a relatively complex channel (at least the lower two-thirds below the 40 Road). The distances between the nearest coho redd in Reach 1 and Rock Creek, however, was relatively long (~1 km) suggesting considerable movement of juvenile coho. In addition, juvenile coho have dispersed ~2 km from the Rock Creek- main stem confluence to the last pool below the culvert near the 40 Road. We have observed no coho above this point, which suggests this structure was a barrier to further dispersal. Installation of a culvert that does not impede fish movement might allow coho access to the large wetland complex upstream of the 40 Road. It is well known that juvenile coho prefer low-gradient, complex habitat for rearing.

Another surprising aspect of coho colonization of Rock Creek was the relatively high density of coho rearing in this stream compared to the main stem. There are few data to compare our results with; however, Milner et al. (2000) observed coho salmon in streams around 43 years of age in Glacier Bay, Alaska. Fish density in these streams was a function of habitat complexity, stream age, water quality, flow stability and food abundance (Milner et al. 2000). The major difference between our study and Milner's et al. (2000) was that the Cedar River has a resident fish community, whereas streams in Alaska were fishless. We speculate that Rock Creek, which has high nutrient levels, a wetland complex potentially stabilizing downstream flows, and high habitat complexity will continue to be a focal point for coho colonization in the future. Our data suggest that lower juvenile trout density in the lower main stem reaches and Rock Creek compared to baseline conditions were a direct consequence of increasing coho populations. We hypothesize that these changes in fish community structure likely reflect pre-dam conditions before Landsburg blocked adult salmon and juvenile migration.

6.3 Ecosystem-effects

Adult salmon are rich in carbon, nutrients and other essential elements they accumulate in the ocean. As a result, they provide a critical resource subsidy to nutrient-poor coastal watersheds (Claeson et al. 2006, Kiffney et al. 2005, Wipfli et al. 2004) and can affect nutrient chemistry (O'Keefe and Edwards 2003, Claeson et al. 2006). In addition, during their ocean migrations they accumulate more N^{15} relative to the lighter N isotope.

We have observed no evidence of ecosystem effects in the Cedar River as a result of adult passage. Between 2003 and 2006, 871 adult salmon have been passed above Landsburg, which translates into an annual increase of about 50 adult fish per year. Approximately 78% of redds from these salmon were located in reach 1 and 2, which translates into annual inputs between 0.0002-0.0005 kg/m^2. These inputs were several orders of magnitude lower than levels shown to affect community and ecosystem attributes (Bilby et al. 2000, Wipfli et al. 2004). For example, Bilby et al. (2000) reported that N^{15} appears to reach an asymptote in resident cutthroat trout at 0.15 kg/m^2 salmon biomass. Based on the current rate of adult salmon returns, we developed a simple predictive model as a heuristic tool to predict when salmon inputs would reach a level where they could saturate N^{15} levels in resident fish. Results from this model suggest that at the current rate of salmon input it will take 600 years for carcass levels in reach 1 to saturate N^{15} levels in resident fish. This model has a number of assumptions that may not reflect future returns as it does not account for an increase in adult populations augmented by offspring of original colonists. Moreover, ecosystem effects may occur at lower levels of salmon input and we speculate that current adult returns lead to local increases in primary and secondary productivity as well as fish growth.

Results from this simple model should be treated cautiously, but it provides a heuristic tool to inform decision-makers regarding the potential impacts of carcasses on water chemistry and ecosystem productivity. The Cedar River above Landsburg encompasses a large area of stream and riparian habitats that can assimilate large quantities of salmon. Adult salmon spawn during fall and winter, when productivity is low because of low light and temperature and high flows. Furthermore, an abundant and diverse fauna of predators and scavengers likely remove salmon from the stream after spawning. As a result of these attributes, we have no evidence that current levels of salmon inputs affected nutrient chemistry or ecosystem productivity.

7.0 Summary

As a result of the mark-recapture study, we have documented high survival of coho emigrating from Rock Creek and anadromy in rainbow trout. Results from snorkel surveys showed that the passage facility has led to rapid expansion of juvenile coho in Rock Creek and the lower main stem. These surveys also suggest an increase in the density of large trout in the lower reaches of the Cedar River, and a decline in juvenile trout in portions of the main stem and Rock Creek. To date, we have no evidence that adult salmon have affected surface water chemistry or ecosystem productivity.

8.0 Acknowledgements

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Table 1. Major accomplishments between summer 2005 and fall 2006.

Task	Accomplishment	Time period
Habitat survey	~16,000 m surveyed	August 2005 and 2006
Main stem snorkel survey	1) ~ 16,000 m snorkeled 2) ~16,000 fish observed	August and September 2005 and 2006
Main stem seasonal pool survey	~1,400 fish observed	3× per year since 2005
Rock and Williams snorkel survey	~5000 fish observed	3× per year since 2004
Mark-recapture fish study	1881 fish tagged: 866 coho, 660 cutthroat, 160 rainbow, and 195 trout fry	3× per year since 2005
Water chemistry analysis	311 samples analyzed	~ bimonthly August-February 2004, 2005
Algal biomass samples	~200 samples collected and processed from main stem and tributary habitat	3× per year in 2005 One collection in 2006
Invertebrate drift samples	56 drift samples: 40 from main stem and 16 from tributaries	July 2005
Stable isotope analysis	~500 samples collected, processed and analyzed across years	September 2004 and August 2006

Table 2. Description of the cover elements to be used for this project.

Cover Type	Description
Boulder (bl)	Rock >=256 mm
Bedrock (br)	Exposed solid rock
Cobble (cb)	Rounded rocks 64-256 mm
Deep water (dw)	Water depths >1m (other cover takes precedence)
Vegetation (vg)	Live, terrestrial vegetation
Plants (pl)	Live, non-woody aquatic vegetation
Pilings (pg)	Vertically drivin logs
Riprap (rr)	Angular boulder sized rock placed for bank protection
Rubble (ru)	Angular cobbles sized rock placed for bank protection
Undercut banks (ub)	Submerged area underneath an overhanging bank
Coconut matting	Coconut matting used to stabilize banks
Wood	Woody debris of various types
Anchored brush (ab)	Branches of non-tree woody plants hanging in the water
Branch (bh)	Woody debris < 20 cm in diameter, not accumulated in debris piles
Bank roots (br)	Roots of live trees and shrubs in the water
Debris piles (dp)	Numerous or single types of wood cover accumulated in a pile or jam
Single log (sl)	Woody debris > 20 cm diameter, not accumulated in debris piles
Rootwad (rw)	Roots and lower trunk of non-growing trees
Hydraulic	Various hydraulic conditions which act as cover from current velocities
Deposition (dep)	Area with slow or no current where sediment deposits. An example would be a point bar.
Eddy (ed)	Back eddy where the current flows in an upstream direction as a result of an obstruction.
Shelf (sh)	Shallow low gradient bank often associated with a steep bank.
No Cover (nc)	Substrate is < cobble size, depth is < 1.0 m, and none of the above present.

Table 3. Total number of tagged salmonids in the Upper Rock Creek, Landsburg diversion, and the main stem Cedar River by tagging event

Date	Location	Total tagged salmonids	cutthroat	rainbow	trout	coho
Summer, 2005	Upper Rock Creek	186	70	0	77	39
Fall, 2005	Upper Rock Creek	393	196	36	49	112
Winter, 2006	Upper Rock Creek	40	13	2	8	17
Spring, 2006	Landsburg diversion	368	16	62	0	290
Summer, 2006	Upper Rock Creek, Main stem Cedar	341	147	2	58	134
Fall, 2006	Upper Rock Creek	553	218	58	3	274
Total		1881	660	160	195	866

Table 4. Total number of salmonid recaptures with electroshocking in Upper Rock Creek by tagging event

Date	Location	Total salmonids recaptured	cutthroat	rainbow	trout	coho
Summer, 2005	Upper Rock Creek	3	1	0	1	1
Fall, 2005	Upper Rock Creek	44	30	4	0	10
Winter, 2006	Upper Rock Creek	10	7	0	0	3
Spring, 2006	Landsburg diversion	6	0	0	0	6
Summer, 2006	Upper Rock Creek, Main stem Cedar	33	32	1	0	0
Fall, 2006	Upper Rock Creek	108	80	5	0	23
Total		204	150	10	1	43

Table 5. PIT tag reader recaptures in upper Rock Creek

Date	Total salmonids recaptured	cutthroat	rainbow	trout	coho
Fall, 2005	14	5	2	2	5
Winter, 2006	206	77	35	23	71
Spring, 2006	102	26	9	7	60
Summer, 2006	61	34	2	13	12
Fall, 2006	74	33	6	7	28
Winter, 2006 (11/1/2006 to 11/7/2006)	97	28	13	10	46
Total	554	203	67	62	222

Table 6. Coho PIT tag hits at upper Rock Creek and the Ballard Locks – 2005

	Number of individual coho
Total number of coho tagged in upper Rock Creek	155
Number of unique coho tags identified moving downstream at upper Rock Creek	76
Number of unique coho tags identified at Ballard Locks from upper Rock Creek	32

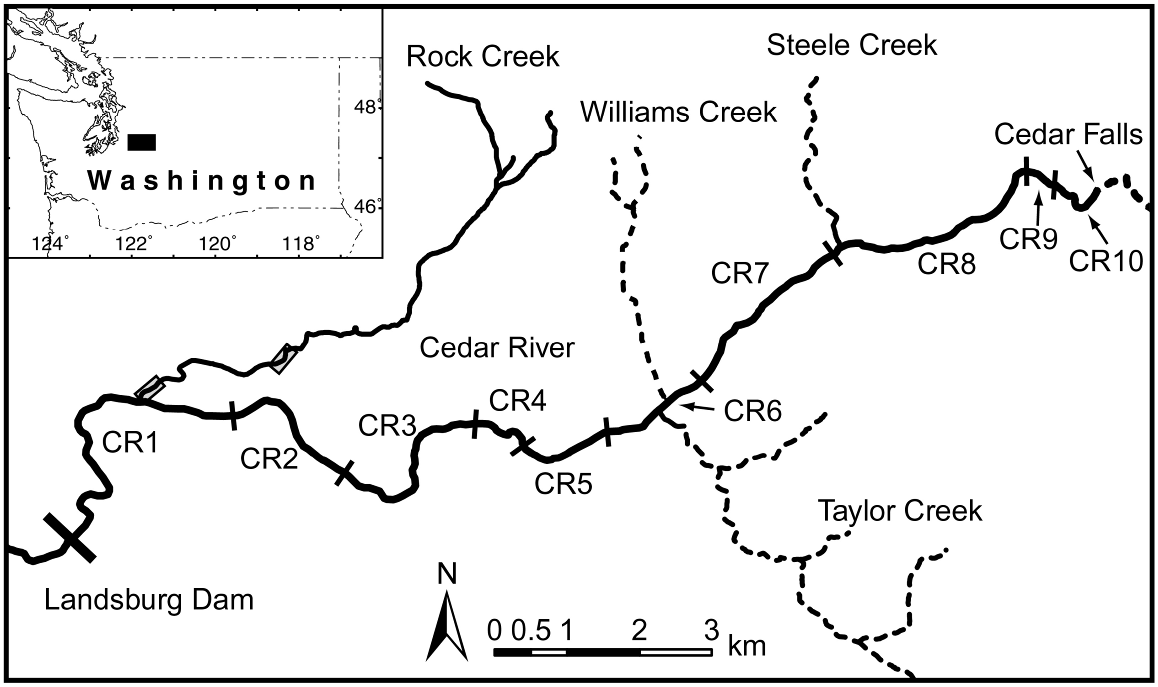


Figure 1. Map of the Cedar River watershed above Landsburg Dam. Snorkel survey reaches in Rock Creek are outlined in gray boxes and dashed lines indicate areas above natural migration barriers inaccessible to salmon.

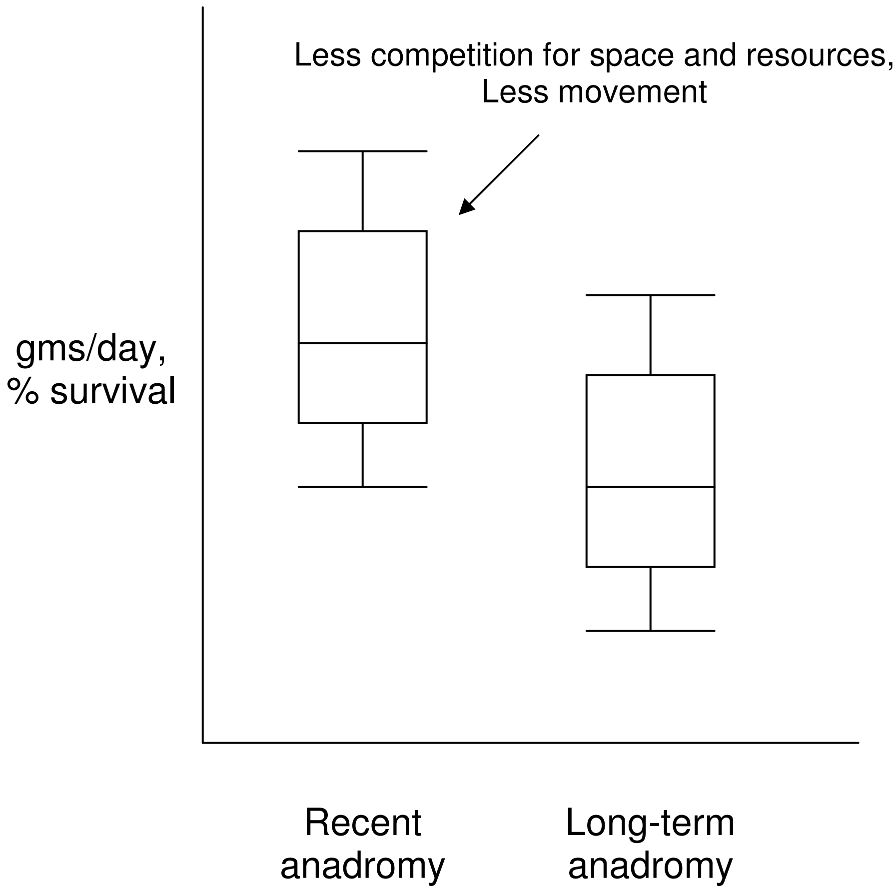


Figure 2. Hypothetical growth and survival patterns for fish in streams with contrasting history of anadromy.

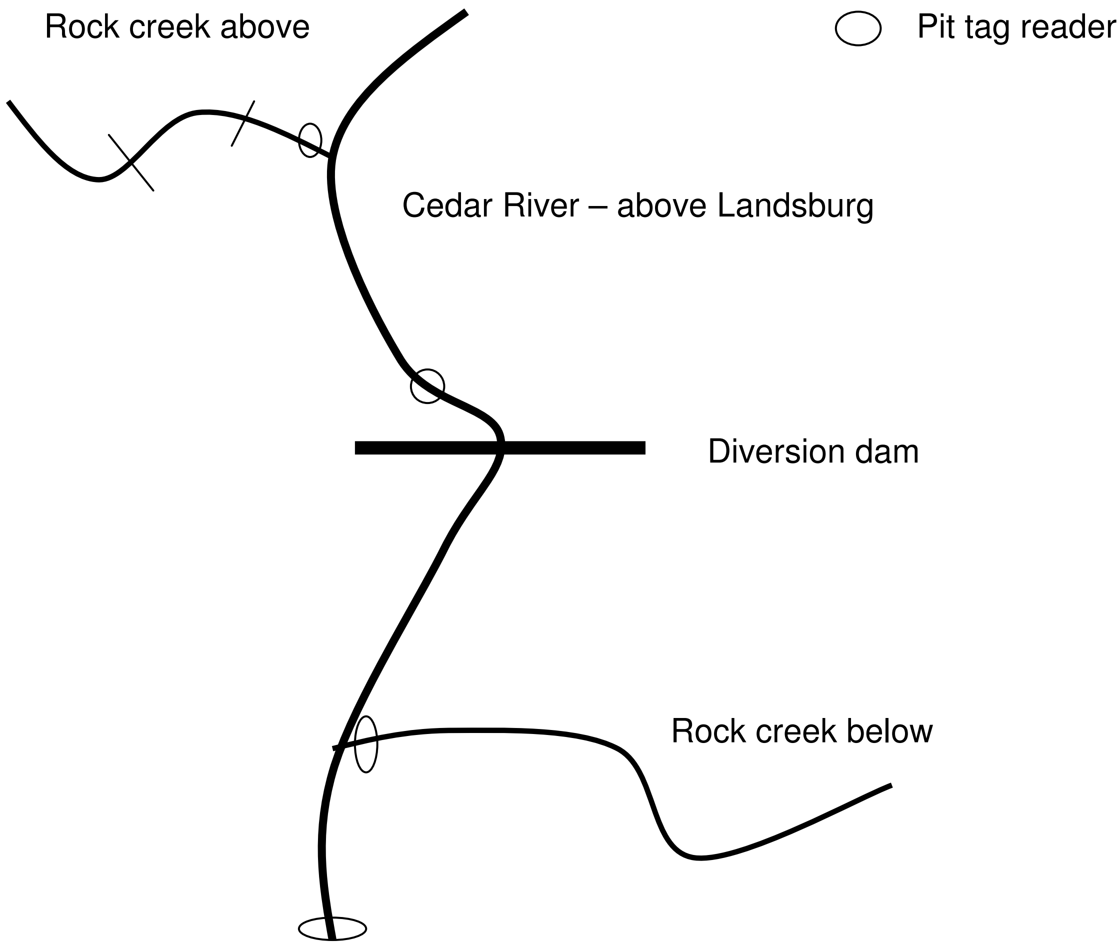
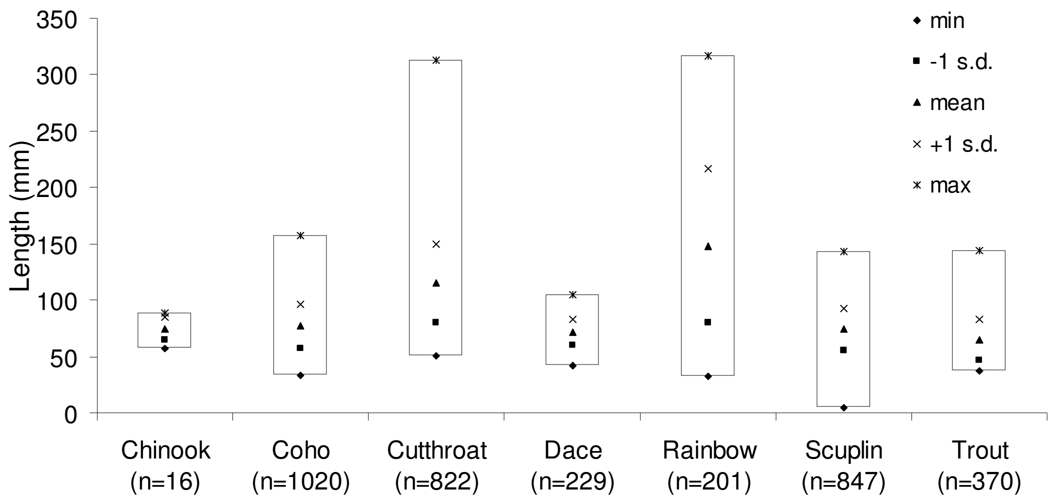


Figure 3. Schematic of PIT reader locations in the Cedar River above and below Landsburg Diversion.

a)



b)

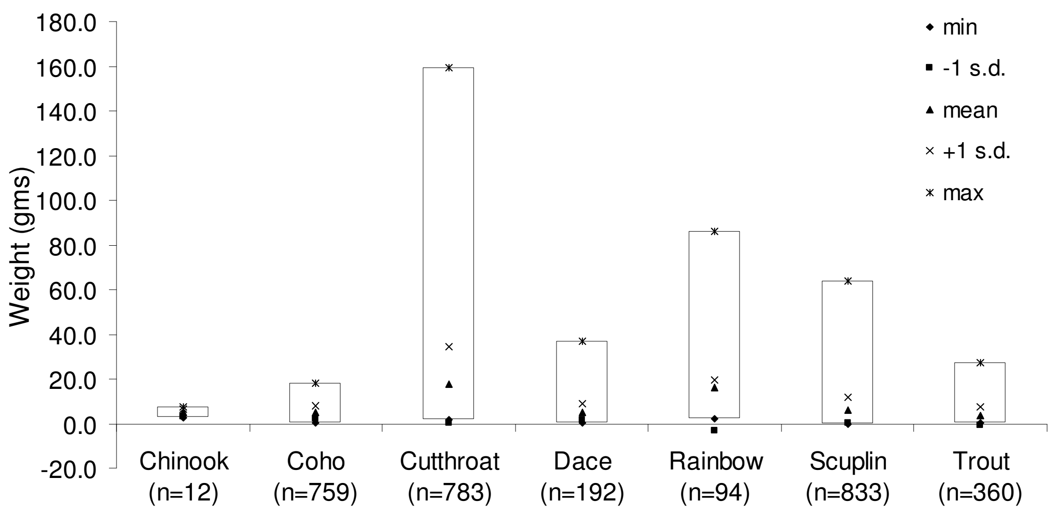


Figure 4. Fish a) length and b) weight by species for fish captured in Rock Creek, the Landsburg Diversion pool, and the main stem Cedar during summer 2005 to winter 2006.

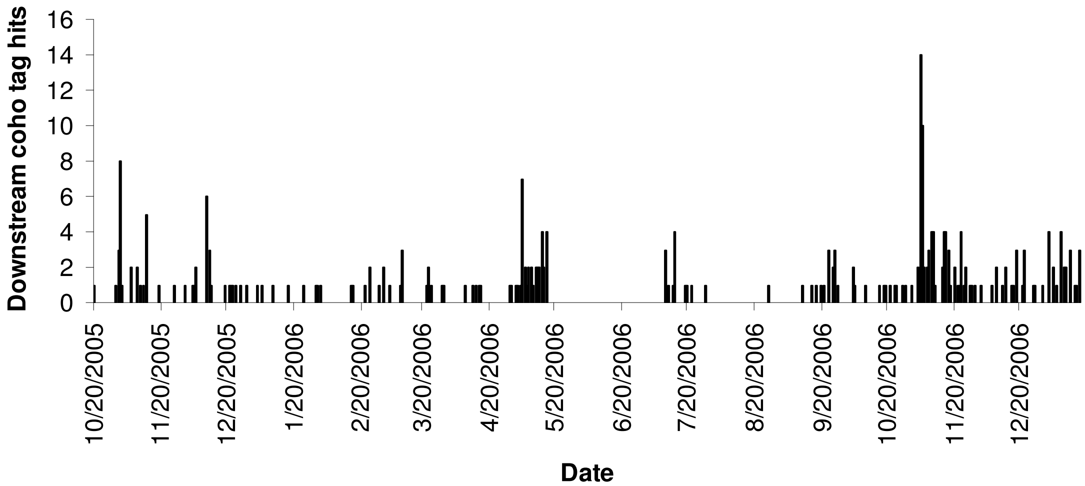


Figure 5. Coho downstream movement past PIT tag array in Rock Creek- October 2005 to present.

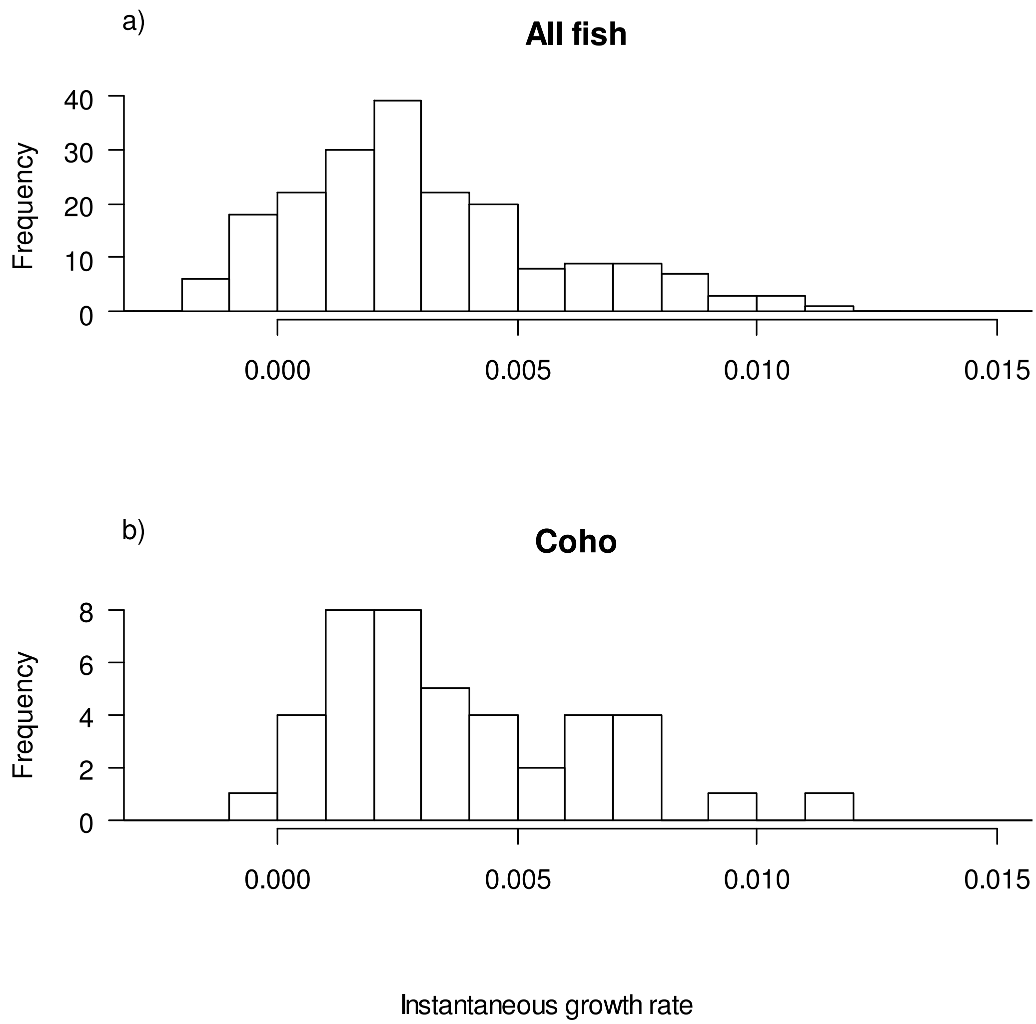


Figure 6. Instantaneous growth rate for a) all recaptured salmonids and b) coho in Rock Creek during 2005-2006.

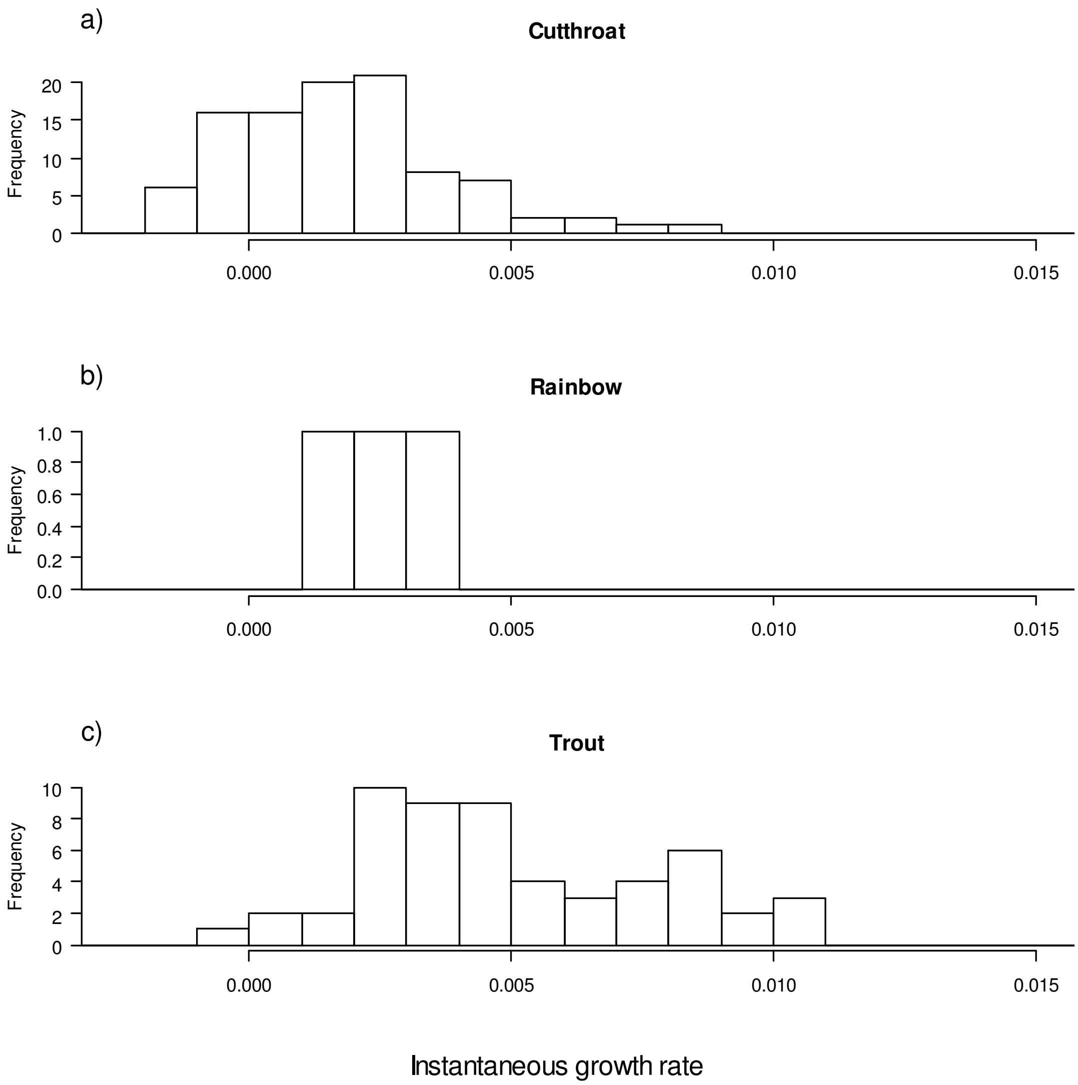
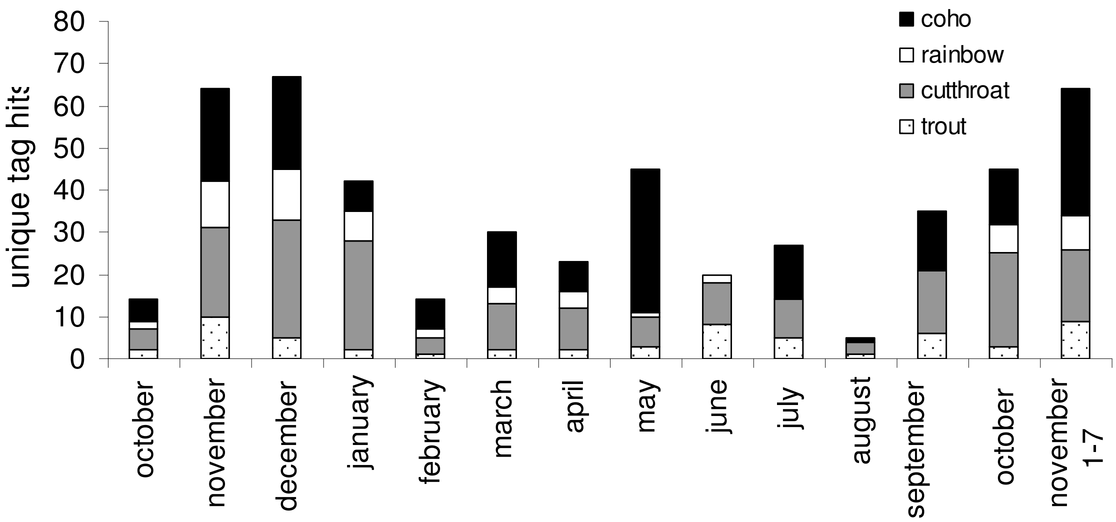


Figure 7. Instantaneous growth rate for a) cutthroat, b) rainbow, and c) trout Rock Creek during 2005-2006.

a)



b)

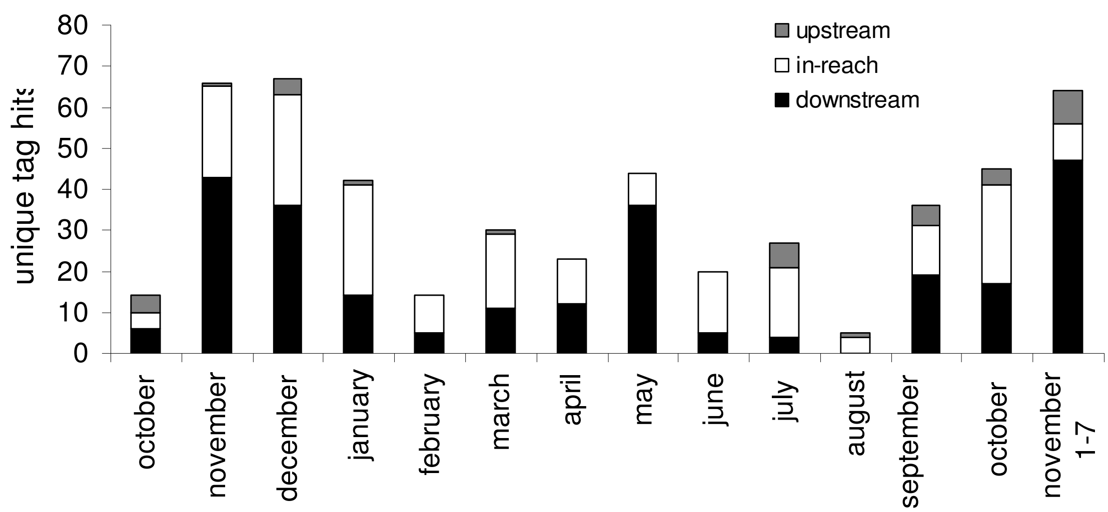
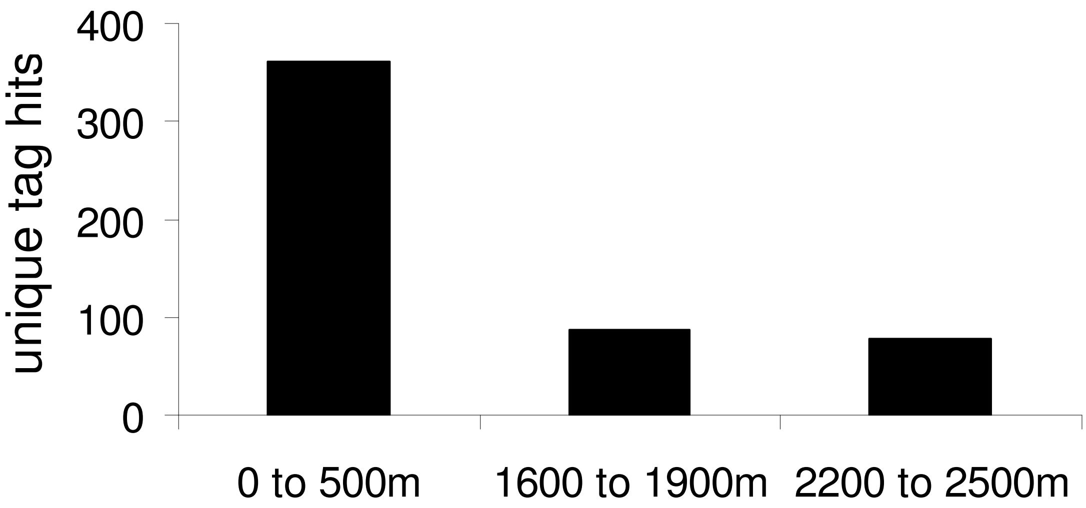


Figure 8. a) Salmonid movement and b) direction of movement past PIT tag array in Rock Creek October 2005 to November 2006.

a)



b)

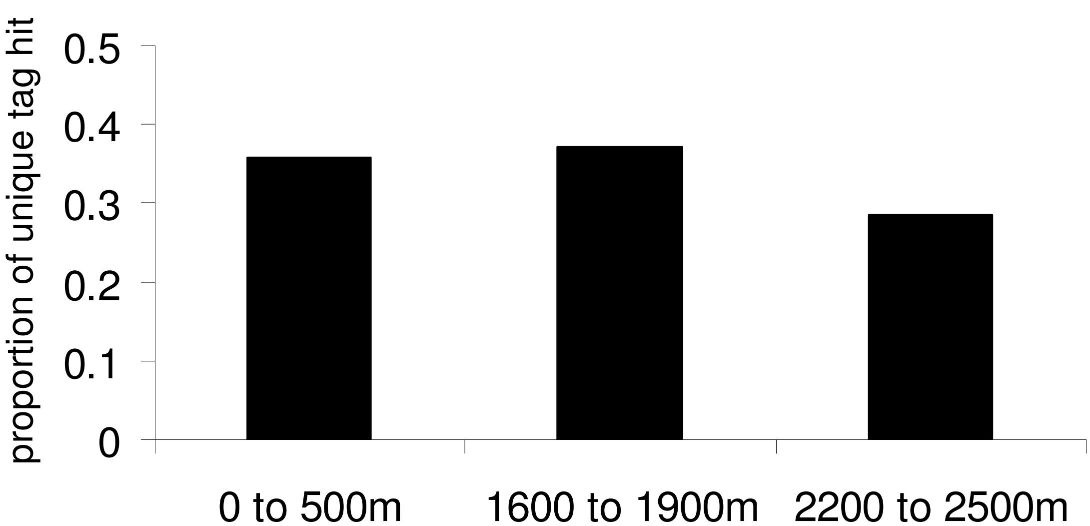


Figure 9. a) Initial reach location of tagged salmonids in Rock Creek that moved past the reader from October 2005 to present and b) proportion of total tagged salmonids from each reach that moved passed the reader from October 2005 to present

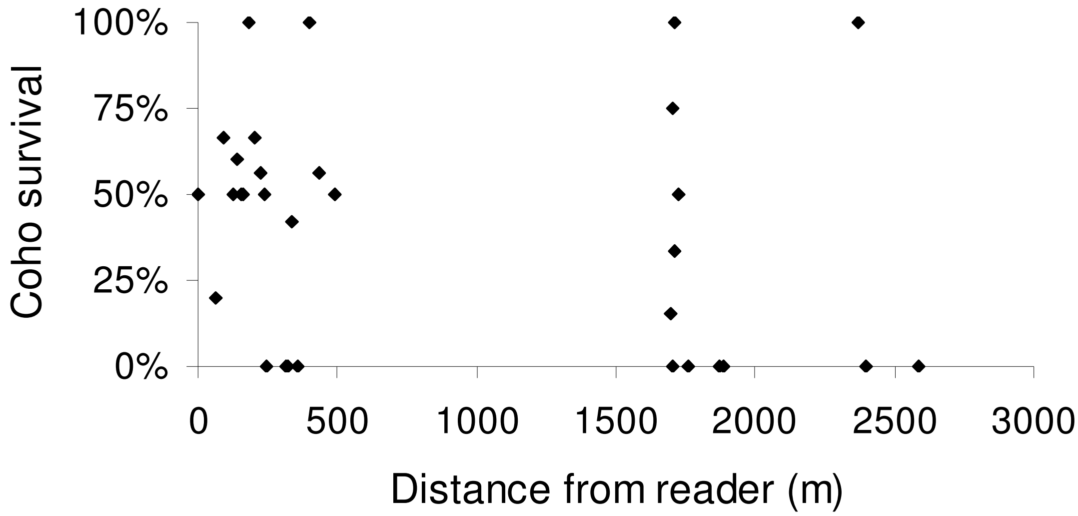


Figure 10. Coho survival by habitat unit in Rock Creek. Each data point represents proportion of fish tagged within a habitat unit that were detected passing downstream at the PIT tag reader near the confluence. Pools near ~1700 meters from the reader are only several meters apart resulting in data points that seem the same distance, but are several meters apart.

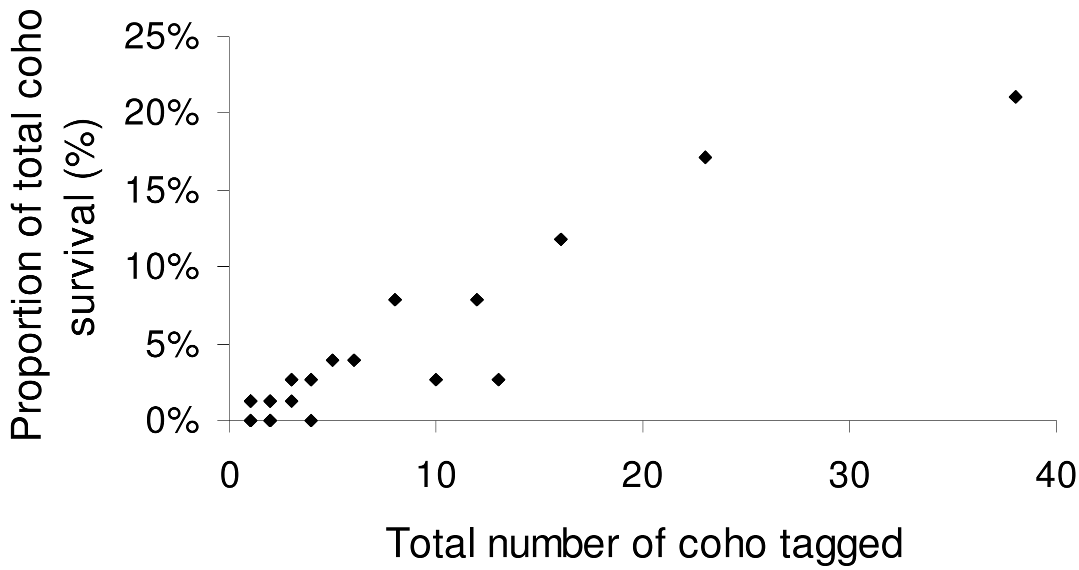


Figure 11. Proportion of overall coho survival as a function of the total number of coho tagged by habitat unit in Rock Creek.

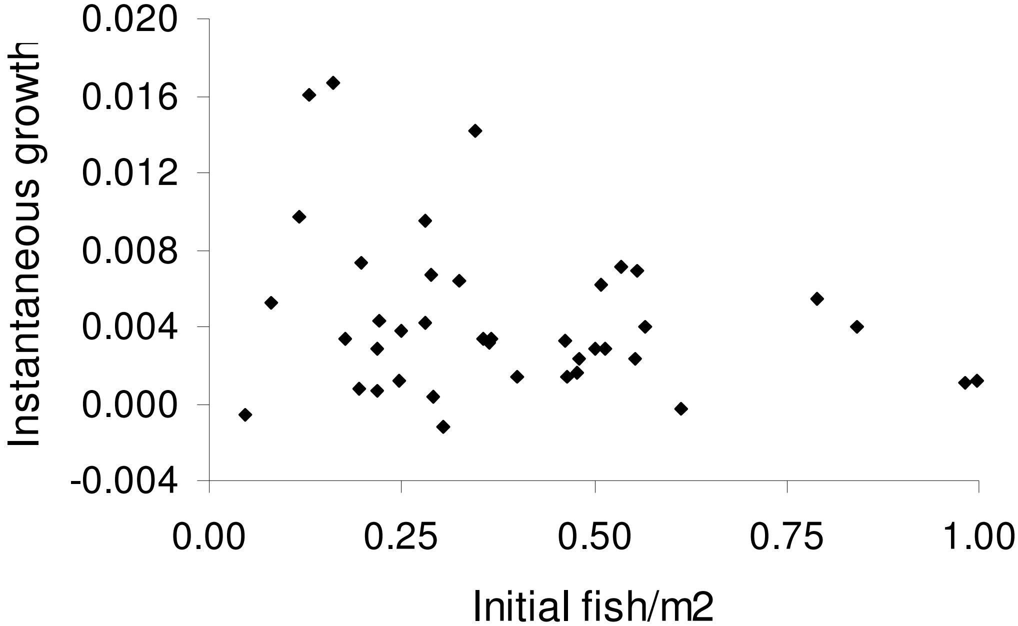


Figure 12. Instantaneous growth vs. initial fish density (fish/m2) in upper Rock creek – 2005/2006

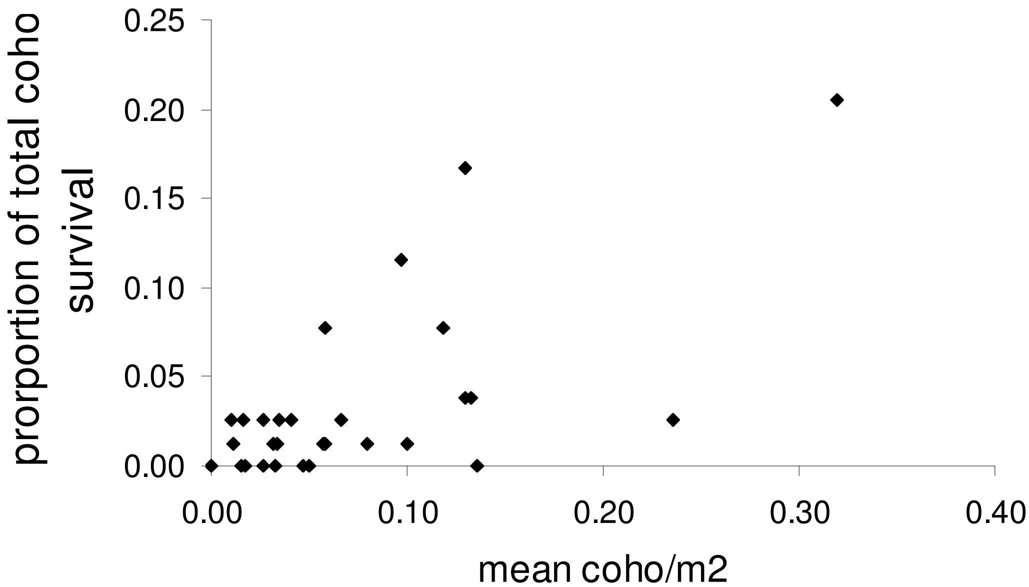


Figure 13. The proportion of total coho survival vs. coho salmon/m2 in upper Rock creek. Proportion of total coho survival = 0.4677(coho salmon/m2) + 5E-06

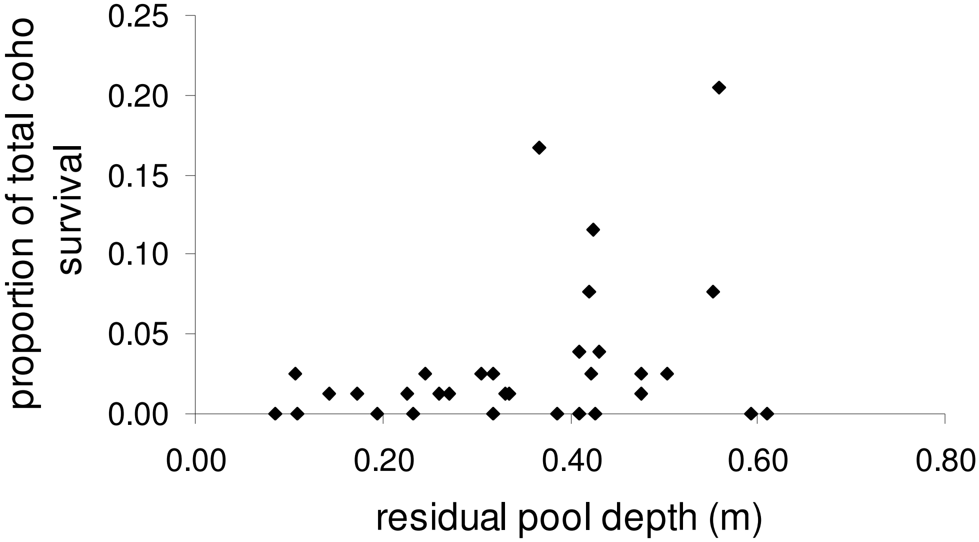


Figure 14. The proportion of total coho survival vs. residual pool depth in upper Rock creek. Proportion of total coho survival = 0.1139*residual pool depth - 0.0083

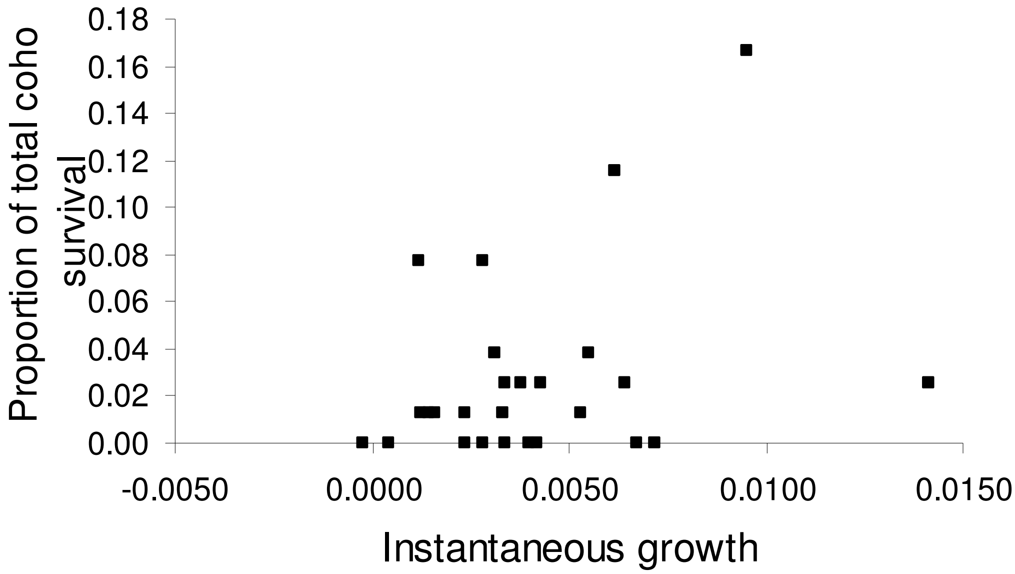


Figure 15. The proportion of total coho survival vs. instantaneous growth in upper Rock creek. Proportion of total coho survival = 4.3467*instantaneous growth + 0.0098

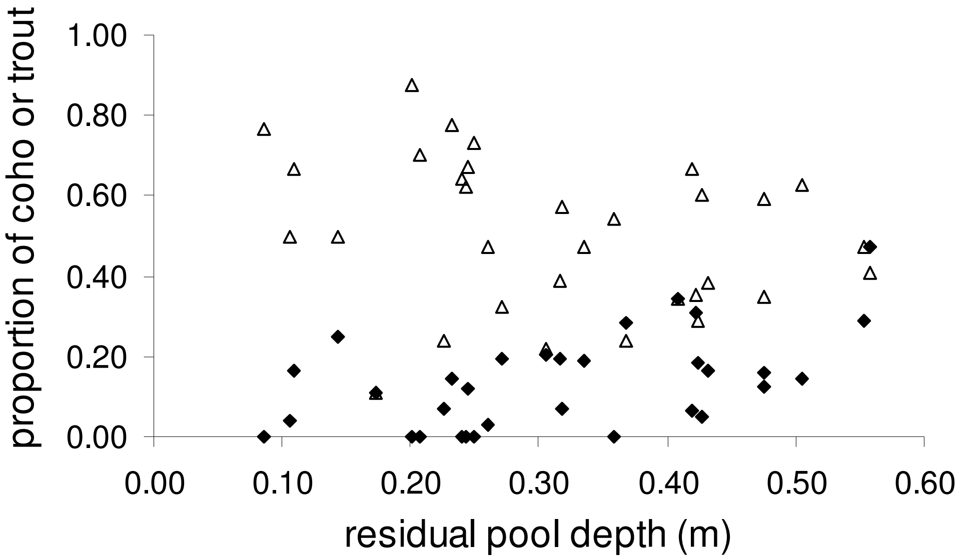
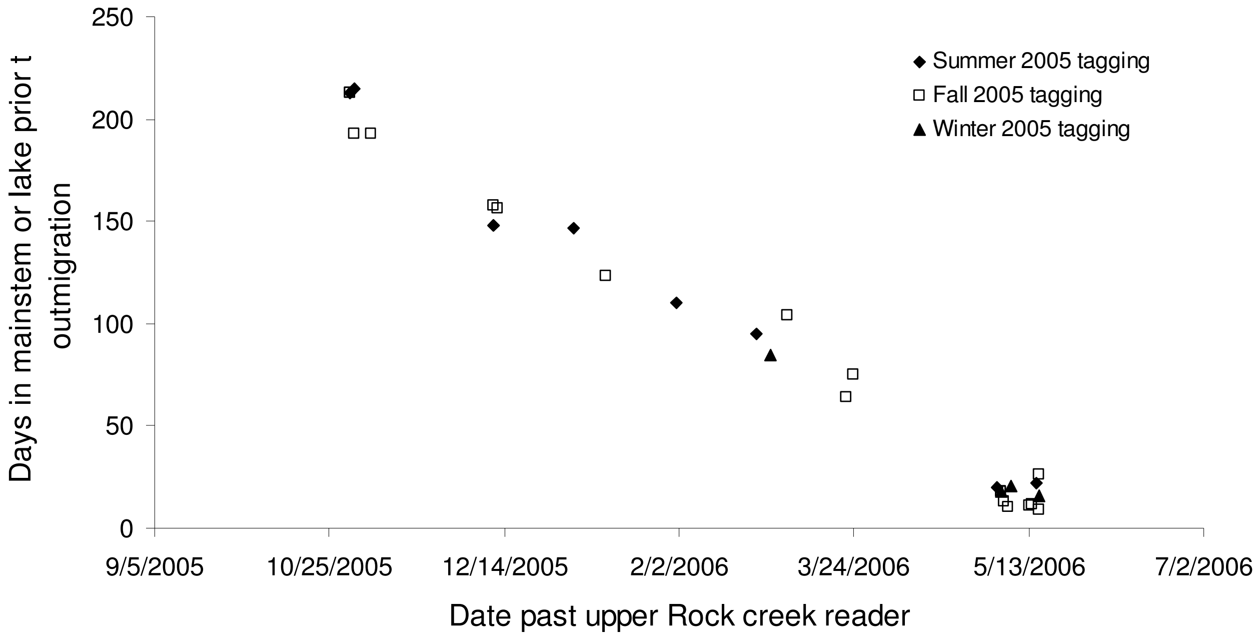


Figure 16. The proportion of coho or trout vs. residual pool depth in upper Rock creek. Solid diamonds denote coho while the open triangles denote the proportion of trout

a)



b)

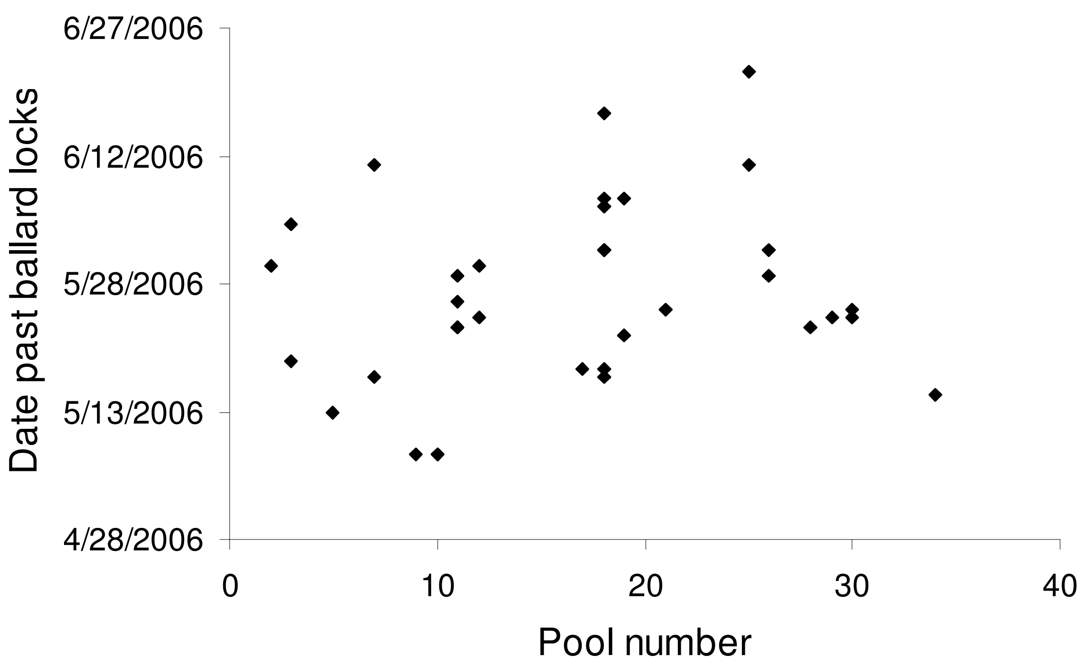


Figure 17. a) Date of outmigration from upper Rock Creek vs. the number of days residing in the main stem or lake prior to smolt outmigration in 2005. b) Date of outmigration at the Ballard locks vs. pool number where coho was tagged in upper Rock creek

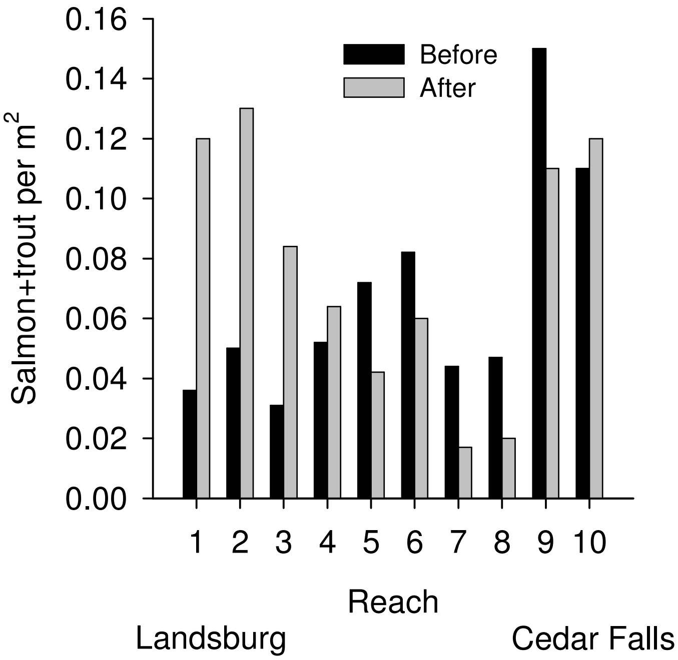


Figure 18. Mean reach-scale salmon + trout densities before (2000-2002) and after (2004-2005) installation of the Landsburg fish passage facility. Reach 1 was ~500 m upstream of the diversion, while reach 10 ended at Cedar Falls. Reaches 7-10 were not surveyed in 2004, while reach 5 was not surveyed in 2005 and reaches 3, 5 and 8 were not surveyed in 2006.

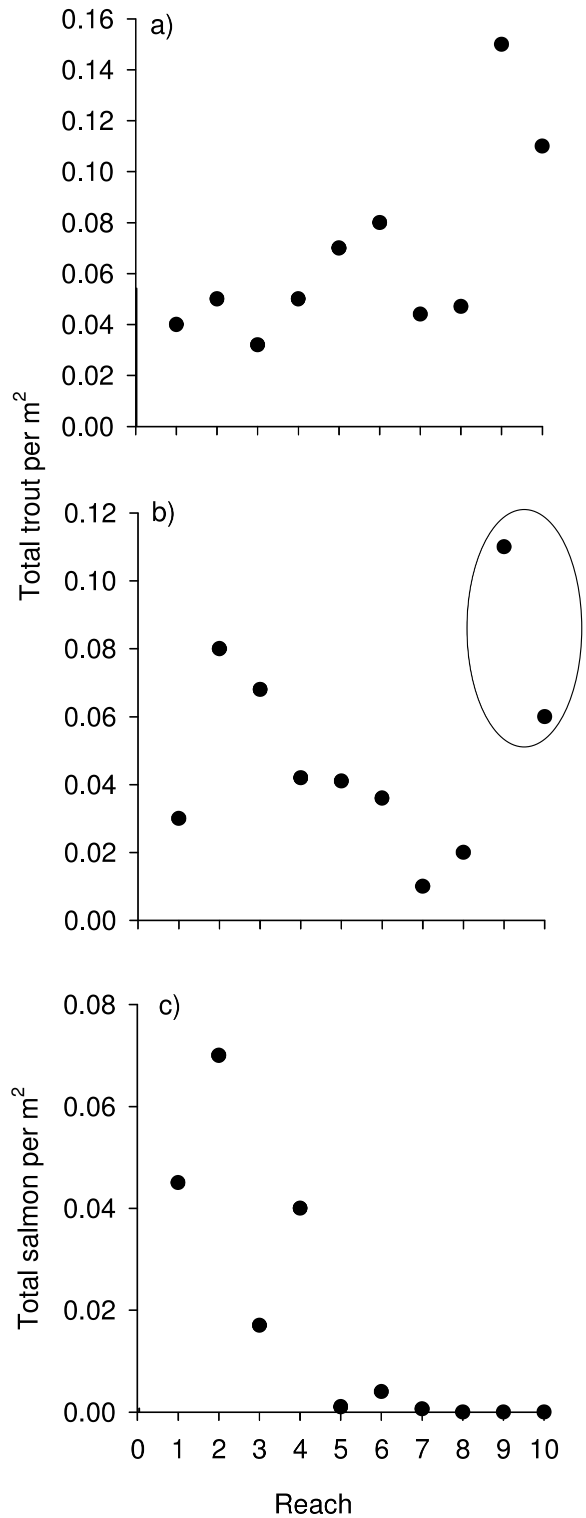


Figure 19. Spatial patterns of reach-scale trout density averaged across a) 2000 and 2001 and b) 2004-2006 (reaches 9 and 10 are circled), and c) salmon density averaged across 2004-2006.

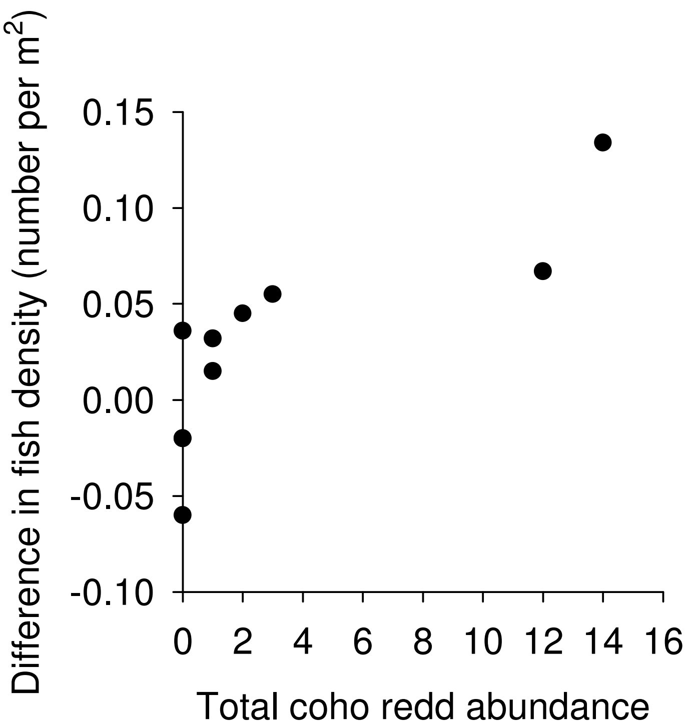


Figure 20. Plot of adult coho abundance per reach summed across 2003-2005 vs. the difference in reach-scale fish density after installation of the passage facility and before (difference in total fish density per m^2 = 0.001 + 0.0083*total coho returns, R^2 = 0.64, p=0.005)

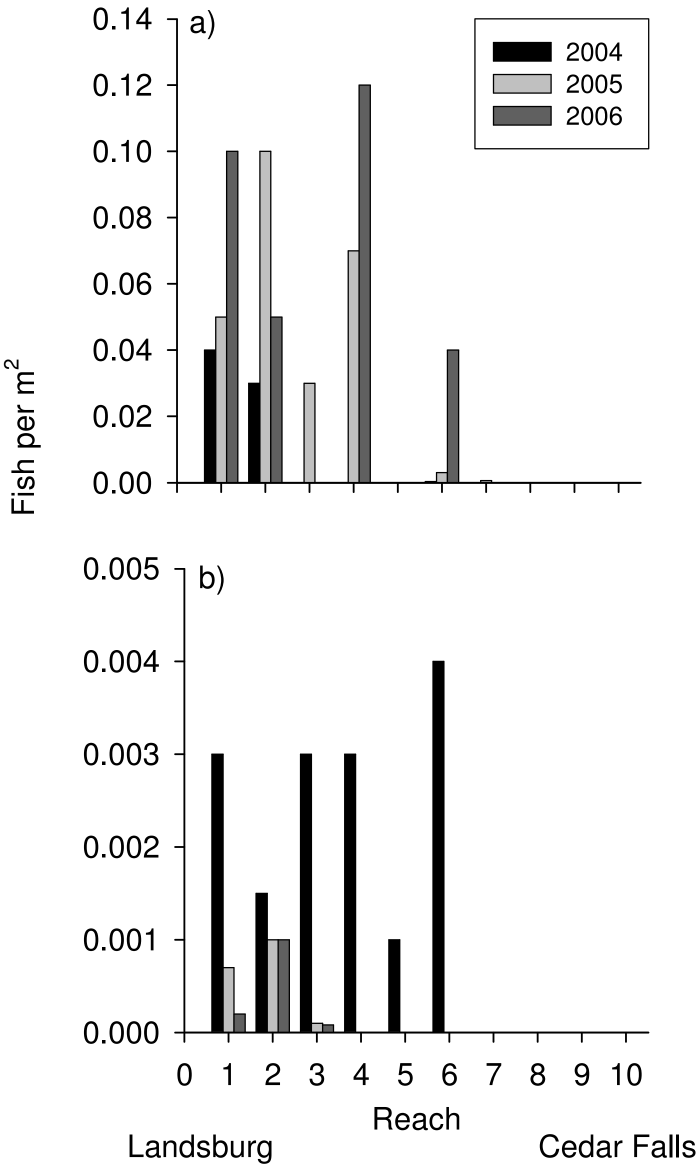


Figure 21. Mean reach-scale summer densities of a) juvenile coho and b) Chinook salmon from 2004 2006 averaged across habitat units.

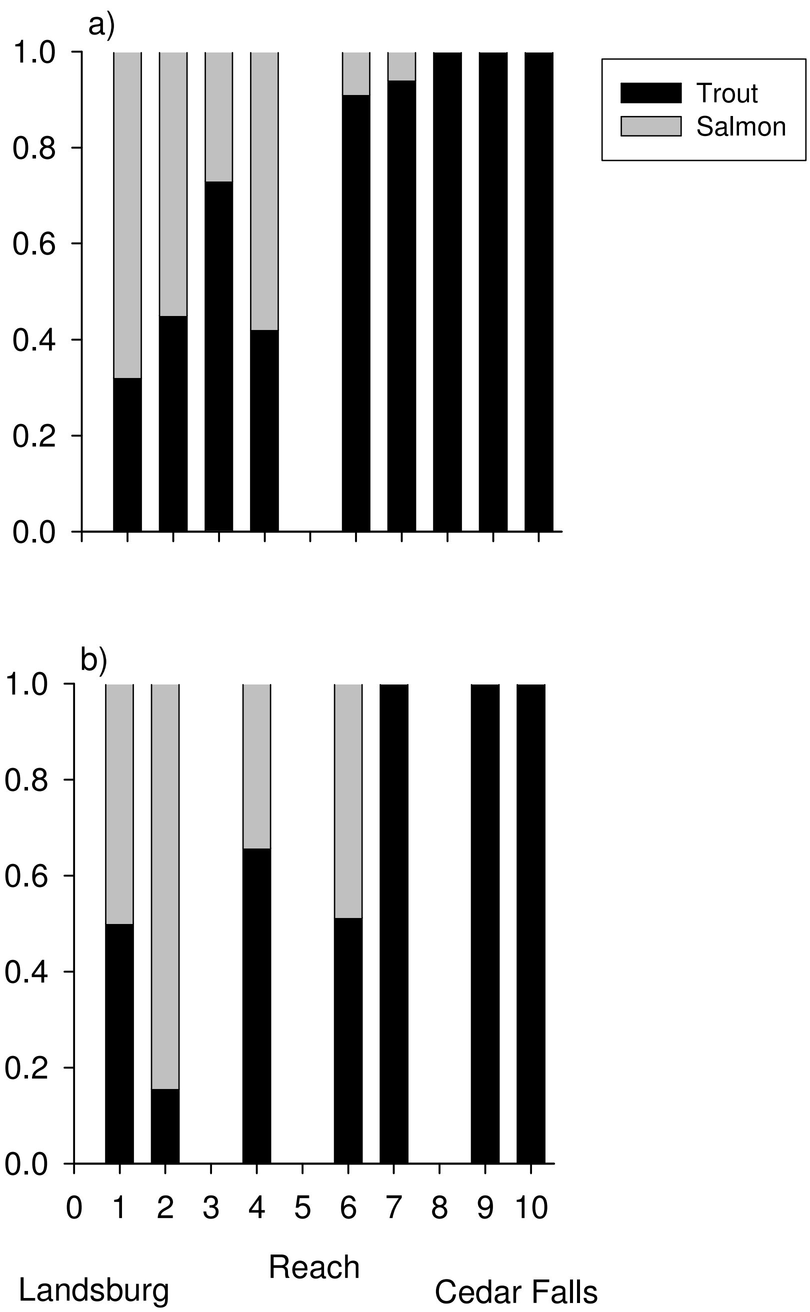


Figure 22. Relative proportion of coho (grey) and trout (black) in a) 2005 and b) 2006.

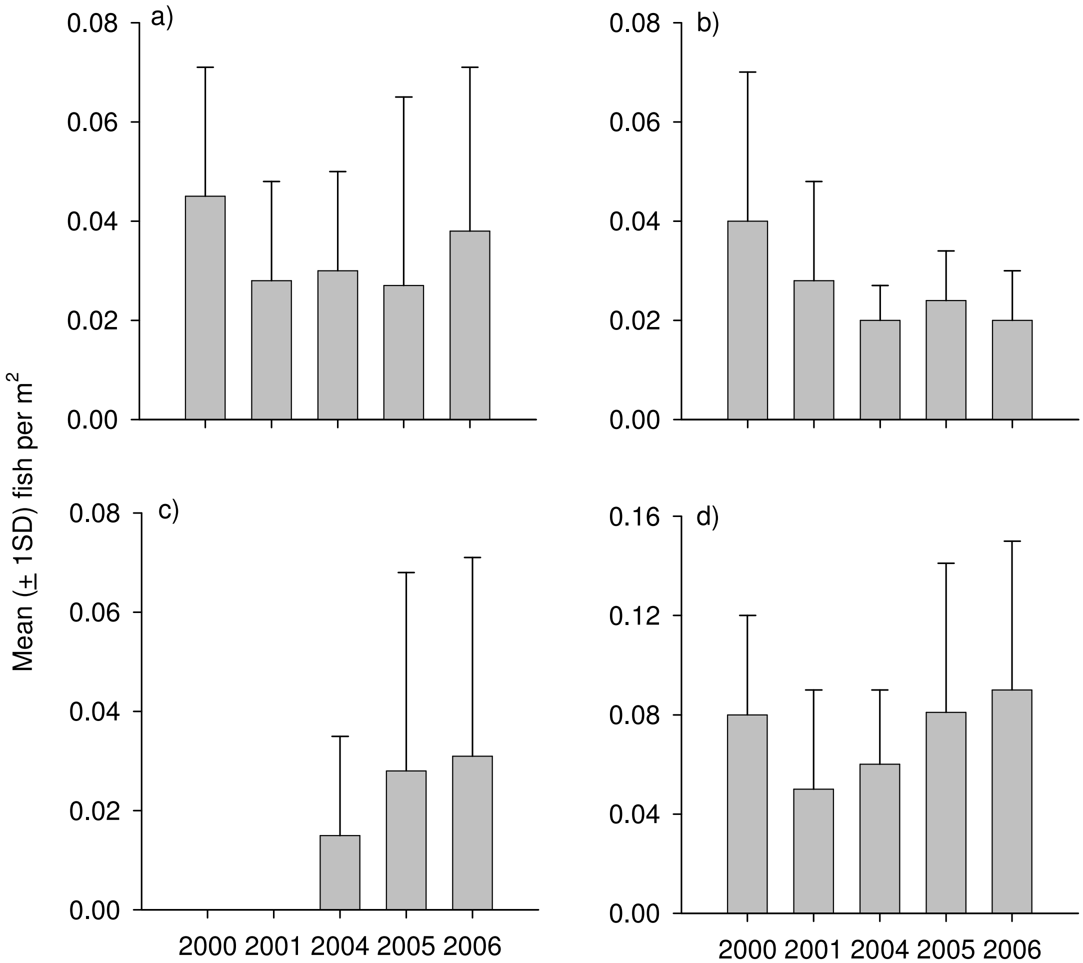


Figure 23. Mean (± 1SD) annual densities of a) trout <80 mm total length, b) trout >80 mm, c) salmon (Chinook+coho) and d) total fish (salmon+trout) averaged across reaches.

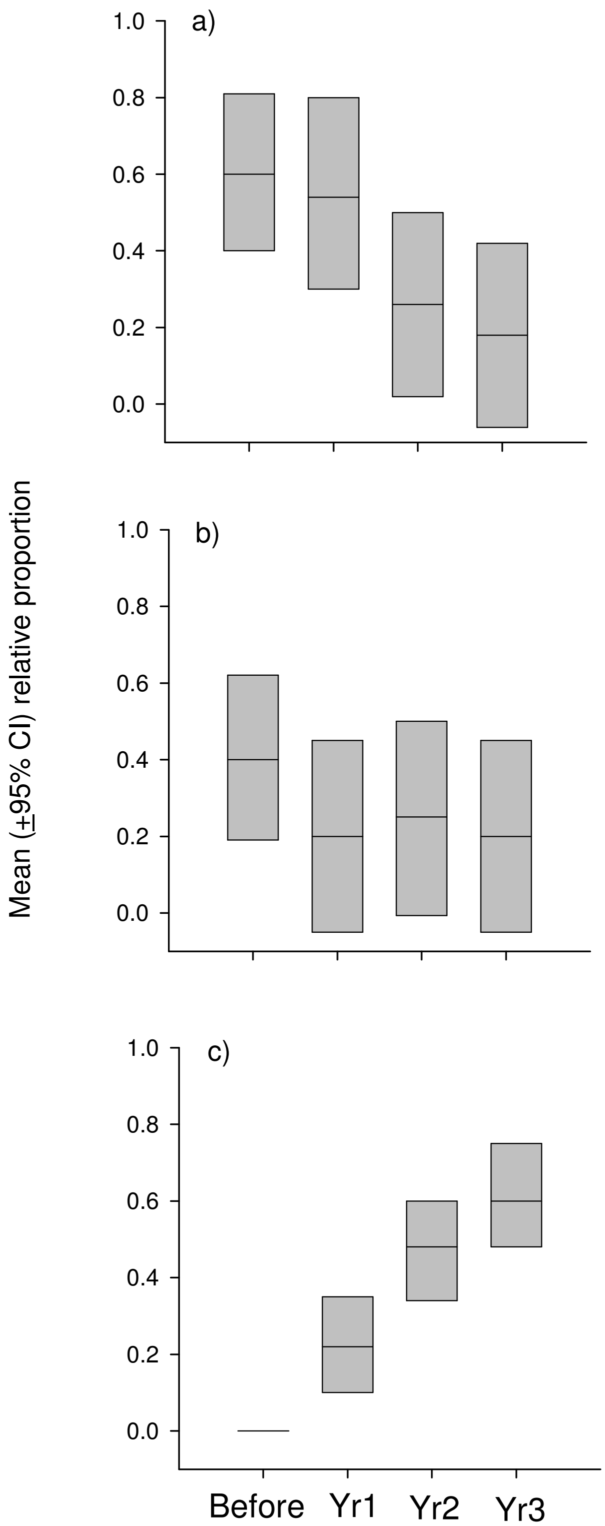


Figure 24. Mean (±95% CI) relative proportion of a) trout <80 mm, b) trout >80 mm and c) juvenile coho in reach in reach 1 of Rock Creek before (2000, 2001) and after (Yr1-3, 2004-2006) installation of the fish ladder.

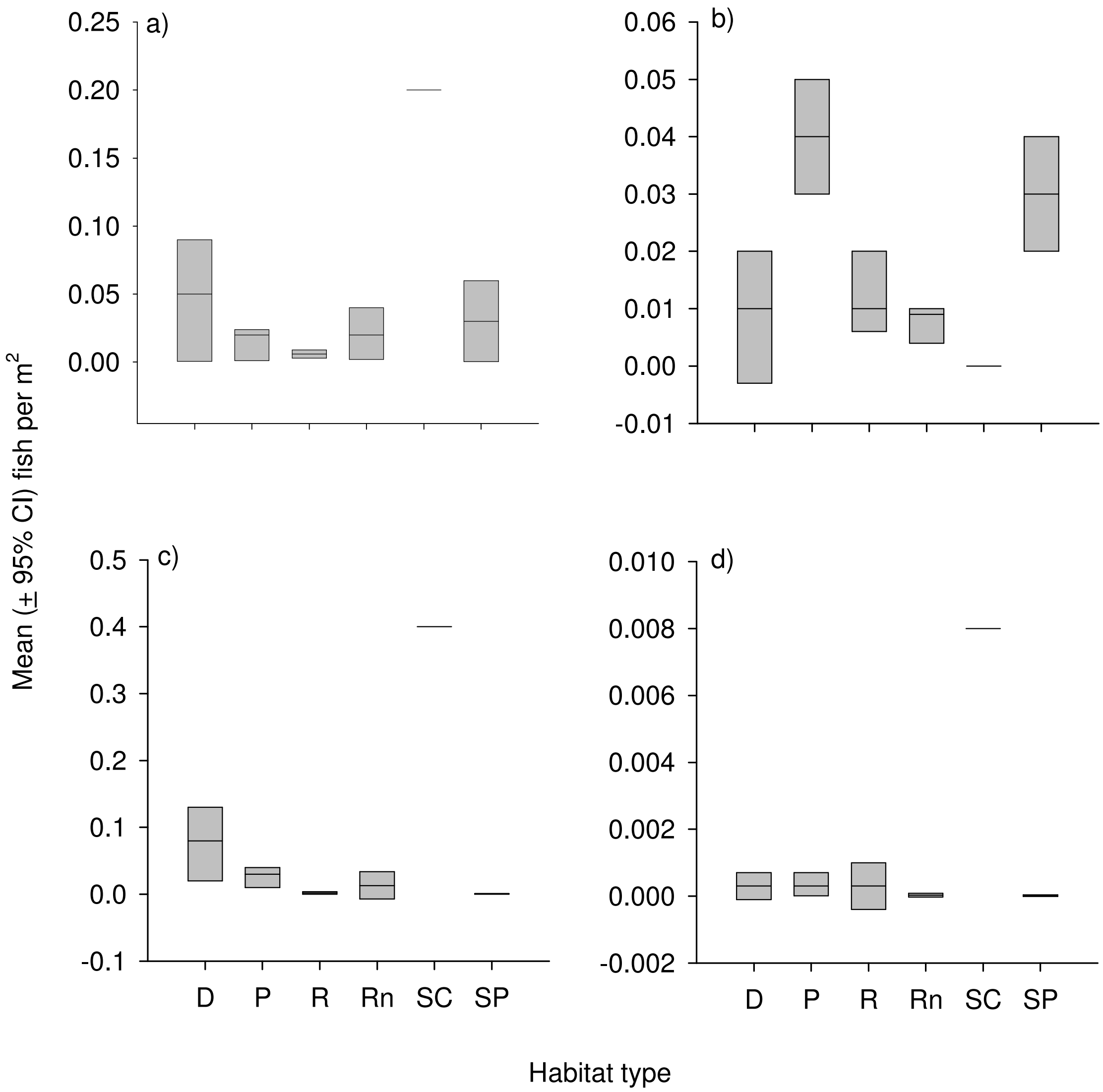


Figure 25. Mean (±95% CI) density of a) trout <80 mm, b)trout >80 mm, c) juvenile coho, and d) juvenile Chinook by habitat types during August 2005. D=depositional, P=pool, R=riffle, Rn=run, SC=side channel, SP=step-pool (see Table 1 for definitions of habitat types.). No confidence intervals plotted for side channel habitat because high variability masked patterns in other habitat types.

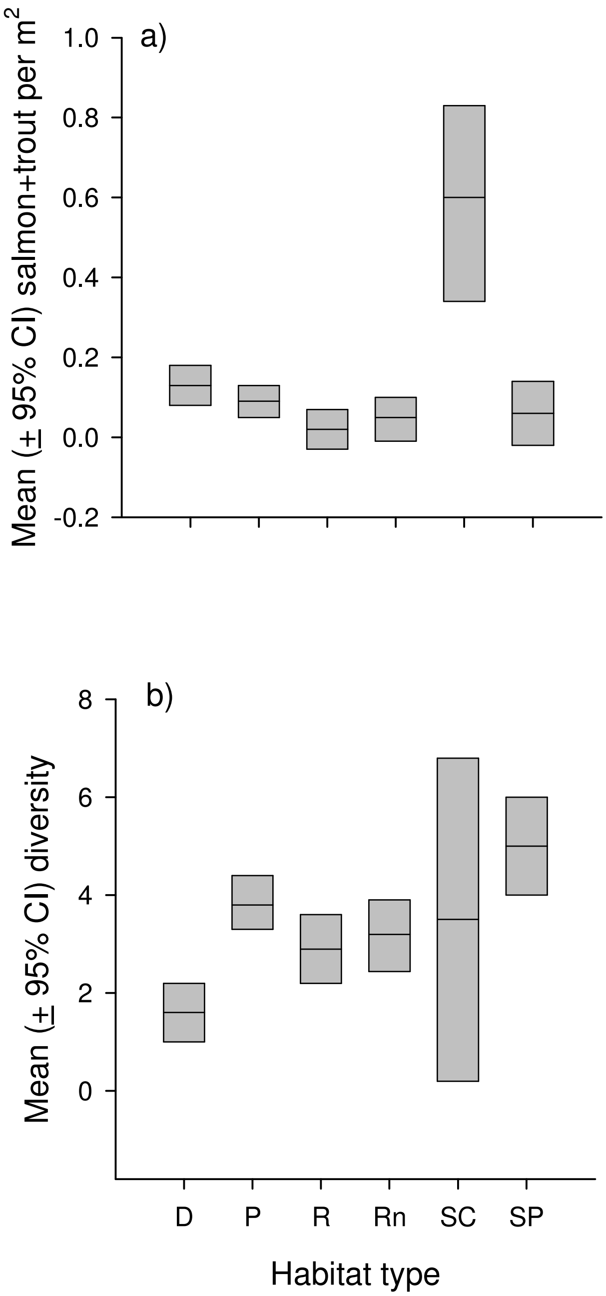


Figure 26. Mean (±95%CI) for a) salmon+trout density and b) species x size class diversity in each habitat type in the main stem during summer 2005. D=depositional, P=pool, R=riffle, Rn=run, SC=side channel, SP=step-pool.

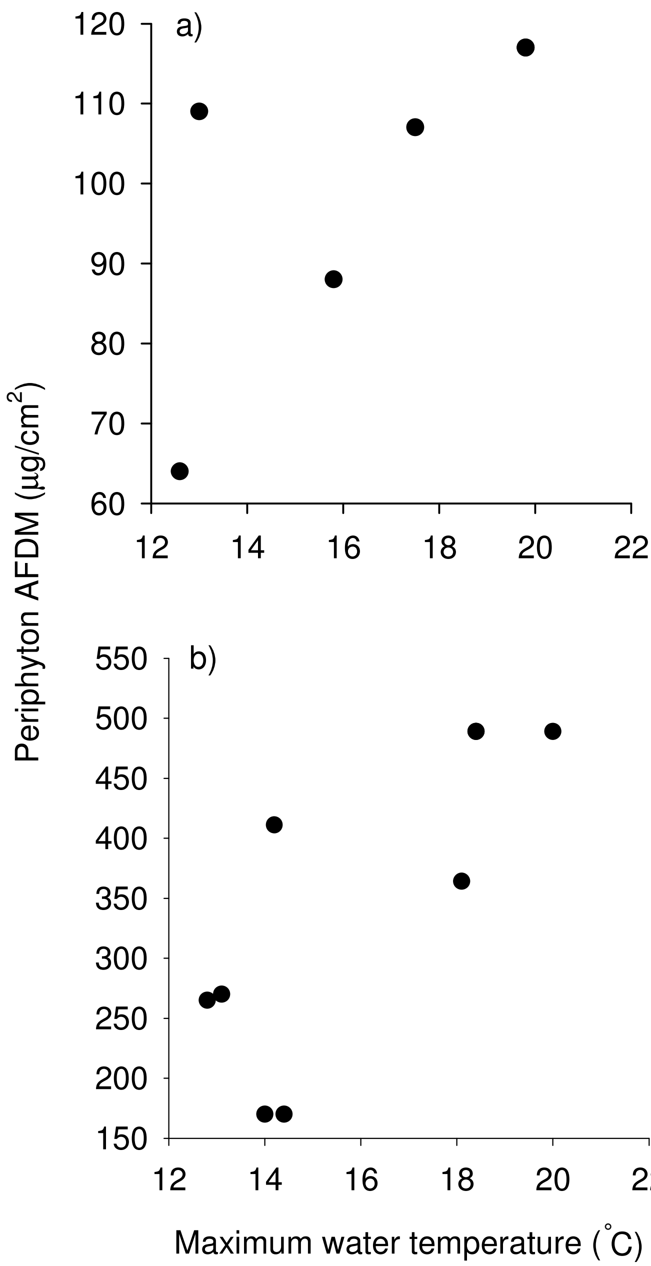


Figure 27. Mean reach-scale periphyton biomass vs. a) maximum water temperature in tributary and b) and main stem during 2005.

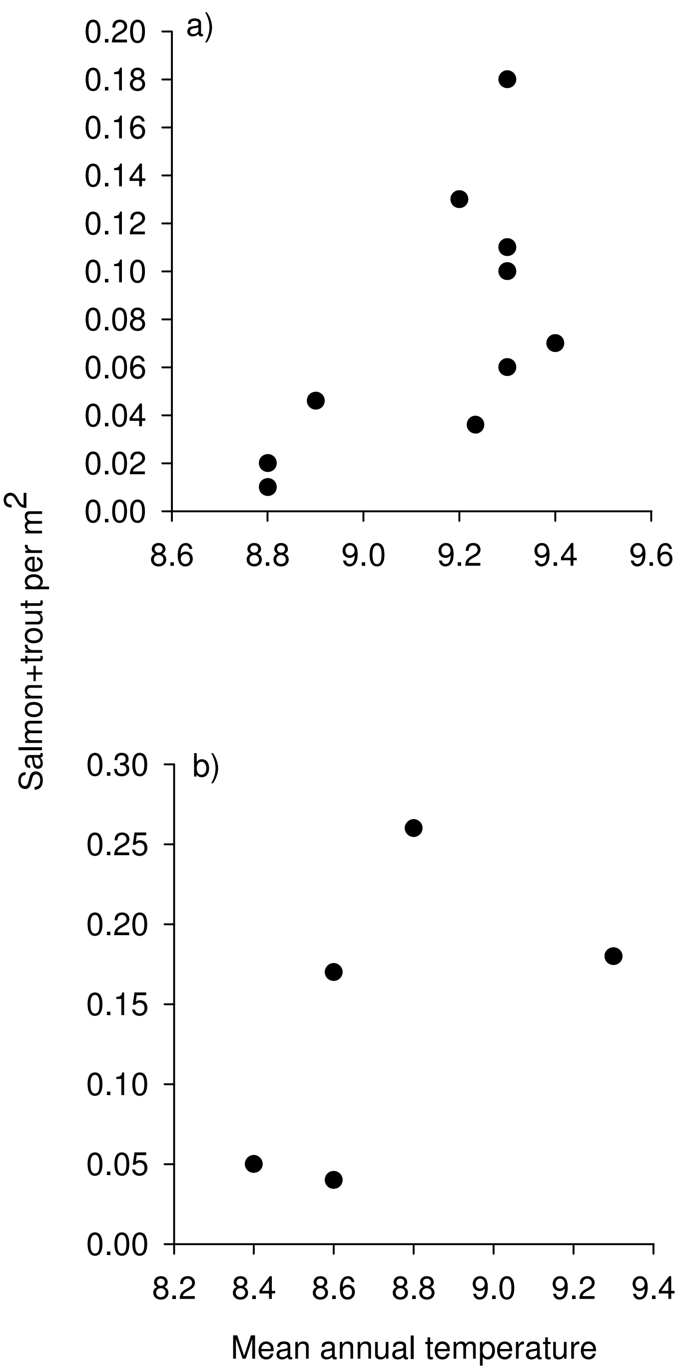


Figure 28. Salmon+trout densities during summer vs. mean annual water temperature in a) main stem and b) tributary reaches in 2005.

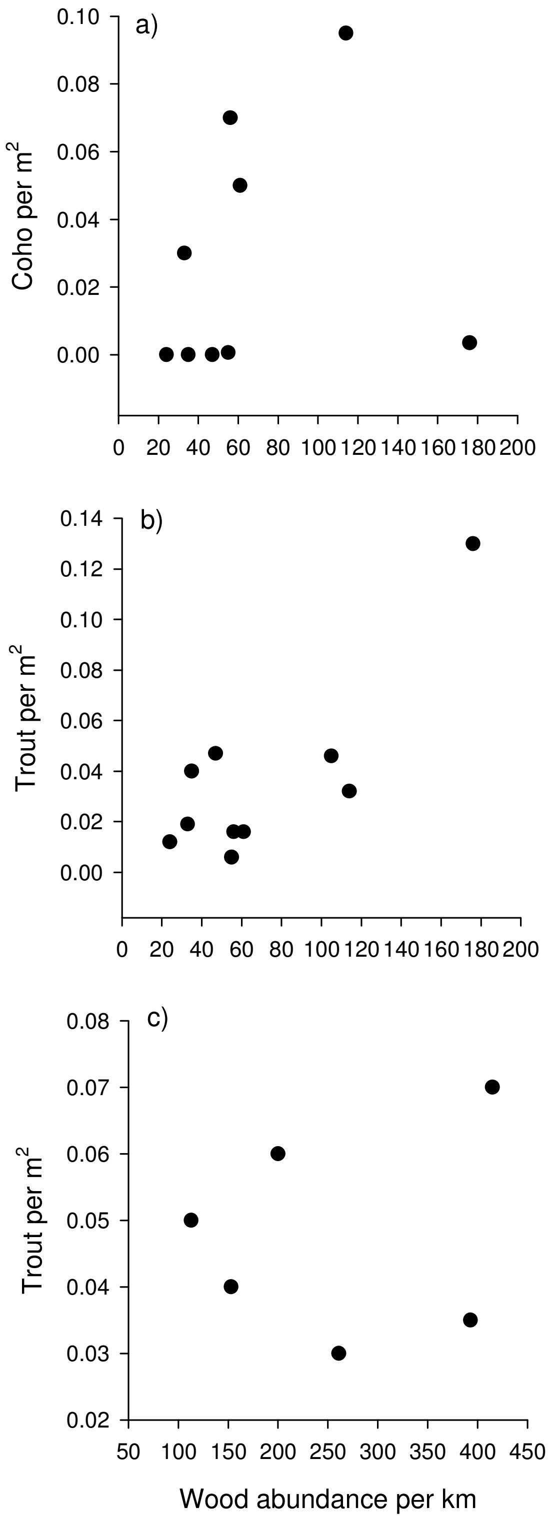


Figure 29. Mean reach-scale density of a) coho and b) trout in the main stem and c) trout in tributaries in 2005 vs. reach-scale wood abundance (wood pieces > 10 cm in diameter and 1 m in length) from 2000 habitat surveys.

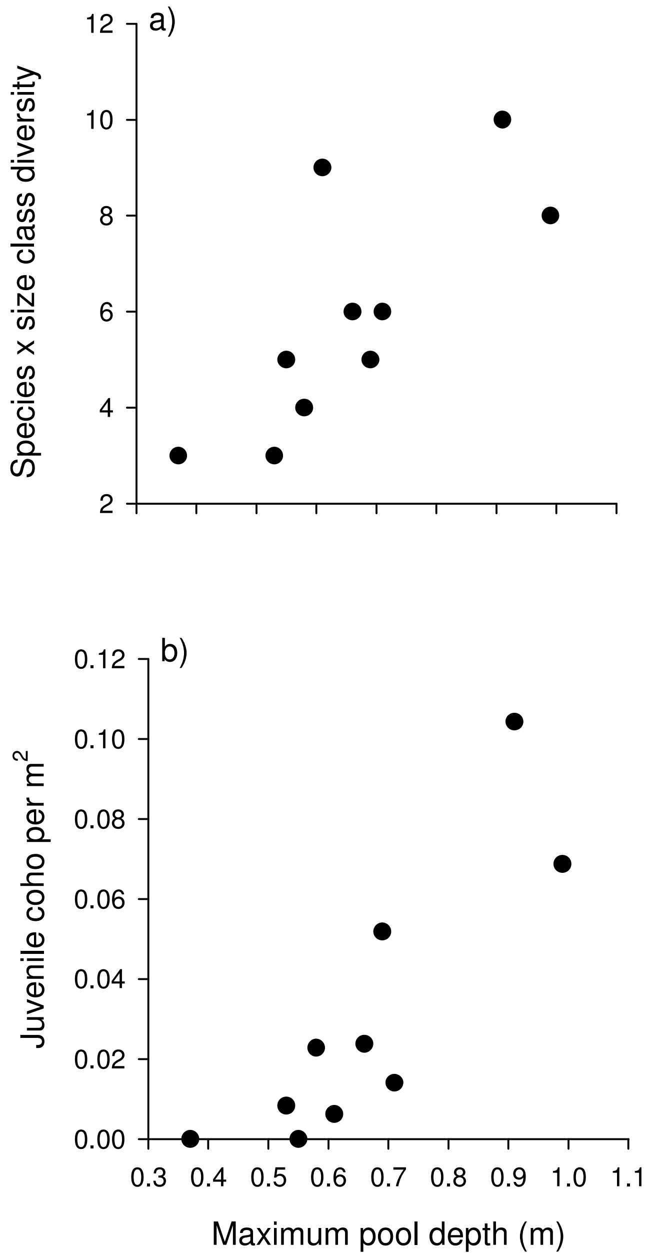


Figure 30. Relationship between maximum pool depth (m) and a) species x size class diversity and b) juvenile coho density in Rock Creek during Fall 2004.

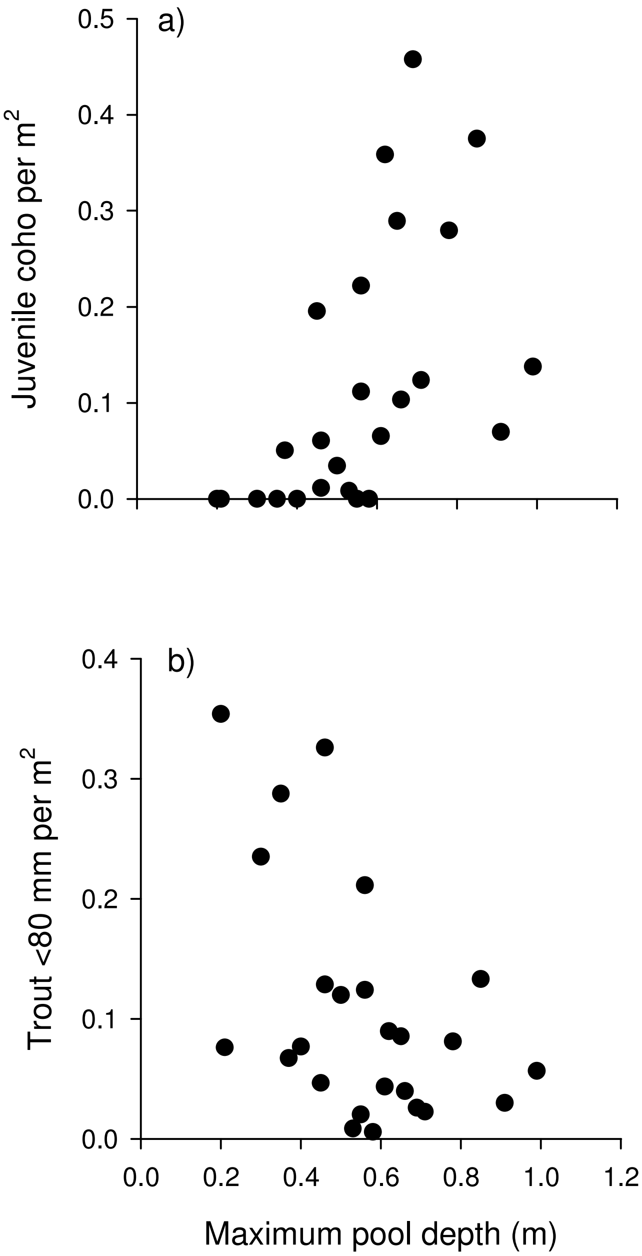


Figure 31. Relationship between maximum pool depth (m) and a) juvenile coho and b) trout <80 mm density during Fall 2006.

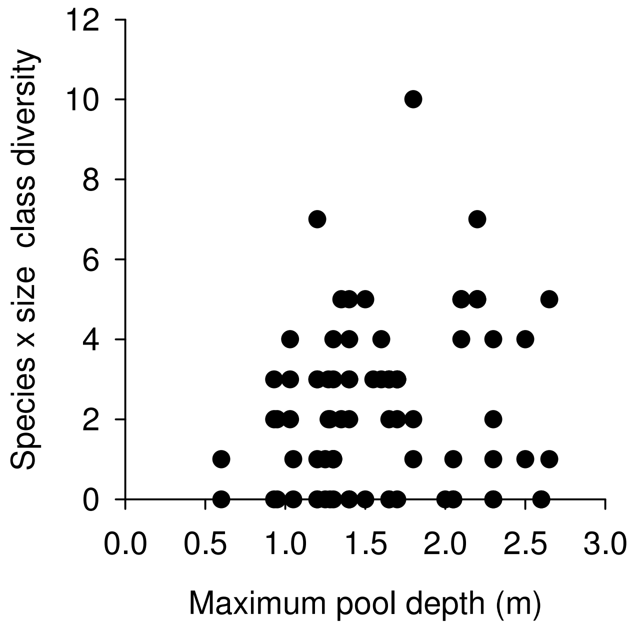


Figure 32. Relationship between maximum pool depth (m) and species x size class diversity in main stem pools during spring 2006.

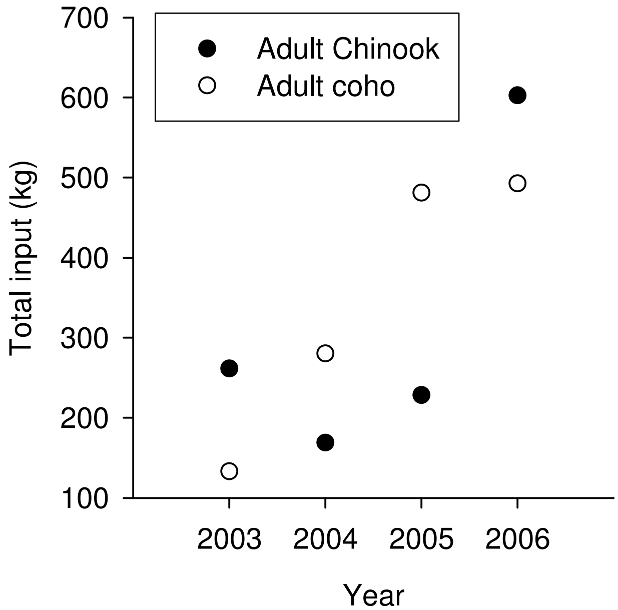


Figure 33. Mean annual input (kg) of adult coho (open circle) and Chinook (filled circle) since installation of the fish ladder in 2003.

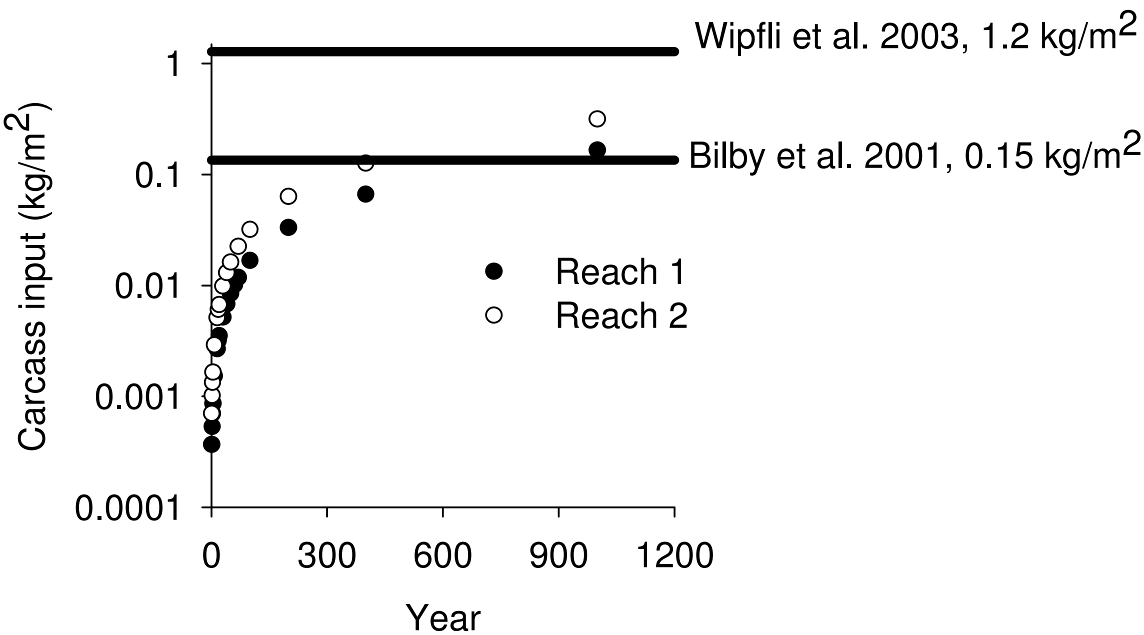


Figure 34. A simple model to predict when carcass inputs would reach levels associated with community or ecosystem saturation based on data from Wipfli et al. (2003) and Bilby et (2001). The model is based on the relationship between adult returns and time (2003-2006) (adult abundance=53*(year) + 65, R^2=0.94, p=0.02).