Version 2.0

Cedar River Municipal Watershed
Upland Forest Habitat Restoration Strategic Plan

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EXECUTIVE SUMMARY

Upland forest habitat restoration is a key component of the Cedar River Watershed Habitat Conservation Plan (CRW-HCP) which aims to accelerate the development of late-successional forest attributes and increase habitat complexity in second-growth forest. Implemented in April 2000, the CRW-HCP effectively placed nearly 85,500 acres of forests in the Cedar River Municipal Watershed (CRMW) in reserve status by prohibiting the harvest of timber for commercial purposes and by committing to a variety of conservation measures intended to restore or improve habitat for species of concern listed in the HCP. Many of these species, such as the marbled murrelet and the northern spotted owl, depend on late-successional and old-growth forest habitats. Forest habitat restoration efforts are aimed at facilitating and restoring natural forest processes while increasing the habitat available for species dependent on late-successional forests. Second-growth forests occupy lands that were logged prior to the adoption of the CRW-HCP and make up 71,500 acres of the CRMW, while the remaining 14,000 acres are late-successional or old-growth forest. Intervention for the purpose of habitat restoration will only occur within the second-growth forest. This plan outlines how forest restoration will be implemented in the CRMW to accelerate the development of late successional forest conditions and increase habitat complexity in second-growth forests.

Two general HCP goals for the municipal watershed are to protect and restore biological diversity and to protect drinking water quality. Additional goals for upland forest habitat restoration include accelerating the development of late-successional forest attributes in second-growth forest, improving habitat for species of concern that depend on late-successional forest, and reducing the risk of catastrophic disturbances that could threaten drinking water quality or habitat for species of concern. Over the term of the HCP, the upland forest habitat restoration program will apply active restoration through a combination of carefully planned interventions in previously logged forest and also passive restoration by protecting a majority of the areas to develop without further intervention. The intent is to increase forest ecosystem function and diversity over the watershed landscape over time by applying strategic intervention and protection in the optimal spatial pattern and temporal sequence such that forest ecosystems provide critical habitat and are resilient to perturbations from climate change, altered conditions surrounding the CRMW, and species invasion. A key approach to creating this resiliency is to develop greater structural and compositional diversity within forest ecosystems. The upland forest restoration program works within an asset management framework to apply interventions in the most cost-effective manner to achieve the overall goals. Upland forest habitat restoration is also implemented within an adaptive management framework so that knowledge gained from program implementation can be applied to future restoration work and shared with other practitioners and scientists.

Using guidance from the Landscape Synthesis Plan, the upland forest restoration program is integrated with other restoration activities across the landscape to produce the greatest overall benefit for species of concern. Upland forest restoration is planned at multiple spatial scales, from the landscape level to the site level, by considering key ecological processes and patterns of distribution of key forest attributes. The strategic approach to restoration is based on a conservation framework called “the measures of success” that was developed by The Nature

Conservancy and other organizations with similar conservation goals. Focusing on our ecological goals, we developed a framework that specifies desired future conditions for forest habitat within the watershed landscape that are based on key forest ecosystem processes, functions, and associated ecological attributes. We then compare current conditions, as defined by specific attributes and their measurable indicators, to the desired future conditions to determine whether restoration interventions are warranted. Within that framework, we present a conceptual model of ecosystem functional states and identify factors that cause resistance in forest development to higher functional states. We parse these resistance factors, which include abiotic and biotic factors, into specific ecological processes that can be altered through restoration interventions in order to improve ecosystem functions, such as habitat, water cycle regulation, and biodiversity. Because ecosystem functions and process are difficult to quantify, we suggest using forest structural attributes as surrogates to indicate levels of ecosystem function and ongoing processes. We use the attributes to track effectiveness in meeting the desired future conditions and restoration goals.

Active restoration of second-growth forest seeks to limit the time forests spend in low functioning states, such as the competitive exclusion stage of forest succession. Conducting restoration to engage key ecological processes, such as canopy differentiation and small-scale disturbance, may reduce the time a forest takes to transition to a higher functioning state that would support large trees, snags, downed wood, and the complex structure and biodiversity typical of late successional and old growth forests. These restoration efforts will take place in the form of *upland ecological thinning* in selected forest areas generally between 30 and 60 years old, *upland restoration thinning* in selected forest areas between 15 and 40 years old, and *upland restoration planting* in areas where biodiversity is lacking. Protection will occur where forests are already developing desired characteristics and/or have high levels of biological diversity and ecosystem function.

The current annual targets for each restoration program type are at least 62 acres for ecological thinning for the first 16 years and then 25 acres for the remainder of the CRW-HCP; 700 acres for restoration thinning through the first 15 years of the CRW-HCP; and upland restoration planting in areas that have low biodiversity and in conjunction with thinning programs. Planting is planned to include non-traditional approaches, such as “inoculating” areas of forest with lichens and mosses. Combining these restoration project types, the HCP calls for the treatment of a total of 13,480 acres, or about 19 percent of the existing second-growth forest, based on costs per acre as originally estimated. This total is based on the assumption that planting will be done on areas that are not thinned, which will often not be the case.

Though the overall goal of accelerating forest development and diversity applies to each of the three forest restoration project types, specific objectives differ. Ecological thinning objectives include increasing tree growth, encouraging tree crown development, increasing species diversity, increasing structural and spatial complexity, accelerating understory development, and improving connectivity between old-growth forest habitat. Restoration thinning objectives include reducing competition among trees to stimulate individual tree growth, adjusting tree species composition, stimulating shrub and herb productivity, reducing long-term fire hazard and other catastrophic loss, and creating small scale heterogeneity in forest structure. The objectives of upland planting are to increase species diversity of trees, shrubs, or other flora in areas of reduced biodiversity.

We prioritize restoration project sites by evaluating forest structural attributes, tree species composition and the proximity of habitat types as well as more specific criteria for each restoration program type. Restoration project selection and design requires specific data and tools that we describe and will continue developing as forests grow and change over time. Near-term project locations are identified in this plan and the process is established for locating projects in the longer term, as refined data becomes available.

There are many forest restoration efforts taking place throughout the Pacific Northwest that can guide current and future restoration in the CRMW. Following the "the measures of success" framework, we identify uncertainties (e.g. forest ecosystem response to global climate change) and knowledge gaps (e.g. long-term forest development response to restoration treatments) that may reduce our chances of success with our conservation goals. We plan to address these uncertainties, knowledge gaps and key research needs within an adaptive management model so that we can intentionally learn and adjust our restoration efforts over time. By monitoring and practicing adaptive management, we hope to improve the confidence of decision-making and increase the success of restoration programs.

Finally, standards and guidelines for implementing individual forest restoration projects are identified in this plan, which is intended to guide the upland forest habitat restoration program in the CRMW and provide program transparency to the larger community.

1.0 INTRODUCTION AND BACKGROUND

Upland forest restoration, or actively accelerating the development of late-successional forest conditions in degraded second-growth forest, is a key component of the Cedar River Watershed Habitat Conservation Plan (CRW-HCP), developed under Section 10 of the federal Endangered Species Act. The CRW-HCP includes a variety of conservation measures, including the active restoration of upland second-growth forest within the Cedar River Municipal Watershed (CRMW), required to meet the terms of an Incidental Take Permit for seven species federally listed as threatened. A total of 83 animal species, including the seven threatened species, are listed in the CRW-HCP as species of concern. This includes 21 birds, 19 mammals, 14 amphibians and reptiles, 10 fish, 14 insects, and 5 mollusks. Old-growth forest is a key habitat for 28 of these species, including the northern spotted owl (*Strix occidentalis caurina*), marbled murrelet (*Brachyramphus marmoratus*), and northern goshawk (*Accipiter gentilis*). The restoration of second-growth forest to late-successional forest habitat will also benefit most of the other species by restoring the CRMW to a more natural landscape condition.

Of the 90,546 acres encompassed by the CRW-HCP, 85,477 acres are forested, with 13,980 acres currently in late-successional or old-growth forest conditions[1]. The remaining 71,497 acres are second-growth forest. These younger forests are available for recruitment into late-successional forest habitat and are potentially available for restoration intervention. As stated in the CRW-HCP:

> *The general objective of the late-successional and old-growth communities component of the watershed management mitigation and conservation strategies is to develop significantly more mature and late-successional forest habitat in the watershed that will support species addressed in this HCP that are dependent on late-successional or old-growth forests, as well as old-growth biological communities in general.* (CRW-HCP 4.2-33).

The importance of natural processes and biological diversity is recognized in the CRW-HCP, and a major objective is to:

> *…develop strategies to restore and sustain the natural processes that create and maintain key habitats for species addressed by the HCP and that foster natural biological diversity of native species and their communities.* (CRW-HCP 4.2-10).

To help achieve these objectives, the upland forest restoration program will use both passive and active approaches to restore forest ecosystems. The passive approach includes protection of key forest habitats and diverse forest stand structures across the watershed. The active approach will use interventions designed to accelerate development of late-successional forest characteristics, enhance natural forest processes, and improve forest habitat for species of concern. This strategic plan provides a conceptual approach to restoration and breaks down the overall goal into more tangible objectives. Techniques will attempt to emulate and/or facilitate the process of forest development and the actions of natural disturbances that result in the complex habitat

[1] Old-growth forest is a subset of late-successional forest, with old-growth forest being loosely defined in the CRW-HCP as forest greater than 190 years of age, and late-successional forest being defined here as those in the understory reinitiation and old-growth stages of forest succession.

structure and biological diversity found in unmanaged late-successional forests in the maritime Pacific Northwest.

1.1 Purpose of This Document

The purpose of this document is to:

- define the goals and objectives of the upland forest restoration program;
- provide an overview of forest restoration, including the current state of the science, the ecosystem restoration rationale, and resulting strategy for implementing forest restoration in the CRMW;
- develop criteria for project site selection and prioritization that will ensure the greatest ecological benefit at the lowest cost;
- review available data that describe forest habitat conditions in the CRMW, define information needs required to obtain restoration goals, and identify the data and tools required to both identify areas in need of restoration and prioritize among them;
- develop a monitoring and adaptive management program for upland forest restoration that will address the most significant scientific uncertainties about natural processes and the effects of restoration activities being undertaken in the CRMW;
- delineate standards and guidelines for the project planning, design, and implementation process; and,
- identify the ongoing role of the Upland Forest Restoration ID Team (UFRIDT), which is made up of members of the Watershed Ecosystems Section, Watershed Services Division (WSD), Seattle Public Utilities (SPU).

1.2 Strategic Plan Organization

This strategic plan has been organized to clearly lay out the rationale, the approach, and the details for planning and implementing upland forest restoration in the CRMW.

- This introduction (Section 1) provides the background and context for upland forest restoration in the CRMW.
- Section 2 provides a framework for conducting forest restoration that includes an overview of forest ecosystem processes and conditions in the CRMW and the "measures of success" framework adapted from The Nature Conservancy. This framework is a systematic approach to defining restoration needs and objectives and provides a basis for evaluating the effectiveness of achieving restoration objectives.
- Section 3 lays out the rationale and process for prioritizing forest restoration projects.
- Section 4 describes how restoration projects are to be planned and implemented.
- Sections 5 and 6 provide a guide for what needs to be done to implement this strategic plan (next steps) and the role of the upland forest restoration ID team in that implementation.

Additionally, there are appendices that develop some of the material in the body of the document more fully or supplement the document with more detail. In particular, refer to Appendix A - Glossary for definitions of technical terms.

1.3 HCP Upland Forest Restoration Program Goals and Objectives

The CRW-HCP establishes the CRMW as an ecological reserve where the harvest of timber for commercial reasons is expressly prohibited and includes a number of active restoration measures required under the Incidental Take Permit. The CRW-HCP identifies and makes explicit commitments regarding three forest restoration activities (*upland restoration thinning, upland ecological thinning, upland restoration planting* described in more detail below and in Appendix B) that are designed to achieve the broad goals of accelerating late-successional forest conditions and restoring and sustaining natural processes while protecting and/or enhancing water quality and quantity. Recognizing that forest structural conditions and processes will continue to evolve with or without intervention throughout the 50-year CRW-HCP implementation period, restoration interventions are intended to accelerate those processes that lead to desirable habitat conditions, restore ecological processes to a more natural state, and increase biological diversity associated with late-successional forests.

Late-successional and old-growth forests can be described in different ways, whether the definitions are process-based or structure-based (Franklin and Spies 1991). In this plan, we aim to use processes to define whether and when to conduct forest restoration in order to accelerate the development of key ecological functions and their associated structural attributes that are present in older forests. However, because processes are often difficult to measure, structural attributes provide great utility in describing forest development stages at different points in time. Current research and management in forest ecology and forest restoration necessarily links forest structure and function and assumes that certain structures support certain functions (Kohm and Franklin 1997). The key structural attributes that are exhibited by late-successional and old-growth forests include:

- trees of diverse size classes and species, including large trees;
- decadence, including large standing dead trees (snags) and large logs;
- multiple forest strata and/or continuous canopy layers (i.e. vertical diversification or vertical heterogeneity);
- patches of different forest structures on the horizontal scale (i.e., horizontal heterogeneity).

In combination, these attributes comprise structurally complex forests. This structural complexity provides many habitat niches, a key habitat function, that is often absent in second-growth managed forests. These structures provide a key ecological function - late-successional forest habitat - upon which many at-risk organisms depend. The protection and creation of these structurally complex forests over time is the overarching goal of the HCP upland forest restoration program.

This strategic plan relies on models of forest succession in order to describe forest development processes that result in particular forest attributes and functions. The successional model is presented in detail in Section 2.4.1 and draws from Oliver and Larson (1996) and Franklin et al. (2002). In general, the forest restoration program targets forests in the least structurally complex competitive exclusion stage of forest development toward more complex successional stages that typically follow.

While there is inherent uncertainty associated with accelerating forest successional processes to achieve higher functioning ecosystem states (see Section 2), there is also a great deal of research that supports the pursuit of forest restoration activities to accelerate the development of old forest conditions (Hunter 2001). Uncertainty arises from a number of factors, including the varied development pathways that may lead to old-growth forest (Tappeiner et al. 1997, Winter et al. 2002a and 2002b), the different structure types exhibited by old-growth forests, the assumed relationship between structure and function (e.g., we assume that if we build it, they will come), and the young science of forest restoration ecology. Given these uncertainties, forest restoration is but one tool employed in the CRMW; protection of varied forest structure types and the allowance of multiple developmental pathways for CRMW forests are other tools. While active forest restoration will be applied in a portion of the second-growth forests in the watershed, passive forest restoration will occur on the majority. Portions of forest will remain untreated in different vegetation zones, which will allow for multiple pathways of forest development and will also provide for future learning opportunities (see next section).

1.3.1 Adaptive Management – Conducting Restoration within a Learning Model

Because the science of forest habitat restoration is relatively new and various key questions remain unanswered, upland forest habitat restoration will be conducted within an adaptive management framework in the CRMW in order to learn as we go (see Section 2.10). Working within an adaptive management framework requires us to clearly define at the outset our restoration objectives, and our learning objectives if they are different. There is often a tension between designing restoration projects for the best possible ecological outcome and designing projects as learning opportunities. If learning is an objective, then we need to be willing to take risks in project designs and actively monitor to detect treatment results. The learning objectives may range from evaluating restoration treatment effectiveness in facilitating the development of certain forest structures and functions over time to examining the feasibility of implementing certain project designs in certain forest types. Care must be taken to explicitly define those learning objectives, both at the project scale and also at larger program scales. The questions should pertain to not just individual projects, but also to how the results might vary between projects and across forest types. In addition to planning restoration projects to meet the overarching objectives of restoring late-successional forest habitat and improving forest complexity and biodiversity, the CRW-HCP upland forest restoration program will be implemented within a larger learning context.

1.3.2 Applying the Upland Forest Restoration Programs

A first step in implementing the forest restoration programs under the CRW-HCP involves identifying where restoration interventions will and will not occur based on specific criteria. Forests that are developing well, provide good wildlife habitat, and have moved beyond the competitive exclusion stage will simply be protected. Those second growth forests that do not fit these criteria and have high stem densities, high relative densities, homogenous forest structure, and provide poor wildlife habitat will be candidates for restoration interventions, depending on their landscape position. However, there may be some cases where the learning objectives take precedence and projects are designed specifically to study the effects of certain restoration treatments in forests that are developing well (e.g., thinning understory hemlock and gap creation in previously commercially thinned forests in the lower Taylor Basin).

The conceptual model for the implementation of forest restoration projects over the chronological age of a forest may include restoration thinning when the forest is 15-30 years old, an initial ecological thinning when the forest is greater than 30 years old, and potentially successive ecological thinnings if forest conditions warrant and if final thinning targets (i.e., structurally complex and biologically diverse forests that are moving toward late successional forest conditions) cannot be achieved with one entry. This scenario would be dependent upon other factors, such as access; in many cases it may be that roads are decommissioned after restoration thinning is completed, in which case subsequent silvicultural activities would be less feasible. Upland restoration planting may be incorporated at any stage of forest development, side by side with restoration thinning or ecological thinning projects or as independent projects. All three forest restoration activities will be designed to create and maintain a mosaic of late-successional forest habitat over a range of spatial and temporal scales, thus providing habitat for a wide range of native organisms and assisting in the development and support of key ecosystem processes (see Section 2.5).

The HCP forest restoration program recognizes that disturbances are natural components of the forest ecosystem in the Pacific Northwest. Therefore, forest restoration treatments will attempt to mimic and/or facilitate small-scale disturbance such as windthrow, lightning, disease, and insect infestations. Large-scale catastrophic disturbances such as fire, however, may negatively impact both water quality (protection of water quality is a primary goal of the CRW-HCP) and wildlife habitat for species of concern in the CRMW, and the CRW-HCP expressly commits to avoid or minimize catastrophic damage from large-scale disturbances. As a result, if the risk of catastrophic disturbance is considered significant, those forest areas that are considered to be highly susceptible to fire will be given high priority and management intervention will be designed to reduce that risk. The Fire Hazard Assessment (Johnson et al. 2007a) provides a basis for evaluating fire hazards and associated risk for the watershed.

While the three upland forest restoration activities focus on different ecological processes and are administered separately, they have similar goals and objectives and necessarily dovetail in their design and implementation. Indeed, the three activities complement each other and must be applied in an integrated manner. For example, thinning and planting can and should occur in the same forest ecosystem restoration project where an objective is increasing plant species diversity. Questions and uncertainties arise in the design and implementation of both the thinning programs, such as issues of spatial complexity, scale, and cost effectiveness. Hence, the restoration treatments may converge in design, application, and monitoring efforts in order to learn how the restoration treatments should most effectively be applied.

1.3.3 Restoration Thinning Goals and Objectives

Upland Restoration Thinning is the thinning of dense second-growth forest areas generally less than 30 years of age that have relatively low biological diversity and are in or approaching the competitive exclusion stage of forest succession. The overarching goal of restoration thinning is to accelerate the development of complex habitat in the near-term and late-successional and old-growth forest conditions in the long-term. More specific objectives of restoration thinning include:

- reduce competition among trees;

- increase light penetration;
- stimulate tree growth;
- increase tree and understory plant species diversity;
- reduce long-term fire hazard;
- minimize the chance of catastrophic windthrow, insect, or disease outbreak;
- accelerate forest development past the competitive exclusion state to a more biologically diverse stage, and/or;
- extend the stand initiation period such that more diverse species and stand structures become established.

1.3.4 Ecological Thinning Goals and Objectives

Upland Ecological Thinning consists of thinning dense, relatively homogenous second-growth forest areas generally between 30-80 years, with the primary goal of accelerating the development of old-growth forest conditions. Ecological thinning aims to reduce the time forests spend in the competitive exclusion stage of forest succession while enhancing structural complexity and biodiversity. More specific objectives of ecological thinning include:

- maintain or increase tree diameter growth;
- encourage tree crown development;
- increase overall species diversity;
- increase structural complexity (e.g., multiple canopy layers, variable tree density, large snags, large downed wood)
- increase patchiness (i.e., horizontal heterogeneity);
- accelerate understory development, and;
- improve old-growth forest habitat connectivity at a landscape scale.

1.3.5 Restoration Planting Goals and Objectives

Upland Restoration Planting will be implemented in upland second-growth forest areas to increase the diversity of forest ecosystems made depauperate in species by past land use and forest management practices. The goal of upland planting is to restore appropriate levels of diversity of trees, shrubs, forbs, bryophytes, lichens, and fungi (and other microflora) characteristic of naturally regenerated areas and old-growth forests. Restoration planting may be used to augment other restoration efforts, including ecological thinning, restoration thinning, and road decommissioning. Because the dispersal rates of some flora associated with late-successional forests are low (Muir et al. 2002), planting of dispersal-limited species in key areas may enhance ecological function and biodiversity at a landscape scale. Planting of some types of these organisms (such as lichens and mosses) has rarely been attempted, making these planting efforts to restore ecosystem components experimental in nature. Appendix C provides more detail on the planting program approach, including specific planting projects.

1.3.6 Additional HCP Goals and Commitments

Several additional goals are identified in this document and will be incorporated in the planning and implementation of upland forest restoration projects.

Use of the Best Available Science in Upland Forest Restoration
The science of forest restoration is a relatively young discipline, with targeted work only beginning within the past several decades. Forest succession in forests west of the crest of the Cascade Mountains in the Pacific Northwest proceeds slowly, over centuries. Consequently, the time needed to judge the success of forest restoration typically is decades or centuries. Not surprisingly, no one has yet restored a functioning late-successional or old-growth forest through active restoration efforts. Since the primary efforts to date to restore second-growth forests to late-successional conditions have been limited and have largely been made in the context of experiments begun within the last two decades (Appendix D), we must consider many of the proposed restoration activities in the CRMW as experimental. In addition, much is unknown about the natural processes of forest succession, especially in later stages of development and in true fir forest types (Curtis et al. 2000, Franklin et al. 2002). Given this uncertainty, the CRW-HCP commits to using the most recent data and scientific understanding available (obtained through literature searches, consultation and collaboration with experts – Appendix D and Section 2.9 and 2.10). Additionally, the upland forest restoration program takes a conservative approach that limits active intervention to a small portion of the landscape and uses monitoring and adaptive management to continue learning (see Section 2.10).

Integrated Information Management Systems
The UFRIDT is using data developed by the Watershed Characterization ID Team (WCIDT) and landscape priorities developed by the Landscape Synthesis Team. The UFRIDT and other planning staff will use a variety of data to guide long-term project site selection and prioritization and also restoration project design (see Section 2.7.2 and Appendix E). These data include remote sensing image data (e.g., LiDAR) and derived attributes from those data, as well as field based data (e.g., forest inventories, permanent sample plot data) and historic data (e.g., GLO notes and historic cruises). The WCIDT provides data dictionaries, standards for data collection, and meta-data methodology, which will be used to standardize, document, and access the data. Critical data, including metadata, will eventually be housed in the Science Information Management System (SIMS), one component of which is specific to Forest Information (FIMS). Ultimately, FIMS will house all of the forest data that staff determine to be high enough quality to import and store. FIMS will have built-in integration with GIS, and will have export functions to be able to use various datasets for forest growth projections and other analyses.

1.4 Linkages to Other Plans and Documents

Planning upland forest restoration projects requires close collaboration and coordination with other WSD restoration planning efforts, including leaders of WSD work units, other interdisciplinary (ID) teams, and WSD Operations and Ecosystem staff. Project coordination has several potential advantages, including an opportunity to combine restoration techniques for greater ecological benefits in a cost effective manner, combine riparian, aquatic, and upland treatments for greater landscape-level effects, combine data collection for planning and monitoring purposes, and limit disturbance to wildlife by concentrating disturbance from various projects in one area into a short time frame. Upland forest restoration projects will be coordinated within sub-basins with riparian and aquatic restoration projects. It is also essential that restoration projects be coordinated with road decommissioning plans to ensure adequate access for project implementation and long-term monitoring.

1.4.1 Landscape Synthesis Plan

In order to provide an integrated, landscape-level approach to planning restoration that most efficiently and effectively achieves the diverse goals of the HCP, a Synthesis Framework (Erckmann et al. 2008) was developed. Using a set of statements regarding an idealized set of future watershed conditions, the delineation of areas with unique species or high inherent biodiversity, and the identification of four interdependent ecological attributes (ecosystem resilience, natural disturbance regimes, natural biodiversity and ecological sustainability, and landscape connectivity), the framework is intended to focus restoration efforts on areas with the highest likelihood of achieving restoration goals set at a variety of spatial and temporal scales.

Statements used to describe an idealized set of future watershed conditions which are most strongly linked to the forest ecosystems are as follows:

- Have a forested landscape dominated by late-successional or old-growth conditions (absent large-scale natural disturbances), including natural diversity of forest structure and composition (including snags and down wood) supporting a full complement of plant, animal, and fungal species characteristic of late-seral forest in the watershed;
- Have no areas of habitat that act as barriers to the movement of species of concern, either horizontally or with respect to elevation, other than those inherent to the habitat type;
- Have minimal residual effects of past land use that are not related to current operations, including habitat permeability related to roads, unnatural forest edges, and unnatural species composition as a result of past logging;
- Have a mix of conifer and deciduous trees across the landscape, within the natural range of variability, that best supports the species of concern in the HCP ;
- Have forest conditions that do not pose an unnaturally high risk of extensive forest fires, taking into account changes in fire [hazard and] risk as a function of climate change and the development of surrounding land;
- Have minimal impact from watershed management activities on processes critical to the formation and maintenance of soil structure, biota, and biogeochemistry;
- Have riparian forests consisting of deciduous, conifer, and mixed deciduous-conifer stands in proportions within the natural range of variability.

Forest ecosystems that provide geographic connections (corridors) between existing patches of late successional forest and good quality second growth forest, and buffers around those older/good quality forest patches, were identified as a means of focusing on areas with the greatest potential for restoration that would benefit species of concern across the watershed landscape and/or the greatest need for amelioration of risks and threats. Forest stands within the high synergy areas identified through the landscape synthesis screen will then be evaluated and prioritized using project-level criteria discussed in detail in Section 3 of this plan.

1.4.2 Restoration Philosophy

The restoration philosophy guiding this and all other CRMW strategic plans is described in the Cedar River Watershed Restoration Philosophy document (Chapin et al. 2005). Consistent with this philosophy, we have defined ecosystem restoration and management in the CRMW as

> "…*a strategy that attempts to repair the composition, structure, processes, and/or function of human-disturbed ecosystems. To the extent possible, we seek to maintain them as self-*

> *sustaining natural systems that are integrated with current ecological landscapes and land use and that eventually require minimal human intervention. In the short-term, we also seek to provide "bridging steps" – restoration actions that will provide ecosystem functions directly until natural processes become self-sustaining." (Chapin et al. 2005)*

Implicit in this definition is that we are using the concept "restoration" very generally since our program is constrained by SPU's purpose and function to supply drinking water. Depending on the particular situation in the watershed, restoration may vary from trying to redevelop conditions similar to those prior to human disturbance (activities that are consistent with the strictest definition of the term) to trying only to redevelop some degree of the functional capacity of some components of ecosystems. In addition, restoration approaches must be tempered by expected changes in regional climate that could influence the advisability or feasibility of trying to achieve particular forest conditions.

1.4.3 Riparian and Aquatic Restoration Strategic Plans

Given the dynamic interactions between upland forests and riparian and aquatic ecosystems, successful restoration requires tight collaboration and integration among restoration programs. While the link between upland and riparian systems are clear, the strongest link that has been identified between upland and aquatic systems is around depressional wetlands. In these special habitats, forest structure, including understory and down wood components, are especially important to amphibians. To ensure that plans are tightly linked and communication between project planning teams occurs in a timely manner, decisions requiring input from other plans are embedded directly into the decision criteria built into the prioritization screens.

1.4.4 Monitoring and Watershed Characterization

The Strategic Monitoring and Research Plan (Nickelson et al. 2008) summarizes the role of monitoring within the CRMW restoration program and describes the probable resources and time needed to complete the project monitoring commitments identified in the strategic plans. The specific elements of both the long-term and project monitoring efforts in upland forests are discussed in Sections 2.9 and 2.10 of this strategic plan. Both CRMW-wide and project-specific monitoring plans for upland forests will be prepared consistent with the Strategic Monitoring and Research Plan, which includes standards and guidelines developed by the Monitoring ID Team (MIDT).

The Watershed Characterization Plan addresses strategies for ensuring integrity of relevant data as well as maintaining information management systems for data critical to the implementation of the CRW-HCP commitments. Data necessary to implement the UFR Strategic Plan are discussed in detail in the Watershed Characterization Plan (Munro et al. 2007).

1.5 Asset Management Framework

Asset management is a priority in SPU's overall management strategy, and is defined by SPU as "the meeting of agreed customer and environmental service levels at the lowest life cycle costs." This plan sets the stage for implementing the Upland Forest Restoration Program within the strategic asset management context, by identifying service levels (e.g., restoration treatment goals), outlining the life cycle costs and benefits of accelerating the development of late successional forest conditions, providing a context for benchmarking with similar forest restoration programs, and outlining a monitoring plan to validate that project objectives are being reached and for instituting adaptive management.

1.5.1 Obtain the Greatest Ecological Benefits for the Financial Cost

The ecological and social values of forests in the CRMW drive their management under the CRW-HCP. Limited allocated funding for upland forest restoration, however, requires that WSD staff be concerned with project efficiency and cost effectiveness. While a standard economic cost/benefit analysis (where costs and benefits are expressed in dollars) is difficult to conduct for forest ecosystem restoration projects because it is hard to put dollar values to the different ecological benefits, the relative ecological benefit can be evaluated against project costs. Projects will be selected and prioritized among potential restoration sites based on criteria designed to achieve the greatest expected ecological benefit and/or the greatest learning potential (using criteria and methods described in Section 2.0 and 3.0). During individual project planning (see Section 4.0), various treatment options will be compared for expected ecological benefits (e.g., improvement in forest structure, tree growth, species composition, successional processes, and wildlife habitat quality). The treatment with the greatest predicted overall benefit for the least cost will, in most cases, be chosen. Treatments with highest benefits for greater costs, however, may be considered in order to mimic or facilitate natural disturbance conditions and the forest processes associated with them and to meet the overall goals of the CRW-HCP. Because precise outcomes of treatments are unknown, achieving expected ecological benefits has some degree of uncertainty. Managing risks in design and evaluation of treatments is essential, and monitoring will be critical for obtaining scientifically sound data on which to evaluate program success and implement adaptive management (see Sections 2.9 and 2.10, and Nickelson et al. 2007) by improving decision-making over time.

1.5.2 Service Levels

The CRW-HCP set minimum performance targets for restoration thinning, restoration planting, and ecological thinning. These targets were based on data that existed at the time of HCP development. The restoration thinning acreage target is approximately 10,500 acres through 2015, which will result in treating most of the young forest stands in the watershed. The restoration planting acreage target is approximately 1,000 acres through 2050, and the ecological thinning target is approximately 2,000 acres through 2050.

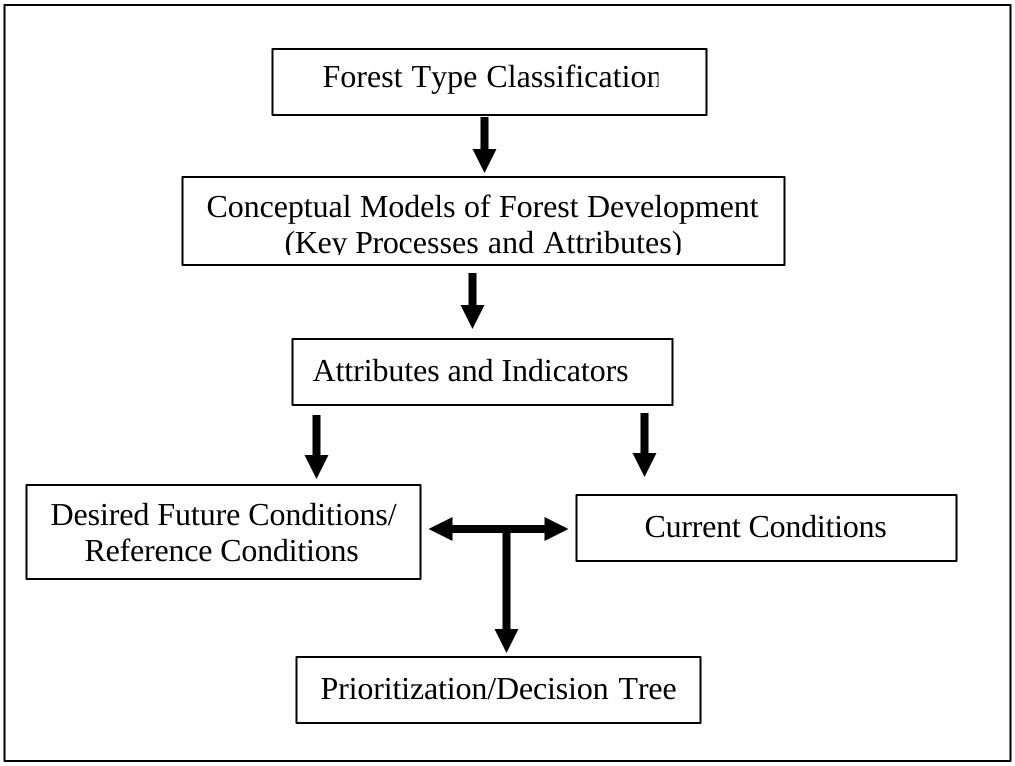
A 2,000-acre level of ecological thinning intervention over 50 years is unlikely to affect forest habitat on a scale appropriate for the restoration of old-growth forest dependent species on a metapopulation scale, particularly for those species that have home ranges in the thousands of acres (e.g., northern spotted owl, northern goshawk, pileated woodpecker [*Dryocopus pileatus*], fisher [*Martes pennanti*], and marten [*Martes americana*]) (Morrison et al. 1998, Smallwood 2001). Therefore, the emphasis on learning about restoration treatment effectiveness becomes more important. Based on the current forest conditions and potential value of restoration, SPU staff may recommend increasing the ecological thinning acreage levels during the course of the 50-year HCP. During the first 16 years of the HCP, the ecological thinning acreage level is an average of 62 acres per year, and that level drops to 24 acres per year for the remainder of the HCP. To date, staff have designed large, intensive ecological thinning projects that consist of diverse treatments at larger patch scales. It needs to be tested whether planning and implementation is more efficient in terms habitat functionality and cost per acre on large, intensive projects or smaller, more extensive projects (e.g, smaller treatment areas within larger untreated areas). Regardless of the project size or acres treated, the net implementation costs cannot exceed the annual budget. The questions regarding the appropriate level of ecological thinning and the spatial application of those treatments to meet wildlife habitat objectives will be addressed as "next steps" to this strategic plan.

2.0 STRATEGIC FRAMEWORK FOR UPLAND FOREST ECOSYSTEM CONSERVATION AND RESTORATION

This section of the strategic plan describes the framework of our understanding of forest ecosystems in the CRMW and sets the stage for applying prioritization criteria and implementing restoration work. We provide information on forest ecosystem classification (Section 2.1) to define the ecosystem targets of this strategic plan. We describe a conceptual model for forest restoration (Section 2.2) that connects ecosystem functions (Section 2.3) and processes (Section 2.4) with structural conditions. From the conceptual model, we identify key attributes and indicators used to describe desired future conditions (DFCs) (Section 2.5) and provide a basis for comparing restoration objectives and results in the long-term. In Section 2.6, we describe how the history of human activity has created current forest conditions, while Section 2.7 describes current conditions, desired future conditions, and the relevant datasets that we use to describe them. Restoration treatments and their rationale, based on the conceptual models, are presented in Section 2.8. We identify key uncertainties and threats to the ability to reach our restoration goals (Section 2.9), how we might address those uncertainties, and how we propose to incorporate adaptive management (Section 2.10) as an integral part of our restoration efforts.

This section of the UFR Strategic Plan draws from The Nature Conservancy's "Measures of Success" framework (Parrish et al. 2003). The model for determining a need for restoration (Figure 2.1) is superseded by the landscape context and restoration synergy outlined in the Synthesis Framework for the Cedar River Watershed Habitat Conservation Plan (Erckmann et al. 2008). In our model application, the ecosystem targets are defined by the forest vegetation types in the CRMW. Key processes and attributes of those ecosystem targets are then described, including potential vulnerabilities and threats to these targets. The specific measurable attributes and indicators of these targets are defined. The indicators of current forest conditions are compared between the DFCs (otherwise called benchmarks or reference conditions) to determine whether restoration actions may be necessary to set the existing forest ecosystem on a trajectory towards the desired benchmark. The degree of difference between current conditions and DFCs then feeds into the prioritization model (Section 3.0) for either enabling passive restoration through protection efforts or designing and implementing active restoration.

Figure 2.1: Measures of Success Framework and the Relationship of Sections 2 and 3.



2.1 Upland Forest Ecosystem Classification

The forest ecosystem types in the CRMW are classified in order to define the ecosystem targets and specific ecological process that may be subject to restoration efforts. Forest vegetation models and existing CRMW data inform this classification. Influenced by environmental gradients (e.g., for elevation, temperature, and precipitation), forest ecosystem types vary primarily in species composition, which in turn affects the successional processes and the structure and function of the forest types.

2.1.1 Potential Natural Vegetation Model

Forests in the CRMW can be classified in zones of potential natural vegetation by dominant tree species and plant association of late successional stages (Franklin and Dyrness 1973). The three forest zones identified in the CRMW are the *Tsuga heterophylla* (western hemlock) zone, the *Abies amabilis* (Pacific silver fir) zone, and the *Tsuga mertensiana* (mountain hemlock) zone (Figure 2.2). Numerous plant associations can be described within each of these zones based on understory species composition, which is thought to change along a moisture, soil, and temperature gradient (Henderson et al. 1992). Plant associations (PAs) are community assemblages that change over time through physiological and ecological processes and can be defined by the shifting abundance of indicator species within forest zones. However, temporal changes in resource distribution and abiotic conditions during succession may influence species abundance and may complicate determination of PAs.

An analysis of recently collected vegetation data on permanent sample plots in the CRMW (PSPs) (Tear 2006) showed that forest vegetation zones identified by Franklin and Dyrness (1973) can be identified in the CRMW based on dominant tree species, elevation, and site index. The forest types below are based on existing vegetation models and corroborated by our own PSP data. The pathways of ecological succession are assumed to differ between forest zones and plant association groups because species-specific growth responses depend on site conditions as well as disturbance regimes. Specific forest development and environmental information included in the following section is drawn from Henderson et al. (1992).

2.1.2 Forest Ecosystem Types, Defining Conditions, and Processes

Specific environmental conditions (e.g., aspect and site class) affect the boundaries between forest zones, but the elevation classes shown in Table 2.1 generally represent the western hemlock zone (<2,800 feet), the Pacific silver fir zone (2,800 to 4,000 feet), and the mountain hemlock zone (>4,000 feet). Forest restoration projects are not currently planned for the mountain hemlock zone, because little timber harvest has occurred in that zone.

Table 2.1. Forest vegetation zones of the CRMW

Forest Vegetation Zone	Area of CRMW	Elevation Zone
Western Hemlock Zone	48,746 acres	Below 2,800 feet
Pacific Silver Fir Zone	35,212 acres	2,800 – 4,000 feet
Mountain Hemlock Zone	6,570 acres	Above 4,000 feet

Western Hemlock Zone

The western hemlock zone covers approximately 50% of the CRMW. It occupies the elevations below 2,800 feet elevation, at which elevation it is replaced by the silver fir zone. Productivity in the western hemlock zone varies as a function of soil type and water availability. Douglas-fir (*Pseudotsuga menziesii*) and western hemlock are the dominant tree species in this forest zone. Douglas-fir occurs as a long-lived seral species, except on the wettest sites where western hemlock and red alder (*Alnus rubra*) are more competitive. Western hemlock and western redcedar (*Thuja plicata*) dominate later seral stages, or occur as shade tolerant components of the understory. Many other deciduous and conifer species are associated with this forest zone and occur locally with varying dominance. Root diseases (e.g. *Heterobasidion annosum, Phellinus weirii, Armillaria melea*) are generally present in most stands and create canopy gaps. This forest type experiences few serious insect disturbances. Among the more prevalent species are Douglas-fir beetle (*Dendroctonus pseudotsugae)* and hemlock looper (*Lambdina fiscellaris lugubrosa*).

Many Douglas-fir dominated forests in the western hemlock zone were established after logging and fire in the CRMW and are now between 60 and 100 years old. Due to logging and, to a much lesser extent, fire history, most stands lack residual snags and down logs. These forests grow mostly on soils of glacial deposits (lower Cedar River and Chester Morse Lake moraine) and colluvial material from igneous bedrock material (lower Taylor River, upper Cedar River, and areas north of Lower Cedar River). Natural regeneration on disturbed sites was usually dominated by Douglas-fir, and tree stem density was typically very high at stand initiation. The duration of the competitive exclusion phase (see Section 2.4.1) is a function of site class and disturbance regime (e.g., root rot or wind). Some of the most productive forests in the watershed (e.g., Lower Taylor Basin) occur in this forest type, and such forests react readily to thinning with diameter growth response and regeneration of western hemlock. Stands growing on outwash gravel, however, have some of the lowest growth potential in this type, show little response to thinning, and develop understories that are dominated by salal (*Gaultheria shallon*). Few stands on this soil type, outside of riparian areas, are composed of balanced mixtures of deciduous and conifer tree species, with conifers highly dominant in most areas.

Mixed western hemlock/Douglas-fir forests in the western hemlock zone occur mainly on sites between 2,000 and 2,800 feet elevation. Many of these forests also originated as natural regeneration after logging and fire and developed high stem densities. While Douglas-fir often grows in dominant canopy positions in this type, hemlock usually dominates the stands by abundance. Stands of this type usually have higher densities due to the greater shade tolerance of western hemlock and often cause the exclusion of the shrub and herb strata from the forest.

Pacific Silver Fir Zone
Forests between 2,800 and 4,000 feet elevation are in the Pacific silver fir zone, which covers approximately 40% of the watershed. In contrast to lower elevation western hemlock forests, this type is characterized by a prolonged snow cover and lower temperatures. Site productivity in this zone is moderate to low and is limited by temperature and soil water capacity. Fog drip can be an important contributor to yearly precipitation in this zone (Harr 1982, Tom Hinckley pers. comm.). The cooler soils in this zone combined with densely regenerating stands often create thick organic layers and well developed organic soil horizons and spodosols. Western hemlock and silver fir dominate stands in this zone, although Douglas-fir and noble fir (*Abies procera*) occur on dryer sites, and western redcedar and Alaska yellow cedar (*Chamaecyparis nootkatensis*) occur on wetter and cooler sites.

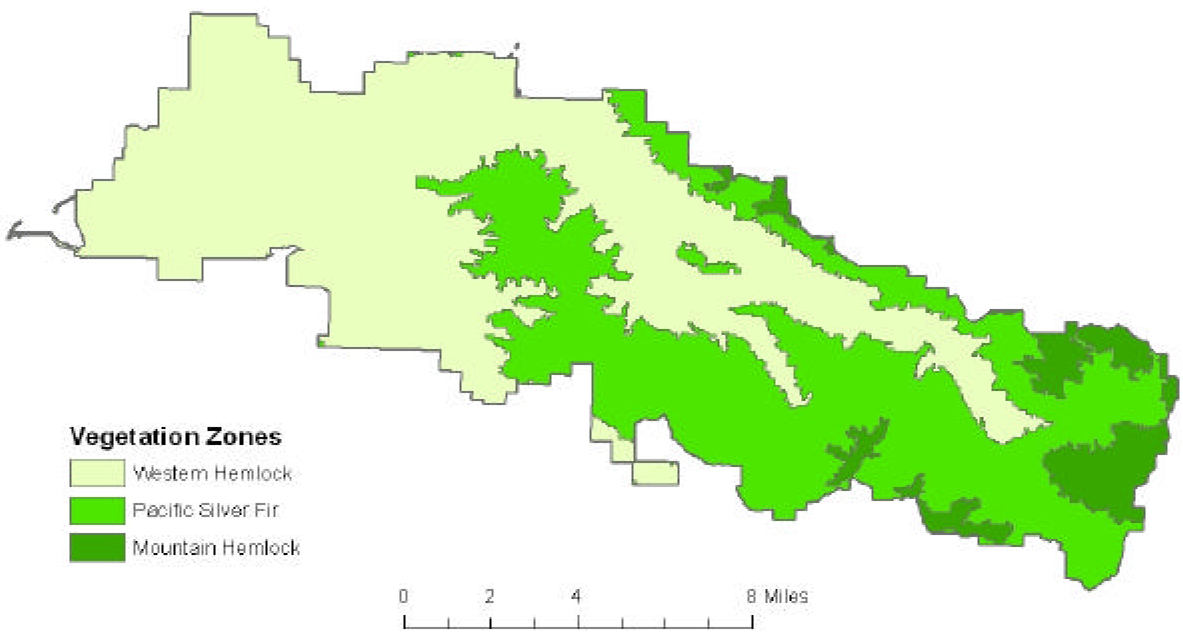
Western hemlock dominated stands occur at lower elevations (2,800 to 3,500 feet) in the Pacific silver fir zone where advanced regeneration of silver fir rarely contributes to early community composition. Natural stands of this type often regenerate after fire and typically go through a phase in early stand development with very high stem density, no understory vegetation, and heavy organic soil layers. Silvicultural manipulation of these stands is problematic if individual tree stability is low due to extreme height to diameter relationships resulting from high density and intense competition. Regionally, there is little experience with thinning in this forest type beyond pre-commercial or restoration thinning (i.e., thinning young stands).

Mixed true fir/western hemlock stands in the Pacific silver fir zone occur generally above 3,500 feet elevation. Sixty-seven percent of the remaining old-growth stands in the CRMW occur in this forest type, and most of these were regenerated after fire. Younger stands present in the CRMW now regenerated after clear cutting, with a result that many stands have a residual component of advanced regeneration silver fir. Fire plays an infrequent, stand replacing role as a disturbance agent in this forest type (Agee 1993), while gap processes initiated by wind disturbance play a major role in community development. Stands that originated under homogeneous establishment conditions often go through extended phases of high stem density and competitive exclusion. Understory vegetation can be very limited due to dense canopy cover and snowpack duration.

Mountain Hemlock Zone

Mixed species stands in the mountain hemlock zone make up about 10% of the forests in the CRMW. These forests are among the least productive due to snowpack depth and duration, which yield very short growing seasons for understory plants and restricted tree growth. Productivity is usually not limited by soil moisture, but by soil temperature. This zone supports well developed spodosols due to higher precipitation and greater stand age and stability (lower fire frequency). Stands are dominated by silver fir, mountain hemlock and Alaska yellow cedar. *Vaccininum alaskaense*, *V. ovalifolium*, *V. membranaceum*, and *Rhododendron albiflorum* are typical shrub associates in this type and often occur with high cover in regenerating stands (Henderson et al. 1992). Most forests in this zone grow in wind-exposed sites and experience small scale gap phase replacement of shade tolerant species at later seral stages. Low fire frequency and root pathogens contribute to the stability of this forest community over centuries.

Figure 2.2: Map of vegetation zones



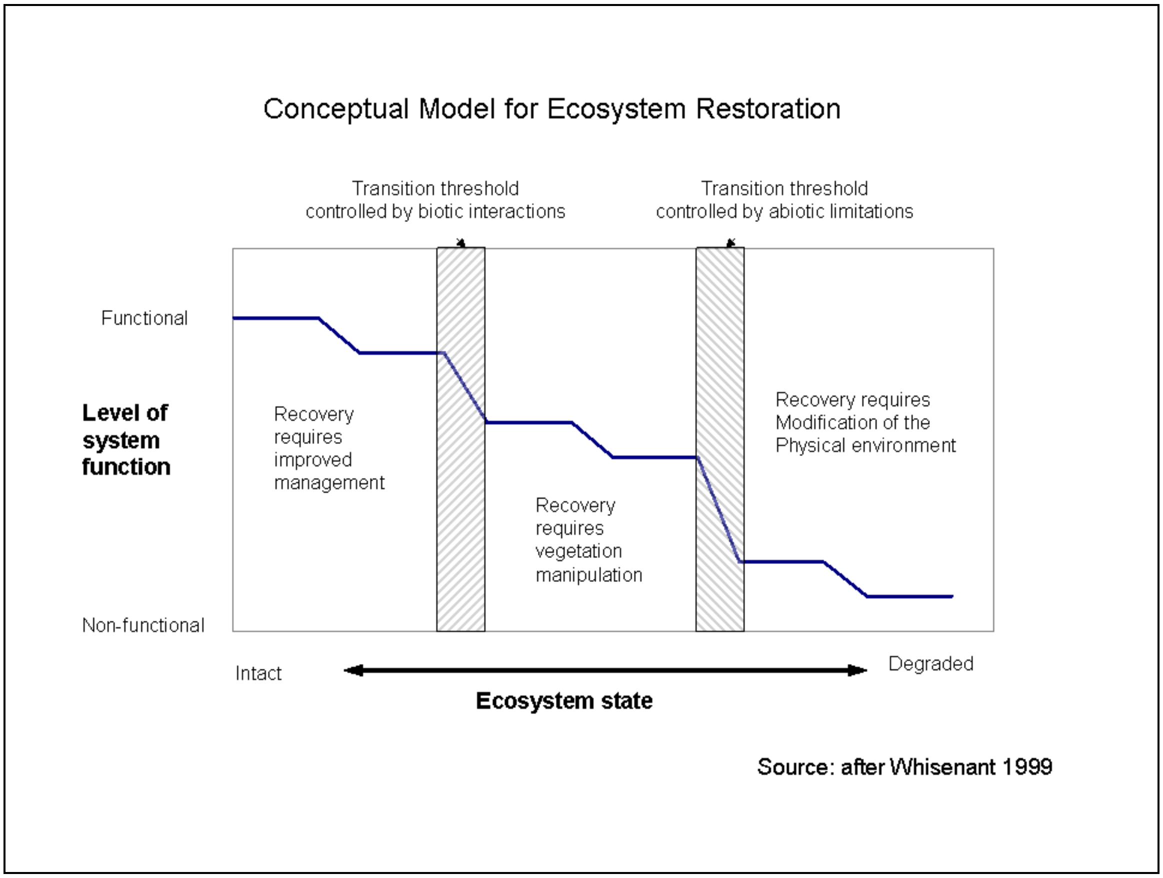
2.2 Conceptual Model of Forest Ecosystem Restoration

We present here a conceptual model of ecosystem development and restoration that can be used to derive measurable objectives for restoration treatments from value driven goals of the Habitat Conservation Plan. The model is based on existing ecosystem restoration models (Whisenant 1999) and is refined here for application to forest ecosystems. It may not apply to every aspect of forest restoration equally well, but its main element of identifying ecosystem processes that become the focus of restoration treatments is equally applicable.

This model presumes that forest ecosystems exist within a wide range of stages defined by structural and compositional attributes, some of which may constitute semi-stable states where successional and structural changes are relatively slow (Hobbs and Norton 2004). While similar stages may have the same level of ecosystem functions (e.g. habitat niches, biodiversity, element cycle regulation), other stages have higher or lower levels of functionality and can be distinguished based on various ecosystem functions. For example, the establishment phase in forest development after stand replacement disturbance has high levels of biodiversity compared to subsequent stages. However, other functions such as water cycle regulation or late-successional habitat are at low levels of functionality in this stage. Aiding a degraded system in restoring ecosystem functions is the basis for ecosystem restoration, and insofar restoring habitat functions and biodiversity of forests is the goal of the HCP. Active restoration is applied where a continual increase in functionality is impeded by developmental thresholds that resist the transition of the forest into stages of higher functionality. Two primary types of thresholds exist: those caused by the abiotic environment and those controlled by biotic interactions. Climate, substrate, and topography are examples of abiotic limitations. Biotic interactions that may present thresholds include competition, trophic interactions, dispersal, mutualism, disturbance, species interactions, and biological legacy. It is important to note that late-successional forest may not have the highest levels of every ecosystem functions (following de Groot et al. 2002), but that they are the predominant goal of the HCP restoration activities.

A stepwise relationship between ecosystem state and level of ecosystem function provides a conceptual model for ecosystem restoration (Figure 2.3, after Whisenant 1999). In terms of structural development, ecosystem states are analogous to structural development stages following Oliver and Larson (1996) and Franklin et al. (2002). Stable sections in ecosystem functional development can then be described as a range of ecosystem conditions with similar functionality; these states and their associated levels of function are used to define restoration benchmarks. For example, the establishment phase of forest development would have low forest habitat functionality, while later stages of development have greater functionality due to tree growth and diversification. The steep sections of the relationships may be defined as thresholds indicating an increase in ecosystem function associated with change of ecosystem state. Such state transitions are often caused by disturbances but can also occur in a very gradual manner (Frelich and Reich 1999). An example for a disturbance mediated transition would be understory development after a gap forming disturbance such as root pathogens or wind. A more gradual change in forest conditions would be the building of an organic soil horizon and the associated increase in soil microbial activity. Abiotic limitations and biotic interactions can cause thresholds in ecosystems transitioning from one state to another with higher ecosystem function. Abiotic thresholds usually act at lower levels of ecosystem function than biotic thresholds. For example, abiotic limitations such as soil development must be recognized or addressed before biotic interactions such as species establishment can be altered through planting to move from a lower functioning to a higher functioning ecosystem state.

Figure 2.3: Conceptual model of transition between ecosystem states with different levels of functionality (after Whisenant 1999). Environmental and biotic factors that create thresholds to transition towards a more functional state become target of restoration activities.



Examinations of forest structure alone will not enable a complete identification of the abiotic limitations or biotic interactions that may delay forest development towards ecosystem states with greater habitat function. Ecosystem conditions and processes must both be understood to fully evaluate which factors resist gradual or abrupt transition to other stages. These resistance factors may include: (a) environmental filters that regulate species assemblages (e.g. cold temperatures that limit the establishment of species to a certain elevation range); (b) biotic processes that regulate species interactions (e.g. intra-species competition, differentiation, and mortality that impede structural development); and (c) species-environment interactions that facilitate or inhibit the development of certain forest structures (e.g. small scale disturbance or lack thereof that creates a patchy forest). The combination of filters, processes, and interactions will determine the resistance to transition at a given site and will indicate appropriate restoration actions that may be taken to pass over the threshold in order to development elements of late-successional forests in younger forests. Most restoration actions will focus on modification of abiotic limitations (amelioration of planting sites), modification of biotic interactions (reducing competitors), or changing susceptibility to disturbance agents (wounding trees). We define the structures and functions of different forest ecosystem states by using attributes and their measurable indicators (Table 2.2). For example, an attribute for developmental stages of late-sucessional habitat are standing dead trees. The occurrence of large living and dead trees >40 inches DBH is an indicator of late successional forest conditions. Because many forest ecosystem functions are poorly understood or difficult to measure, forest structure often becomes a surrogate for function.

In any given case, the restoration to a historical reference state, if desired, might be impossible due to changing environmental conditions, such as climate change. Currently existing old-growth forests which are used as reference for late successional forest conditions (e.g. Franklin and Spies 1991) initiated and have developed under different climatic and environments conditions compared with recently established second growth forests. The dynamic nature of resistance factors makes it highly unlikely that the exact structure and composition of a desired reference state will be recreated, either with passive or active restoration. Because of altered establishment conditions (e.g. seed source, fire, advanced regeneration), it may be impossible to re-establish a comparable species composition in a young forest as existed in the preceding primary forest. Furthermore, given that this prior condition was a result of environmental conditions at stand initiation, and given that climate change is expected to be altering future environmental conditions (Lucier et al. 2006), trying to recreate forest conditions that were present centuries ago may not even be advisable. However, information on forest structure and composition, as found in historic County Cruise Records, does provide us with an example of forest density and species composition of an assemblage that has evolved over a long period of time (300-500 years) and gives insight into distribution of species over the landscape and heterogeneity at that scale.

It is possible that a range of plant species assemblages may have the same ecological functionality and that restoration goals can be achieved without establishment of a particular species combination. For example, a large western hemlock tree with a broken top may provide as functional a nesting site for certain avian species as a large western redcedar tree with a broken top. However, some functions may not be achieved to the same extent with altered species composition, such as the high value of western redcedar trees for foraging and cavity nesting species (more detailed examples of how biodiversity can affect ecosystem function is given in Section 2.3.2). Given the complexity of forest ecosystems and their ever changing nature, there is inherent uncertainty whether the same functions are achieved with similar, but not identical, structural conditions.

While some exogenous processes (e.g., small scale disturbance) may facilitate rapid threshold transition, most endogenous processes (e.g., biomass accumulation) cause rather gradual ecosystem transition (Frelich and Reich 1999). For example, a Douglas-fir forest may undergo forest stand dynamics (Section 2.4.1) driven by endgenous processes of intra-species competition, differentiation, mortality, and crown elongation and expansion, without the influence of exogenous disturbance. Interaction with wind during these stages of development can cause reduction of canopy density and initiation of understory layers, thus driving structural development at a greater rate. Contrary to that, resistance factors may lead to establishment or perpetuation of alternate ecosystem states, some with comparable function and structure, others with limited values. For example, a mature Pacific silver fir forest may be dominated by a dense silver fir understory, resulting in stand dynamics that rarely increase the forest ecosystem function of increased biodiversity; the forest remains in a "steady state" until a large scale disturbance occurs (Lertzman 1992). Factors that affect state transitions, such as pathogen disturbance, can set the system either forward in development, move it back in development, or perpetuate a particular state in development with little functional change. Further, depending on susceptibility of the ecosystem component (e.g. species, plant class [shrubs, herbs, trees], canopy layer, etc.), the same disturbance agent can have very different affects on system state transitions; pathogens, fire, insects, or physical damage will affect different tree species or forest structural states in unique ways.

2.3 Ecosystem Functions

Our forest restoration program aims to improve three general functions provided by the forest ecosystems: habitat, biological diversity, and regulation of water, nutrient and carbon cycles (de Groot et al. 2002). These three functional goals are mandated in the CRW-HCP, more specifically by: (1) providing habitat for species that depend on late-successional forest, (2) facilitating the development of biological diversity, and (3) regulating the water cycle as it affects instream habitat. These primary ecosystem functions are described in more detail in the sub-sections below and are outlined in Table 2.2.

Since there are knowledge gaps regarding specific relationships among ecosystem components and the functions that arise from them, it is usually difficult and impractical to measure the primary relationships and resultant functions. Therefore, we use measurable attributes as surrogates to denote certain ecosystem functions. We assume that certain structures and the processes that create them signify that certain functions are occurring in the ecosystem (after Franklin et al. 2002). These attributes and their associated indicators provide a means to define current and benchmark conditions, however, not all of which are available from inventory and monitoring plots or remotely sensed data. Some attributes will be derived from correlation with other indicators, for example foliage distribution, others are currently not measured, including siol, detritivores, or trophic cascades. We introduce specific attributes and indicators in Table 2.2 and refer to them in the remainder of this strategic plan.

2.3.1 Forest Ecosystem Structure and Wildlife Habitat

Approximately 84 percent of the forests in the CRMW were logged and are in early- to mid-successional stages, where much of the habitat complexity and functionality characteristic of late-successional forest (LSF) is lacking (Hunter 2001, Muir et al. 2002). Consistent with the current condition of the watershed forests, there has been only one documented northern spotted nest in the CRMW in the last 15 years, along with one northern goshawk nest and two occupied marbled murrelet sites. A comprehensive northern spotted owl survey in 2005 detected no spotted owls in the watershed. The theoretical carrying capacity of the CRMW with fully restored LSF would be 14 pairs of spotted owls, 15 pairs of goshawks, and an unknown number of murrelets, though certainly more than two pairs. Old-growth forests have been shown to support a larger number of wildlife species and more individuals within a species than young

Table 2.2: Key ecological functions of upland forests in the CRMW and their attributes and indicators.

Ecological Function	Attributes	Indicators
Late Successional Forest (LSF) Habitat	Large live trees	Species, density, diameter, height
	Large dead standing trees	Species, density, diameter, height, decay class
	Large coarse woody debris (logs)	Species, density, volume, decay class
	Tree canopy	Depth, layers, branch size, reiterations
	Foliage distribution	Vertical distribution, density, species
	Horizontal structure	Patch size, structure, and distribution
Biodiversity	Species assemblage: vascular and non-vascular species, fungi	Species, abundance, distribution, interaction, invasive non-natives
	Animal species	Species, abundance, distribution, interaction
	Food webs	Species assemblage
Water cycle regulation	Vegetation	Canopy structure and composition, interception rate, transpiration rate
	Soil	Structure, depth, organic content, water capacity, infiltration rate
Nutrient cycle regulation	Vegetation	Species, productivity
	Edaphic community	Species, productivity, symbiosis, redundancy
Carbon cycling	Primary producers	Species, productivity
	Trophic cascade	Depth, width, redundancy
	Detritivores	Species, density, productivity

plantation forests (Aubry 1997, Erickson 1997, Manuwal and Pearson 1997, West 1997). This is primarily due to the complexity of the forest structure, including a large amount of standing and downed dead wood, a heterogeneous canopy, and high plant and fungal species diversity. Together these structural and biological attributes provide numerous habitat niches that support a diverse array of wildlife species.

In addition to the obvious benefits of restoring habitat for wildlife species dependent on late-seral forest conditions, restoration of a complex forest structure and plant species diversity in previously logged stands can simultaneously provide increased ecological functionality and improved wildlife habitat for species of concern in the near to mid-term. Standard commercial thinning (i.e., removing only suppressed trees from the lower and intermediate crown classes by “thinning from below”, resulting in even spacing of trees and generally favoring one tree species, Smith 1997) has been shown to benefit many wildlife species, including bats, several small mammals, amphibians, and many bird species (Aubry et al. 1997, Aubry 2000, Erickson 1997, Manuwal and Pearson 1997, Haveri and Carey 2000, Hagar et al. 1996, Hayes and Larson 2001, Suzuki and Hayes 2003). Variable density thinning, which creates variable spacing between trees and retains deciduous species, logs, and snags has resulted in even greater wildlife benefits than standard commercial thinning (Carey and Wilson 2001).

Given the difficulty of developing information on the spatial distribution of complex habitat structures, Johnson and O'Neil (2001) developed a forest habitat classification for Washington and Oregon based on three relatively simple forest structural attributes, independent of forest zone or elevation: tree diameter (DBH), tree canopy cover, and tree canopy layers (Table 2.3). The classes represent early successional forest occurring after relatively large-scale disturbance (e.g., forest fire, clearcut timber harvest) through late-successional/old-growth forest. Wildlife species have also been associated with each of the forest classes (Appendix F). Although most species also require special habitat elements (e.g., large snags, downed wood), this general approach allows the identification of potential habitat for all species likely to occur in the CRMW, given a landscape-scale delineation of forests based on the three attributes.

2.3.2 Biodiversity

Biodiversity is a term that has a variety of meanings, and numerous definitions of the word have been put forth. A good example of a broad definition of biodiversity is that developed by the Keystone Dialogue on Biological Diversity on Federal Lands (Keystone Center 1991 as cited in Noss and Cooperrider 1994):

> *Biodiversity is the variety of life and its processes. It includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, yet ever changing and adapting.*

High biodiversity results in a functioning and resilient system. For example, species diversity can result in functional redundancies, where different species can play similar roles if one is lost due to disturbance or environmental change. Because it has been shown that many plant functions such as seed dispersal or nutrient uptake are dependent upon small mammals, birds, or fungi, a high diversity of these species supports high plant diversity. The presence of a diversity of species sustains the resilience (Peterson et el. 1998) of the forest ecosystem. In some situations, the presence of high species richness has been shown (Pokorny et al. 2005, Martin et al. 2008) to deter invasion by non-native species. Having species that respond differently to environmental change or stress is important. For example, a wildfire will often have less detrimental effects on a forest community composed of species with different life history traits. Trees with thick bark are more likely to survive a ground fire, while others may be capable of sprouting and regenerating after being top-killed. An ecosystem with a diversity of species is also going to be more capable (Peterson et al. 1998) of maintaining its functions while responding to changes in climate.

Plant species diversity contributes to ecosystem function and is an integral component of LSF. Understory vegetation (herbs, shrubs, and trees), deciduous trees, and canopy epiphytes (lichens,

Table 2.3: Forest habitat structural classification (Johnson and O'Neil 2001).

#	Forest Class Name	Tree DBH (")	Tree Canopy Cover (%)	Tree Canopy Layers	Comments
1	Grass/Forb – Open	NA	<10	NA	<70% coverage by grasses/forbs
2	Grass/Forb – Closed	NA	<10	NA	>70% coverage by grasses/forbs
3	Shrub/Seedling – Open	<1	<70	1	
4	Shrub/Seedling – Closed	<1	>70	1	
5	Sapling/Pole - Open	1-9	10-39	1	
6	Sapling/Pole - Moderate	1-9	40-69	1	
7	Sapling/Pole - Closed	1-9	>70	1	
8	Small Tree - Single Story - Open	10-14	10-39	1	
9	Small Tree - Single Story - Moderate	10-14	40-69	1	
10	Small Tree - Single Story - Closed	10-14	>70	1	
11	Medium Tree - Single Story - Open	15-19	10-39	1	
12	Medium Tree - Single Story - Moderate	15-19	40-69	1	
13	Medium Tree - Single Story - Closed	15-19	>70	1	
14	Large Tree - Single Story - Open	20-29	10-39	1	
15	Large Tree - Single Story - Moderate	20-29	40-69	1	
16	Large Tree - Single Story - Closed	20-29	>70	1	
17	Small Tree - Multi-story - Open	10-14	10-39	≥2	
18	Small Tree - Multi-story - Moderate	10-14	40-69	≥2	
19	Small Tree - Multi-story - Closed	10-14	>70	≥2	
20	Medium Tree - Multi-story - Open	15-19	10-39	≥2	
21	Medium Tree - Multi-story - Moderate	15-19	40-69	≥2	
22	Medium Tree - Multi-story - Closed	15-19	>70	≥2	
23	Large Tree - Multi-story - Open	20-29	10-39	≥2	
24	Large Tree - Multi-story - Moderate	20-29	40-69	≥2	
25	Large Tree - Multi-story - Closed	20-29	>70	≥2	
26	Giant Tree - Multi-story	≥30	>40	≥2	<40% canopy cover classified as #23

bryophytes, and mistletoe) provide wildlife forage and habitat, contribute to nutrient cycling and forest hydrology, and determine the future species composition of the forest. Insects, forest pathogens (typically fungi), and mistletoe play roles in the mortality of overstory trees, creating gaps in which understory dynamics can continue. Overstory structure is an important factor in determining the diversity and density of plant species in the forest (Halpern and Spies 1995, Thysell and Carey 2001, Peterson and McCune 2003, Lyons et al. 2000). However, we are learning that propagule or seed source availability is an equally important factor, especially in forested landscape impacted by widespread timber harvest (Halpern et al. 1999, Sillett et al. 2000).

2.3.3 Water Cycle Regulation

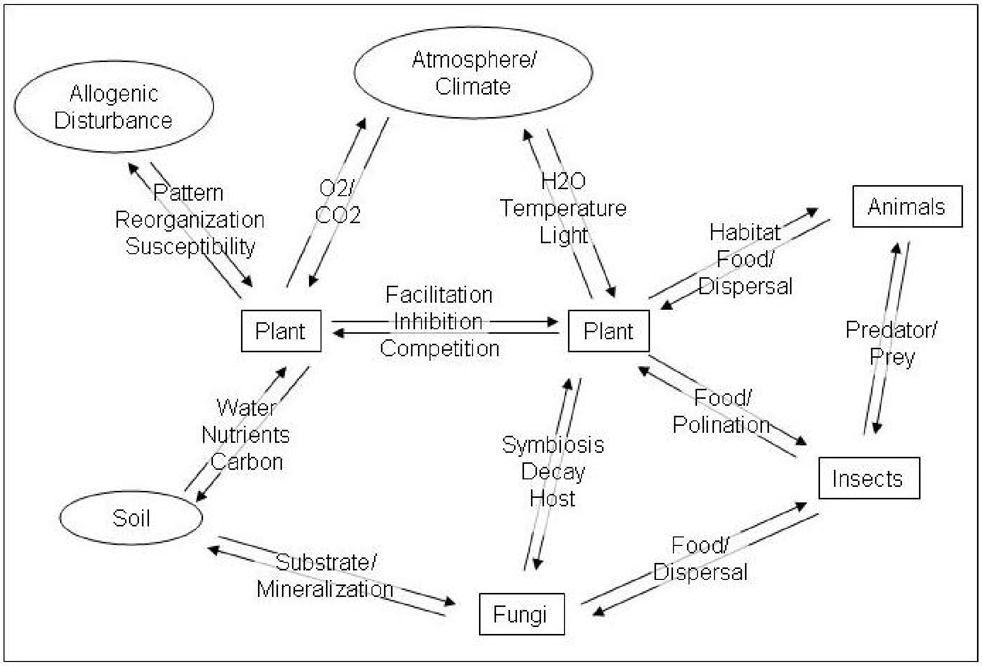
Forests have measurable effects on regulation of the water cycle and comprise an important element in the water supply of the CRMW. Forest canopies affect precipitation rates through cloud harvesting (Harr 1982), reduce water yield through transpiration and interception, and change infiltration rates and stream flow regimes (Zhang et al. 1999). Biomass accumulation in and on the forest floor increases the water holding capacity of the soil, while canopy shading can lower snow melt and change stream flow regimes (Berris and Harr 1987). Given the size, topography, and climate of the CRMW, snow has an important storage function for the water supply and complex forest canopies can decrease melting rates and affect storage capacity and peak flow regulation.

While the overall water yield from land without forest cover on the western slope of the Cascades is only slightly higher than from mature forest, studies have shown that annual yield from young forests is temporarily reduced during periods of peak stem densities (Ingwersen 1985). Similar effects can be shown with regard to spring peak flow and baseline flows during the summer (Perry 2007). Mature forests appear to have an ameliorating effect on stream flow regimes through increased soil biomass and shading, whereas large open areas can exacerbates rain-on-snow events. The rough canopy of mature forest has been shown to increase precipitation yield through condensation of cold moisture on foliage and trees in areas where clouds form through orographic advection (Harr 1982). These factors make mature forest cover with complex canopy structures the preferred land cover for the regulation of the water cycle in the CRMW.

2.4 Key Ecological Processes

Due to the dynamic nature of forests, we expect currently simplified forest structures to evolve over time, become more complex, and eventually provide suitable habitat for species associated with late successional forest structures. As outlined in Section 2.3, mature forest structures provide greater ecosystem functions with respect to habitat, biodiversity, and water regulation. With passive restoration alone, the forest conditions will improve over time as succession and localized disturbances occur. But this may take tens or even hundreds of years. Through active restoration, we attempt to improve wildlife habitat in the short term, while facilitating forest structural development toward conditions exhibited by mature forests by changing developmental processes, such as tree growth and mortality. We effect these changes in prioritized portions of the CRMW (see Section 3) by manipulating the existing forest structure and composition. These interventions are guided by theories of forest ecology and forest stand dynamics as well as by existing target and benchmark structures (Sections 2.5 and 2.7). This section describes two key natural processes, succession and disturbance, that govern forest ecosystem dynamics and state transitions, and their relationship to restoration management. Other ecosystem processes that are important for developing restoration objectives are summarized in Figure 2.4.

Figure 2.4: Generalized conceptual model of interaction between ecosystem processes (arrows) and ecosystem components (boxes and ovals).



2.4.1 States of Ecosystem Development

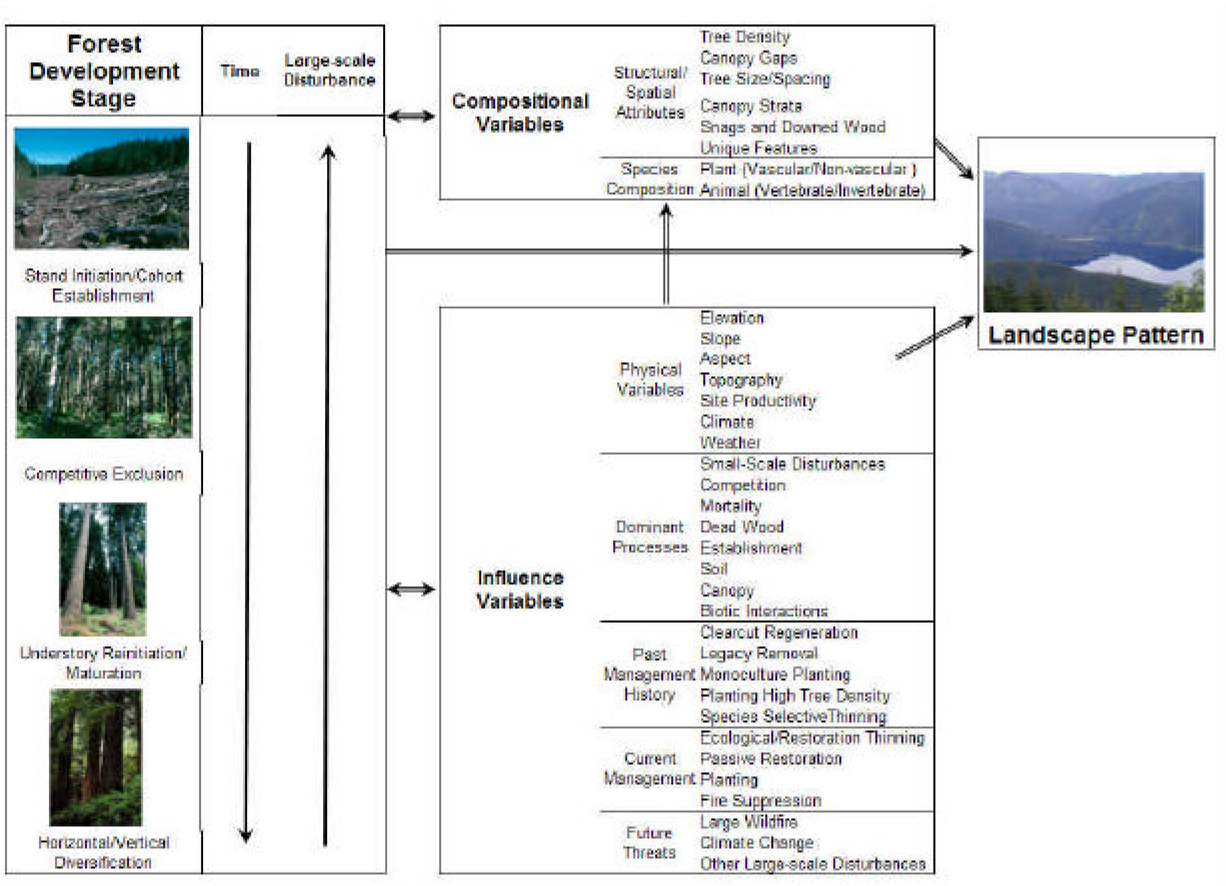
The theory of vegetation dynamics assumes multiple pathways for a given ecosystem, depending on physiological variables and disturbances (Picket et al. 1987). It is generally thought that a linear successional model does not explain observations on processes and dynamics in most forest ecosystems. The non-equilibrium paradigm of ecosystem development recognizes the dynamic interaction of biological assemblages with the abiotic environment and disturbances, causing alterations in the composition and assemblages and the spatial patterns of the environment. Predictable endpoints to the successional process following disturbance are rare, multiple stable states exist, and some quasi-stable states can persist for long periods (Fiedler et al. 1997, Hobbs and Norton 2004, Pickett and White 1985, Noble and Slatyer 1980). Thus, a predictable sequence of development towards a stable old-growth forest is unlikely. Spatial and temporal variability of vegetation dynamics creates patchiness that is important for ecological processes and fluxes of material and organisms within and between different parts of the landscape (Levin 1992) as well as creating landscape level ecosystem resilience.

Changes in forest structure after major disturbances (stand replacing) are referred to as stand dynamics, of which generally applicable stages have been distinguished. The stand development model proposed by Oliver (1981) can be used to explain many of the existing forest structures in the CRMW and provides a coarse template of forest stand dynamics. The development from a single cohort stand to a multi-cohort old forest is divided into four distinct developmental stages (defined and discussed below): stand initiation, competitive exclusion, understory reinitiation, and old-growth stage. The model generally agrees with other models of forest deve lopment (Bormann and Likens 1994), but can be augmented to incorporate greater resolution in structural dynamics in mature forests such as vertical and horizontal diversification as described for

Douglas-fir forests (Franklin et al. 2002). Attention to greater resolution in those stages is warranted for habitat restoration, as forest attributes such as vertical foliage distribution and spatial mosaics of structural conditions determine habitat values for species dependent on late successional conditions.

Vegetation dynamics models use structural attributes to separate developmental stages and are based on attributes such as growing space distribution, tree size, and vertical and horizontal structure (Kimmins 1997, Oliver and Larson 1996). For the purpose of forest habitat restoration, we can define patterns of vegetation development that are expected to occur, given site conditions and land use history, and provide guidance for management interventions. In this section, we define stages of succession and provide attributes and indicators for structural conditions and vegetation composition. Figure 2.5 provides an overview of forest developmental stages of forest development, attributes that provide habitat function, and influence variables (abiotic and biotic filters) that affect vegetation dynamics and may cause resistance to transition into stages of higher ecosystem function.

Figure 2.5: Conceptual model of forest development stages, compositional variables, and influence variables.



Stand Initiation

The establishment of a new cohort of trees following a stand-replacing disturbance is defined as the *stand initiation stage*. This stage is controlled by the availability of resources (including propagules) and initial environmental conditions, is characterized by relatively high plant species diversity, and ends when all growing space is occupied by trees (i.e., canopy closure). The composition of subsequent stages is determined by available seed sources and propagules, environmental conditions, competition, and herbivory. Residual structures such as dead wood, live tress, and microbial communities of the previous forest have a strong effect on establishment conditions (e.g., can result in patchy regeneration) and community composition (e.g., as a result of sprouts and seedbanks), as does active reforestation (e.g., planted species, herbicides and/or fire). The forest stand reaches its highest stem densities at this stage while tree mortality is predominantly caused by adverse environmental conditions. Trees finally overtop herbs and shrubs, and lateral crown growth closes the tree canopy.

The length of the establishment period depends largely on site conditions (e.g., soil moisture), availability of seeds or propagules (e.g., existence of advanced regeneration and residual living trees), environmental conditions (e.g., frost, snow, and weather), and competing vegetation. Planted forest stands can reach canopy closure within 15 years (e.g., in mixed Douglas-fir), while naturally regenerating stands on shallow rocky soils (e.g., on the south side of Little Mountain) may take 40 years or more to reach canopy closure. The stand initiation stage provides a number of ecosystem functions that are essential to large scale resilience. The availability of resources creates suitable establishment condition for most species and increases biodiversity. High plant species diversity provides foraging habitat for a wide range of primary consumers.

Competitive Exclusion

The *competitive exclusion stage* is characterized by competition for light resources, biomass accumulation, and competition mortality. Trees reach their greatest annual height growth in this stage, causing the canopy to rise and create a low light environment below the canopy in which many herb and shrub species can no longer persist. Species diversity decreases in this phase. Due to differences in height growth among trees (as a function of age, species, genetics, and micro-site), the tree canopy differentiates into crown classes, and overtopped trees eventually die. Canopy differentiation and competitive mortality happens faster on more productive sites with greater nutrient and water supply (Larson et al. 2008).

The length of the establishment (stand initiation) phase and resulting variation in tree size and species have a large influence on processes in the competitive exclusion stage. A short establishment period (e.g., due to active reforestation or a good seed year) can lead to homogeneous stand conditions with little differentiation over time. Species that exhibit rapid early height growth (e.g., red alder, noble fir, and Douglas-fir) or those that arrive on the site earlier (e.g., advanced regeneration of Pacific silver fir) often grow into dominant canopy positions. The rate of biomass accumulation at the stand level reaches a peak in this stage when a maximum amount of leaf area is attained in the upper canopy. The intense competitive mortality and slow decomposition rates in this stage lead to biomass accumulation on the forest floor.

Stands in the competitive exclusion stage are structurally simple, as most leaf area is located in the upper canopy layer, and competitive mortality leads to more uniform stem distribution of the initially clumped patterns in the stand initiation stage. Establishment of shade tolerant trees in the understory (ingrowth) is sporadic. This stage ends when the upper tree canopy breaks up due to disturbance or senescence of individual trees, and the remaining overstory trees are no longer able to recapture the available growing space. A prolonged duration of the competitive exclusion stage can be expected on sites with limited nutrient and water supply, in stands of predominantly shade tolerant species, and sites that experience little disturbances. While ecosystem functions of habitat and biodiversity are lower in this state, it still plays an important role in carbon sequestration.

Understory Reinitiation/Vertical Diversification
As the upper canopy breaks up, growing space (as well as light, water, and nutrients) becomes available to lower canopy layers, and *understory reinitiation* begins, leading to vertical differentiation of the canopy. Tree mortality through disturbance, insects, and diseases become more important than competition induced mortality, reversing the trend toward a uniform tree distribution in the overstory. The dominant process in this developmental stage is the establishment of trees and other vegetation in the lower canopy layers. Understory development is often patchy due to aggregated tree mortality and is dominated by shade tolerant species.

The distributions of tree sizes and canopy foliage (i.e., factors that influence effecting growing space) are often bimodal. In those cases where a prolific understory develops, competition for limited resources in the lower canopy layers can be high, and competition mortality occurs. The development of those lower canopy layers depends largely on resource gradients within the overstory canopy (e.g., gaps), since height growth of understory trees can be stalled under a stable, closed overstory. Where an understory of shade tolerant trees and shrubs develops in canopy gaps, species diversity increases and improves habitat values. Over time the vertical distribution of foliage becomes more balanced as understory trees grow into intermediate canopy positions and overstory density declines. The development of epicormic sprouts contributes to crown development and development of a continuous foliage profile (Ishii and Ford 2001, Ishii and Wilson 2001).

While such forest structures are less productive in terms of biomass accumulation than stands in the competitive exclusion stage, productivity occurs throughout the canopy strata (herb, shrub, tree strata), providing a more diverse habitat due to a more even light distribution. Mortality in the top canopy layer through insects and disease produces a larger and thus more stable and ecologically valuable form of dead wood than in earlier stages. Those large standing and downed dead trees provide some of the habitat elements that are largely lacking in young second-growth forests in the watershed. Consequently, this stage has greater habitat functionality and biodiversity values than the competitive exclusion stage.

Horizontal Diversification
Further development of forest structure can be described by *horizontal diversification* (Franklin et al. 2002) or shifting-mosaic steady state (Bormann and Likens 1979). Small scale disturbances that kill individual trees or groups of trees continue to open the canopy where, over time, patches of different structural stages develop. Lacking a unifying structural component, this stage can best be characterized as a shifting mosaic of stand development stages. Biomass in the old-growth stage is often high and shows great spatial variation. This horizontal diversification requires integration of forest stand attributes on a larger spatial scale to characterize habitat structure of old-growth forest. The range of tree sizes can create the

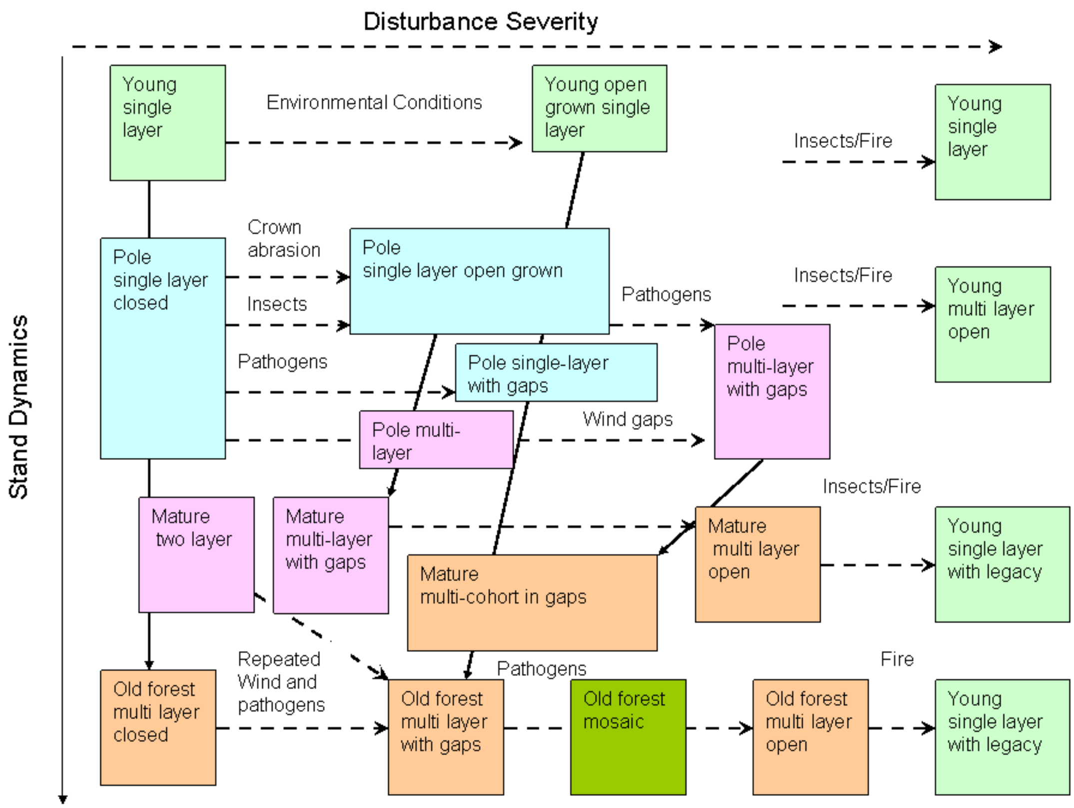
characteristic negative exponential or sigmoidal diameter distributions of uneven-aged forests with a low frequency of very large trees and high frequency of small trees. In the absence of large and infrequent disturbances, a pathogen-dominated disturbance regime can maintain a forest composition that is often dominated by shade tolerant, late successional species, such as Pacific silver fir and western hemlock. Loss of the pioneer cohort is sometimes used as a process-based definition of old-growth (Oliver and Larson 1996).

2.4.2 Disturbances

Natural disturbances are an integral part of forest development and shape the appearance of forests at different spatial scales. Disturbances are understood as distinct events that alter the composition of the natural community and redistribute resources, affect substrate availability, or alter the physical environment (Picket and White 1985). Consequently, large-scale disturbances can set ecosystems back in development, skip stages in development, or establish and perpetuate certain stages of ecosystem development. High severity disturbances, for instance, can lead to dominance of adapted (tolerant to disturbance agent) species while disturbances with lower severity and higher frequency may lead to coexistence of species with a range of adaptations (Frelich and Reich 1999). An understanding of the effect of natural disturbances on forest dynamics is of particular importance for restoration management, where the objective is to affect structure and composition of forests and influence developmental trajectories. Severe stand-replacing disturbances such as fire have long return intervals of >400 years on the western slope of the Central Cascades (Agee 1993). Many of the late-successional forests in the CRMW originated after fire disturbance around 300 years ago (Henderson and Peter 1981). Smaller scale disturbances such as wind, insects, and pathogens, and their combinations, vary in severity and occur at greater frequency, but have long lasting effect on forest structural development (Castello et al. 1995). Their effect on forests largely depends on the changes in susceptibility to the disturbance agent during forest development. Small scale disturbances promote forest structural development and can perpetuate dominance of late-seral species (Lertzman 1992). Depending on the predominant disturbance regime, disturbances create patterns on the landscape, which in turn can affect the disturbance regime.

At the forest stand scale, disturbances interact with forest development processes and can overcome resistance to transition between ecosystem states, for example between stages of competitive exclusion and understory reinitiation. Figure 2.6 shows a conceptual model where stand structural stages are placed in a matrix of disturbance severity and forest stand dynamics. Structural stages are described in terms of attributes that can be translated into wildlife habitat values following Johnson and O'Neil (2001; also see Section 2.3.1). Succession of habitat types along the stand dynamics axis shows the development from young single-cohort forests to multi-cohort mature and old forests along developmental pathways (solid arrows). Similar colors indicate stages with potentially similar levels of ecosystem function. Disturbance interaction (dashed arrows) along the horizontal axis (i.e., disturbance severity) changes stand structure and cohort development, and may lead to developmental stages with different functional levels. Because each habitat type differs in its susceptibility to disturbance agents (e.g., environmental conditions, such as wind or ice, and pathogens), only the predominant interactions are shown. With increasing disturbance severity, canopy gaps increase in size and at high disturbance severity eventually replace the existing cohort. At intermediate disturbance severity, cohort establishment creates multi-layer canopy structures that develop into complex canopy structures.

Figure 2.6: Transition of structural stages in a forest stand development – disturbance severity diagram.



This model extends conventional successional theory that predicts a gradual development towards multi-cohort late-seral forest structure, by incorporating disturbance interaction as a determinant of vegetation dynamics. It also indicates that some structural stages may not be achieved due to early disturbance interaction. Ultimately, the model demonstrates how changes in forest structure caused by natural disturbance or silvicultural interventions will set forest vegetation dynamics on different trajectories with different habitat values or other ecosystem functions. Different treatment options become apparent when natural disturbance analogs are considered for restoration treatments. Early interventions such as thinning or planting do not necessarily lead to the development of structurally complex forests. Future repeated small scale disturbances are going to play an integral role in forest development and will be considered in all restoration treatments (thinning density, pattern, scale).

We propose to integrate natural disturbances into active restoration management and will manage to promote rather than prevent natural processes to alter forest structural conditions and drive forest development. We believe that integrating disturbance effects on forest stand development is integral to implementing process-based restoration management in the CRMW. Disturbances include pathogens, insects, fire, wind, and geomorphic disturbances.

2.4.3 Conceptual model of forest ecosystem process interaction

As agents of change, ecosystem processes provide the mechanisms of, as well as the resistance factors to, state transitions. Ecosystem processes are the interactions of ecosystem components with the physical environment (e.g., assimilation of carbon) and among each other (e.g., competition). Ecosystem processes create patterns of distribution (e.g., patchiness) and changes in structure and composition (e.g., stand structure). In turn, these patterns influence interaction strength and importance of processes in a particular ecosystem state. Figure 2.4 provides a generalized conceptual model that describes some of the primary interactions between ecosystem processes and ecosystem components.

The importance of individual ecosystem processes differs between ecosystem states and depends on site conditions. Therefore, it is most practical to define key ecosystem processes at the individual project level depending on the site-specific physical environment and conditions of the ecosystem components. In ecosystem states that have pronounced patchiness, dominant processes may differ locally. Transition to other ecosystem states may occur slowly or be perpetuated through species-specific mortality and regeneration patterns, as for example in western hemlock/Pacific silver fir old-growth where small scale mortality through root pathogens and shade tolerant regeneration can perpetuate forest composition and structure.

Our success in ecosystem restoration depends in part on understanding those ecosystem processes that create resistance factors and how they can be modified to enable transition to states of higher functionality. For instance, the absence of a species from a particular community cannot be changed by reducing competition if dispersal or substrate conditions prevent establishment at a given site (e.g., establishment of an herb stratum under a forest canopy with little light penetration). On the other hand, the multitude of ecosystem processes makes it difficult to identify all interactions that may create thresholds, and substantial uncertainty exists in the possible outcomes of passive or active restoration.

Table 2.4 provides examples of stage-specific thresholds and appropriate restoration actions. Thresholds for the transition into the understory reinitiation stage for instance, could be expressed by the attributes of existing stem density and understory environment. Processes that create resistance to this transition may include competition for resources, the lack of external disturbance, and possibly dispersal limitation of understory plants under given conditions. Thinning and creation of canopy gaps would be possible restoration activities to reduce competition; ground disturbance and introduction of pathogens could be used to increase disturbance; and planting could be used to increase species dispersal.

Table 2.4: Transition processes and associated resistance factors that may be modified by restoration treatments.

Transition Process	Resistance Factor	Restoration Treatment
Stand Initiation Stage		
Dispersal	Seed source, predation, herbivory	Planting, protection of seedlings
Establishment	Climate, weather, soil, disturbance	Shelter vegetation, site preparation
Growth	Competition, inhibition, herbivory	Vegetation control (e.g., for invasive plants), protection
Stem Exclusion Stage to Understory Reinitiation Stage		
Differentiation, competition mortality, growth	Shade tolerance, density, competition	Alteration of growing space distribution (e.g., by thinning), retain productivity of dominants
Disturbance, pathology	Stability, resistance to insects and pathogens	Create local instability (gaps, wound trees, introduce pathogens)
Regeneration, establishment, invasion	Resource distribution, dispersal	Reduce leaf area index, substrate modification, planting
Vertical Diversification Stage		
Height growth	Resource conditions, growth plasticity, disturbance	Growing space distribution, species selection
Disturbance mortality, pathology	Stability, resistance to disease	Create local instability (gap, organism)
Crown expansion, reiteration of juvenile growth pattern	Resource conditions, competition	Growing space distribution, crown topping
Horizontal Diversification Stage		
Disturbance mortality, pathology	Stability, resistance to disease and damage	Create instability (gap)
Regeneration	Resource distribution, dispersal	Reduce canopy competition (increase light penetration), substrate modification, planting
Differentiation	Shade tolerance, density, competition	Growing space distribution, retain productivity

2.5 History of Anthropogenic Disturbance and Current Conditions

Historic landscape pattern, or the spatial arrangement and juxtaposition of habitat types within the surrounding matrix of geology and landform, provides guidance for watershed-scale restoration management. Mimicking the historic variation of landscape pattern when planning restoration treatments in the CRMW is important, because our management goals preclude using fire as a landscape–scale disturbance regime to maintain natural landscape patterns (e.g., Baker 2007). As a source of landscape pattern and historic vegetation, we will use timber cruise maps and notes of the original land surveys (circa 1890-1910) that describe forest structure and distribution over large parts of the CRMW. This information, when developed, will be used to guide design of patch sizes, connectivity, and seral-stage diversity.

However, equally important as understanding historic landscape pattern is knowledge of anthropogenic disturbance that led to the development of current forest and landscape structures (Turner et al. 1995). The following section provides a brief summary of historic land use in the CRMW.

2.5.1 History of Land Use in the CRMW

The land use history in the CRMW over the past century has converted 71,500 acres of native older forest to earlier successional stages, now ranging in age from approximately 10 to 100 years old (Figure 2.7, Table 2.5). Most of the forest disturbances are attributed to clearcut logging and associated road building and related human activity, although there were also several town sites and railroad logging camps scattered throughout the CRMW. The most intense logging operations in the lower watershed occurred between 1910 and 1920 and harvested almost all forest in this area. In addition, wildfires were ignited by railroad trains and slash burning and spread through portions of the CRMW. Biological legacies, such as snags, were removed from logged and burned sites to reduce fire risk and aid reforestation efforts. During the same period, forests around Chester Morse Lake (CML) were cleared up to 1,600 feet in elevation. A large fire that burned forests between CML and Cedar Falls in 1922 led to the first coordinated reforestation program in the watershed. Lands that transferred to City ownership after logging were planted, primarily with Douglas-fir. Regulated forest harvesting continued primarily on private and federal forest lands between 1945 and 1995. Second-growth forests resulting from these disturbances span the western hemlock, Pacific silver fir, and mountain hemlock forest zones. Only a few areas have received silvicultural treatments such as commercial thinning (for example, along the lower Cedar River and in the lower Taylor basin in the 1970s and 1980s) to increase residual tree growth. Timber extraction from the watershed ended in 1995 when the remaining land in-holdings were transferred to the City. The remaining old-growth forests in the CRMW (14,130 acres) are primarily found in the Pacific silver fir and mountain hemlock zones, although small remnants of high-graded old-growth exist in the lower watershed.

Figure 2.7: Forest ages by year of origin in the CRMW

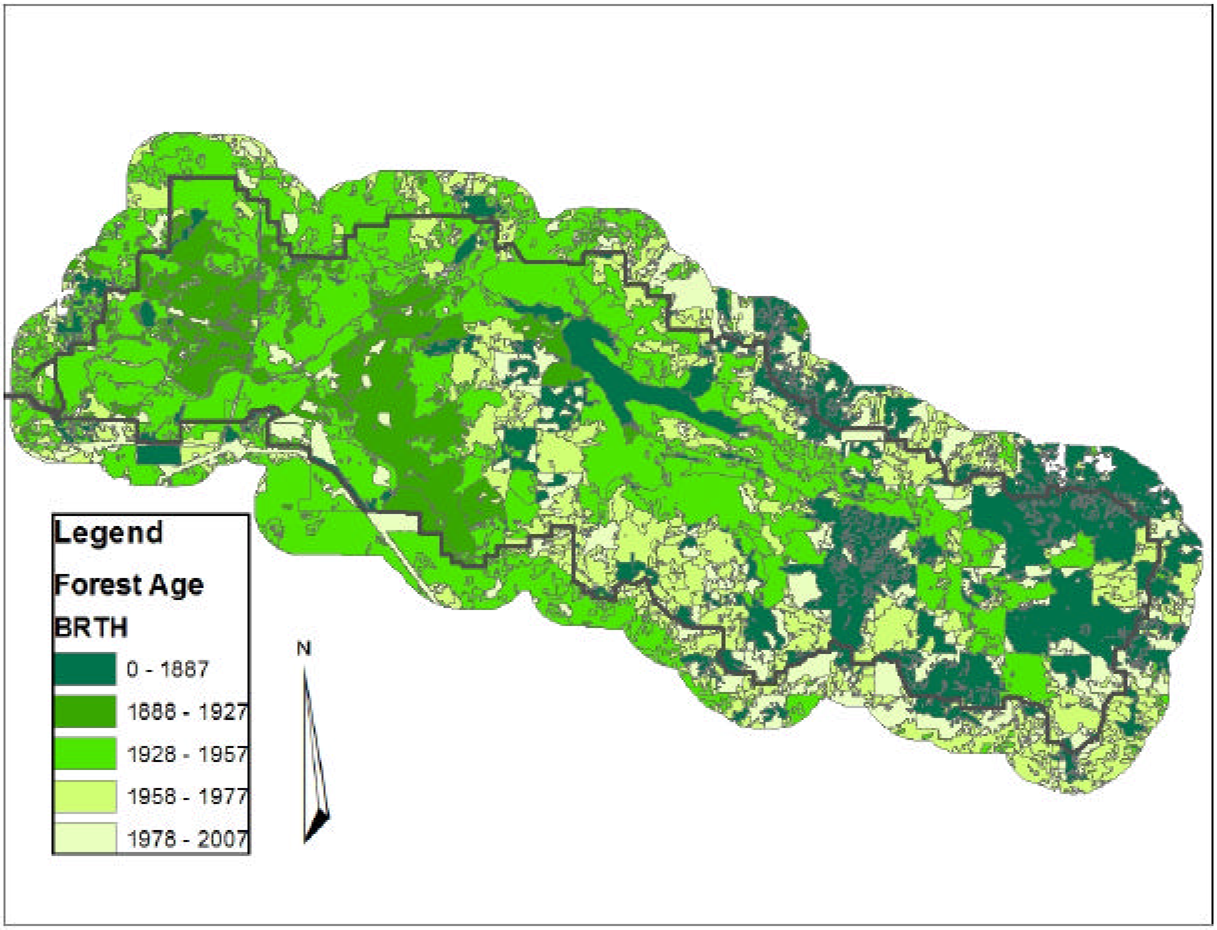


Table 2.5: Estimated acres of forest in the CRMW by age and elevation (based on CRW-HCP Table 4.2-7, and increased by 10 years).

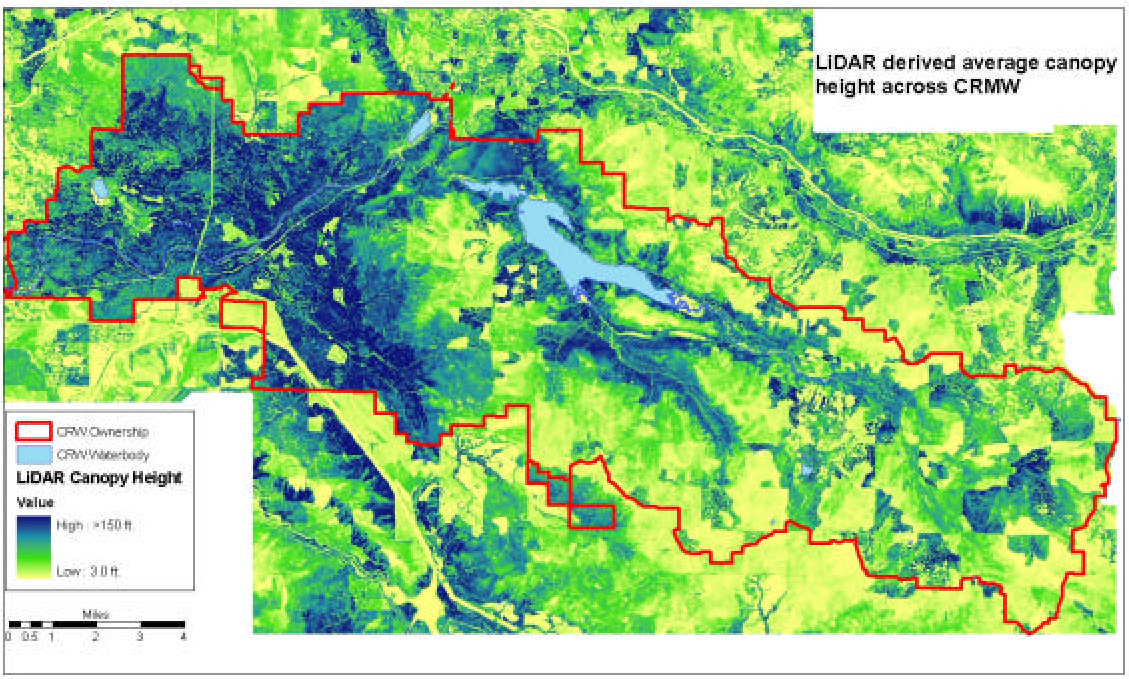
Forest Age	Elevation <3,000'	Elevation 3,000-4,500'	Elevation >4,500'	Total
0-39	5,400	9,397	813	15,610
40-89	45,655	8,785	151	54,591
90-129	1,074	0	0	1,074
130-199	91	0	0	91
>200	2,565	9,217	2,107	13,889
Unknown	150	60	12	222
Total	54,935	27,459	3,083	85,477

2.5.2 A Brief Picture of Current Forest Conditions

The current condition in the CRMW consists of a landscape pattern in which most of the forests originated from large scale anthropogenic disturbance (clearcutting) and have developed into single cohort forests with little structural variability. These disturbances removed most of the residual structures or biological legacy (sensu Swanson and Franklin 1992), and establishment conditions were homogeneous compared to natural regeneration patterns. Consequently, the second growth forests exhibit simplified developmental conditions in terms of both structure and composition. Most forest stands are in or entering the competitive exclusion successional stage, have little dead wood, and low overstory and understory species diversity.

Estimates of the current condition of the forests in the CRMW are based on existing data and are subject to change as new data sources become available. Figure 2.8 illustrates the average canopy height of forests in the CRMW and is derived from newer remote sensing data.

Figure 2.8: Landscape distribution of canopy height derived from LiDAR data.

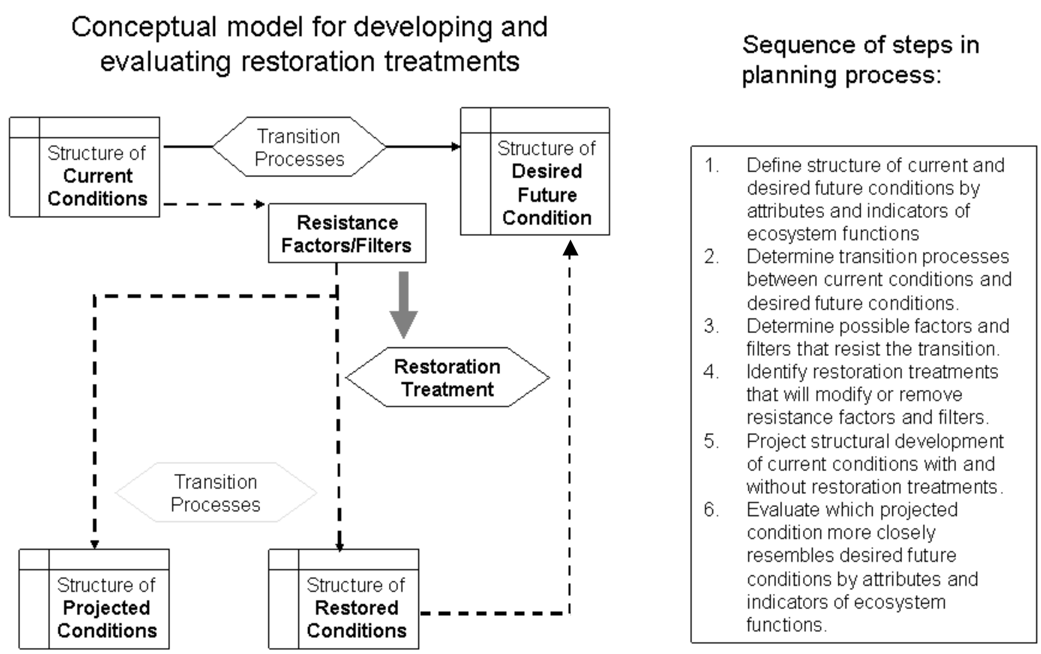


2.6 Desired Future Conditions, Attributes and Relevant Datasets

Establishing desired future conditions (or benchmark conditions) provides a framework for developing restoration goals to guide restoration treatment design at the stand and landscape levels. While the general restoration goal for upland forests under the CRW-HCP is the development of late-successional forest conditions for the benefit of species of concern, those structures are the result of long-term interactions between forest dynamics and disturbances, resulting in a wide range of structural conditions and species composition (Zenner 2005). For the design of restoration treatments, it is more useful to define benchmark conditions of forest development that reflect intermediate stages in structural development and to determine factors that create resistance to state transition. This approach enables forest restoration practitioners to (a) better evaluate whether restoration interventions are having the intended effects and (b) be more explicit in developing restoration objectives and treatments.

We use the forest development stages in Section 2.4.1 as a framework to define benchmark conditions as restoration goals and identify attributes and indicators to describe current conditions and DFCs we expect in each stage. The general ecosystem processes in Section 2.4.3 help us define abiotic and biotic factors that resist transition to ecosystem states of higher functionality. These factors then become targets of restoration intervention (Figure 2.9). Attributes and indicators also serve as measures of success of our restoration interventions.

Figure 2.9: Conceptual model for developing and evaluating restoration objectives and treatments



Specific ecosystem functions that result from current structural conditions are compared with DFCs and their associated ecosystem functions. From the distance between current conditions and DFCs, as well as processes that are involved in stage transition, we can define the resistance factors that impede the transition of the ecosystem. These factors are targeted in restoration treatments designed to change developmental pathways. Post-treatment structural conditions will still require ecosystem development to reach DFCs or projected future conditions, as the DFC is not immediately achieved by installing forest restoration treatments. Forest development and response to processes and disturbances takes time. Uncertainty in reaching DFCs may be reduced if the projected post-treatment conditions closely resemble DFCs. The following section describes in more detail benchmark conditions, the attributes and indicators used to describe them, as well as resistance factors and transitions processes.

2.6.1 Benchmark Conditions and Attributes

Stand Initiation

The establishment of trees on a non-forested site is one of the initial benchmarks of forest restoration. While early colonizers (pioneer species) often dominate such sites, limits to seed banks, seed source, and dispersal distance of vectors may limit tree species diversity for a long time. Germination conditions, existence of nurse logs, exposed mineral soil, and early survival conditions often appear as abiotic filters to establishment of trees and increased species diversity. Residual elements of the previous forest (biological legacy) often create micro-site variability and enhance species diversity through niche differentiation. A minimum number of established trees and their spatial distribution, as well as high diversity of desired plant species, would serve as attributes for this stage.

Open stages of young forests may persist for long periods of time through frequent disturbances, below ground competition, or long establishment periods. While trees grow in size and increase canopy depth, foliage profiles are not top-heavy, and stem diameter distribution is unimodal with a wide range. If this stage is prolonged through abiotic filters or disturbance, vegetation dynamics will likely lead to a structurally diverse forest. Unless residual snags and down logs exist, however, this stage is characteristically low on dead wood. The horizontal structure of open young forests is often patchy and increases niche diversification.

Competitive Exclusion

In forest ecosystem stages where a strong competition for resources (light, water, nutrients) causes exclusion or death through competition, biodiversity and habitat values may be reduced. Attributes such as stem density or productivity can vary widely as long as competition for limited resources persists. Concentration of leaf area in the upper canopy reaches a maximum and creates a resource-poor environment under the canopy, resulting in limited colonization of understory species. Transition to states of higher habitat and biodiversity values may be limited due to resource deficiencies and competition. Attributes of this stage are limited species diversity (especially in the forest understory), a narrow range of stem diameters, concentration of leaf area in the upper canopy, and dominance of few very competitive trees. This stage may also be perpetuated by spatial homogeneity of resources through lack of residual structures or ground disturbance.

Understory Reinitiation

Understory reinitiation is a stage of higher resource availability and better establishment conditions in lower canopy layers. Attributes such as diameter, tree height, or foliage distribution are often bimodal, and species composition diversifies despite dominance by a few species. At this stage of stand development, crown class differentiation is complete and leads to more even spacing between dominant overstory trees. This stage might exhibit the highest density of large diameter trees in stand development. Other attributes such as size and persistence of dead standing trees is higher than in previous stages, and a temporal peak in the amount of down wood can be observed in stands from competitive exclusion and disturbance mortality. Factors that resist the transition to this stage are usually resistance to disturbance and limited dispersal distance of understory species. This stage might be perpetuated by competition for limited resources through very competitive species and lack of patchy disturbances (e.g., the 300-year-old western hemlock stand along 815.5 Road). This stage occurs earlier in forests with lower leaf area density such as Douglas-fir dominated stands than in stands dominated by shade tolerant western hemlock or Pacific silver fir that show slower crown class differentiation.

Vertical Diversification
The presence of disturbance agents such as wind and root pathogens is important for the vertical diversification stage of the forest canopy development. Attributes of this stage include increased gap size in the upper canopy, greater understory light resources and advancement of the regeneration into mid-canopy layers. Foliage distribution shows small scale clumping as tree crowns rebuild through epicormic sprouts after disturbance or infection by mistletoe. Both processes lead to development of a continuous foliage profile from the forest floor to the top of the canopy. Persistence of disturbance agents also increases down and standing dead wood in the forest.

Horizontal Diversification
A patchy mosaic of different stages of forest development is the characteristic for the horizontal diversification (Franklin et al. 2002) or shifting mosaic steady state (Bormann and Likens 1979). At a small spatial scale, this stage would exhibit a range of the structural attributes described above in a patchy distribution of developmental stages with maximum niche differentiation such as described for mature Douglas-fir forest (Spies and Franklin 1991). At a larger scale of integration, habitat attributes (e.g., tree size, canopy layers) show a continuous distribution, depending on forest growth and disturbance regime. We expect a rather gradual development towards this stage developing after very long time has passed since a large scale disturbance, when separate development processes dominate in individual patches. The reoccurrence of large scale disturbance would synchronize vegetation dynamics and reset this development. The extent of small scale disturbances would determine the spatial patterns of this stage, while the severity of small scale disturbances would determine how rapidly this stage could develop.

2.6.2 Data Sources to Describe Forest Conditions

Data acquisition for habitat characterization and restoration project design has multiple objectives. Information on forest structure attributes and habitat values at the landscape scale are necessary to describe current habitats in the watershed, as well as to locate potential restoration areas. Landscape-level data coverage is used to describe watershed-wide forest structure and habitat. Primarily acquired from remote sensing data sources, this information can represent current conditions of the entire forest. Ideally, these watershed-wide data will be updated periodically to reflect landscape scale changes over time.

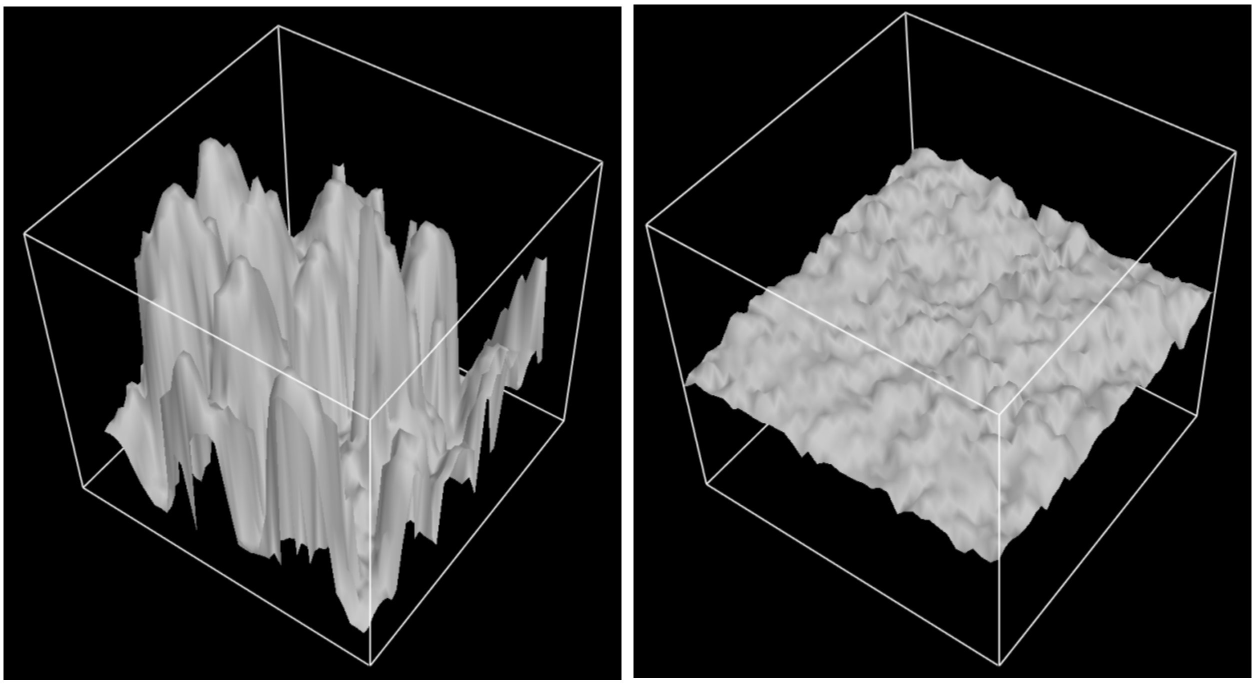
At the landscape scale, the synergy layer (Section 1.4.1) has facilitated determination of high priority restoration areas within the watershed and has therefore streamlined where to prioritize collection of detailed field data to support restoration decisions. Given the site selection and prioritization framework (Section 3.0 and Appendix G) and the essential criteria to determine where forest restoration activities should be implemented, specific data are needed to describe the current condition of second growth forests in high synergy areas. To fulfill this need, detailed information on composition and structure from intensive forest inventory information is being collected on a project area basis, starting with high synergy areas. Refer to the Forest Habitat Data Acquisition Strategy (LaBarge 2005) for a more detailed discussion of scale and resolution of data types given the management, restoration, and monitoring needs under the CRW-HCP.

Remote Sensing Data Sources
Remote sensing data sets for the CRMW exist from multi-spectral Landsat satellite imagery and King County LiDAR data. Remote sensing MASTER data images were used for classification of riparian forests (Chapin et al. 2007). LiDAR data were used to create topographic maps and forest canopy height maps (e.g. Figure 2.8). Early Landsat imagery was used to extrapolate forest inventory data sets, but was not successful in adequately describing forest structure and composition.

A reliable map of forest age is currently available from historic inventory and forest stand classification efforts (Figure 2.7), but maps and datasets describing other criteria are also needed. We expect that an array of forest attributes may be derived from LiDAR remote sensing data sources, and efforts to derive these attributes are under development at the landscape scale. To date, we have a landscape map showing average canopy height that is derived from initial and final return LiDAR data, as shown in Figure 2.8. There is a correlation between forest age after clearcut harvest and both tree density and tree size. Younger forests tend to have greater tree density and smaller tree size, although other environmental factors also have a large influence on forest characteristics. As shown in Figure 2.8, average tree height generally declines with increasing elevation, due to logging history, except in the old-growth forest at higher elevations. The analysis of LiDAR point cloud data will hopefully provide attributes of stand density and stand diameter distributions that can be portrayed watershed-wide.

Another example of a forest attribute that has been derived from LiDAR point cloud data is a forest structural complexity index (SCI, also called the “rumple index”) as shown in Figure 2.10, which shows three-dimensional graphs of forest canopy surface area for an old-growth forest and a young second-growth forest. The ratio of canopy surface to ground surface area can be used to classify forests by structural complexity which correlates with structural habitat elements of late-successional forests. Ongoing research collaboration between SPU and the University of Washington, College of Forest Resources is exploring the use of LiDAR and satellite imagery to derive ecologically relevant forest metrics via Nearest Neighbor Imputation (Van Kane, personal communication). Refer to the Watershed Characterization Strategic Plan (Munro et al. 2007) for more discussion regarding data acquisition plans and current status.

Figure 2.10. Canopy surface area derived from LiDAR data to calculate Structural Complexity Index (SCI) for old-growth forest (left) and second growth forest (right).



Recent Forest Inventory Data Sources
Pre-HCP data sets of forest structure were designed to provide average stand attributes of forest structure and composition and to extrapolate from sample stands to similar un-sampled stands in the watershed. These data sets encompass a representative sample and are spatially referenced at the stand polygon level. Forest Inventory data sets (post HCP) were designed to provide detailed information of forest structure from tree lists and timber value information for project planning. These inventories also include information on other habitat elements such as understory vegetation, snags, and down wood.

Permanent Sample and Other Plot Data Sources
Permanent Sample Plot data sets were established to monitor the development of forest structure, composition, and yield. A pre-HCP dataset in the lower watershed was established between 1946 and 1979 (Larson 2004) and has been re-measured periodically through 2006. A series of PSPs were established post-HCP to characterize the forest vegetation in the CRMW and to monitor vegetation development. These PSPs were established on a grid with a random starting point and sample all of the forest in the watershed. They are anticipated to be revisited every 10 years. Project monitoring data sets exist from restoration thinning and ecological thinning projects to evaluate the effectiveness of the prescribed treatments and to monitor long-term development of forest structure and composition.

Historic Data Sources
The earliest information of forest structure in the CRMW can be found in General Land Survey Records (1880-1910), as well as King County timber cruise data (1907-1914). These data sets

include information on species distribution, tree size, and timber volume, and serve as reference conditions for primary forests in the CRMW.

Research Site Data Sources
A number of data sets exist from abandoned research sites in the lower (Thompson Site) and upper watershed (Findley Lake). These data sets are not stored at SPU locations. Two research plots in primary *Abies amabilis* forests were established between 2002-2004 (Larson and Franklin 2006), to investigate structural development of *A. amabilis* forests. In the future, the understory vegetation sampling and overstory structural features of the University of Washington forest restoration experiment at Pine Creek and Bear Creek (Halpern et al. 2005) will have great value for showing interactions of different overstory removal patterns with understory development and potentially overstory development.

2.6.3 Development of Benchmarks and Desired Future Conditions

In order to define explicit ecological objectives for restoration projects and to track success in meeting those objectives, we develop benchmark conditions that are along the forest developmental trajectory from the early seral condition (when implementation occurs) to late-seral conditions. We recognize that there is a long time span between when we implement forest restoration projects and when old-growth forest conditions will be achieved. Therefore, it is valuable to develop benchmark conditions for decades, rather than centuries, along the developmental course. These benchmarks are also DFCs, although they are transitional conditions to the ultimate late-seral goal.

To facilitate identification of benchmarks as well as reasonable ranges of attributes and indicators, we will use four types of information. First, we will use a series of existing reference stands in the CRMW that are classified by forest vegetation type and stand development stage. Table 2.6 shows several existing PSPs and research plots in the CRMW that may currently provide reference information for benchmarks. The reference stands provide information on structural attributes such as species distribution, tree size class distribution, stand age, horizontal and vertical structure, and down and standing dead wood. We can derive information regarding stand dynamics from current and past growth rates. These reference stands can provide specific benchmark conditions for restoration projects if they match in site conditions (e.g., soil type, forest type, elevation). The attributes from these stands will be augmented by known attributes and indicators from the scientific literature to guide restoration project selection, development of objectives and treatments, and effectiveness monitoring of restoration treatments.

Second, where reference stands cannot be found in the CRMW, we will use data from the scientific literature, including the Forest Inventory and Analysis (FIA) Program of the USDA Forest Service, to fill in the gaps. Federal plot data will be screened by forest type, stand age, and species composition to derive reference conditions for developmental benchmarks. The problem with using FIA data is that management history is variable among the plots and is often unrecorded. Where specific attributes of benchmark conditions (down wood, snags, spatial structure) cannot be derived from current plots within the CRMW reference stands, FIA data or other literature sources, we may collect additional data to specify benchmark conditions, if funds allow.

Table 2.6: Reference stands for structural benchmark conditions.

Benchmark Condition	Vegetation Zone	Location/Description
Mature single story	TSHE zone	56.6 Rd Plot/1 ac. PSP 12/0.2 ac. PSP 2208323128/0.2 ac. PSP 2208291128/0.2 ac. PSP 2208334128/0.2 ac. PSP 2208301128/0.2 ac.
	ABAM zone	PSP 2110044092/0.2 ac.
Understory reinitiation	TSHE zone	PSP8/0.25 ac. PSP 13, 19, 18, 20/0.2 ac.
	ABAM zone	815.5 rd./no data PSP 2208261128/0.2 ac.
Vertical diversification	TSHE zone	PSP 11/0.2 ac. PSP 2209164/0.2 ac. PSP 2110153128/0.2 ac.
	ABAM zone	Mosquito Lake Plot/2.4 ac. Sutton Lake Plot/2.4 ac. PSP 2111053128/0.2 ac.
	TSME zone	PSP 2110213128/0.2 ac. PSP 2110134034/0.2 ac.
Horizontal diversification	TSHE zone	PSP 2110224128/0.2 ac.
	ABAM zone	PSP 2109142222/0.2 ac. PSP 2109154010/0.2 ac. PSP 2208141124/0.2 ac.

Third, we will use forest growth models to project how current restoration project site conditions may develop with and without treatments. We will compare specific attributes from these growth projections to data from PSPs and the literature in order to confirm predictions about tree size and stand density. We can use the growth models to compare forest development with different treatment options, although we also recognize that the models have limitations such as inability to model understory development and spatial heterogeneity.

Finally, we will derive general targets for species distribution and composition on the landscape level from GLO notes and historic timber cruise data of the 1907-1914 County Cruise, which was done for the purposes of a timber assessment. Available data on timber volume by species will be analyzed and correlated with topography, elevation, and site class, and targets for species distribution and mixtures in mature stands will be used to guide thinning and restoration planting. For example, these data will be used to determine specific areas of historic distribution and associated site conditions of *Pinus monticola* (western white pine) and *Thuja plicata* (western redcedar) and will guide reintroduction efforts through planting. In order to account for species shifts relative to future climate change, we will work with other scientists to incorporate the most current thinking about facilitating species shifts through planting.

2.6.4 Information Sources regarding Plant Diversity - Cryptogam and Botanical Surveys

In 2006 and 2007, cryptogam surveys were conducted in the watershed. In May 2006 bryophytes and lichens were surveyed at monitoring plots in an ecological thinning project site (the 700 Road Forest Restoration Project). Eleven permanent plots were sampled with the intention of evaluating cryptogam diversity and abundance before and after thinning. Additional plots were sampled in late 2006 and early 2007 to explore how lichen and bryophyte diversity and abundance vary with forest development. These plots were installed in forests of different ages and management histories and also utilized a few PSP locations so that they can serve as baseline data for monitoring changes in the cryptogam community over time. This information may also serve as rationale for restoration planting of lichens, which are known to be dispersal limited.

In addition to the cryptogam inventories, botanical forays have been conducted in the CRMW in the past several years. A comprehensive list of plant species diversity exists (stored in the Science Information Catalog as the Cedar River Municipal Watershed Master List Plants-20-Jan-2006.xls) and should be used to protect less common species and to guide potential reintroductions of underrepresented species to their typical habitats.

2.7 Restoration Treatments and Rationale

While the foremost tool of upland forest restoration in the CRMW is the reserve status of the forests within the hydrographic boundary, active restoration treatments will be employed to remove or alter resistance factors that impede transition to ecosystem states with greater functionality. All the available silvicultural tools may be used in active restoration treatments, including thinning, gap creation, snag creation (topping, girdling, and/or inoculation), and planting. Tree killing activities may or may not involve tree removal from the site, depending on the ecological objectives, logistical issues and cost of project implementation. The process of developing restoration objectives involves defining transition processes and barriers which were discussed in Sections 2.2 through 2.4. Whether or not restoration treatments will be implemented at a given site depends on restoration priorities and the likelihood of making significant changes in ecosystem development and functionality. This decision process is further described in Section 3.

In the following section we describe how different treatments are known to move forests towards specified restoration objectives. The treatments are designed to alter resistance factors that act as thresholds to transition. The treatments are often specific to ecosystem stages and their predominant processes. The objectives and potential treatments are summarized in Table 2.7.

2.7.1 Species diversity and niche differentiation

Planting conifers has been used to change species composition in young stands and to provide advanced regeneration in older forests. Inter-planting of deciduous species in conifer plantations has been used to improve nutrient cycling and increase community diversity. Canopy arthropod assemblages are specific to tree species, and species diversity is increased in mixed conifer-deciduous forests (Schowalter and Zhang 2005). Planting other vascular species and non-vascular plants would potentially lead to increased species diversity, but little is known about successful strategies and effects (Harrington et al. 2002, Neitlich and McCune 1997, Sillett et al. 2000).

Table 2.7. Summary of restoration objectives and potential treatments

Restoration Objective	Restoration Treatment
Increasing species diversity and niche diversification	Planting, underplanting, thinning, gap creation
Reducing resource competition and increasing crown development	Thinning, understory thinning
Reducing migration barriers	Thinning, slash treatment, down wood augmentation
Increasing vertical diversification	Thinning, gap creation, inducing crown damage, pathogen infection, underplanting
Increasing horizontal diversification, patchiness, and habitat mosaics	Thinning with skips and gaps, variable density thinning
Creating decadence	Snag creation, down wood augmentation, log bundling, retention, and release of character trees
Enhancing carbon sequestration, productivity, and nutrient cycling	Thinning, interplanting mixed species

Creating variability in canopy cover by thinning has been shown to establish and improve understory vegetation layers in young Douglas-fir stands (Beggs 2004). While the initial response of understory vegetation to thinning is expected to be reversed through overstory canopy closure in lightly thinned stands (residual density >120 TPA), canopy gaps can sustain understory vegetation for a longer time.

Thinning to increase light levels at the forest floor can increase species richness, diversity, and cover (Bailey et al. 1998, Curtis et al. 1998, Thomas et al. 1999, Thysell and Carey 2000). Muir et al. (2002) found that understory communities in thinned stands were not necessarily more similar to those in old-growth stands than to those in un-thinned stands, but that biodiversity and cover was increased in thinned stands dominated by Douglas-fir. Carey and Wilson (2001) found understory species diversity was enhanced in thinned mosaics of variable overstory density. Chan et al. (2006) found increased understory species richness and growth of understory trees in thinned, 40 year-old Douglas-fir with wide residual tree spacing (100-130 TPA) as compared to un-thinned controls (220 TPA). Thinning encourages seedling establishment of shade-tolerant conifers (Del Rio and Berg 1979), deciduous trees (Fried et al. 1988), and shrubs (Huffman 1994, O'Dea et al. 1995, Tappeiner and Zasada 1993), but it also results in vegetative expansion of shrubs by rhizomes (Tappeiner et al. 1991) and layering. By reducing overstory density and providing a seedbed of disturbed soil, thinning results in colonization by new plants not previously in the stand (Thysell and Carey 2001) and the spread of those already established.

2.7.2 Resource competition and crown development

Thinning young stands has been shown to reduce resource competition and improve crown development, thus increasing tree productivity. Tappeiner at al. (1997) and Poage (2001) observed that the diameter of trees in old forests was positively correlated with growth at young age (50 years). High diameter growth rates were the result of low initial stand densities and long establishment periods. Wilson and Oliver (2000) observed that resistance of trees to windthrow and breaking is affected by the height to diameter ratios at younger age, pointing towards the importance of rapid diameter growth during early stand development. Curtis and Marshall (1986) found that the growth of young trees thinned to about 50 trees per acre was similar to that of old trees. Growth is relatively slower in un-thinned stands at high tree high density (>250 TPH) (Curtis et al. 2000, Harrington et al. 2004, Davis et al. 2007) than in thinned stands of lower density.

Thinning studies in Douglas-fir have shown that stands growing below 60% of maximum stand density index have greater tree diameter increment than trees in stands at higher stand density. Thinning trials in western hemlock, Pacific silver fir, and noble fir have shown relatively higher diameter growth rates in trees and vascular plant diversity at lower stem densities (Curtis et al. 2000). Latham and Tappeiner (2002) found that old trees were able to respond to thinning with increased diameter growth.

Understory thinning can reduce intra- and inter-cohort competition (Canham et al. 2004). Average diameter was twice as high in 80 year-old Douglas-fir stands (30-inch dbh) with western hemlock understory thinned to 50 TPA compared to unthinned controls (15-inch dbh) with higher understory hemlock densities (Curtis and Marshall 1993).

2.7.3 Reducing migration barriers

At a landscape scale, facilitating development of late-successional structures through thinning between existing patches of old forest can reduce dispersal barriers for animal species associated with late-successional forest such as the northern spotted owl, fisher, and American marten. Similarly, creating special habitat elements (e.g., downed wood) adjacent to streams and wetlands can reduce dispersal barriers for amphibian species moving from riparian areas to and through upland forests.

At the stand scale, thinning stands with high stem density can positively affect movement and use by bats in the canopy (Erickson 1997), while movement of large vertebrates may be hindered by large accumulation of thinning slash. Down wood can provide migration corridors for amphibians between habitats. Treating slash in young stands, for example by removal or piling, has been postulated to reduce movement barriers for large vertebrates, particularly in migration corridors.

2.7.4 Vertical diversification

Vertical diversification of the canopy leads to a continuous foliage profile throughout the canopy (Franklin et al. 2002). This can be achieved through height growth of understory trees or epicormic branching and reiterations (development of unique branching structures) in the overstory. Gaps in the upper canopy and the sub-canopy lead to improved resource conditions and branch and foliage development. Foliage clumping and reiterations are the result of crown damage and are connected with stem and branch pathogens. There is little information on the effectiveness of introduced pathogens on crown development. Underplanting may be used to begin the development of multiple canopy layers. Western hemlock planted under 40 year-old low density Douglas-fir (50 TPA) has been found to develop into two-layered stands at age 80 (Curtis and Marshall 1993). At higher overstory density underplanted trees may stagnate in growth and slow the process of vertical diversification. Density, survival and growth of conifer seedlings and shrub species increase after thinning (Bailey and Tappeiner 1998, Bailey et al. 1998, Brandeis et al. 2001, DeBell et al. 1997, Muir et al. 2002) and allow for development of multiple canopy layers with continuous foliage profiles throughout the canopy.

2.7.5 Horizontal diversification, patchiness, mosaic

Heterogeneity of forest structure and composition lead to patchiness of habitats and a mosaic of stand development stages. Such mosaics can be created by silvicultural group selection systems, where regeneration harvest is occurring in small patches, or by habitat restoration thinning with skips and gaps (Harrington et al. 2005). Variability at the patch scale is also achieved through variable density thinning (Thysell and Carey 2000) or variable retention harvest systems (Franklin et al. 1997). Patchiness can also be caused by root pathogens (e.g., laminated root rot pockets in the lower watershed) or water table fluctuation at small scale (e.g., as seen at Lake Youngs) which may cause persistent edaphic gaps.

2.7.6 Creating decadence

While retaining fallen trees will create downed wood, the functionality of downed wood depends on piece size and state of decay (Harmon et al. 1986). Creation of log bundles has been suggested for improving the functionality of small diameter logs (A. Carey, pers. communication). Several techniques have been suggested for creating dead standing trees including girdling, topping, inoculation with pathogens, and wounding. Retaining and releasing trees with forked tops, large branches, broken tops, stem deformation, or reiterations will provide current and future structural diversity and habitat value. Busing and Garman (2002) showed in a modeling simulation that thinning Douglas-fir stands could expedite development of large dead trees.

2.7.7 Enhancing carbon sequestration, productivity, and nutrient cycling

Thinning young stands can reduce litter depth and improve nutrient cycling (Thomas et al. 1999). Mixed-species plantations of Douglas-fir and red alder have been shown to have enhanced nutrient cycling and soil microbial activity (Binkley 1983, Tarrant and Miller 1963). Increased nutrient cycling may not only enhance productivity through enhanced nutrient supply (Prescott, 2002), but also increase carbon sequestration through increased leaf area index and higher woody biomass accumulation rates.

2.8 Risks, Uncertainties, and Threats in Reaching Desired Future Conditions

The restoration programs for upland forests in the CRMW face a number of risks, uncertainties, and threats (as defined by Erckmann et al. 2008) to their successful implementation and long-term effects. While ample experience exists with silvicultural treatments for timber production and wildlife habitat improvement in second-growth forests, the long-term development of late-successional forests is largely unknown. As outlined in earlier sections, our current knowledge of forest development pathways is based upon retrospective studies and past conditions. Projection of those pathways using forest growth models holds uncertainty, given the expected changes in regional climate. Given this uncertainty, we use a conservative approach to forest restoration and retain young forests stands in multiple conditions to follow different developmental trajectories. This section outlines known risks, uncertainties, and threats to the strategic forest habitat restoration efforts as well as approaches to mitigation.

2.8.1 Variable developmental pathways and unpredictable disturbances

The long-term development of late-successional forests is the combined result of establishment conditions, availability of propagules, local and regional climate patterns, assembly rules (i.e., patterns due to interactions among species), stand dynamics, and site specific disturbance regimes that occur over time. Given that disturbance events are often unpredictable, specific DFCs for late-successional forest structures may be reasonable on a landscape level, but setting specific DFCs locally is more challenging and must allow for developmental variability. Our approach to meeting long-term restoration goals therefore includes passive restoration (i.e., no treatment) in many areas, employing a range of restoration treatments thereby incorporating multiple pathways of forest development, and being conservative with respect to risk in the choice of treatments.

2.8.2 Forest restoration paradigm requires new tools to evaluate treatment effects

Our expectations of responses in tree growth and plant dispersal are largely derived from experiences in commercially managed second-growth forests or forests in different vegetation zones (such as Douglas-fir forests in the *Tsuga heterophylla* vegetation zone). Where those expectations are based on experience from commercial forests, such assumptions may differ for the CRMW, as it has not been managed as traditional commercial forestland since the harvest of primary forest. In addition, there may be important differences in specific establishment conditions, the physical environment, and forest composition in the CRMW compared to other areas from which data are available. While many of the concepts and applications of forest restoration from Douglas-fir forests may be similar to forests in the *Abies amabilis* vegetation zone, some of the basic assumptions may be different (e.g., processes of competition and appropriate stand densities, see Franklin 1982), so the forest responses to treatments may differ. Further, many forest growth models are based on commercial forest species and structures and may not appropriately model forest growth with variable densities and species composition. There are, however, very applicable forest restoration research studies that relate directly to the work conducted in the CRMW, including the True Fir Hemlock Spacing Trial (Curtis 2008) and the Olympic Habitat Development Study (Harrington et al. 2005). The forest projection systems development needs to keep pace with on-the-ground restoration applications. In order to track restoration effectiveness and potentially inform new models, forest restoration programs should contain elements of monitoring. Analysis of forest restoration monitoring results as well as adaptive management installations in second growth forests will provide the necessary information to adjust management in response to a changing knowledge base and refined management objectives.

2.8.3 Effects of climate change

The magnitude and effects of global climate change create uncertainties for future development of species assemblages, ecosystem functions and ecosystem resilience. Effects of climate change on ecosystem functions may hinge on symbiotic relationships or existence of keystone species and therefore may result in larger shifts in ecosystem processes than we might otherwise presume. Both climatic variables and soil conditions affect plant distribution. Scientists predict that species within a community may respond differently to climatic shifts (Iverson and Prasad 2001), so responses of species assemblages to climate change may be more visible through invasions than through local changes in abundance. However, shifts in the elevational location of ecotones have also been suggested for subalpine forests in this region, due to changes in regional climate (Zolbrod and Peterson 1999). Additionally, carbon sequestration is expected to change due to regional climate change and shifts in vegetation cover (Prichard et al. 2000). Climate change is therefore likely to change the stability of forest ecosystems and affect ecosystem resilience in a manner that may varies among forest ecosystem types.

Because restoration treatments aim to maintain and improve biological diversity and maintain ecological patterns and processes with the goal to increase ecosystem resilience, treatment strategies must address both the uncertainties and risks associated with climate change and evolve over time as scientific understanding of climate change impacts improves. Monitoring potential shifts in ecotones and species may be important. SPU has been conducting an evaluation of the potential impacts of climate change on several key elements of the utility's activities, including water supply and storm-water management, and developing strategies for mitigation and adaptation. This effort is expected to include the issue of ecosystem impacts in the municipal watersheds.

2.8.4 Invasive species

In addition to altering the distribution of native species, climate change is expected to increase the spread of non-native, invasive species. Already a concern because of increased global transport, these species may expand because changed disturbance regimes and higher CO_2 content in the atmosphere have been shown to favor invasives over natives (Dukes 2007, Williams et al. 2007). Many invasive species alter community composition by out-competing native vegetation. Invasives often establish in monocultures and provide poor habitat for wildlife species. The combination of increased globalization of trade and shifts in climate will increase the problem of non-native, invasive organisms in the future. SPU has initiated a program of monitoring, evaluation, and control of invasive plants in the watersheds, which is being integrated with other elements of watershed management.

2.8.5 Wildfire

The threat of wildfire constitutes a dominant management threat in the CRMW. Despite long to very long fire return intervals in the forest zones in the west-central Cascades (Agee 1993), wildfire of any significant magnitude would threaten the water supply and reset restoration efforts that aimed to accelerate development of late-successional forest habitat conditions. A recently concluded assessment of fire hazard in the CRMW found that the high hazard areas were almost entirely in young, dense forests, due to dense canopies and low live crowns.

Restoration thinning treatments in these forests did not substantially change fire hazard, and various surface fuel treatments were largely ineffective in changing fire hazard over time (Johnson et al. 2007a, 2007b). Uncertainties still persist despite the report's findings, however, as climate change and fire spread were not included in the model analysis.

For the time being, because of limited anthropogenic ignition sources in the watershed, very large areas of high fire hazard, the high cost of fuel removal, and the limited potential to lessen hazard conditions significantly with feasible treatments, SPU is applying surface fuel treatments only in young forests stands with a high hazard rating that are in critical areas, such as near remnant old-growth forest. SPU has greatly increased the preparedness of staff for initial response to a wildfire, and upgraded its equipment for that purpose. An evaluation of the need for other fire risk management measures is planned.

2.8.6 Critical knowledge gaps regarding attributes, indicators and application of restoration treatments

Many knowledge gaps currently exist in areas that are important for planning and conducting the upland forest habitat restoration program. Needs range from improving understanding about historic conditions and desired future conditions to better understanding potential forest ecosystem responses to restoration treatments. Examples include:

- defining the desired future conditions of restoration sites using benchmark stands, models, and data from the literature;
- projecting forest development, including understory development, with and without restoration treatments;
- determining whether similar forest structural conditions and species compositions will provide the same functions as primary forests (if we build it, will they come?); and
- addressing changes in species diversity relative to primary forests.

Table 2.8 describes current information needs and status for attributes and indicators related to the late-seral habitat ecosystem functions that were described in Section 2.3. Many research questions are included in Table 2.8, but it is not intended to be an exhaustive list.

2.8.7 Next steps in addressing knowledge gaps

Many of the knowledge gaps that are listed in Table 2.8 are already under investigation using a combination of data sources. Other knowledge gaps either require a different approach altogether (Table 2.9), or require concerted monitoring in an adaptive management context to address (Table 2.10 in Section 2.10).

Table 2.8. Information needed to quantify attributes and indicators in forest habitats and key knowledge gaps (research questions) related to the LSF habitat function. Knowledge gaps that cannot be addressed by data sources listed in this table (*italicized*) are described in more detail in Table 2.9. Knowledge gaps (<u>underlined</u>) that can be addressed by monitoring in an adaptive management context are described in more detail in Table 2.10.

Attribute	Indicator	Data Source	Status	Knowledge Gap
Live Trees	Species	MASTER data, PSPs, inventory data,	Complete watershed-wide coverage (MASTER) for deciduous versus coniferous forests but no watershed-wide coverage to discern coniferous species composition; Plant Association layer shows generalized vegetation zone; Systematic grid of PSPs provide species composition information; Field based inventory complete for many portions of watershed, including some high synergy areas.	R1 – What is distribution of coniferous and deciduous species in the CRMW? *R2 – Will existing species composition in second-growth forests in the Pacific Silver fir zone allow for development to late-seral conditions without active restoration planting?*
	Density	LiDAR, inventory data, PSPs	Working to calculate tree density at the watershed scale from LiDAR data; Systematic grid of PSPs provide tree density information; Field based inventory complete for many portions of watershed, including some high synergy areas.	R3 – What is distribution of stand densities across the CRMW? *R4 – How does stand density in the CRMW differ by site class, age, elevation, and site history?*
	DBH	LiDAR, inventory data, PSPs	Working to calculate tree diameters at the watershed scale from LiDAR data; Systematic grid of PSPs provide tree diameter information; Field based inventory complete for many portions of watershed, including some high synergy areas.	R5 – What is distribution of average diameters and range of trees diameters within stands in the CRMW?
Standing Dead Wood	Species, Density, Size, Decay class	inventory data, PSPs, literature, Forest Inventory Analysis (FIA) data	Systematic grid of PSPs provide snag information across the watershed; Forest inventory includes snag data; data from the literature on snag distribution in unmanaged and old-growth stands.	R6 – What is the range of snag densities at different size and decay classes in the late seral benchmarks? *R7 – Does accelerating through the competitive exclusion stage have impacts on soil development, carbon cycling, tree form, species composition, or biomass accumulation?*
Down Wood	Species, Density, Size, Volume, Decay class	inventory data, PSPs	Systematic grid of PSPs provide down wood information across the watershed; Forest inventory includes down wood data; literature review and FIA dataset.	*R8 – What is the optimum range of down wood volumes by size and decay classes in the late seral benchmarks?*

Table 2.8 (continued). Information needed to quantify attributes and indicators in forest habitats and key knowledge gaps (research questions) related to the LSF habitat function. Knowledge gaps that cannot be addressed by data sources listed in this table (*italicized*) are described in more detail in Table 2.9. Knowledge gaps (underlined) that can be addressed by monitoring in an adaptive management context are described in more detail in Table 2.10.

Attribute	Indicator	Data Source	Status	Knowledge Gap
Forest Canopy and Foliage Distribution	Depth, Layers, Branch Size	PSPs, inventory data, LiDAR derived indicators	Systematic grid of PSPs provide tree canopy information for forest stands across the watershed, including effectiveness monitoring plots; Forest inventory includes foliage distribution data by sampling all tree sizes and subsampling heights; LiDAR derived variables, including structural complexity index (rumple) and canopy density.	R9 – How do forest canopies develop over time with and without restoration treatments in different forest types? R10 – How does species diversity change in lower forest strata with and without restoration treatments in different forest types?
Horizontal Structure	Patch Size, Patch Structures, Patch Distribu-tion	Research Plots, LiDAR	Large (1-2 ha) research plots provide some information on horizontal structure in *Abies amabilis* late-seral forests; LiDAR can provide estimates of "gapiness" and canopy roughness.	*R11 – What is the optimum patch size and proportion of patch structures in different benchmarks and forest types?* *R12 - What is an effective way to sample patch size in potential restoration areas?* *R13 – At what spatial scale should restoration treatments be applied?*

Table 2.9. Plans for addressing knowledge gaps (see *italicized* knowledge gaps listed in Table 2.8)

Knowledge Gap	Approach	Status/Timeline for Completion	Constraints	Collaboration Opportunities
R2 – Will existing species composition in second-growth forests in the Pacific Silver fir zone allow for development to late-seral conditions without active restoration planting?	Conduct forest growth modeling and compare to habitat structural classifications.	2008 – related to Forest Stewardship Council (FSC) corrective action request (CAR) regarding "benchmarks".	High uncertainty, little research	Inform potential management activities in the Tolt Watershed, MIT habitat efforts, and regional forest restoration efforts.
R4 – How does forest structure in the CRMW differ by site class, age, elevation, and site history?	Conduct an analysis with LiDAR attributes and site variables.	Tbd – 2009	Do not have attribute data to describe forest structure across the watershed.	Adds to watershed characterization, old growth classification, and upland and riparian restoration efforts.
R7 – Does accelerating through the competitive exclusion stage have impacts on soil development, carbon cycling, tree form, species composition, or biomass accumulation?	In addition to the data sources identified in Table 2.8, additional efforts are needed, including a literature review and investigation of the FIA dataset. These questions pertain not just to the remaining FSC CAR on "benchmarks" but also support the effectiveness of restoration project design and evaluation.	Tbd	High uncertainty, little research	Inform potential management activities in the Tolt Watershed and regional forest restoration efforts.
R8 – What is the optimum range of down wood volumes by size and decay classes in the late seral benchmarks?		Tbd – related to FSC CAR regarding "benchmarks" that needs to be addressed in 2008.	High variability, little research in Pacific silver fir forests	Inform potential management activities in the Tolt Watershed and regional forest restoration efforts.
R11 – What is the optimum patch size and proportion of patch structures in different benchmarks and forest types?		Tbd – related to FSC CAR regarding "benchmarks" that needs to be addressed in 2008.	High variability within and between forest types.	Inform potential management activities in the Tolt Watershed, MIT habitat efforts and regional forest restoration efforts.
R12 - What is an effective way to sample patch size in potential restoration areas?		Developed in 2008; will be evaluated in 2009.	Increased cost.	Inform regional forest restoration efforts.
R13 – At what spatial scale should restoration treatments be applied?		Tbd.	High variability within and between forest types.	Inform potential management activities in the Tolt Watershed, MIT habitat efforts and regional forest restoration efforts.

2.9 Adaptive Management and Evaluation

It is only through monitoring that we will know whether we are successful in achieving the goals and objectives of the upland forest habitat restoration program. Because data collection can be expensive and time consuming and SPU is committed to asset management, it is essential that monitoring data be collected to evaluate program effectiveness for the purpose of informing future management decisions and actions. All upland forest monitoring will be designed to address management needs, with a clear adaptive management feedback loop to inform future management decisions. In addition, it will focus on those actions or techniques that will be repeated, so that learning is relevant to programmatic decisions, and will utilize at least some indicators with near-term responses that can provide timely information for the design of future restoration treatments.

Currently identified knowledge gaps and questions regarding restoration effectiveness are listed in Table 2.10 along with the attributes and indicators that will be sampled in order to address those questions. We also identify the trigger points that indicate when we might change our management course as well as the time frame when we expect results relative to the question at hand. The variety of projects that have been completed for which monitoring efforts are underway are also listed in Table 2.10.

Adaptive management, in which learning is explicitly defined as a project goal, is critical because of the uncertainty involved with forest habitat restoration and the experimental nature of some restoration techniques. An adaptive management approach enables us to implement management actions even when faced with some uncertainty regarding the outcomes, while not requiring the statistical rigor of a traditional ecological research experiment. Adaptive management is considered to be intermediate between traditional natural resources management (which often uses best professional judgment to achieve land management goals and does not test assumptions or collect data used to inform future management decisions) and traditional ecosystem scientific research (which tests hypothesis within a strict statistical design, but often is focused on a very narrow question and not on management goals) (Holling 1978, Walters 1986, Lee 1993).

There are two types of adaptive management (Walters and Holling 1990, Marmorek 2003):

- **Passive adaptive management** entails monitoring a single type of management activity or technique and responding to pre-established trigger points or ranges with specified management actions. The choice of technique is based on what managers believe to be the most favorable model for how a treatment will affect the ecosystem. The treatment is often conservative, involving a small risk of adverse environmental impact. This method has been used in CRMW upland forest habitat restoration, because the complexity and cost is less than when employing active adaptive management.

Table 2.10. Plan for applying monitoring and adaptive management to address upland forest restoration knowledge gaps in the CRMW (see underlined knowledge gaps listed in Table 2.8)

Knowledge Gaps and Specific Restoration Effectiveness Questions	**Attributes/ Indicators** (relate attributes to trigger points)	**Trigger Point** (more specific trigger points will be developed for specific projects)	**Time Frame**	**Possible Actions**	**Relevant Projects***
Can restoration activities accelerate LS characteristics?	Live Trees, Standing Dead and Down Wood, Forest Canopy and Foliage Distribution, Horizontal Structure	No modeled or demonstrated progress toward benchmark conditions.	20-50 years	More aggressive restoration design, follow-up treatments, better project site selection.	UW Experiment, 700 Rd ET, 45 Rd ET, RT Thinning Trial, other RT projects, Lower Shed Planting Trial
What are tree growth responses to various thinning treatments?	Live Trees, Forest Canopy	Diameter, height, or crown growth response neither maintained nor increased.	10-20 years	More aggressive restoration design, follow-up treatments, or better project site selection.	700 Rd ET, 45 Rd ET, RT Thinning Trial, other RT projects
R9 – How do forest canopies and foliage distribution develop over time with and without restoration treatments in different forest types?	Forest Canopy and Foliage Distribution	No tree crown response, understory regeneration or crown elongation	10-20 years	More aggressive restoration design, follow-up treatments such as canopy gap creation, understory thinning, or planting, or better project site selection.	UW Experiment, 700 Rd ET, 45 Rd ET, RT Thinning Trial, other RT projects
R10 – How does species diversity change in lower forest strata with and without restoration treatments in different forest types? **Also:** Is changing overstory structure adequate for restoring plant species diversity?	Foliage Distribution	No increase in species diversity with restoration	Within 10 years	Follow-up treatments such as canopy gap creation, understory thinning, or planting	UW Experiment, 700 Rd ET, 45 Rd ET, RT Thinning Trial, other RT projects, Lower Shed Planting Trial
Is there an increased windthrow effect with various thinning treatments?	Volume of down wood, residual overstory density	Increased volume of down wood relative to untreated areas	Within 10 years	Less aggressive restoration design, plan for windthrow, site selection	UW Experiment, 700 Rd ET, 45 Rd ET, RT projects

Table 2.10 (continued). Plan for applying monitoring and adaptive management to address upland forest restoration knowledge gaps in the CRMW

Knowledge Gaps and Specific Restoration Effectiveness Questions	Attributes/ Indicators	Trigger Point	Time Frame	Possible Actions	Relevant Projects
What are the long-term results (e.g., longevity, plant species composition, edge tree growth, etc.) of creating canopy gaps of various sizes?	Gap persistence, understory development and regeneration, edge tree growth	Rapid gap closure, low diversity of understory vegetation	Within 10-15 years	Larger gaps, follow-up treatments such as planting and vegetation management	Green Valley Project, UW Experiment, 700 Rd ET, RT Thinning Trial, Other RT projects
How do skips develop and function in a thinned matrix?	Compare live tree and dead wood attributes to other patch types	Windthrow, low use by wildlife, others TBD	10-20 years	Larger skips, smaller skips, better located skips around key features (e.g., snags)	UW Experiment, 700 Rd ET, 45 Rd ET; RT Thinning Trial, other RT projects
What is the response of key wildlife to restoration and ecological thinning treatments?	Key wildlife species (presence/absence, abundance)	No increase in pre-existing species, no new species detected	2-10 years	More aggressive restoration design, follow-up treatments such as canopy gap creation, understory thinning, or planting.	Bat monitoring: 700 Rd ET, 45 Rd ET
How effective is planting in changing future overstory species diversity in second-growth forests?	Survival and growth of planted species	Poor survival, poor growth	10-20 years	Select better planting sites, stock, vegetation management, and/or change overstory density	Lower Shed Planting Trial, Green Valley Project, 45 Rd ET, 700 Rd ET
What is the decay process of snags created from different species, sizes, and creation methods? **Also:** What is the relative use of these snags by wildlife?	Snag decay class over time, snag longevity, snag use	Short longevity, slow decay rates, limited use	Within 2-20 years	Determine “best” methods, species, and sizes	Created Snag Study, Shotgun Creek Fungal Inoculation and Snag Study
Do large volumes or surface areas of downed wood impede understory plant development?	Down wood volume, understory development	Impeded understory development	Within 10 years	Change restoration designs as needed to meet ecological objectives	UW Experiment, 700 Road ET, RT
Does leaving a large amount of downed logs increase the risk of bark beetle outbreak?	Down wood volume, bark beetle populations, mortality from beetles	Excessive mortality from beetles	Within 5-10 years	Change restoration designs as needed to meet ecological objectives	BPA Bark Beetle Study

Table 2.10 (continued). Plan for applying monitoring and adaptive management to address upland forest restoration knowledge gaps in the CRMW

Knowledge Gaps and Specific Restoration Effectiveness Questions	Attributes/ Indicators	Trigger Point	Time Frame	Possible Actions	Relevant Projects
Does piling smaller diameter logs (log bundling) provide the functions (i.e., amphibian habitat) of large diameter logs?	Amphibian use, decomposition, soil processes	No use by amphibians	2-10 years	Do not pursue further log bundling	Barneston Blowdown ET
How long do created log piles last?	Log pile longevity	Short duration	Within 10 years	Change restoration designs to account for reduced longevity	Barneston Blowdown ET; BPA Log pile study;
What species use created log piles?	Presence of species on or near the piles (remote cameras, direct observation, sign)	No use of created piles	2-10 years	Change log pile design, location	Barneston Blowdown ET; BPA Log pile study;
Do different designs of created log piles have different relative habitat use?	Presence of species on or near the piles (remote cameras, direct observation, sign)	No use of certain designs of created piles	2-10 years	Change log pile design, location	Barneston Blowdown ET; BPA Log pile study;
Are lichen, bryophyte, mistletoe, heart rot, etc. at similar levels in second-growth forests and late-seral forests?	Plant diversity in select locations	Low diversity, unexplained by other factors (e.g. air pollution)	Within 10 years	Incorporate planting these species into restoration projects	Started with cryptogam study.
What is the relative success of different methods of lichen seeding, mistletoe transplant or fungal inoculation into second-growth forest?	Survival, growth and reproduction	Poor survival or growth, no reproduction	Within 10 years	Change restoration designs to account for results	Shotgun Creek fungal inoculation. Lichen and mistletoe projects not commenced yet.

* UW (University of Washington), ET = Ecological Thinning, RT = Restoration Thinning

- **Active adaptive management** is designed to provide more information about the ecosystem being modified by using a range of treatments, and often more rigorous scientific protocols. However, it may involve greater risk of adverse impact if there is great uncertainty about some treatments and thus requires additional statistical rigor, such as randomized controls and replicates, and consequently greater effort, resources, and cost. The advantage of active adaptive management is that a range of treatments can be evaluated for success in achieving management objectives, resulting in a greater likelihood of interpretable results. However, because of the increased cost and risk, we will this approach on a limited basis to address specific questions.

We will use a combination of both active and passive adaptive management approaches in designing upland forest habitat restoration project monitoring.

Most project monitoring designs will incorporate a pre- and post-treatment design (sample the same site before and after treatment), plus a treatment/control design (sampling both treated and similar non-treated areas through time). These designs can be used to assess a single treatment repeated across different sites or different treatments repeated across similar sites. Project monitoring results with the widest possible area of inference will provide the greatest future management utility. Therefore, monitoring similar projects installed in areas throughout the watershed will be a priority. For a complete discussion of monitoring and adaptive management see the Strategic Monitoring and Research Plan for the Cedar River Municipal Watershed (Nickelson et al. 2008).

Where necessary, some limited traditional research projects may be required to investigate poorly understood upland forest processes, and to test assumptions about cause-effect relationships (e.g., tree, shrub, and herb response to different understory light regimes in different vegetation associations). These will be done on small research plots in collaboration with research institutions such as the University of Washington.

There are four general types of monitoring that apply to upland forest restoration, all of which are encompassed in the adaptive management framework. Each is briefly described below.

2.9.1 Compliance monitoring

Compliance monitoring is required for most upland forest restoration projects, and is designed to provide quality control, ensure contract specifications are met, and in some cases to meet legal requirements. It answers the question "Was the restoration action installed as designed?" If not, we will document how the installation varies from the design in an "as-built report" that is appended to the project plan. Compliance monitoring involves the installation of a series of compliance plots, especially in the case of restoration and ecological thinning projects, which indicate whether the intended residual tree density, species composition, and patchiness were achieved. Compliance monitoring also checks on other contract specifications, such as slash disposal, use of biodegradable oils, sanitation, and other contractual details.

2.9.2 Effectiveness monitoring

Effectiveness monitoring examines the degree to which restoration actions and techniques meet the specified ecological objectives. Each project team will delineate specific objectives and develop hypotheses about the type, magnitude, and time frame of the changes expected by restoration actions. Effectiveness monitoring will assist in answering questions like: "Did the project result in the anticipated, positive changes in forest ecosystem structure and function, alter the resistance factors acting as thresholds to transition, or increase the current forest habitat value?" This type of monitoring will be done for selected individual projects, and will be designed, as part of adaptive management, to evaluate the effectiveness of upland forest restoration techniques across several projects and areas.

2.9.4 Validation monitoring

In addition to the three types of monitoring discussed above, we may also do limited validation monitoring. We often proceed on the assumption that "if we build it, they will come." Validation monitoring would be designed to test whether that assumption is valid by monitoring certain wildlife species to see if they begin using created habitat elements, or if their population indices increase in response to a management action. Due to the high cost, variability, and difficulty in sampling wildlife populations, this type of monitoring will be very limited, and will be focused on projects where the uncertainties are highest or the risk of undesired effects is greatest.

2.9.5 Long-term trend monitoring

The CRW-HCP mandates that long-term trends in upland forest habitat be monitored so that landscape-level effects of the CRW-HCP can be documented and tracked through time. Monitoring long-term trends in the forest on a watershed-wide scale will:

- document the range of conditions and variability of the forest in a statistically valid manner;
- monitor the change in condition, extent, and location of forest types;
- document the cumulative effects of both habitat restoration projects and natural recovery in the future;
- provide greater understanding of the natural processes we are influencing through management activities; and
- identify new and track ongoing threats to ecological processes, functions, and wildlife habitat.

The framework for long-term ecological monitoring of upland forests is the grid-based system of upland forest PSPs that samples the forest throughout the CRMW (Munro et al. 2003), supplemented by vegetation plots from numerous projects. Repeated remote sensing data, such as MASTER or LiDAR, will also contribute to long-term trend monitoring across the landscape.

3.0 FRAMEWORK FOR PRIORITIZING, SELECTING, DESIGNING, AND IMPLEMENTING FOREST HABITAT RESTORATION PROJECTS

It is important to prioritize where forest habitat restoration actions would be most ecologically beneficial and cost-effective, so that the level of effort and funding is efficiently applied. If all potential areas that might benefit from active restoration in the CRMW were treated, the level of available funding would be far exceeded. The Landscape Synthesis Plan helps to prioritize restoration areas on the landscape scale. Within the framework set by the Synthesis Plan, this section of UFR Strategic Plan sets out the prioritization framework for selecting and prioritizing upland forest restoration project sites within or near high synergy areas. This prioritization framework uses a set of forest attributes and their associated indicators to guide prioritization of restoration efforts.

While we ultimately want to affect the ecological processes that are associated with the development and functioning of late-successional forest ecosystems, the processes are difficult to measure as specific criteria. Therefore, as mentioned previously, structural attributes serve as surrogate criteria for the processes in which we are interested. This section along with Appendix G addresses these criteria for each of the three restoration program types.

The prioritization framework moves from the larger spatial scale to the smaller spatial scale to focus on habitat connectivity, maintaining multiple forest development trajectories at multiple spatial scales, and the most appropriate restoration effort. The upland forest prioritization is an iterative process wherein larger areas are prioritized within high synergy areas, then project areas are selected within those areas in each restoration program, and finally individual project sites are prioritized within the project areas for particular restoration treatments.

3.1 Conceptual Framework for Applying Forest Restoration Treatments

Upland forest restoration will be conducted in second- or third-growth forests only. No restoration interventions will be implemented in old-growth forest ecosystems, as these are protected by the CRW-HCP and provide a reference for restoration activities. Similarly, second-growth forests that have well-developed structural complexity and species diversity will be lower priority for restoration activities (such as certain forests in the lower Taylor Basin), as they are already meeting many ecological needs as outlined in the CRW-HCP. If these well-developed second-growth forests are manipulated, the activities would be done to meet specific learning objectives or ecological objectives. The ecological objectives would be focused on increasing species diversity (for example, by planting cyanolichens that are associated with older forests) or structural complexity (for example, by thinning understory hemlock, creating snags and gaps in forest structures that have resulted from past forest management activities). These areas will also be used for comparative purposes and may serve as benchmark stands for restoration activities in less structurally complex and adjacent second-growth areas.

3.2 Landscape Synthesis Prioritization Guidance and Development of Restoration Candidates

The Landscape Synthesis Plan (Erckmann et al. 2008) identified old-growth and complex second-growth forests as the foci around which forest restoration activities should occur to improve habitat connectivity of late-successional forest. Five distinct "high synergy areas" were identified in that plan, providing a landscape-scale prioritization framework (see "Areas of Synergy" Map in Appendix E of the Synthesis Plan). The Synthesis Plan, however, does not tackle the issue of current conditions and whether restoration is needed in these high synergy areas. Therefore, within these high synergy areas, forest habitat data has been and will be collected from areas where restoration could be warranted. This field based data can then be used to accurately describe forest attributes, compare existing conditions to DFCs in forest growth projections, prioritize restoration efforts within larger project areas, and design appropriate treatments to achieve restoration objectives.

Staff has already used a combination of remotely sensed data, the synergy layer of the Synthesis Plan, and field-based inventory data for planning both the restoration thinning and ecological thinning programs. In 2006, the pool of remaining potential restoration thinning forest stands was identified using average canopy height information derived from LiDAR data. All forests that had an average canopy height between 3 feet and 30 feet were selected, excluding areas that have been manipulated since the HCP inception, which resulted in the delineation of approximately 12,000 acres. These identified forest stands (called the "restoration thinning candidates") were then scored based on synergy layer weightings, and ranked to provide a prioritization of 100 stands (ranked 1-100) encompassing approximately 7,000 acres. These potential thinning sites were then evaluated in the field; forest stand data were collected to describe existing species composition, diameter distribution, tree height, and other variables. This stand exam data is then analyzed within the context of the larger project area and within the unit to prioritize which candidates should actually undergo restoration manipulations and helps to define the restoration design.

Potential ecological thinning projects areas have also been selected from the synergy layer, including:

- Taylor Creek Basin
- Barneston Blowdown Area
- Cabin Creek & Boulder Creek Area
- North Fork and South Fork Cedar River Confluence
- South facing slopes above Cedar River (between 100 and 121.1 roads) and along the Cedar River above Camp 18

Forest habitat inventory data were collected in these areas from 2005 through 2007. Recent forest habitat inventory information was also collected in portions of the lower watershed that reflect high to moderate synergy. All combined, there are inventory data for approximately 8,000 acres of potential ecological thinning within these higher priority synergy areas.

Staff evaluated Upland Restoration Planting candidate sites for tree stocking in 2002 and 2003. These sites included most recently harvested areas as well as areas that had been difficult to plant (e.g. the south side of Little Mountain). Staff concluded that none of these sites needed higher tree stocking with conifer species, as they all supported a minimum of 190 trees per acre. Upland Restoration Planting projects are now tightly linked with the restoration and ecological thinning programs, since it is difficult to use remote sensing data to identify independent planting sites. Planting to diversify species composition will be prioritized, in conjunction with thinning projects, in high synergy areas and appropriate sites within larger project areas.

3.3 Applying Tools – Thinning, Planting and Protection in Forest Habitat Restoration

The specific upland forest habitat restoration tools – thinning, planting and protection – will be integrated within projects, across the landscape and over time as much as possible. In many cases, restoration planting projects will be dependent on forest structural manipulation via thinning in order to be effective in meeting ecological objectives. For example, a second-growth forest may be dominated by a western hemlock or Pacific silver fir overstory, while a stump survey indicates that more mixed species (western redcedar, Douglas-fir) were present in the original forest. In order to shift the species composition, planted trees must have growing space in the second-growth forest, so thinning or gap creation, possibly by creating snags and/or down wood, would be needed. Table 3.1 shows how planting for different ecological objectives might be integrated with thinning activities. In many cases, no action may be the best option for portions of project areas and larger portions of the landscape.

Table 3.1. Objectives for planting different species groups

Species Group	Planting Objectives	Appropriate Forest Conditions
Trees, shrubs	Species diversity and niche diversification; vertical diversification; enhancing carbon sequestration, productivity, and nutrient cycling; compete with invasive species	In conjunction with restoration thinning or ecological thinning, removal of invasive species
Herbs	Species diversity	To be determined, depending on the species
Lichens, bryophytes	Replacing species lost due to past management or other forest impacts (e.g. acid rain); enhancing nutrient cycling	In older second-growth forest
Mistletoe, pathogens	Replacing species lost due to past management or other impacts (e.g., acid rain); vertical diversification	In second-growth forest and/or in conjunction with ecological thinning

Restoration planting does focus on species groups beyond trees and shrubs. While forest structural changes may also be required for effective planting of other species groups, such as herbs and lichens, it is possible that restoration planting alone will be sufficient in some situations. For example, if lichen surveys indicate that lichen diversity is lower than expected in naturally regenerated second-growth and/or old-growth forests but the structural conditions exist to support them, then restoration planting experiments may proceed independent of any other manipulations.

While this plan sets forth specific criteria for prioritizing thinning and planting restoration activities, the interventions should be done in an adaptive management context. For example, there is much to be learned about how thinning alone can increase understory plant species diversity, so the need for concurrent restoration planting with thinning projects must be evaluated. Factors may point to a need for planting, such as relatively diverse tree species in the primary forest and reduced species diversity in the regenerated forest. For example, in the 700 Road Forest Habitat Restoration Project, thinning and gap creation is being implemented without specific restoration planting plans, but the understory species diversity will be closely monitored for the first 3-5 years post-thinning. If the post-thinning understory diversity is low, then active restoration planting will be implemented. As another example, new ideas regarding restoration planting, such as introducing hemlock mistletoe to increase the development of unique crown structures in western hemlock, have not been tried. These uncertainties point to the need for experimentation when applying such innovative restoration activities.

3.4 Prioritization Framework

While the Landscape Synthesis Plan establishes a landscape prioritization framework, it provides no information on current conditions of target ecosystems. The more specific prioritization framework and criteria of the UFR Strategic Plan guides the restoration project site selection, prioritization, and design. Once high and medium priority sites are selected using the decision tree (Figure 3.1), then key attributes and indicators with program areas are used to further refine the site prioritization.

3.4.1 Decision Tree for Initial Project Site Prioritization

The following decision tree (Figure 3.1) will help to prioritize potential forest habitat restoration sites for project planning and implementation. This decision tree sorts projects into the forest habitat restoration programs within which specific site selection prioritization criteria must be used.

3.4.2 Attributes and Indicators: Criteria for Final Project Site Selection

These key attributes describe both the current conditions of existing stands within high synergy areas and the desired future conditions of those forests. Forest growth modeling, primarily using the USDA Forest Vegetation Simulator (FVS) and its modules, will enable comparison of current conditions to desired future conditions. If modeling indicates that existing (untreated) forests will reach the specified benchmarks within a specified time frame, then no active restoration will be done. However, if modeling indicates that existing forests will not attain benchmarks within a specified time frame while specific restoration treatments will facilitate that attainment, then active restoration interventions will be designed and implemented in some areas. As in the development of benchmark conditions, additional data sources will be used in conjunction with model outputs to aid decision-making about restoration treatments.

Table 3.2 describes the stand-level key attributes and indicators that will be used for project site selection and prioritization within high synergy areas. Forest stands that meet the described indicators are highest priority candidates for restoration. Table 3.3 addresses additional factors that will be considered when selecting and prioritizing restoration sites. These factors affect project implementation efficiency, cost effectiveness, and continued learning potential and will be considered in final selection of restoration sites. These attributes, indicators, and other factors are described in more detail in Appendix G.

Figure 3.1. Decision Tree for Implementing Prioritization Framework from the Synthesis Model to the upland forest habitat restoration programs and their specific site selection criteria.

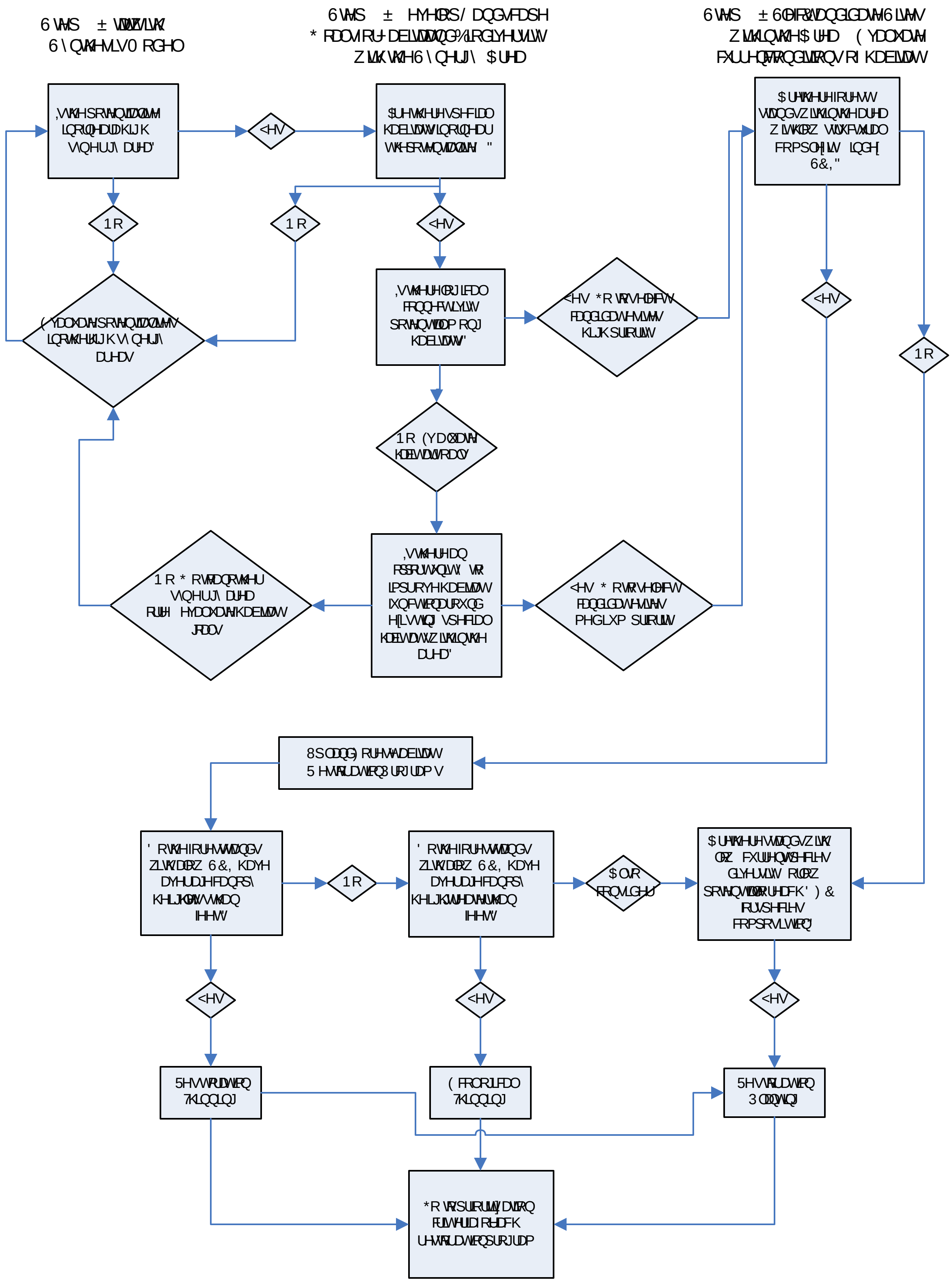


Table 3.2. Stand-scale restoration project site prioritization criteria for upland forest restoration programs in the CRMW.

Project Type	Attribute	Indicator
Restoration Thinning	Tree Density	>1,000 trees/acre
	Tree Diameter	<8" dbh
	Tree Age	15-30 yrs
Ecological Thinning	Tree Density	400-1000 trees/acre
	Tree Diameter (average or QMD)	>8" dbh
	Tree Diameter Distribution	Narrow, unimodal
	Stand Density Index/Relative Density	>290 SDI, >50 RD
	Tree Age	30-60years
	Canopy Closure	>90%
	Site Class	III, IV
	Live Crown Ratio	>40%
	Canopy Layering	1 layer
	Tree Species Diversity (abundance)	1 species >50-80%
	Understory Development (ground cover)	<10%
	Understory Species Diversity (abundance)	1 species >65%
	Snag Density Index and Sizes	<2/acre, >15" dbh & >20' tall
	Downed Wood	<500 ft^3/acre, >6" diameter
	Horizontal Structural Diversity	Homogeneous
Restoration Planting	Tree Stocking	<190 trees/acre
	Tree Species Diversity (abundance)	1 species >80%
	Understory Species Diversity (abundance)	1 species >65%

* RT = Restoration Planting, ET = Ecological Thinning, UP = Upland Planting

Table 3.3. Factors to consider when selecting restoration project sites for optimized efficiency, effectiveness, and learning opportunity.

Factor	Reason	Decision Criteria
Project Area Size	Efficiency	Minimum 5 acres for RT and 10 acres for ET
Road Access	Efficiency, cost, risk management	Must have drivable access for ET, must have fire tools within 5 minute turn-around for RT
Tree Diameter Distribution	Effectiveness	Wider range of diameters presents more opportunity for response; narrower range in greater need for treatment
Plant Species Diversity	Effectiveness	Higher tree species diversity presents more opportunity for treatment response; lower species diversity has greater need for treatment
Specific Wildlife Benefit	Effectiveness	Specify wildlife benefit in objectives
Affordability/Cost Effectiveness	Efficiency	Must be affordable with HCP or other funds
Restoration Method	Effectiveness	Minimize soil and residual stand damage; ensure cost effectiveness
Likelihood of need for re-entry	Efficiency, effectiveness	Minimize need for re-entry to be able to maximize use of funds across watershed
Monitoring Efficiency – learning objectives	Learning opportunity	Ensure road access or reasonable pedestrian access for monitoring time frame
Cultural Resource Probability	Efficiency, risk management	Check cultural resource probability layer and adjust project area boundaries to minimize impacts; coordinate with P/CP Manager
Water Quality Impacts	Risk management	Avoid impacts by site selection and project design

All of these prioritization criteria and additional considerations are also used during the project design phase of project planning. There may be additional attributes and factors that are also considered in project design, and staff will include these elements in the detailed project plans.

3.5 Evaluation of Cost Effectiveness

The HCP requires certain expenditures of funds for restoration project implementation, and these funds must be allocated to optimize the benefits of restoration work. Certain selection and prioritization criteria will substantially affect project implementation cost as well as ecological effectiveness. A highly cost-effective project would have low cost and be effective in reaching ecological goals. We will strive to prioritize and implement restoration projects that are the most cost-effective. Clearly, access to a restoration site can affect the cost, where limited access will increase the cost and feasibility of implementing the project. Access limitations may also affect the feasibility of long-term project monitoring. Forest structural conditions can also affect project cost, such as if a forest has high stand density, small tree diameters, and species with low market value (e.g., western hemlock and Pacific silver fir).

Highly effective projects are those done in forests responsive to restoration activities and that are predicted to meet the defined benchmark conditions in a specified time period. Criteria that indicate potential responsiveness, and therefore ecological effectiveness, include live crown ratio, site class, and species composition, to name a few. Analysis of historic data from permanent sample plots in the lower watershed indicates that higher productivity sites may be more responsive to restoration treatments (Larson et al., 2008) than lower productivity sites. Conversely, it is often the lower productivity sites that exhibit slower stand differentiation and development of complex forest structures, and therefore may be higher priority areas for restoration action within a landscape context.

Both cost and ecological effectiveness may be affected by woody accumulations and potential removal of wood from the restoration sites. In a thinning project, if all cut trees are left on the site, the residual down wood volumes may inhibit the development of desired ecological responses, such as understory development. Conversely, leaving logs to stay within natural levels of downed wood can produce substantial ecological value (Harmon et al. 1986). Removing woody biomass that has limited market value can be extremely costly, until new markets, such as biofuels, develop. In thinning projects where the cut trees do have market value, such as in ecological thinning, and when the cut trees are not needed to meet ecological objectives, then the value of the logs can actually carry the cost of project implementation. This "goods for services" arrangement is critical for implementing the ecological thinning program, in particular, because funding is limited for project implementation.

Opportunities exist to pair highly cost-effective projects (low cost, high ecological effectiveness) with relatively cost-ineffective projects (high cost, high to moderate ecological effectiveness) in order to implement certain projects that might otherwise be cost-prohibitive. For example, the US Forest Service has used stewardship contracts in order to complete high cost restoration work that offset by a more lucrative commercial thinning project. Similarly, the 700 Road Forest Habitat Restoration Project included restoration areas that cost money to implement along with restoration areas that produced some income to offset the cost of HCP implementation. This model could be used to pay for forest restoration activities that are implemented in forests with smaller diameter trees with limited marketability.

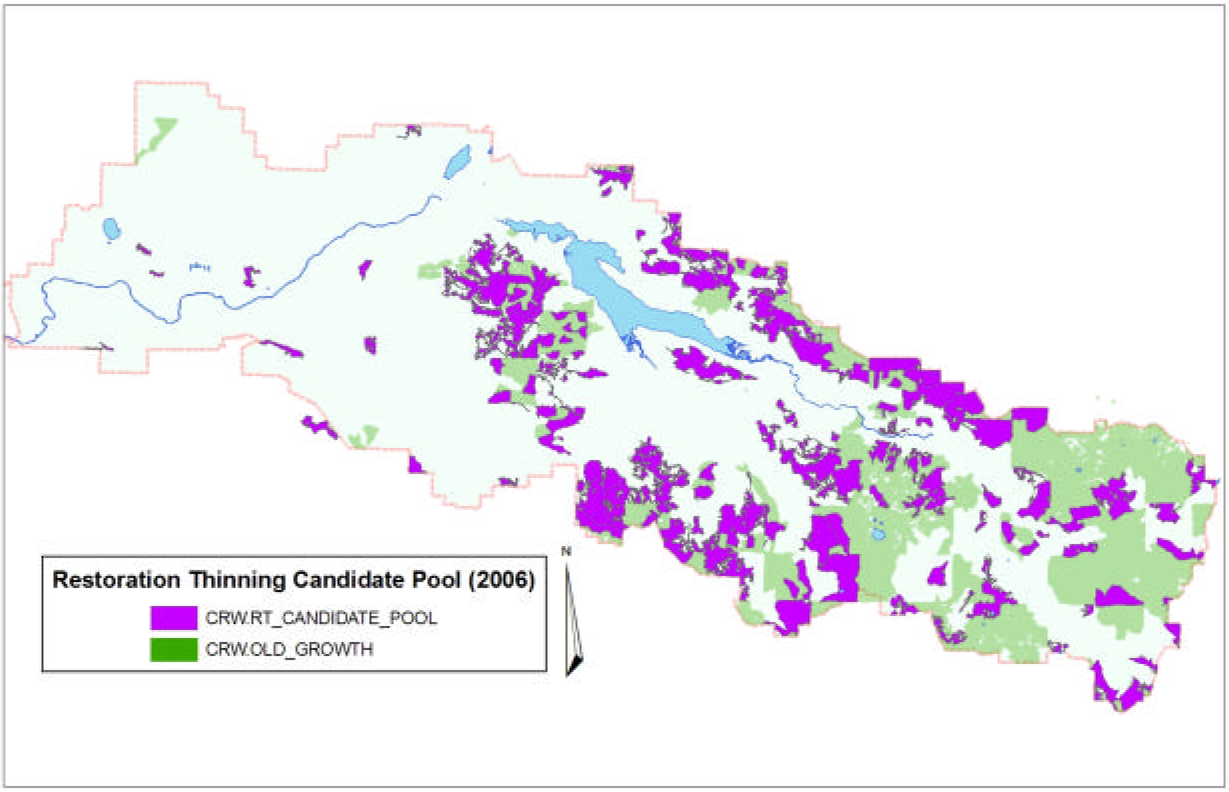
3.6 Near-term List of Forest Habitat Restoration Projects

The following sections detail how near-term candidate sites have been identified in recent years for the different forest habitat restoration programs. Each near-term list is consistent with the prioritization framework described above.

3.6.1 Restoration Thinning Candidate Pool

The restoration thinning candidate pool development was described above in Section 3.2. As of 2006, approximately 6,000 acres has already undergone restoration thinning. Another 4,500 acres must be completed in order to meet the minimum HCP target of 10,500 acres by 2015. The restoration thinning candidate pool is ranked according to the synergy layer weighting scheme. The candidates are ranked 1-137, with unit 1 having the highest priority and unit 137 having the lowest. Due to current conditions, not all candidate units will be treated, nor will all of the acres of candidates be treated. Stand inventory data have been collected on thinning candidates 1 through 57, and data are needed on the remaining units in order to best inform site prioritization, selection, and restoration thinning design.

Figure 3.2. Restoration Thinning candidate pool in the CRMW as developed in 2006.



3.6.2 Ecological Thinning Candidate Sites

Taylor Creek Basin – Consultants collected forest inventory information in the Taylor Basin in 2005, before the Synergy layer was completed. It is moderate priority in the synergy layer, as it serves as a connectivity zone between the upper and lower watershed. Staff are finalizing a Basin Plan for this area that will identify ecological objectives and project focus areas within the basin. Once the Basin Plan is complete, a project team will commence planning for ecological thinning implementation in priority focus areas in 2010.

Barneston Blowdown Area – This project area has a moderate priority in the synergy layer, as it serves as a connection zone between mature forest in the lower Taylor Basin and Rock Creek. It is also near the 14 Lakes area and adjacent to habitat improvement projects along the Bonneville Power Administration right-of-way. The Barneston project is being planned to increase species composition and diversify the developmental trajectories of young Douglas-fir plantations that were planted in 1984 after blowdown salvage operations and subsequently thinned to 300 trees per acre (TPA). Approximately one-third of the area will remain at 300 TPA, while another third will be moderately thinned and planted with diverse species and the final third will be heavily thinned and planted with deciduous species. Gaps will be included in all three thinning treatments. Implementation is planned for 2009.

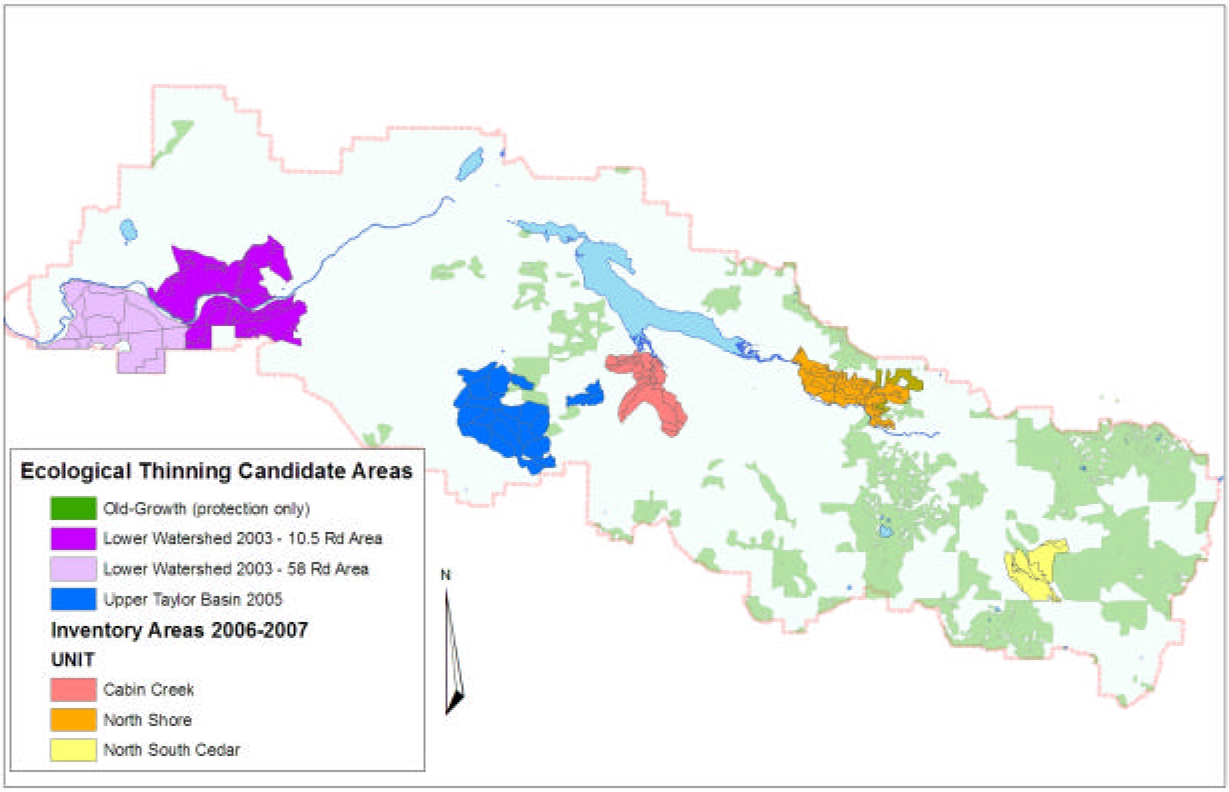
Cabin Creek/Boulder Creek Area - This area has high priority in the synergy layer due to its proximity to the reservoir and the Boulder and Rex River systems. It also has connectivity along these river systems to old-growth forest in the upper elevations. Consultants collected inventory information in this area in 2006-2007. Staff need to analyze inventory information and prioritize project areas for implementation in the coming years.

North Fork and South Fork Cedar River Confluence Area- This area has high priority in the synergy layer due to its proximity to the North and South Forks of the Cedar River and their confluence, as well as proximity to old-growth forest patches in the area. Consultants collected inventory information in this area in 2006-2007. Staff need to analyze inventory information and prioritize project areas for implementation in the coming years.

North Shore Cedar Area (South facing slopes above Cedar River between 100 and 121.1 roads and along the Cedar River above Camp 18) - This area has high priority in the synergy layer due to its proximity to the reservoir, the Cedar River, special habitats and old-growth forest patches at higher elevations on the north ridge. Consultants collected inventory information in this area in 2006-2007. Staff need to analyze inventory information and prioritize project areas for implementation in the coming years.

With all of these ecological thinning candidate areas, staff need to consider road decommissioning needs as well as other restoration priorities and incorporate those factors into the planning and implementation schedule for ecological thinning. For example, the 121.1 Road is necessary for implementing ecological thinning with tree removal from the North Shore Cedar Area, and it is a mid-slope road with multiple stream crossings that is a high priority for decommissioning.

Figure 3.3. Ecological Thinning candidate areas in the CRMW as identified between 2003-2007.



3.6.3 Restoration Planting Candidate Sites

Candidates arise from species composition criteria (Figure 3.1 and Table 3.2) as information on current conditions is obtained through forest inventories. As indicated above, this inventory information is usually associated with planning thinning projects. However, restoration planting opportunities also can be identified with the same data and will often be implemented in conjunction with thinning projects because we need to create growing space in order to change species composition of existing stands. Some areas may be considered "understocked" with trees by traditional forest standards (e.g., south side of Little Mountain), but at a stand, basin or landscape perspective, we have determined that they provide important heterogeneity in cover and habitat types. All of the youngest clearcuts were inventoried for stocking levels in 2003, and staff found no areas that needed stocking improvements. Therefore, the priority for planting trees in the upland restoration planting program is to increase tree species diversity relative to current conditions.

Specific projects may be designed and implemented that are not tied to thinning projects (Table 3.1). Examples of these include introducing species diversity in areas where appropriate structure already exists (e.g., lichen seeding or planting in natural gaps), using upland planting to prevent the establishment or spread of invasive species, and experimental use of native tree pathogens to alter forest structure and reintroduce natural processes. Lichen and bryophyte surveys from 2007 and 2008 will guide where experimental planting of non-vascular plants might be beneficial and effective. Additional scoping of where less common vascular plants, like orchids, might be planted to restore native diversity needs to occur and will draw upon extensive plant inventories that have already been completed in the CRMW. Refer to Appendix C for additional information on planting non-traditional species.

4.0 STANDARDS AND GUIDELINES FOR PLANNING AND IMPLEMENTING FOREST HABITAT RESTORATION PROJECTS

This section describes the standards and guidelines that are expected for both planning (Section 4.1) and implementing (Section 4.2) forest habitat restoration projects. These standards and guidelines are drafted with the advantage of hindsight, since several projects have already been planned and implemented.

4.1 Standards and Guidelines for Planning Forest Habitat Restoration Projects

4.1.1 Project Site Selection

The process for selecting restoration sites is outlined in Section 3. Once staff have completed the landscape to stand level analysis, they identify the initial project site(s) and the ecological objectives for those sites. Staff may also indicate the types of treatments that should be planned in more detail to meet the objectives. The UFRIDT Lead then sets the timeline for project planning and implementation and strives to stay consistent with CRW-HCP performance commitments over time.

4.1.2 Project Team Assignment

The UFRIDT will recommend membership for project teams for the selected project sites, usually consisting of three people with appropriate expertise. These recommendations will be presented to the Watershed Ecosystems Section Manager and affected Work Unit Leads, who will have final approval of all projects and project team composition. The project team will conduct an in-depth analysis, design the project, and prepare a project management plan. Consultants may be employed to augment staff resources, if that is determined beneficial to the ecological outcome and workload management and is cost-effective. The Forest Ecology Work Unit will coordinate field layout (e.g., boundary tags and right of way marking), required permit application and acquisition, appraisal, contracting, and where applicable, city ordinance acquisition.

4.1.3 Project Plan Development

The project team will consider the site selection process that has occurred thus far, including the landscape, basin, and stand level criteria. They will familiarize themselves with existing conditions of the project site and any project objectives or special considerations that have already been defined. The project team will consult the “special considerations” map layers that were developed by the Landscape Synthesis Team, in order to determine if there are special considerations or constraints to the project site.

The team will discuss and prepare a basin plan and/or a project plan depending on the scope of the assignment from the UFRIDT, following the templates that have been established by prior projects and described in Appendix H. Once project sites are selected, project teams will develop project plans that describe the restoration project(s) for the site. In some cases multiple restoration projects will be components of one overall basin plan, as in the case of Taylor Basin, wherein the Basin Plan identifies key project sites, ecological objectives for those sites, and suggested treatments. Further, an ecological thinning project site may have an upland restoration planting project as an integral part of the overall goals and objectives, as in the case of the Barneston Project. In this case, one project plan will incorporate both the ecological thinning and the upland restoration planting components.

Format of project plans will generally follow the outlines provided in Appendix H. Project plans are intended for a varied audience (from the general public to experts) and their value is both immediate and long-term. The plan will serve as a guide for implementation as well as providing detailed information to interest groups and other agencies regarding HCP-related activities. These plans will provide information to City Council members and staff, especially where city ordinances are required (as in ecological thinning). The plans, along with any "as-built documents" will also provide an historical perspective of HCP-related restoration activities and information necessary for long-term monitoring activities.

Project plan development will generally include the following steps:

- delineate site boundaries based on ecological characteristics and logistics;
- obtain site description and forest inventory data, if needed, and analyze data;
- identify project goals, objectives, current conditions, and desired future conditions, including benchmarks between current conditions and the ultimate DFCs;
- identify key ecological processes and related attributes;
- state hypotheses guiding interventions and effects on processes, including conceptual models;
- identify measurable indicators of processes;
- describe monitoring activities, including hypotheses and indicators, protocols, and sampling schedules, following the Science Information Quality System (SIQS) methodology if applicable;
- develop silvicultural prescriptions and examine alternatives;
- develop transportation and yarding plans as applicable;
- conduct a cultural resource survey, if needed;
- perform a risk analysis, including any potential effects on water quality, as well as an analysis of the risks and uncertainties both of implementing the project and of leaving the area untreated;
- perform a cost/benefit analysis, considering the total project costs and the relative ecological benefit; and

- develop an implementation schedule.

The development of silvicultural prescriptions will stem from the ecological objectives and desired future conditions of the restoration project, using the best available science. The Project Team must consider operational feasibility during project design. The transportation system must meet the regulatory requirements, and pose no long-term environmental risk. New road construction will be avoided.

Throughout prescription development, the project team may solicit input from Watershed Services Division interdisciplinary teams, professional consultants, or scientists with appropriate expertise, as well as consulting current scientific literature. Prescriptions will be site-specific, but may also address larger monitoring and research questions as appropriate within the CRMW. Because restoration projects are being planned and implemented in an adaptive management approach, there should be specified objectives related to learning (i.e., reducing uncertainty and increasing our understanding of ecological processes and methods to restore those processes). The monitoring component of the plan should elaborate on these objectives, including the development of questions and hypotheses for each objective. The monitoring plans contained within project plans will be sent to the Monitoring ID Team for review.

The plan should describe the relationship of this project to other upland, riparian, aquatic, or road restoration projects. If the project is part of a sub-basin-scale set of projects, a brief description of the sub-basin restoration plan should be provided and reference made to any larger plan of which this project is a part.

4.1.4 Project Plan Review

The project plan will first be made available for SPU internal review, starting with other Watershed Ecosystems Section staff and the Watershed Ecosystems Section Manager. Following or concurrent with internal review, the project plan may be made available for external review, including scientific experts, forest practitioner colleagues, and stakeholders, depending on the type and complexity of the project and the issues involved. In addition, other interested parties (including environmental organizations such as the Sierra Club and Conservation Northwest, Tribes, and neighboring landowners) will be contacted as appropriate and their input solicited. Clear review objectives and processes should be provided up front with the release of the document. In some cases, the review will be informational only, but in other cases substantive feedback will be desired and incorporated.

For ecological thinning projects that entail sale of logs, the project plan will accompany an ordinance to the Mayor's office for staff review, if the annual wood volume to be sold exceeds 250,000 board feet. If the project plan requires Seattle City Council approval in order to implement the project, then it is imperative to seek stakeholder review several months ahead of the Council presentation.

Staff will also present information on upland forest restoration activities in the CRMW to a broader audience, including presentations at workshops, symposiums, and conferences, and, in some cases, publication in peer-reviewed journals. When appropriate, on-site workshops, lectures, and field tours relating to restoration activities will be hosted by Watershed Ecosystems staff. The intent of this public outreach and involvement is to share CRW-HCP restoration objectives and activities with a varied audience. Staff will make efforts to share project outcomes on the HCP website over time. The ideal result will be that the public and other managers, scientists, and restoration practitioners are informed about the restoration activities implemented under the CRW-HCP.

4.1.5 Coordination With Other Restoration Projects

The UFRIDT will oversee coordination with other restoration projects by participating in annual and long-term basin level planning efforts and by working with the Monitoring ID team. This coordination will address such issues as selecting project sites that best fit into the long-term landscape restoration plan, timing of road decommissioning, timing of construction projects, and coordination of monitoring.

4.1.6 Contracts and Permits

The Forest Ecology Work Unit will be responsible for developing, advertising, and awarding implementation contracts for forest restoration projects, unless delegated otherwise. Likewise, the Forest Ecology Work Unit will be responsible for developing and submitting Forest Practice Applications (FPAs) for forest restoration projects, although consultation may be needed with other staff members.

4.2 Standards and Guidelines for Implementing Forest Habitat Restoration Projects

Once the project plan is complete, the project team lead, in consultation with the Forest Ecology Work Group supervisor, will oversee project implementation. Components will generally include:

- layout of boundaries, roads, and yarding systems;
- contract development, including development of clear specifications for project implementation (i.e., criteria for how trees are selected for thinning, limitations regarding snags, downed wood, leave trees, etc.);
- forest practice application and notification;
- contract advertisement and award;
- baseline monitoring;
- contract administration and compliance monitoring during treatment implementation;
- post-treatment monitoring;
- project evaluation; and
- reporting in the form of an as-built document to determine any changes that occurred to the final project design.

City of Seattle Department of Executive Administration Purchasing Services will be utilized to assist designated Watershed Ecosystems staff in contract language development, advertisement, contract award, and subsequent payment.

The project team will ensure that seasonal ecological issues (e.g., access issues, sensitivity of trees to bark damage, nesting seasons) are taken into consideration during project implementation. Data collected for project planning, baseline monitoring, compliance monitoring, costs, and other purposes will be compiled, formatted, and stored in the appropriate files, as designated by the Watershed Characterization ID team.

It is anticipated that at least an average of 62-acres of ecological thinning project will be implemented annually over the first 16 years of the CRW-HCP and 40 acres annually over the remaining years. In most cases, we expect that larger projects will be planned, up to 500 acres, and implemented over several years, in order to produce ecological benefits on the scale appropriate to many species of concern. In some cases, small projects not requiring yarding of trees may be planned to create gaps or habitat patches with particular characteristics. Most major ecological thinning projects will be subject to a 3-year effort, including phase I (site selection and prioritization), phase II (planning), and phase III (implementation). Ideally, in any given year there will be at least one project in each of the phases.

Similarly, it is anticipated that restoration thinning will occur on approximately 700 acres annually until the highest ranked restoration thinning candidates are treated. The effort to complete individual restoration thinning projects will generally be subject to a 2-year timeline, combining phases I and II into a single planning year and phase III occurring in the second year.

Upland planting projects will be applied primarily in conjunction with ecological thinning and restoration thinning projects, as well as with road decommissioning and invasive plant species control projects. These planting projects have target levels that are specified within certain timeframes of the HCP, which estimates that 1,000 acres will be planted over 50 years.

4.3 Project Budgets

Project costs will be tracked throughout the planning, implementation, and monitoring phases of every project. Administered by the Forest Ecology Work Unit lead or assigned delegates, staff time and contract costs will be tracked through the City financial tracking system. Alternative funding sources may be used to supplement the SPU budget through grants, use of volunteers, collaboration, or other sources (e.g., BPA Mitigation Fund). Any revenues resulting from the sale of surplus thinned trees that are removed from project sites will be deposited in the SPU Water Fund to offset costs of HCP implementation, and surplus logs may be made available to the Muckleshoot Indian Tribe pursuant to the 2006 Settlement Agreement between the Tribe and the City. A portion of any revenues may be used to offset upland forest restoration planning and implementation costs, but this budget authority must be approved by the Seattle City Council via ordinance.

5.0 Oversight Role of the Upland Forest Restoration ID Team

Once this strategic planning process is completed, the ID Team will focus efforts in two areas. First, the Upland Forest Restoration ID Team will assist with implementing adaptive management, in partnership with the Monitoring and Watershed Characterization ID Teams. Through the Adaptive Management program, the ID Team will help to coordinate individual restoration project selection and design, such that the key questions can be addressed through consistent planning and monitoring. Coupled with this role, the ID Team will review individual project management plans and provide guidance on the design of those plans such that they are consistent with this Strategic Plan and the Synthesis Plan. In addition, members of the team will analyze monitoring data as they become available to continue to refine and improve techniques for upland forest restoration, again, in coordination with the Monitoring and Watershed Characterization ID Teams. Members of the ID Team will work to establish a review process to track and facilitate the collection of data to inform long-range site selection and prioritization.

Second, The ID Team will also assist in recommending project teams and work with the ID Team lead to set realistic timelines for project completion. The ID Team, will not, however, oversee all activities of the project teams that are working directly on individual project plans, but rather serve to ensure consistency and long-term vision to the range of individual projects that are planned and implemented.

6.0 Summary and Tactical Plan

Several items require follow up in this version of the UFR Strategic Plan, including:

- continue to develop reference conditions from the literature and from existing stands in order to provide benchmarks for restoration project design and effectiveness monitoring;
- resolve the question regarding the appropriate overall level of ecological thinning to substantially improve habitat suitability for at-risk species in the CRMW landscape;
- continue to develop landscape-scale attributes from remote sensing data to describe forest habitats across the CRMW;
- evaluate impacts of climate change on watershed forests and develop strategies to mitigate and adapt to those impacts;
- continue scoping where planting of non-traditional plant species might improve ecosystem function and biodiversity;
- continue to practice active adaptive management in restoration project design and implementation, focusing on key questions that are documented in Tables 2.8-2.10 and also others that may arise during program implementation;
- continue to network and dialog with scientists and practitioners in the forest restoration and forest science community; and
- strive to learn from our mistakes.

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APPENDIX A: Glossary

Adaptive Management – As applied in the CRW-HCP, the process of adaptive management is defined with three basic elements: 1) an initial operational decision or project design made in the face of uncertainty about the impacts of the action; 2) monitoring and research to determine the impacts of the actions; and, 3) changes to operations or project design in response to new information.

Aspect – The direction a slope faces with respect to the cardinal compass points. For example, a hillside facing east has an eastern aspect.

Basal Area – The cross sectional area of a tree at breast height, usually summed by species over a given area.

Biodiversity – Biological diversity; the combination and interactions of genetic diversity, species composition, and ecological diversity in a given place at a given time.

Biological Legacies – As defined in the CRW-HCP: Features of a previous forest that are retained at timber harvest or left after natural disturbances, including old-growth or other large diameter snags, stumps, live trees, downed wood, soil communities, deciduous trees, and shrubs. Also referred to as legacies.

Canopy – The cover of branches and foliage formed collectively by the crowns of trees or other growth. Also used to describe layers of vegetation or foliage below the top layer of foliage in a forest, as when referring to the multi-layered canopies or multi-storied conditions typical of ecological old-growth forests.

Canopy Closure – The degree to which boles, branches, and foliage (canopy) block penetration of sunlight to the forest floor.

Cedar River Municipal Watershed (CRMW) – An administrative unit of land owned by the City of Seattle for the purposes of providing a municipal water supply. The 90,546-acre municipal watershed within the upper part of the Cedar River Basin lies upstream from the City's water intake at Landsburg Diversion Dam. It is composed of eight major sub-basins and 27 sub-basins, 26 of which drain into the Cedar River. It supplies about 2/3 of the drinking water to Seattle Public Utilities' water service area.

Clearcut – A silvicultural system involving the removal of nearly all standing trees within a given harvest area.

Co-Dominant Trees – Trees or shrubs with crowns receiving full light from above, but comparatively little from the sides. Crowns usually form the general level of the canopy.

Competitive (Stem) Exclusion – A phase of forest succession in which the canopy closes and competition among trees becomes intense in a developing forest area. This successional stage is often low in species diversity.

Compliance Monitoring – Monitoring performed to determine whether CRW-HCP programs and elements are implemented as planned.

Conifer Trees – A tree belonging to the taxonomic order Gymnospermae, and comprising a wide range of trees that are mostly evergreen. Conifers bear cones and have needle-shaped or scale-like leaves.

CRW-HCP – Cedar River Watershed Habitat Conservation Plan; see Habitat Conservation Plan.

Decay Class – One of five recognizable stages of wood decay as a fallen tree decomposes and is reincorporated into the soil. Factors that categorize stages of decay include bark and twig presence or absence, log texture and shape, wood color, position relative to the ground, and presence or absence of invading roots (Maser and Trappe 1984).

Deciduous Trees – Flowering trees, belonging to the taxonomic order Angiospermae, with relatively broad, flat leaves, as compared to conifers or needle-leaved trees.

Diameter at Breast Height (dbh) – The diameter of a tree in inches, including bark, measured 4.5 feet above the ground on the uphill side of the tree.

Differentiation – Differential tree growth in a forest stand that results in trees occupying different amounts of growing space and therefore having different competitiveness. Differentiation can be observed in both diameter growth and height growth.

Disturbance – Significant change in forest structure or composition through natural events (such as fire, flood, wind, earthquake, or disease) or human-caused events (forest management).

Dominant Tree – Trees with crowns receiving full light from above and partly from the side; usually larger than the average trees in the forest area, with crowns that extend above the general level of the canopy and that are well developed but possibly somewhat crowded on the sides. A dominant tree generally stands head and shoulders above all other trees in its vicinity.

Downed Wood – Large pieces of wood in forests, including logs, pieces of logs, and large branches.

Ecological Thinning – As defined in the CRW-HCP: The silvicultural practice of cutting, damaging, or otherwise killing some trees from some areas of older, overstocked, second-growth forest (typically over 30 years old). The intent of ecological thinning is to encourage development of the habitat structure and heterogeneity typical of late-successional and old-growth forest areas, characterized by a high level of vertical and horizontal forest structure, and to improve habitat quality for wildlife. It is expected that techniques will include variable-density thinning to create openings, develop a variety of tree diameter classes, develop understory vegetation, and recruit desired species; and creating snags and downed wood by uprooting trees, felling trees, topping trees, injecting trees with decay-producing fungus, and other methods. Ecological thinning does not have any commercial objectives. However, in those cases in which an excess of woody material is generated by felling trees, trees may be removed from the thinning site and may be sold or used in restoration projects on other sites.

Ecosystem Function – The roles played by the living and nonliving components of ecosystems in driving the processes (e.g., carbon, water, and nutrient cycles) that sustain the ecosystem.

Ecosystem Process – Something that is going on in the ecosystem; a natural phenomenon in an ecosystem that leads toward a particular result or function.

Effectiveness Monitoring – Monitoring to determine whether implemented CRW-HCP conservation strategies result in anticipated habitat conditions or effects on species.

Epicormic Branching – Branches that sprout from the bole of a tree, usually when it is subjected to increased sunlight.

Even-Aged Forest – A forest area with minimal differences in age between trees, generally less than 10 years.

Forest Inventory – An assessment of forest resources that describes the location and nature of forest cover (including tree size, age, volume, and species composition) as well as a description of other forest values such as snags, downed wood, soils, vegetation, and wildlife features.

Forest Area – A group of trees that possess sufficient uniformity in composition, structure, age, spatial arrangement, or condition to distinguish them from adjacent groups of trees.

Forest Structure – The arrangement of the physical parts of the forest ecosystem, both vertically and horizontally.

Forest Succession – The sequential change in composition, abundance, and patterns of species that occurs as a forest matures after an event in which most of the trees are removed. The sequence of biological communities in a succession is called a sere, and they are called successional or seral stages.

Geographic Information System (GIS) – A computer system for collecting, storing, retrieving, transforming, displaying, and analyzing spatial or geographic data, linking areas or map features with associated attributes for a particular set of purposes, including the production of a variety of maps and analyses.

Habitat – The sum total of environmental conditions of a specific place occupied by plant or animal species or a population of such species. A species may require or use more than one type of habitat to complete its life cycle.

Habitat Connectivity – A measure of the extent to which conditions between different areas of similar or related habitat provide for successful movement of fish or wildlife species, supporting populations on a landscape level.

Habitat Conservation Plan (HCP) – As defined under Section 10 of the federal Endangered Species Act, a plan required for issuance of an incidental take permit for a listed species. Called "conservation plans" under the Act, HCPs can address multiple species, both listed and unlisted, and can be long term. HCPs provide for the conservation of the species addressed, and provide certainty for permit applicants through an implementation agreement between the Secretary of the Interior or Secretary of Commerce and a non-federal entity.

Habitat Heterogeneity – The degree of variation of physical forms across an area of forest that provide a variety of habitat niches. See "forest structure" and "structural complexity".

Interior (Core) Forest Conditions – Forest conditions that are not largely affected by edge effects, which occur where large openings abut the forest. Edge effects that are know to occur in some areas include penetration of light and wind, temperature changes, and increased predator activity. Interior forest conditions are achieved at sufficient distance from an edge so that edge effects are minimal.

Landscape – A large regional unit of land that typically includes a mosaic of biological communities.

Late-Successional Forest – Forest in the later stages of forest succession (e.g., after the competitive exclusion stage), the sequential change in composition, abundance, and patterns of species that occurs as a forest matures. As used in the CRW-HCP, refers to conifer forests 120-189 years of age. Characterized by increasing biodiversity and forest structure, such as a number of canopy layers, large amounts of downed wood, light gaps (canopy openings), and developed understory vegetation.

Lower Watershed – That area of the Cedar River Municipal Watershed generally west and south of Cedar Falls which largely drains to the mainstem of the Cedar River downstream of Masonry Dam.

Mean Annual Increment – The annual average growth rate for a tree.

Metapopulation – A set of local populations connected by migrating individuals.

Monitoring – The process of collecting information to evaluate if objectives and anticipated results of a management plan are being realized or if implementation is proceeding as planned. This may include assessing the effects upon a species' habitat.

Old-Growth Forest – As used in the CRW-HCP, native, unharvested conifer forest in the Cedar River Municipal Watershed that is at least 190 years of age.

Old-Growth Forest Conditions – Conditions in older conifer forest areas, with vertical and horizontal structural attributes sufficient to maintain some or all of the ecological functions of natural "ecological old-growth" forest, which is typically at least 200 years old and often much older.

Overstory – That portion of the trees, in a forest of more than one story, forming the upper or uppermost canopy layer.

Quadratic Mean Tree Diameter (Qdbh) – The diameter at breast height (dbh) of a tree of average basal area in a given forest area; generally slightly larger than the average dbh.

Regeneration – The seedlings and saplings existing in a forest area; the act of establishing young trees naturally or artificially (replanting).

Relative Density (RD) – A measure of tree density in a forest area indexed to an observed maximum for a species over various diameters; generally describes tree growth potential based on density. As defined by Curtis (1982), relative density for Douglas-fir is $BA/(Qdbh^{0.5})$, where BA is basal area and Qdbh is the quadratic mean stand diameter, and ranges from 0 to 100.

Restoration Planting – Planting of native trees, shrubs, and other plants to encourage development of habitat structure and heterogeneity, to improve habitat conditions for fish and wildlife, and to accelerate development of old-growth forest conditions or riparian forest function in previously harvested second-growth forest.

Restoration Thinning – As used in the CRW-HCP, a silvicultural intervention strategy applied in the Ecological Reserve in areas of young (usually 10 to 30 year-old) over-stocked forest with the intent of increasing biological diversity and wildlife habitat potential, accelerating the development of mature forest characteristics, and minimizing the amount of time a forest area remains in the competitive exclusion stage (a stage characterized by minimal light penetration and low biological diversity). This strategy protects water quality by reducing the risk of large scale catastrophic damage to the watershed (primarily through development of windfirmness and increased resistance to insect attack, which is exacerbated by the stress on intense competition among trees). Techniques for restoration thinning include cutting, girdling, or otherwise killing some trees in variable density thinning patterns, retaining a mix of species that is characteristic of natural site conditions, and leaving small gaps or openings characteristic of naturally regenerated forests that result from small natural disturbances such as wind or disease.

Second-Growth Forest – Forest areas in the process of regrowth after an earlier cutting or disturbance.

Seral Stage – A particular stage (ecological community) in a sere, or pattern of succession. As used in the CRW-HCP, applies to forest succession.

Silviculture – The theory and practice of controlling the establishment, composition, growth, and quality of forest areas in order to achieve management objectives. Includes such actions as thinning, planting, fertilizing, pruning, and leaving seed trees at harvest.

Site Class – A classification of forestland based on ecological factors (e.g., soils) tree growth potential.

Slope – A measure of the steepness of terrain, equal to the tangent of the angle of the average slope surface with the horizontal, expressed in percent. A 100 percent slope has an angle with the horizontal of 45 degrees.

Snag – A standing dead tree.

Species Assemblage – A group of species that is expected to be at a certain site and may often serve as an indicator of a particular site or plant association.

Structural Complexity – The degree of variation of physical forms across an area of forest (e.g., tree density, tree size, canopy layering, snags, downed wood, understory vegetation). See “forest structure” and “habitat heterogeneity”.

Successional Stage – Phases of forest development have been identified as various stages; generally as stand initiation, competitive exclusion, understory reinitiation, and old-growth forest stages (Oliver 1981), although development complexity has also been recognized (Franklin et al. 2002). See “forest succession”.

Tree Density – The number of trees over a given area. Traditionally this has been expressed as trees with a commercial value (e.g., greater than 6 inches dbh) per acre. For forest restoration in the CRMW, it is more appropriate to look at tree density in terms of canopy strata.

Understory – All forest vegetation (e.g., herbs, shrubs, seedlings, smaller saplings) growing under an overstory (e.g., taller trees and shrubs).

Upper Watershed – That area of the Cedar River Municipal Watershed generally east of Cedar Falls which drains to the Chester Morse Lake Basin.

Watershed – A basin contributing water, organic matter, dissolved nutrients, and sediments to a stream, lake, or ocean. As applied in the CRW-HCP, used also to refer to the Cedar River Municipal Watershed above the Landsburg Diversion Dam and water intake, some of which does not drain into the Cedar River above the Landsburg water intake.

Windthrow (aka Blowdown) – Trees felled by high wind.

APPENDIX B: Upland Forest Restoration Programs – Restoration Thinning, Ecological Thinning, and Restoration Planting

Restoration Thinning: When the tree density of a young forest is particularly high, thinning can have a beneficial effect on biological diversification (Carey and Johnson 1995, Carey and Curtis 1996, Hayes et al. 1997). Prescriptions will vary by site and will include creating variable spacing and favoring less common species to create a more diverse forest.

The CRW-HCP has committed to spend $2,620,000 (in 1996 dollars) for implementing restoration thinning (exclusive of WMD staff time), including $201,750 per year for the first 8 years and $143,714 per year for the next 7 years (CRW-HCP: 4.2-35). Treatment and implementation costs were estimated at $250 per acre resulting in base treatment objectives of 807 acres per year for the first 8 years and 575 acres per year for the next 7 years (10,480 acres total), though official commitments are in terms of money spent and not acres treated. The cost commitments described above do not include the cost of project design or administration, but these additional costs are covered by the SPU budget for this activity. Currently, our project goals include implementing a restoration thinning project annually on 600 to 1,000 acres, within the constraint that implementation costs do not exceed the annual budget. At this treatment rate, all of the areas that are likely to benefit from restoration thinning are anticipated to be treated in this 15-year period, although some areas will be left untreated intentionally in order to provide a basis for comparison and to allow the currently existing forest development and successional processes to occur.

Ecological thinning: may include thinning of various tree canopy strata, thinning across diameters, creating gaps, and killing or injuring trees to create snags and downed wood or unique features that foster biodiversity. Thinning may also be supplemented by restoration planting (see Section 2.3.3) to increase plant diversity and structural development. Examples of how thinning may be used to achieve these conditions include:

- creating variable spacing among trees, leaving a diversity of tree diameters and heights, and encouraging several canopy layers;
- creating small openings to recruit a diversity of plant species and stimulate growth of large trees, as well as understory trees, shrubs, and herbs;
- increasing light levels to release co-dominant and intermediate-sized trees and advanced tree regeneration;
- retaining desired species and unique trees; and,
- creating snags, downed wood, tree cavities, and other unique tree features where it is determined they are deficient.

The CRW-HCP has committed to spend $1,000,000 (in 1996 dollars) for implementing ecological thinning (exclusive of WMD staff time), including $31,250 per year for the first 16 years and $14,706 per year for the final 34 years (CRW-HCP: 4.2-36). The CRW-HCP estimated treatment and implementation costs at $500 per acre resulting in minimum treatment target of 62.5 acres per year for the first 16 years and 29.4 acres per year for the final 34 years (2,000 acres total). This level of intervention equates to less than 3 percent of the 71,500 acres of second-growth forest in the CRMW. The cost commitments described above do not include the cost of project design, project administration, or removal of some thinned trees from the site; these additional costs are covered by the SPU budget for this activity. The CRW-HCP allows sale of some trees thinned from ecological thinning projects, however, if ecological objectives are met. The CRW-HCP requires that any revenues from ecological thinning be used to offset the costs of CRW-HCP implementation.

Restoration Planting: The CRW-HCP has committed to spend $300,000 (in 1996 dollars) for implementing upland restoration planting (exclusive of WMD staff time), including $9,375 per year for the first 16 years and $4,412 per year for the final 34 years (CRW-HCP: 4.2-34). Treatment and maintenance costs were estimated at $300 per acre, based largely on the cost of planting tree seedlings, resulting in treatment goals of 31.3 acres per year for the first 16 years and 14.7 acres per year for the final 34 years (1,000 acres total). The cost commitments described above do not include the cost of project design or administration, but these additional costs are covered by the SPU budget for this activity. Since few areas have been determined to be under-stocked with trees, the primary program goals include implementing upland planting to enhance biodiversity in conjunction with ecological thinning projects with nonspecific acre targets. As more is known about planting other species that exist in old-growth forest but are lacking in second-growth (e.g., lichens, mosses), upland restoration planting may evolve more specific treatment goals. The costs of planting species other than coniferous trees are largely unknown, but implementation costs will not exceed the annual budget.

APPENDIX C
Upland Restoration Planting Program

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INTRODUCTION

Upland forest restoration planting is a specific program area under the Cedar River Watershed Habitat Conservation Plan (HCP). According to the HCP, upland restoration planting will be used to diversify the plant species composition in previously logged areas. Upland planting will help restore the forests of the Cedar River Watershed to better provide biological diversity, high quality water and late successional habitat. Forested areas "that will receive highest priority for restoration planting will be those that have plant diversity much lower than expected, based on site characteristics, and those with the greatest potential for beneficial results" (CRW-HCP 4.2-34). The restoration planting program aims to return species critical to ecosystem functioning to areas where the establishment, reproduction, or persistence of these species was known or assumed to be reduced by past management of the land.

Disturbance on the landscape yields varied habitats for plant establishment and survival. The scale, severity, and frequency of disturbance influence plant diversity. Disturbance is a natural part of the ecosystems of the Cedar River Watershed, but the scale and severity of disturbance have changed drastically due to substantial logging during the 20th century. Historic disturbances such as windthrow and insect outbreaks would have affected smaller areas than the clearcuts have impacted in the watershed. Historic fires may have covered similar or greater areas than logging, but the impacts would have been more variable. As a result, disturbances that historically provided a heterogeneous ecosystem were replaced by an anthropogenic disturbance (timber harvest) that homogenized the landscape and the habitat for plant species.

Plant species diversity contributes to ecosystem function and is an integral component of late successional forests. Understory vegetation (herbs, shrubs and trees) as well as canopy species (lichens, bryophytes and mistletoe) provide wildlife forage and habitat, contribute to nutrient cycling and forest hydrology, and determine the future species composition of the forest. Insects, forest pathogens (typically fungi), and mistletoe play roles in the mortality of overstory trees, creating gaps in which understory dynamics can continue. Overstory structure is an important factor in determining the diversity and density of plant species in the forest (Halpern and Spies 1995, Thysell and Carey 2001, Peterson and McCune 2003, Lyons et al. 2000). However, we are learning that propagule or seed source availability is an equally important factor, especially in forests impacted by a history of timber harvest (Halpern et al. 1999, Sillett 2000).

In Douglas-fir forests of western Washington and Oregon, research shows that species abundance changes as stands progress through the various stages of stand development but species diversity changes little (Halpern and Spies 1995, Bailey et al. 1998). Many species survive through the stem exclusion phase of forest succession as seeds in the soil seed bank while others re-invade once the overstory conditions are appropriate (Halpern et al. 1999). Therefore, clearcut harvesting and burning appear to have little long-term effect on understory species abundance or diversity (Halpern 1988, Harrington et al. 2002, Bailey et al. 1998). However, species diversity and reestablishment in maturing stands is dependent on dispersal from neighboring patches as well as the seed bank (Halpern et al. 1999).

We expect that our ecological thinning projects, emphasizing canopy openings of various sizes, will result in an immediate increase in understory abundance and a long term increase in or maintenance of understory diversity (Harrington et al. 2002, Thysell and Carey 2001, Halpern and Spies 1995). It is possible, however, that the management history in the watershed has eliminated populations of some species. Altering forest structure is an important first step in providing habitat for the species groups discussed in this plan, however, creating structure may not be sufficient for the reestablishment of all species, especially those that may be dispersal limited.

The approaches used to address restoration planting are varied and encompass traditional and experimental techniques. Due to the uncertainty of success on a landscape scale, non-conventional restoration planting projects in the Upland Restoration Planting Program will be done under an adaptive management framework.

BACKGROUND

Linkages with other restoration programs

Restoration planting of conifers, hardwood trees, shrubs, herbs, rare plants, cryptogams, mistletoe, fungi, and soils may be implemented to augment other restoration efforts including ecological thinning, restoration thinning and road decommissioning. Planting can occur in otherwise untreated forests, but it would be dependent on the existence of appropriate overstory structure. Therefore, linking with restoration projects that alter forest canopy structure will often lead to a more cost-effective and successful planting project. Appropriate structure for understory planting is generally going to mirror the goals of other restoration projects. For example, including lichen habitat as an objective in thinning prescriptions would yield forests with hardwood gaps and large overstory trees with existing lichen populations (Neitlich and McCune 1997).

Coordination with each of the other restoration programs in the CRMW HCP can also serve to augment the benefit the goals of those programs. For example, a portion of the snag creation in ecological thinning can be accomplished by planting heart-rot in trees; tree species diversity in restoration thin units can be greatly enhanced by planting after thinning; and soil stabilization can be achieved on decommissioned roads by the establishment of early successional native species.

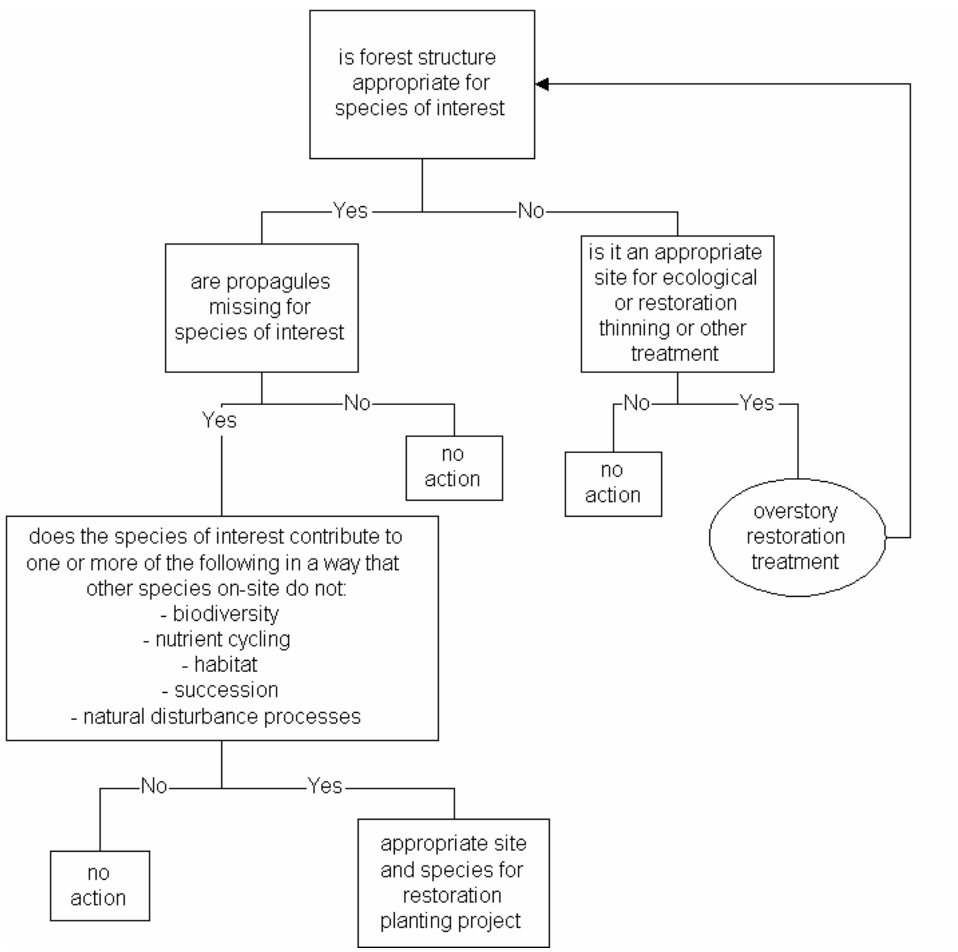
Planting of Non-Traditional Species

Although work to date has focused on more traditional planting projects (typically trees and shrubs), planting of non-traditional species (e.g., herbs, shrubs, epiphytes, and pathogens) may also be an important tool for restoring the watershed to provide late-successional habitat and ecosystem function. Each of these groups of species plays an important role in the processes that lead to and maintain late-successional habitat. Shrubs, herbs, foliose lichens, and mistletoe provide cover and forage for wildlife and insects (Hawksworth and Geils 1996). Bryophytes on tree boles and branches absorb rainwater and slowly release it back to the ecosystem, playing an important role in forest hydrololgy (Hutten and Woodward 2002). Cyanolichens are nitrogen fixing and therefore capable of capturing atmospheric nitrogen. When these lichens die and decompose the nitrogen is available to surrounding plants. Fungal pathogens contribute to tree mortality which is one of the primary ways that forest gaps (a key feature in late successional forest) are created.

Species Selection Approach

Planting projects will be implemented that contribute to the ecosystem as a whole (rather than individual species restoration). Characteristics that will be considered when selecting species for planting projects include the contribution of each species of interest to developing biodiversity, supporting wildlife habitat, furthering natural successional processes, and nutrient cycling. Figure 1 shows a decision tree for selecting appropriate sites and species for upland planting. It emphasizes that planting should only occur where appropriate forest structure exists and propagules are absent, and planting should utilize species that contribute to ecosystem processes in a way not already addressed by on-site species.

Figure 1: Decision tree for upland planting species and site selection.



COMPLETED PLANTING PROJECTS

Assessing species composition on the landscape

A variety of previously completed work can be leveraged to provide a baseline for species diversity and abundance in the CRW. Projects and findings are as follows.

Stocking Assessment

An initial goal of the upland restoration planting program for the CRW is the establishment of conifer seedlings in ecologically appropriate areas (e.g., sites with low stocking, sites that were conifer dominated but shifted to hardwood or shrub dominated after logging). Based on historical knowledge, aerial photos, and site visits, some upland forest areas in the CRW that would be expected to support a relatively high tree density were identified as possibly having a low (< 190 trees per acre [TPA]) conifer stocking. Some of these were more closely examined in 2003 to determine their potential for planting. Appendix I contains a description of methods and results for this project. All conifer-dominated areas examined were found to have adequate stocking levels (a minimum of 190 TPA). Though stocking was often quite patchy (between 0-2000 TPA) the average TPA was found to be between 400 and 600 TPA. All hardwood dominated upland areas were found to have conifer regeneration. Some of these sites are prioritized for future restoration thinning to release the conifers from hardwood competition.

Sites were evaluated both individually and in a landscape context. Individual stands were measured to determine current stocking levels and species compositions. Stands that could be prioritized for thinning or planting to conifer may be providing other functions that are lacking on the landscape (such as plant and animal habitat diversity or nitrogen fixation).

Although an attempt was made to examine all understocked or conifer dominated stands using existing information, additional stands will be evaluated for potential conifer planting as they are identified by staff. Occasionally forestry staff members have found a stand with low stocking while they are in the field and these have been reported to the plant ecologist for further evaluation.

Botanical Forays

Coordinated by Clay Antieau, these forays took place in the summers of 2001 and 2002. Volunteers surveyed different areas throughout the CRMW and spent the day creating species lists and collecting specimens that are housed in the University of Washington Herbarium. These lists for specific locations in the watershed provide information about diversity and distribution of the species found.

Permanent Sample Plots and Project Monitoring

A system of Permanent Sample Plots (PSPs) has been established in the CRMW. Data collected includes overstory tree size and species, shrub cover along transects and herb cover in microplots. A species list for the entire sampling area (1/10 – 4/10 acre plots) was also collected. In the summer of 2003, 19 of these plots focused on old growth forest, providing a baseline for understanding the species diversity that we may be trying to achieve through our restoration efforts. Seventy-eight second growth PSPs were completed from late 2003 through the summer of 2004.

Monitoring in ecological thinning and restoration thinning projects includes tree, shrub and herb cover similar to the PSPs. These data will provide information about the current condition of plant diversity in stands that qualify for restoration. These thinning project areas may also be project sites for restoration planting, since thinning is intended to increase habitat complexity and provide microsites for a greater variety of species.

Cryptogam Surveys

In 2001, Tammy Stout (University of Washington) performed a series of surveys of bryophytes and lichens in the CRMW. Although her scope was limited to a few sites, her report provides us with critical information to pair with the PSPs in an effort to characterize old growth conditions and as a way to evaluate current conditions in some forest stands. These surveys will be important to continue, either in conjunction with monitoring or as a separate study to enhance current knowledge. Surveyors should be trained to include mistletoe and heart rot in their data collection. Although Stout's surveys found that richness was greatest in late successional and old growth habitats, moderate in mid seral and lowest in early seral, more detailed information would be useful to our restoration projects. For example, it would help in restoration planning and implementation to better understand the specific species distributions in relation to age, stand structure, and vertical distribution in the canopy. Recommendations at the end of Stout's reports include additional surveys in specific habitats including forest canopies, CWD, and rock outcrops. Surveys in these habitats would help inform upland restoration planting throughout the CRMW, although we may also want to target these surveys in habitats in which we'll be doing restoration projects.

Planting Projects

45 Road Planting: completed December 2003-April 2004

As a result of historic logging and seedling planting, small diameter Douglas-fir trees dominated the 45 Road Forest Restoration Project Area; a low productivity site with limited structural heterogeneity and low biological diversity. This site was not effectively developing towards desired late-successional wildlife habitat. Silvicultural techniques such as ecological thinning and planting can help this site, and other similar low productivity sites, to develop late-successional forest conditions more rapidly. The 45 Road Project Area is located along the western border of the Cedar River Watershed. The Project Area consists of 321 acres, of which 157 were ecologically thinned in the winter of 2003. Stem density was reduced from an average of 200 TPA to an average of 155 TPA. The Project Area is dominated by small (<20 inch diameter at breast height [dbh]) 70 year-old Douglas-fir (*Pseudotsuga menziesii*) trees, with a relatively dense salal (*Gaultheria shallon*) understory. Current species and structural diversity is low. Laminated root rot (*Phellinus weirii*) is present throughout the Project Area.

In December of 2003 a portion of the thinned Project Area was treated with the Hy-Gro Tiller, a piece of equipment that creates plantable spots 3' across and 30" deep. This pre-planting treatment helped remove rocks from the planting spots and reduce brush competition (mainly by removing salal roots from planting sites). Sixty-four acres were planted at a density of 100 TPA in order to diversify the understory of the thinned stand by establishing root-rot and shade tolerant trees. Species planted were western red cedar, big leaf maple, and red alder. In addition, a volunteer planting event on April 17th 2004 provided the labor to plant an additional 300 plants (a combination of western red cedar, big leaf maple, red alder, ocean spray, Indian plum, serviceberry, red elderberry, and snowberry) on landings and in a small portion of the forest. Species were selected that are found on the site, are root rot resistant or immune, and/or can survive in the droughty soil typical of the site. Planting this combination of species will both increase the shrub/hardwood component and diversify the conifer understory. The planted trees and shrubs will provide multiple canopy layers for wildlife habitat, meeting objectives of vertical diversity.

PROPOSED PROJECTS

Assessing species composition on the landscape
Assessment of diversity and proposal for augmentation

Little Mountain

This site was logged and then replanted multiple times, with little to no success. The site is drier and more exposed than many parts of the watershed, likely limiting seedling survival. Based on studies conducted in southwestern Oregon, a lack of soil organisms may also be a factor in limiting tree establishment on the site (Amaranthus and Perry 1987). One more restoration planting treatment can be attempted at this site using more innovative planting techniques than have been tried previously, as well as an adaptive management approach. The site may be planted with a mixture of Douglas-fir, western white pine and Pacific yew, but the planting holes will be first filled with soil collected in a mature forest of similar aspect and elevation in the CRMW. This project will be established as a study design, leaving some planting sites without imported soil, thereby allowing us to better test our assumptions.

Planting in the 700 Road Forest Restoration Project

Ecological thinning targets 30-60 year old overstocked forest stands. Those forests with the least biological and structural diversity and yet the greatest potential for beneficial results are prioritized (CRW-HCP 4.2-37). Three forest management goals specified in the CRW-HCP are addressed by ecological thinning: accelerating the development of late-successional characteristics, providing wildlife habitat and fostering natural biological diversity. Upland restoration planting may aid in achieving these goals in combination with ecological thinning activities, since the dispersal rates of some flora associated with late-successional forests are often low and seed source may be reduced by past land management activities. Upland restoration planting of dispersal-limited biota and other understory species may improve ecological function and biodiversity.

A method to better understand which species may be limited by past management will be to grow in a greenhouse (or other controlled environment) the seeds found in soil samples from the site. This will yield information about what species are expected to establish in thinned areas from what is on-site. Soil would be collected from the site and treated in such a way as to allow for germination and growth of any seeds in the soil. Species would be identified and compared against what is already seen on the site and what establishes naturally in gaps and the thinned matrix. This experiment would provide information about the sources for species establishment (e.g. seedbank versus offsite colonizers). Finally, if it is determined that there are certain species lacking from the community composition in the field, appropriate planting stock could be selected from the plants grown in the greenhouse.

In the 700 Road Forest Restoration Project, overstory will be treated in three different ways: 100% retention, 30-35% overstory basal area removal, and small gaps with nearly 100% removal. Understory response is expected to be different in the three types of treatment. Long-term monitoring plots in the thinning unit that span all three treatments will provide information about changes in cover and diversity of understory herb and shrub species. In addition, comparing understory response in gaps to the results of the seedbank study will provide a method for assessing the effectiveness of gap size in stimulating understory response to increased light.

Improving our understanding of Chronosequence of Species Diversity

One of the biggest upland planting knowledge gaps is a clear understanding of what species exist in the CRMW in relation to stand structure and age. Using effectiveness monitoring and PSP data augmented with additional field sampling we can begin to evaluate the differences between the species we expect to see on the landscape and what is actually there. With the corresponding overstory data, the understory data can be compiled as a chronosequence, similar to the methods used in Halpern and Spies (1995). Results from this project will then help us identify any species that we expect on the landscape (based on evidence in old-growth forests) but are not found to be re-establishing in older second growth stands. Old growth data would come from our sampling plots as well as other local data such as those acquired by the U.S. Forest Service (Jan Henderson) both near and within the CRMW boundaries. Species that are expected but not present in second growth forests would provide an initial list for planting.

This project would combine existing survey data with additional plots to sample herbs and shrubs as well as initiating a set of plots to sample lichens and bryophytes. Other monitoring projects should be leveraged as opportunities for gathering chronosequence data, especially on cryptogams. PSPs and monitoring plots that are established to track ecological responses in recent blowdown should include lichen and bryophyte plots.

Planting Projects

Growing Native Stock for CRMW Planting Projects

Western white pine and Pacific yew, two species that we would like to include in our species mix for conifer underplanting projects, are difficult or impossible to find for our seed zone in commercial nurseries. We will work with commercial growers to collect seed source for these species in the CRMW or nearby, contracting with them to grow out bare root stock that we can use for restoration projects.

Planting in Collaboration with Restoration Thinning

Restoration thinning in the CRMW targets forests less than 30-years-old with trees less than 8" dbh. The majority of these stands are at higher elevations and dominated by Pacific silver fir.

The clearcut harvesting of a Douglas-fir, hemlock and scattered true fir overstory left behind an understory of advanced regeneration Pacific silver fir. These forests are now dominated by Pacific silver fir averaging between 1” to 11” dbh. Thinning in these forests is intended to accelerate the growth of the remaining trees, but little can be done via thinning to alter the species composition. Although thinning targets silver fir and leaves all other tree species (including hardwoods) on the site, the change in composition is very small due to the overwhelming uniformity in starting conditions. Concerns have been raised regarding the resilience of silver fir under climate change and/or disease outbreak and the appropriateness of having this shade-tolerant, typically late-seral species as the initial species in the forest. Planting seedlings (Douglas-fir, western hemlock, mountain hemlock, noble fir, western white pine) in collaboration with restoration thinning and creating gaps could ameliorate the species composition concerns for these forests.

Planting in association with the 700 Road Forest Restoration Project

In addition to the monitoring in the 700 Road, we may plant trees (both conifer and hardwood) in a portion of the canopy gaps. Some of the gaps will be left un-planted to be able to compare natural regeneration with the planted sites. Big leaf maple, vine maple, alder, Douglas-fir and Pacific yew might be species selected for planting in gaps. Planting these species would accelerate the development of diverse trees as wildlife habitat and forage and substrate for epiphyte colonization. Planting of species other than trees on this site is addressed below.

Lower Cedar River Municipal Watershed Experimental Planting

In stands in the upper CRMW our restoration approach will emphasize thinning to reduce light competition to understory plants. However, our assumption in the lower CRMW is that the low level of advanced tree regeneration is largely due to below-ground limitations, understory competition and insufficient seed source rather than light limitations. A large portion of the lower CRMW consists of droughty, low-quality soils. In addition, the history of logging greatly reduced seed source for species other than Douglas-fir and western hemlock. Douglas-fir was planted after logging and fires impacted these areas, and stands are now dominated by heavily competing Douglas-fir trees with very fairly short crowns and open canopies. However, understory tree regeneration is very limited. We will plant a variety of conifer species (such as western white pine, western red cedar where appropriate, Pacific yew) to see if any species will persist in these moisture and nutrient limited soils.

Road Removal

When roads are decommissioned by ripping back the roadbed, seeding or planting helps stabilize the loose soil and restore the site. Seeding has been used to prevent the road surface from becoming impermeable to moisture and future seed establishment. However, seeding with non-native species may also limit the establishment of native seeds dispersed from neighboring sites. Currently, seeding with a three-species mix to capture the site and limit erosion follows road removal activities. Due to current costs, availability, and proven effectiveness, the current mix contains red fescue (native), blue wild-rye (native) and white oats (not native but theoretically will not persist on the site). Possible seed mix compositions will be explored to find affordable alternatives that combine only native species that provide appropriate diversity and erosion control. Additional native species could be added to the mix that maintain current beneficial aspects while also providing others, such as nitrogen fixation, habitat values, and biodiversity. Possible species include fireweed, pearly everlasting, lupine, and mountain hairgrass. Grass species known to occur in the CRMW that would be good candidates for restoration mixes include *Agrostis exarta, A. idahoensis, Calamagrostis canadensis, Danthonia intermedia, and Deschampsia atropurpurea*.

Pulled back roadbeds also provide a unique opportunity for other plantings including trees, shrubs, and forbs. Roads decommissioned in the last few years and upcoming decommissioning projects will be evaluated to assess what is establishing already and identify opportunities to increase diversity on the old roads by planting. There are also special cases where roads were removed at stream crossings. In these critical locations, plantings have been implemented in collaboration with the hydrology group to establish trees, shrubs, or forbs that will serve to stabilize the streambanks over the long term. Utilizing a volunteer workforce can mitigate the higher cost of planting over seeding.

Non-Traditional Planting Projects

Historically, forest management attempted to remove all natural pathogens from forest stands (e.g., mistletoes, heart rot, root rot). As our understanding of the dynamics in forest ecosystems has evolved to include the importance of disturbances, some land managers have begun to explore the use of pathogens in ecosystem restoration in order to restore the ecological functions that these biotic disturbances provide. Planting these types of organisms has rarely been attempted, so these efforts will be experimental in nature.

Mistletoe

Douglas fir dwarf mistletoe (*Arceuthobium douglasii*) does not naturally grow on the west side of the Cascades and therefore we would not use it as a planted pathogen. In contrast, western hemlock dwarf mistletoe (*Arceuthobium tsugense* subsp. *tsugense*) historically is found on the west side. When a tree is infected with mistletoe, it typically forms large, irregularly branched limbs or brooms that provide nesting habitat for various birds and small mammals. As mistletoe establishes on trees it weakens them and mistletoe stem cankers serve as opportunities for decay fungi establishment (Hawksworth and Wiens 1996). Because of the way dwarf mistletoe spreads, trees will be infected in patches. Though mortality from hemlock dwarf mistletoe alone is rare, interactions between dwarf mistletoe and other pathogens (fungi, insects, and diseases) can cause tree death. Trees that die after dwarf mistletoe infestation will likely die in clumps, leaving canopy gaps, a structure critical for old growth development. Because of its impact on timber values, many landowners actively managed against western hemlock dwarf mistletoe in the CRMW until the late 1990's.

By removing overstory trees that were host to mistletoe, the population was likely significantly reduced. In support of this, mistletoe was found in only one of 19 old-growth PSPs in 2003. However, besides the small patch in the PSP near the 215 Road, patches of hemlock dwarf mistletoe have been identified in second growth in the lower CRMW (the 16/40 Road junction and the east side of Williams Creek east of the old 30/33 Road junction). The distribution of hemlock dwarf mistletoe was not captured in PSP surveys, so the extent of existing hemlock dwarf mistletoe in the CRMW (both second and old growth) needs to be assessed through additional field surveys. To assist with this assessment, all effectiveness monitoring and PSP protocols collect data on the presence of mistletoe. If hemlock dwarf mistletoe levels in second growth stands are found to be significantly lower than levels identified in old growth forests, we may pursue a program of inoculating a limited number of western hemlock trees with hemlock dwarf mistletoe seeds. Planting has been tried in an experimental context by more than one researcher, but we do not know of any trials in a restoration context (D. Shaw, personal communication, December 18, 2002).

The intent of re-introducing mistletoe to the CRW would be to create brooms for habitat and possibly lead to the mortality of a few trees, providing snags and eventually canopy gaps. Since mistletoe spread and tree mortality is a slow process (on average it takes 7 years from seed germination to the development of a reproductive plant), our belief is that a light inoculation in localized areas would meet these goals. In sites where broom development is desired, hemlock dwarf mistletoe inoculation may be used to accelerate development of these habitat structures. Dwarf mistletoe also responds readily to increases in light (Hennon et al. 2001). Thinning a stand where mistletoe already exists may increase the presence of brooms and new mistletoe establishment.

Snag Creation via Heart Rot Inoculation

Heart rot is present in the CRMW, but its distribution is likely reduced relative to historical levels because the types of trees that are generally susceptible (older, larger conifers) are greatly reduced from previous numbers (D. Shaw, personal communication, December 18, 2002).

There are stands throughout the CRMW where snag development is desired. In conjunction with ecological thinning projects, inoculation techniques for heart rots may be used to reintroduce these ecological components and their associated processes that occur in the development of old growth forests. Currently, there are several tested snag creation techniques, each providing a different rate of tree mortality (Harris and Seitz 2002). In projects in the CRMW it would be appropriate to use multiple techniques, yielding snags at different points through time, rather than using a single technique which would kill all the trees at roughly the same time. Snag creation techniques include topping or wounding trees and introducing heart rot fungi directly into trees. The two heart rot producing species likely to be targeted for inoculation are *Fomitopsis pinicola* – red belted conk or brown crumbly rot and *Fomitopsis officinalis* – quinine conk or brown trunk rot.

Snag creation using heart rot inoculation could be applied within the context of ecological thinnings. In the 700 Road Forest Restoration Project, the stand has a dearth of snags and a very continuous overstory canopy. The 700 Road Forest Restoration Project is in a mixed conifer stand with tree diameters up to 33 inches. One goal of the thinning is the retention and creation of snags. Some of the trees that are to be left for snags will either be inoculated with a heart rot fungus or topped or scarred to allow the fungus to naturally colonize the tree. Overall, this thinning aims to accelerate the development of old growth characteristics. Heart rot inoculation can be used for snag creation outside the confines of ecological thinning as well.

Lichens and Bryophytes

Forest canopy structure (Lyons et al. 2000) and propagule dispersal limitations (Sillett et al. 2000) both influence lichen and bryophyte abundance and distribution. One of the lichen functional groups that we are most interested in promoting in the CRMW (nitrogen fixing cyanolichens) are found mainly in the moderate light regime of the mid-canopy stratum in large trees (Lyons et al. 2000). Thinning may help provide the habitat required for these lichens to establish, but the propagule source may be unavailable due to both harvest history and the limited dispersal ability of the heavy thallus fragments used for reproduction (Sillett et al. 2000, Neitlich 1993). In addition to light, substrate availability is important for a diversity of epiphytic species to establish (Peterson and McCune 2003, Neitlich and McCune 1997). Neitlich and McCune (1997) found that tree species diversity and stand structural diversity in mid-seral forests led to lichen diversity that rivaled that of old growth forests. Stout (2001) found cryptogam richness in the CRMW to be greater in old-growth and late seral sites than either mid or early seral. Ecological thinning addresses the lack of overstory structural diversity in our mid-seral forests while planting addresses dispersal limitations.

The initial step in this project is to determine the existing species and population levels of lichen groups of interest. Tammy Stout completed initial surveys in 2001. However, Stout's work was limited to cryptogams on the ground or tree boles while most of the species we are interested in increasing occur in the canopy. Additional surveys would be completed as a part of our chronosequence study described above. In addition, we may contract with an expert to identify any species of interest providing both baseline diversity information and identifying propagule sources for planting. This work could take place over a single summer. Meanwhile, we will consult with lichenologists and bryologists who are familiar with this region (B. McCune, P. Neitlich, P. Muir and others), determining which species we want to work with and appropriate planting techniques.

Armed with information about existing lichen diversity, appropriate species and planting techniques for the CRMW, and sources of propagules, we can identify sites for planting. Lichen planting projects should be planned in conjunction with ecological thinning but also independent of thinning. Appropriate post-thinning areas will have low lichen diversity, appropriately open canopy structure, and a lack of neighboring propagule source.

SUMMARY/TIMELINE

The goal of the Upland Forest Restoration Planting Program is to diversify plant species composition in the CRMW. Initial efforts will provide an understanding of where species diversity has been decreased by past harvest and/or where dispersal is limited. Subsequent planting projects will utilize this knowledge to identify priority areas and species for restoration work. With this in mind, Table 1 lays out a chronology with projects to examine existing species diversity and distribution in the CRMW first, followed by planting projects that utilize this knowledge. The chronosequence project, additional lichen/bryophyte surveys, and mistletoe surveys all use existing data for the CRMW and augment with further field work or data collected in nearby areas. This information will help us locate additional projects, similar to those outlined in this plan, where past management has decreased biodiversity and where restoration planting will help reestablish a resilient community of native species.

Table 1: Timeline of proposed projects by quarter.

Project	**1Q 2007**	**2Q 2007**	**3Q 2007**	**4Q 2007**	**1Q 2008**	**2Q 2008**	**3Q 2008**	**4Q 2008**	**2009-beyond**
Chronosequence analysis of existing vascular data	■	■							
Additional lichen/bryophyte surveys (contracted) /Consult with lichen/bryologist experts on planting techniques and species		■	■	■					
Collection of Western white pine seed/establish contract with grower			■						
Plant lichen in an experimental context (as determined appropriate by surveys above)						■	■		
Experimental planting of conifers at a poor site near 10.5 Road				■				■	■
Greenhouse study of plants in 700 Road seedbank			■	■		■	■		
Planting in 700 Road Forest Restoration Project						■	■		
Mistletoe: compile existing data on current distribution, augment as appropriate			■						
Mistletoe: plant in areas identified as appropriate in above effort							■	■	■
Planting of western white pine and other species in restoration thinned areas									■

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Appendix D. Selected studies related to ecological thinning, restoration thinning, and upland planting in the CRMW.

Olympic Habitat Development Study. The principal investigators for this study are Andy Carey and Connie Harrington with cooperators from the Pacific Northwest Research Station (PNW) of the US Forest Service (USFS), Washington Department of Natural Resources (WDNR), University of Washington (UW), and Olympic National Forest (ONF) (http://www.fs.fed.us/r6/olympic/ecomgt/research/habitat.htm and Reutebuch et al. 2002).

- *Goals*: Accelerate development of plant and animal communities and structures typical of late-successional/old-growth forests.
- *Sites:* Blocks of 30 to 70 year-old forest in the Adaptive Management Area (AMA) of the Olympic National Forest on the Olympic Peninsula in western Washington.
- *Methods*: The project includes implementing variable density thinning treatments in a randomized block design experiment. Each of eight blocks contain four or five 15- to 25-acre treatment plots. Treatments used a "thin from below" prescription (e.g., 209 trees per acre thinned to 135, 319 trees per acre thinned to 245) leaving a proportion of canopy, sub-canopy, and understory trees. Less prevalent deciduous and conifer species were also retained. Five treatments were implemented: control; thinning with scattered slash and supplemental downed wood; thinning with scattered slash and clumped supplemental downed wood; thinning with piled slash and clumped supplemental downed wood; and thinning with scattered slash and no supplemental downed wood. Thinning was augmented by 0.1-acre clearcut gaps totaling 10 percent of the area, and 0.8- to 1.5-acre skips totaling 25 percent of the area where no entry was allowed. Gap sizes were intended to simulate those found in old-growth forests, and skips were frequently located to protect existing snags.
- *Status*: Pre-treatment measurements were taken from 1995 to 1998 (including density, diameter, height, basal area, and volume by tree species in each of three strata, cover of shrubs, ferns, herbs, mosses, lichens, and downed wood) in all eight blocks. One 3.5-acre stem-mapped plot was measured per block. Four blocks were thinned in 1997-99. Post-treatment measurements (same as pre-treatment) were taken on the four thinned blocks. Two blocks have had some downed wood treatments. Monitoring will continue for tree growth and yield, understory plant development, use by small mammals, fungal communities, flying squirrels, and amphibians.
- *Results.* The prescription was operationally feasible. Any trees less than six inches in diameter were cut. Cascara was knocked down during thinning, but has since resprouted. There was little damage from the thinning operation to remaining trees. Windthrow occurred but appeared to be unrelated to the treatments (note: windthrow is a large problem in this region). After five years, individual trees in the thinned area are growing faster than those in the skips. Some gaps have a carpet of hemlock. Further treatments will be base on future monitoring results; treatments may include overstory or understory tree thinning.

Multiple-Objective Thinning on the Olympic National Forest. This project is being implemented by the USFS in compliance with the 1994 Northwest Forest Plan (NWFP) (http://www.fs.fed.us/r6/olympic).

- *Goals:* The multiple-objective commercial thinning program is intended to accelerate the process of late-successional forest development by creating conditions that encourage the growth of a diverse understory and complex forest structure that enhances biological diversity.
- *Sites:* Throughout second-growth forests in Late-Successional Reserves (LSRs) and AMAs in the ONF on the Olympic Peninsula in western Washington.
- *Methods:* The project utilizes contemporary thinning prescriptions including variable density thinning, gaps and skips, and maintaining and creating snags and downed wood. Thinning prescriptions generally call for the removal of some of the trees within a certain size range (e.g., 6 to 20 inches diameter at breast height (dbh)) to release the dominant cohort and smaller understory trees (e.g., less than 6 inches dbh), allowing them all to grow more quickly. The upper limit of the cut range is based on the diameters of the dominant trees in the stand, and the desired post-thinning conditions. A post-thinning relative density target of 30 to 40 (see Section 5.3 for explanation) is generally used, except where windthrow is a serious concern or western hemlock is the predominant species, in which case the treatment is based on the removal of approximately one-third of the stand's basal area. Deciduous species, minor conifer species, and damaged and diseased trees are retained to enhance species diversity. Efforts are also made to protect existing understory plants. Techniques to minimize soil compaction and erosion include the use of designated skid trails, narrow cable corridors (e.g., 8 to 10 feet), and partial or full elevation of logs off the ground when using skyline cable yarding systems. Where cut-to-length processors are used to fell and stack trees, they are restricted to the designated skid trails and one 'ghost trail' pass between skid trails as necessary to reach all the trees to be cut. The heavier forwarder must remain on the skid trails.
- *Status:* Currently, thinnings on the ONF are proceeding on a stand-by-stand basis, with interest in developing a comprehensive landscape-based thinning program. Although most thinnings have been conducted in AMAs, the goal of the project is to thin all of the LSRs before they reach 80 years old.
- *Results:* Numerous examples of commercial thinnings took place on the ONF prior to the NWFP provide clues about how thinned areas may develop over time. A site thinned ten years ago where understory plants were retained during thinning operations currently exhibits a well-developed, multi-species understory, with high relative vertical diversity. Another stand, thinned from below in 1978 to roughly 80 trees per acre, currently exhibits a well-developed, multiple-species understory and a diverse undergrowth component. A third stand, also thinned from below with some removal of dominant trees, now contains a well-developed understory of western hemlock, western red cedar, and rhododendron under a Douglas-fir overstory.

Silvicultural Options for Harvesting Young-Growth Production Forests. The principal investigators of this project are David Marshall (USFS), Robert Curtis (USFS), Dean DeBell (USFS), and Jeffrey DeBell (WADNR), with the PNW, WDNR, UW, and the University of Idaho (UI) as cooperating organizations (http://www.fs.fed.us/pnw/olympia/silv/selected_studies/blue_ridge/blueridge_poster.htm).

- *Goals:* The objectives of this study are to evaluate forestry practices and silvicultural systems that can be used to reduce visual impacts of harvesting operations while maintaining a productive forest for future generations. Results will provide managers with data on a range of contrasting silvicultural systems and quantitative information about public response, economic performance, and biological responses of the treatments.
- *Sites:* On 30- to 75-acre plots, replicated at 3 different sites, on the Capitol State Forest in the Puget lowlands in western Washington.
- *Methods*: This study involves six randomly assigned treatments plus controls: 1) clearcut; 2) retained overstory (approximately 15 trees per acre); 3) small patch cutting (clearcut 1.5- to 5.0-acre patches with 20 percent harvested every 15 years); 4) group selection (clearcut groups of trees less than 1.5-acre with thinning every 15 years to maintain the same average basal area as the patch cutting treatment); 5) extended rotation with commercial thinning (repeated thinnings to maintain high growth rates until deferred clearcut); and, 6) extended rotation without thinning (deferred clearcut harvest). All open areas greater than 0.1 acres are planted.
- *Status*: The first replication was installed during the summer of 1998 in a 69-year-old, naturally regenerated site class II (see Section 5.3 for definition) Douglas-fir stand. The second replication of the study was harvested during the summer of 2002 using a cable thinning system. The third replication will be harvested during the summer of 2004. The B.C. Ministry of Forests Research Branch installed a study during 2002 on Vancouver Island near Campbell River, called the Silvicultural Treatments for Ecosystem Management (STEMS) project. The same treatments, plot design, and measurements were used, plus one additional aggregated variable retention treatment was added.
- *Results*: No results are currently available.

Forest Ecosystem Study. The principal investigators for this project are Andy Carey, David Thysell, and Angus Brodie of the PNW-USFS (USFS PNW-GTR-457, 1999).

- *Goals:* To address the development of spotted owl habitat and enhance biodiversity through experimental manipulation of managed areas.
- *Sites:* On two stands of approximately 514 acres on the Fort Lewis Military Reservation in the Puget lowlands of western Washington. One stand was clearcut in 1925 and had two commercial thinnings prior to the study. The second stand was clearcut in 1937 with no previous thinning.
- *Methods:* The study uses a randomized block experimental design, with two blocks per stand. Each block was divided into four 19.4-acre treatment areas to include: 1) a control; 2) variable density thinning with underplanting; 3) flying squirrel den

augmentation with no thinning; and, 4) flying squirrel den augmentation with variable density thinning and underplanting. Thinning was implemented at three intensities in 49 0.4-acre grid cells in corresponding treatment areas: 1) a light thin (thin trees greater than 8 inches dbh to 125 trees per acre); 2) a heavy thin (thin trees greater than 8 inches dbh to 75 trees per acre); and, 3) a root rot thin (remove trees from root rot pockets and thin trees greater than 8 inches dbh to 16 trees per acre). All thins were thinning from below, removing suppressed and subdominant trees. Deciduous trees, shrubs, and all snags greater than 12 inches dbh were retained. Planting was done in heavy and root rot thin treatments, using red alder (*Alnus rubra*), western redcedar (*Thuja plicata*), western white pine (*Pinus monticola*), and grand fir (*Abies grandis*) at a density of 206 trees per acre. Flying squirrel den augmentation has done by installing 24 nestboxes, creating 16 cavities, and inoculating six trees with decay fungi per treatment block. Two or more thinning entries are planned in the future, likely ten years apart.

- *Status:* Baseline monitoring of vegetation, downed wood, small mammals, arboreal rodents, and owls was conducted in 1991-1992. Cavities and nest boxes were installed in 1992, variable density thinning occurred in 1993, and planting was done in 1994. Post-treatment monitoring includes live trees, snags, downed wood, understory vegetation (shrubs and herbs), soil food webs (fungal, mycelia, bacteria, and nematodes), epigeous and hypogeous fungi, arboreal and forest floor mammals, and winter birds. Study sites will be protected from further management for a minimum of 20 years.
- *Results:* Specific cell-by-cell thinning target tree densities were not always reached, but the overall goal of creating a mosaic of variably stocked cells while retaining wind firmness was achieved, with little windthrow occurring even during a severe storm event in 1995. Soil food webs appear resilient to active timber management, although past management does appear to have reduced fungal dominance. Mechanical disturbance during thinning appeared to destroy fungal mats, but impacts on truffle production were brief, and the heterogeneity created by thinning increased sporocarp diversity to a richness that approximates old-growth forest. Past commercial thinning produced stands with understories dominated by clonal natives with numerous exotics present, few shade-tolerant understory trees, and little spatial heterogeneity. Unthinned stands had depauperate understories and low abundances of small mammals and winter birds. Five years after thinning there was increased diversity and abundance of native understory plants, with an ephemeral increase in exotics. Planting is leading to increased spatial heterogeneity. Thinning also had positive affects on forest floor mammals and winter birds. Some arboreal mammals increased, while flying squirrels (initially rare) showed a brief decline, but remain rare. Use of supplemental nest boxes and created cavities increased steadily after installation. By 1995, 80 percent of all nest boxes exhibited use.

The Young Stand Thinning and Diversity Study. This study is being implemented by the Cascade Center for Ecosystem Management, an interdisciplinary team from the PNW-USFS and the Oregon State University College of Forestry (http://www.fsl.orst.edu/ccem/yst/ystd.html).

- *Goals:* The goal of this study is to determine if different thinning, underplanting, and snag creation treatments can accelerate the development of late-successional habitat in 35 to 50 year-old plantations. A primary objective is to better understand how to provide wood fiber while enhancing diversity. The study will assess treatment effects on stand growth and mortality, understory plants (shrubs, herbs, bryophytes), dead wood, chanterelle productivity, small mammal, amphibian, and diurnal songbird abundance and diversity, arthropods, planning and layout costs, thinning costs, soil disturbance, nutrient cycling, and special forest products.
- *Sites:* The study encompasses approximately 1,200 acres, with 16 Douglas-fir stands averaging 74 acres each. Study sites were located on three ranger districts of the Willamette National Forest, in the western Oregon Cascades, and originated from clearcut harvesting 35 to 42 years prior to study initiation in 1991.
- *Methods:* There are four replications of four stand treatments: 1) control (which had about 250 trees per acre); 2) light thin (to 100-110 trees per acre); 3) heavy thin (to 50-55 trees per acre) with underplanting; and, 4) light thin with gaps and underplanting (to 100-110 trees per acre, with two 0.5-acre gaps every five acres). When light thin stands reach a relative density (RD) of 50, they will be thinned to RD 30, with thins expected every 15 to 20 years. Gaps will be precommercially thinned, with the stands maintained at 20 percent gaps. Heavy thins will be thinned to RD 20 when the overstory reaches RD 50, with thins expected every 25 to 30 years. One pre-commercial thin is expected in the understory. Three types of thinning systems will be compared: tractor, cable, and mechanical (harvester/forwarder). All treatments will retain deciduous species. It was proposed to create one snag per acre, with a minimum of 12 inoculated and 12 topped trees per stand.
- *Status:* Baseline data was collected from 1991 to 1994. Thinning took place from 1994 to 1996. One- and three-year post-treatment data have been collected. Snag creation was anticipated to occur in 2001. Permanent vegetation plots (0.25 acres) have been established. It is hoped that the study will continue indefinitely.
- *Results:* Post-treatment residual tree densities averaged 251 trees per acre for the control, 60 trees per acre for the heavy thin, 106 trees per acre for the light thin, and 86 trees per acre for light thin with gaps. Three years post-treatment, bryophyte ground cover (mosses) had no significant treatment effects but was positively correlated with overstory cover. Herb cover was significantly greater in heavy thin and light thin with gap treatments than controls. Short shrubs showed no response and tall shrubs appear to have been set back by thinning damage. Productivity of chanterelle mushrooms declined after treatment, and did not rebound after three years. Thinning had few detectable impacts on small mammals and amphibians, with no species eliminated as a result of the treatment. Deer mouse and ensatina populations increased in the light thin and light thin with gaps treamments, but not in the heavy thin treatment. Trowbridges's shrew decreased in the heavy thin treatment. Bird species richness and diversity increased in all three thinning treatments, with several uncommon bird species present in thinning stand that were absent or nearly so prior to treatment.

New skid trails covered 26-29 percent of the harvested portion of the stand. Harvester and forwarder traffic was found to increase bulk density (a measure of compaction) an average of 11 to 12 percent on undisturbed soil, but there was no evidence that this traffic increased bulk density on old skid trails. Planning and layout costs did not differ between treatments. The mechanized system had the lowest contractor layout costs, followed by the tractor systems, and the skyline system had the highest costs.

Density Management Studies. These studies are being implemented by the U.S. Bureau of Land Management (BLM) in western Oregon (http://ocid.nacse.org/nbii/density/overview.html).

- *Goals:* Determine whether density management treatments result in differences in stand structural characteristics and species diversity. Evaluate the response of various plant and animal taxa to density management. Develop stand-level density management treatments that may accelerate late-successional habitat development while producing wood for the regional economy.
- *Sites:* Seven sites were selected in 40 to 70 year-old Douglas-fir forests on BLM land in western Oregon (in both the Cascade and Oregon Coast Range). Sites are a minimum of 50 acres in size.
- *Methods:* Four treatments were designed: 1) control (200 to 350 trees per acre); 2) high density retention (70 to 75 percent of area thinned to 120 trees per acre, 20 to 30 percent of area unthinned riparian reserves or leave islands); 3) moderate density retention (60 to 65 percent of area thinned to 80 trees per acre, 20 to 30 percent of area in unthinned riparian reserves or leave islands, and 10 percent of area in circular patch openings); and 4) variable density retention (10 percent of area thinned to 40 trees per acre, 25 to 30 percent of area thinned to 80 trees per acre, 25 to 30 percent of area thinned to 120 trees per acre, 20 to 30 percent of area in unthinned riparian reserves or leave islands, and 10 percent in circular patch openings). Within the control, high density, and moderate density treatments, nine 1-acre areas were underplanted with western hemlock and western red cedar trees. Western hemlock, Douglas-fir, western red cedar, and grand fir trees were planted in all patch openings and in the 40 trees per acre areas of the variable density treatment.
- *Status:* Harvesting was 95 percent complete in 2001. Permanent vegetation monitoring plots (0.25 acre) are being installed. Monitoring of stand and vascular plant species development will occur within two years of treatment and then periodically for about 30 years. Plot data will address overstory tree response to density management, snag recruitment, large and small downed wood recruitment and dynamics, shrub and herb dynamics under density management, tree regeneration (planted and natural regeneration), and presence of vascular plant species closely associated with late-successional or old-growth forests within the range of the northern spotted owl.
- *Results:* No results are available.

Experimental Gap Study. The principal investigators of this study are Tom Spies (PNW-USFS, OSU), Jerry Franklin (UW), and Andrew Gray (PNW-USFS) (http://www.fsl.orst.edu/lter/data/abstractdetail.cfm?dbcode=TV025&topnav=135, http://www.fs.fed.us/pnw/sciencef/scifi43.pdf, http://outreach.cof.orst.edu/silvopt/posters/Grayab.htm).

- *Goals:* 1) To examine the long-term response of overstory and understory trees to creation of canopy gaps in mature Douglas-fir/western hemlock forests in the Cascade Range. 2) To uncover the role of gaps in creating forest diversity, their different effects on multi-layered old-growth forests and single-layer mature forests, and their effects on below ground ecosystem attributes such as root density, soil moisture and nutrient cycling. 3) To discover if gaps facilitate the development of late-successional forests.
- *Sites:* Four stands were used, three in the Wind River Experimental Forest in the south-central Washington Cascades and one in the H.J. Andrews Experimental Forest in the western Oregon Cascades. Two stands were old-growth forest (approximately 500 years old), and two stands were naturally regenerated mature forest (88 and 130 years).
- *Methods:* Two circular gaps in each of four sizes (diameters of 0.2, 0.4, 0.6, and 1.0 times the canopy height) and controls were established in each of the four stands (totaling 32 gaps and 8 controls). The largest gaps were 0.5 acre. Overstory trees within 40 to 80 feet of gap edges were mapped and their diameters measured before gap creation and again seven years later. A subsample of trees were cored to quantify growth before and after gap creation. Overstory tree mortality was evaluated annually. Processes studied included tree establishment, survival, and growth, and understory vegetation cover within and surrounding gaps. Solar radiation, air and soil temperature, and soil moisture were also measured. Litter input, decomposition, root density, N-mineralization and N-leaching, soil microbial response and mycorrhizal mats, understory herbs and shrubs, composition and abundance of small mammal communities have also been studied at the sites.
- *Status:* The gaps were created in 1990, with various studies ongoing. This is intended to be long-term study, so sites are protected.
- *Results:* As of 2002, 18 journal articles, theses, and dissertations have been published that address findings from this study (see list at websites above). Key findings include: 1) adjacent old-growth trees had a greater growth response to gap formation (137 percent of pre-gap growth rates) than mature trees (114 percent), and adjacent tree growth increased with gap size; 2) Douglas-fir and other conifer trees can successfully regenerate in a wide range of gap sizes, although Douglas-fir had more success in gaps larger than 1/3 acre; 3) growth of intermediate, shade-tolerant trees tended to be greater on north sides of small gaps than on south sides, with the reverse true for large gaps (e.g., the southern portions of the gaps were more shaded); 4) seedling size increased with gap size and was greatest at gap centers; 5) Douglas-fir growth was relatively low except in the largest gaps while western hemlock growth increased dramatically with gap size and Pacific silver fir (*Abies amabilis*) growth responded least to gap size; 6) below ground gaps are created by all above ground

gaps; 7) higher temperature and increased moisture in gaps leads to increased decomposition rates and higher nutrient availability, boosting the productivity of the surrounding forest; 8) soil moisture in gaps varies with distance from gap edge and orientation with gap centers usually wetter than gap edges, which are wetter than surrounding forest; 9) plant species diversity was higher in gaps than in closed-canopy forest, with some weedy species but also many native species; and, 10) gaps can remain devoid of tree saplings for as much as 50 years after formation. Lack of seeds may mean that planting becomes a necessity in created gaps.

Response to Commercial Thinning in Older (110 years) Douglas-fir Forests. This study was published in 1982 by Richard Williamson (USFS Research Paper PNW-296).

- *Goal:* Investigate the merits of commercially thinning older stands.
- *Sites:* A 70-acre site of 110-year-old Douglas-fir forest on the Wind River Experimental Forest, Wind River District of the Gifford Pinchot National Forest, in the south central Washington Cascades.
- *Methods:* A randomized block design was used testing a control and two treatments (a light thinning, where approximately 20 percent of the volume was cut, and heavy thinning, with 25 to 33 percent of the volume cut). Each treatment was replicated three times. Stands were sampled 19 years after thinning. Because of the wide range in site index among plots and stocking differences, results were tested by comparing response ratios of gross volume growth to normal gross growth for the same site index (e.g., ratios of volume-growth percentages of treated plots relative to control, adjusted for differences in site index and stocking). Increases could result from either the removal of slow-growing trees in thinning or an actual increase in growth rate of residual trees, or both. Individual trees were also compared.
- *Status:* The study is complete.
- *Results:* Gross growth of the heavily thinned plots was 27 percent better than expected if growth were directly proportional to growing stock. Lightly thinned stands had no difference in gross growth compared to controls. Lightly thinned stands averaged 119 percent of normal net growth and heavily thinned stands averaged 136 percent, with unthinned stands averaging much less than normal. Average mortality on control plots was five times the mortality on heavily thinned plots and three time that on lightly thinned plots. Individual tree responses showed a 30 percent greater growth than controls in the heavily thinned stands, and eight percent greater in the lightly thinned stands. The relative response of suppressed trees in the heavily thinned stands was almost double the control, with codominant and intermediate trees with 112 and 108 percent respectively. Dominant trees had a gain of 30 percent. This study indicated that older trees can respond positively to thinning.

Very Young Stand Management, an Adaptive Management Case Study. The principal investigators of this study are Connie Harrington (PNW-USFS), Jim Mayo (USFS), and John Cissel (USFS) through the Cascade Center for Ecosystem Management (http://www.fsl.orst.edu/ccem/pdf/veryyss.pdf).

- *Goals:* 1) Demonstrate options and improve understanding of alternative approaches to precommercial thinning. 2) Produce forest stands that differ in species composition and structural components; monitor short and long-term plant responses. 3) Accelerate development of late-successional forest characteristics in some treatments. 4) Determine effects on forest growth and yield.
- *Sites:* Study plots are located on the Willamette National Forest, in the western Oregon Cascades, and are at least 15 acres in size.
- *Methods:* The study design utilizes a control and four treatments. The control will be thinned to 8-foot spacing (680 trees per acre). The treatments will include: 1) thin to 12-foot spacing (300 trees per acre); 2) thin to 12-foot spacing with 8 uniformly distributed 0.05-acre gaps per acre and interplanting with shade-tolerant conifer and deciduous species; 3) thin to 12-foot spacing with 0.02-, 0.04-, and 0.05-acre gaps; and, 4) thin to 12-foot spacing with 0.02-, 0.04- and 0.05-acre gaps and interplanting with shade-tolerant conifer and deciduous species. Monitored response variables will include ecological and economic measures such as stand structure, plant composition, and tree growth. Costs and values of treatments will be compared. If funding becomes available, sampling of small mammals, amphibians, and birds will be conducted.
- *Status:* Five plots have been established.
- *Results:* No results are currently available.

Alternative Silvicultural Treatments for Young Plantations in the Pacific Northwest. The principal investigators for this study are Connie Harrington, Dean DeBell, and Leslie Brodie through (PNW-USFS) (http://www.fs.fed.us/pnw/olympia/silv/selected_studies/clearwater/alternative_poster.htm).

- *Goals:* Increase diversity in stand structure and species composition in young stands.
- *Sites:* Plots are in 10 to 13 year-old stands. The oldest installation is on the Mt. St. Helens National Volcanic Monument in western Washington, where five plots (each 16 acres) of each treatment were installed in 1994-5. Other installations of this trial have been established near Blue River in the Oregon Cascades (one), and Forks on the Olympic Peninsula (five).
- *Methods:* Four treatment levels were implemented in the study with controls. The treatments include: 1) uniform thinning; 2) uniform thinning and planting other species in small uniform openings (about 0.04 acre); 3) irregular thinning with variable sized gaps; and, 4) irregular thinning with variable sized gaps and planting other species. The treatments will require multiple entries to meet their goals. Tree growth, stand structure, and understory plant composition and cover are being monitored.
- *Status*: All plots have been treated and sampled from two and five years post-thinning.

- *Results:* The control treatment had a lower percentage of trees in the larger diameter classes. Cover of herbaceous plants (2 and 5 years after thinning) decreased in the control and increased with thinning and gap creation.

Numerous other smaller projects that include thinning and planting for heterogeneity and biodiversity, or have components that may be applicable to restoration in the CRMW, have also been started since 1990. In particular, the Department of Forest Science at Oregon State University and its Cooperative Forest Ecosystem Research (CFER) program have several ongoing thinning projects in the Oregon Cascades and Oregon Coast Range, many of which include wildlife responses to thinning (see: www.fsl.orst.edu and www.fsl.orst.edu/cfer). A long-term interdisciplinary study of the ecological effects of regeneration harvest with alternative levels and patterns of canopy retention focuses primarily on shelterwood treatments, but does include one 75 percent aggregated retention treatment that may be applicable to the CRMW (Franklin et al. 1999). Although these projects are not included in the summary above, we will continue to monitor them as data become available.

We have also reviewed restoration projects that have similar goals, but that are not directly applicable to upland forest restoration in the CRMW. An example is the recent plan for the Klamath Tribe's management of the reservation pine forest in Oregon (Johnson et al. 2003). This plan advocates active management to restore forest complexity and big game habitat. Methods recommended include prescribed fire, mechanical thinning, planting, mowing, and other silvicultural manipulations.

The long history of commercial forestry in the Pacific Northwest has taught us much about thinning to grow big trees faster. In addition to maximizing tree growth, commercial thinning may also have some positive influences on other organisms and forest structure. A retrospective study comparing commercially thinned areas, unthinned areas, and old-growth in western Oregon found that 32 areas commercially thinned 10 to 20 years previously had greater herb species richness, greater density of conifer seedlings, and greater density of both tall and short shrubs than unthinned areas (Muir et al. 2002). Standard commercial thinning creates uniformity in overstory tree size and spacing, however, and a late successional forest consists of much more than large uniform trees.

The True Fir-Hemlock Spacing Trial

The principal investigators are Robert O. Curtis, Gary W. Clendenen and Jan A. Henderson, in cooperation with USDA Forest Service Pacific Northwest Research Station and Mt. Baker-Snoqualmie National Forest.

- *Goals:* To provide a unique source of information on early development of managed stands of these species, for which little information now is available. Study objectives were (1) to determine the quantitative responses of Pacific silver fir, noble fir, and western hemlock to a range of precommercial thinning stocking levels; and (2) to obtain long-term growth data applicable to young managed stands, as a basis for estimates of development patterns and potential yields.

- *Sites:* A series of 18 precommercial thinning trials was established in true fir-hemlock stands in the Olympic Mountains and along the west side of the Cascade Range in Washington and Oregon from 1987 through 1994, in the MBS, OLY, GP, MH, and WIL National Forests. All sites are within the Coastal True Fir-Hemlock Type primarily within the *Abies amabilis* zone (Franklin and Dryness 1973) but also with a few in the *Tsuga mertensiana* zone.

- *Methods:* Five thinning treatments, retaining 100-700 trees per acre, plus a control, resulting in six treatments per block.

- *Status:* As of 2008, 10- and 20-year post-treatment measurements have been completed on different blocks.

- *Results:* From the 10-year post-treatment re-measurement (published by Curtis 2008, PNW-GTR-749), diameter growth of all species increased with increase in spacing. Height growth of Pacific silver fir decreased with increase in spacing. The largest 80 trees per acre of all species showed some increase in diameter and basal area growth with increased spacing, while height growth declined slightly and volume growth was nearly constant.

Appendix E. Information Management Outline for ID Team Strategic Plans

Information Management Goal

Data acquisition, analysis and management are optimized over the life of the HCP.

Information Management Objectives

1. Plan and design of data acquisition and analysis.
2. Consistent use of documented protocols for data acquisition.
3. Rigor in analytical methods
4. Create metadata products that describe data acquisitions.
5. Provide access to data and information products derived from them.

1. Plan and design of data acquisition and analysis to answer key questions

- Purpose / key questions addressed
- Statement of data quality objectives
- Sampling and Analysis Planning
- Peer review and consultant input

2. Consistent use of documented protocols for data acquisition

- Definitions of attributes and domains
- Description of methods for measurements and observations
- Equipment requirements
- Association with GIS

3. Rigor in analytical methods

- Currency and best practices for data analysis
- Description of methods
- Statistical assessments of the results of analysis

4. Create metadata products that describe data acquisitions

- Data Acquisition Description Document
- Structured metadata built on templates

5. Provide access to data and information products derived from them.

- Managed access
- GIS enabled interface
- Query tools
- Output tools

Appendix F: Forest Habitat Associations for Wildlife Species Potentially in the Cedar and South Fork Tolt River Watersheds

F/B = Feeds and Breeds R = Reproduces with habitat elements present D = Dispersal U = Unsure
F/R = Feeds and Reproduces with habitat elements present F = Feeds C = Cover

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Beller's Ground Beetle																										
Carabid Beetle 1																										
Carabid Beetle 2																										
Carabid Beetle 3																										
Carabid Beetle 4																										
Carabid Beetle 5																										
Carabid Beetle 6																										
Carabid Beetle 7																										
Carabid Beetle 8																										
Carabid Beetle 9																										
Fender's Soliperan Stonefly																										
Hatch's Click Beetle																										
Johnson's (Mistletoe) Hairstreak																										
Long-horned Leaf Beetle																										
Blue-gray Taildropper																										
Oregon Megomphix																										
Papillose Taildropper																										
Puget Oregonian																										
Snail																										
River Lamprey																										
Western Brook Lamprey																										
Pacific Lamprey																										
Pygmy Whitefish																										
Mountain Whitefish																										
Coastal Cutthroat Trout																										
Coastal Cutthroat Trout, Sea-run																										
Coho Salmon																										
Rainbow Trout																										
Steelhead Trout																										
Sockeye Salmon																										
Kokanee																										
Chinook Salmon																										
Dolly Varden																										
Bull Trout																										
Peamouth																										
Northern Pikeminnow																										
Longnose Dace																										
Speckled Dace																										
Redside Shiner																										

F/B = Feeds and Breeds
F/R = Feeds and Reproduces with habitat elements present
R = Reproduces with habitat elements present
F = Feeds
D = Dispersal
C = Cover
U = Unsure

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Longnose Sucker																										
Largescale Sucker																										
Threespine Stickleback																										
Large-mouth Bass																										
Yellow Perch																										
Torrent Sculpin																										
Riffle Sculpin																										
Shorthead Sculpin																										
Coastrange Sculpin																										
Prickly Sculpin																										
Northwestern Salamander	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Long-toed Salamander	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Cascade Torrent Salamander								F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Larch Mountain Salamander	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Van Dyke's Salamander	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Pacific Giant Salamander	F	F/R	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Ensatina	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Western Redback Salamander	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Roughskin Newt	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Western Toad	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Pacific Treefrog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Tailed Frog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Northern Red-legged Frog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Cascades Frog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Oregon Spotted Frog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Bullfrog	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Western Pond Turtle	F/R	F/R	U	U	U	U	U	U	U	U	F/R	U	U	F/R	U	U	U	U	U	U	U	U	U	U	U	U
Northern Alligator Lizard	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Fence Lizard	F/B		F/B		F/B			F/B			F/B			F/B			F/B			F/B			F/B			
Rubber Boa	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Terrestrial Garter Snake	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Northwestern Garter Snake	F/B	F/B							F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Common Garter Snake	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Common Loon																										
Pied-bill Grebe																										
Horned Grebe																										
Red-necked Grebe																										
Eared Grebe																										
Western Grebe																										
Double-crested Cormorant														F/B						F/B						
Great Blue Heron											R	R	R	R	R	R				R	R	R	R	R	R	R

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Green Heron			F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Trumpeter Swan																										
Canada Goose																										
Wood Duck											R	R	R	R	R	R				R	R	R	R	R	R	R
Mallard																										
Cinnamon Teal																										
Harlequin Duck																						R			R	R
Common Goldeneye											R	R		R	R		R	R		R	R		R	R		
Barrows Goldeneye											R	R		R	R		R	R		R	R		R	R		
Bufflehead								R	R		R	R		R	R		R	R		R	R		R	R		
Hooded Merganser											R	R	R	R	R	R				R	R	R	R	R	R	R
Common Merganser											R	R		R	R					R	R		R	R		
Gadwall																										
Green-winged Teal																										
American Wigeon																										
Eurasian wigeon																										
Northern Pintail																										
Northern Shoveler																										
Ruddy Duck																										
Canvasback																										
Ring-necked Duck																										
Greater Scaup																										
Lesser Scaup																										
American Coot																										
Killdeer	F/B	F/B																								
Spotted Sandpiper																										
Common Snipe																										
Wilson's phalarope																										
Marbled Murrelet																							R	R	R	R
Turkey Vulture	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Osprey											R	R	R	R	R	R				R	R	R	R	R	R	R
Bald Eagle	F/R	F/R	F/R	F/R	F/R	F/R		F/R	F/R		F/R	F/R		F/R	F/R		F/R	F/R		F/R	F/R		F/R	F/R		F/R
Golden Eagle	F	F	F	F	F			F			F/R			F/R	F/R	F/R	F			F	F/R	F/R	F/R	F/R	F/R	F/R
Sharp-shinned Hawk	F	F	F	F	F	F/B	F/B	F	F/B	F/B	F	F/B	F/B	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B
Cooper's Hawk	F	F	F	F	F	F	F	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B
Northern Goshawk	F	F	F		F	F		F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red-tailed Hawk	F/B	F/B	F/B	F/B	F/B	R		F/B	F/B		F/B	F/B	R	F/B	F/B	F/B	F/B	F/B	R	F/B	F/B	R	F/B	F/B	R	F/B
American Kestrel	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F	F/R	F/R	F/R	F/R	F/R	F/R
Merlin	F	F	F	F	F	F	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B
Peregrine Falcon	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Wild Turkey	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B			F/B	F/B	F/B	F/B			F/B			F/B	F/B		

F/B = Feeds and Breeds | R = Reproduces with habitat elements present | D = Dispersal | U = Unsure
F/R = Feeds and Reproduces with habitat elements present | F = Feeds | C = Cover

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Blue Grouse	F/B	F/B	F/B	F/B	F/B	C	C	F/B	F/B	F/B	F/B	F/B	F/B	C	C	C	F/B	C	C	C	C	C	F/B	F/B	C	F/B
Ruffed Grouse			F	F/R	F/R	R	R	F/R	R	R	F/R	C	C	C	C	C	F/R	F/R	R	R	F/R	R	F/R	C	C	C
California Quail	F/B	F/B	F/B	F/B	F/B	C	C	F/B			F/B			F/B			F/B			F/B			F/B			
Mountain Quail	F/B	F/B	F/B	F/B	F/B	C	C	F/B			F/B			C	C	C	F/B	F/B		F/B	F/B					
Band-tailed Pigeon	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Western Screech Owl	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Great Horned Owl	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B		F/B	F/B	F/B	F/B	F/B		F/B	F/B	F/B	F/B	F/B	F/B	F/B
Northern Pygmy Owl	F	F	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Northern Spotted Owl			F	F	F	F/R	F/R	F	F	F/R	F	F	F/R	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F	F/R	F/R	F/R
Barred Owl			F	F	F	F	F	F	F	F	F	F	F	F/R	F/R	F/R	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Northern Saw-whet Owl	F	F	F	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Common Nighthawk	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F	F/B	F	F	F/B	F	F	F	F	F	F	F	F	F	F	F	F
Black Swift	F/R	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R
Vaux's Swift	F	F	F	F	F	F	F	F	F	F	F	F	F	F/R	F/R	F/R	F	F	F	F	F	F	F	F/R	F/R	F/R
Rufous Hummingbird	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Belted Kingfisher	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Red-breasted Sapsucker					F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Downy Woodpecker	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Hairy Woodpecker	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Northern Flicker	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Pileated Woodpecker	F	F	F	F	F	F	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F	F	F	F	F/R	F/R	F	F/R	F/R	F/R
Three-toed Woodpecker	F/R	F/R			F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Olive-sided Flycatcher	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B		F/B			F/B			F/B			F/B
Western Wood Pewee			F	F				F/B	F/B		F/B	F/B	F/B	F/B	F/B	F/B				F/B			F/B			F/B
Willow Flycatcher			F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B							F/B	F/B	F/B							
Dusky Flycatcher			F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B		F/B	F/B		F/B			F/B			F/B			
Hammond's Flycatcher								F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B				F/B	F/B	F/B	F/B	F/B	F/B	F/B
Pacific-slope Flycatcher									F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Purple Martin	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R			F/R			F/R			F/R			
Tree Swallow	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R			F/R			F/R			F/R			F/R
Violet-green Swallow	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R			F/R			F/R			F/R			F/R
Northern Rough-winged Swallow	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R												
Cliff Swallow	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R												
Barn Swallow	F/R	F/R	F/R	F/R																						
Bank Swallow	F/R	F/R	F/R	F/R	F/R			F/R			F/R			F/R												
Gray Jay	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Steller's Jay			F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
American Crow	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Common Raven	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Clark's Nutcracker	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	
Black-capped Chickadee	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R

F/B = Feeds and Breeds R = Reproduces with habitat elements present D = Dispersal U = Unsure
F/R = Feeds and Reproduces with habitat elements present F = Feeds C = Cover

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Chestnut-backed Chickadee	F	F	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Mountain Chickadee			F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Common Bushtit			F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red-breasted Nuthatch	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
White-breasted Nuthatch	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Brown Creeper	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Bewick's Wren			F/R	F/R	F/R	F/R	F/R	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F			
House Wren			F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Winter Wren	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Marsh Wren																										
American Dipper	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Eastern kingbird	F/B	F/B	F/B		F/B			F/B			F/B			F/B												
Golden-crowned Kinglet	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Ruby-crowned Kinglet	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Bluebird	F/R	F/R	F/R		F/R			F/R			F/R			F/R												
Mountain Bluebird	F/R	F/R	F/R	F/R	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F/R	F/R	F	F
Townsend's Solitaire	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Swainson's Thrush			F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
American Robin	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Varied Thrush						F	F		F/B	F/B		F/B	F/B	F/B	F/B	F/B				F/B	F/B	F/B	F/B	F/B	F/B	F/B
Hermit Thrush	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Cedar Waxwing	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Northern Shrike																										
Loggerhead Shrike	F/B	F/B	F/B	F/B	F/B			F/B			F/B			F/B												
Cassins Vireo									F/B	F/B		F/B	F/B		F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Hutton's Vireo					F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Warbling Vireo				F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red-eyed Vireo									F/B	F/B		F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Orange-crowned Warbler	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Yellow Warbler				F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B				F/B	F/B	F/B	F/B	F/B	F/B				
Yellow-rumped Warbler	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Black-throated Gray Warbler			F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Townsend's Warbler					F	F	F	F	F/B	F/B	F	F/B	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B
MacGillivray's Warbler	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Common Yellowthroat			F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B		F/B	F/B		
Wilson's Warbler	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Tanager	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Black-headed Grosbeak	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Snow Bunting																										
Spotted Towhee			F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Savannah Sparrow	F/B	F/B	F		F			F/B			F/B			F/B												

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F/R = Feeds and Reproduces with habitat elements present
R = Reproduces with habitat elements present
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Fox Sparrow			F	F	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B											
Song Sparrow	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Lincoln's Sparrow	F/B	F/B	F/B	F/B	F/B			F/B			F/B			F/B												
Golden-crowned Sparrow	F	F	F	F	F	F		F	F		F	F		F	F		F			F			F			
White-crowned Sparrow	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B		F/B	F/B		
Dark-eyed Junco	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Lark Sparrow	F/B	F/B	F/B		F/B			F/B			F/B			F/B												
Chipping Sparrow	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red-winged Blackbird																										
Brewer's Blackbird	F/B	F/B	F/B		F/B			F/B			F/B			F/B												
Brown-headed Cowbird	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Northern Oriole								F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Meadowlark	F/B	F/B	F/B	F/B	F/B			F/B			F/B			F/B												
House Finch	F	F	F/B	F/B	F/B	F/B	F/B	F/B			F/B			F/B			F/B			F/B			F/B			
Purple Finch						F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
American Goldfinch	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Pine Siskin	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red Crossbill					F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Evening Grosbeak									F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Big Brown Bat	F	F	F	F	F	F	F	F	F		R	R	R	R	R	R	F	F		R	R	R	R	R	R	R
Silver-haired Bat	F	F	F	F	F	F	F	F	F		R	R	R	R	R	R	F	F		R	R	R	R	R	R	R
Hoary Bat	F	F	F	F	F	F		F	F		F	F		F	F		F	F		F	F		F	F	F	F
Townsend's Big-eared Bat	R	R	R	R	R			R	R		R	R		R	R	R	R			R			R	R	R	R
California Myotis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Long-eared Myotis	R	R	R	R	R			R	R		R	R		R	R	R	R			R			R	R	R	R
Keen's Myotis	F	F	F	F	F	F	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Little Brown Myotis	R	R	R	R	R			R	R		R	R		R	R	R	R			R			R	R	R	R
Fringed Myotis	R	R	R	R	R	R		R	R		R	R		R	R		R	R		R	R		R	R	R	R
Long-legged Myotis	F	F	F	F	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Yuma Myotis	R	R	R	R	R			R	R		R	R		R	R	R	R			R			R	R	R	R
Marsh Shrew	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Masked Shrew	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Montane Shrew	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Northern Water Shrew	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Trowbridge's Shrew	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Vagrant Shrew	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Shrew-mole	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Coast Mole	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Townsend's Mole	F/R	F/R	F/R	F/R	F/R	F/R		F/R																		
Bushy-tailed Woodrat											F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Deer Mouse	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B

F/B = Feeds and Breeds | R = Reproduces with habitat elements present | D = Dispersal | U = Unsure
F/R = Feeds and Reproduces with habitat elements present | F = Feeds | C = Cover

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Keen's Deer Mouse																										
Southern Red-backed Vole	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Long-tailed Vole	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Creeping Vole	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Townsend's Vole	F/B	F/B	F/B	F/B	F/B	F/B		F/B																		
Water Vole	F/B	F/B	F/B					F/B			F/B			F/B			F/B			F/B			F/B	F/B		
Heather Vole	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B			F/B			F/B			F/B			F/B			F/B			F/B
Pacific Jumping Mouse	F/B	F/B	F/B	F/B	F/B	F/B		F/B	F/B																	
Muskrat																										
Cascade Golden-mantled Ground Squirrel	F/R		F/R		F/R			F/R			F/R			F/R			F/R			F/R			F/R			
Townsend's Chipmunk			F	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Douglas' Squirrel								F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B
Northern Flying Squirrel						F/R	F/R		F/R	F/R		F/R	F/R	F/R	F/R	F/R		F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Hoary Marmot	F/R	F/R						F/R			F/R			F/R												
Yellow-bellied Marmot	F/R	F/R	F/R		F/R			F/R			F/R			F/R												
Mountain Beaver	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Beaver	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Porcupine	F	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Snowshoe Hare	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Pika	F/R	F/R																								
Black Bear	F	F	F	F	F	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R
Grizzly Bear	F	F	F	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Raccoon	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Amercian Marten								U	F/R	F/R	U	F/R	F/R	F/R	F/R	F/R	U	F/R	F/R	U	F/R	F/R	F/R	F/R	F/R	F/R
Fisher								U	U	U	U	F	F	U	F	F	U	F	F	U	F	F	U	F/R	F/R	F/R
Short-tailed Weasel (Ermine)	U	U	U	U	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Long-tailed Weasel	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Mink	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Northern River Otter	D	D						D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Wolverine	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Striped Skunk	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Western Spotted Skunk					F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Cougar	F	F	F	F/B	F/B	F/B	F/B	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Bobcat	F	F	F	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Lynx				F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Red Fox	F	F	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R	F/R
Coyote	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Gray Wolf	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Elk	F/B	F/B	F/B	F/B	F/B	F/B	R	F/B	F/B	R	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	R	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Black-tail (Mule) Deer	F/B	F/B	F/B	F/B	F/B	F/B	R	F/B	F/B	R	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	R	F/B	F/B	F/B	F/B	F/B	F/B	F/B

F/B = Feeds and Breeds
F/R = Feeds and Reproduces with habitat elements present
R = Reproduces with habitat elements present
F = Feeds
D = Dispersal
C = Cover
U = Unsure

Common Name	1 Grass/ Forb - Open	2 Grass/ Forb - Closed	3 Shrub/ Seedling - Open	4 Shrub/ Seedling - Closed	5 Sapling/ Pole - Open	6 Sapling/ Pole - Moderate	7 Sapling/ Pole - Closed	8 Small Tree - Single Story - Open	9 Small Tree - Single Story - Moderate	10 Small Tree - Single Story - Closed	11 Medium Tree - Single Story - Open	12 Medium Tree - Single Story - Moderate	13 Medium Tree - Single Story - Closed	14 Large Tree - Single Story - Open	15 Large Tree - Single Story - Moderate	16 Large Tree - Single Story - Closed	17 Small Tree - Multi-story - Open	18 Small Tree - Multi-story - Moderate	19 Small Tree - Multi-story - Closed	20 Medium Tree - Multi-story - Open	21 Medium Tree - Multi-story - Moderate	22 Medium Tree - Multi-story - Closed	23 Large Tree - Multi-story - Open	24 Large Tree - Multi-story - Moderate	25 Large Tree - Multi-story - Closed	26 Giant Tree - Multi-story
Mountain Goat	F	F	F	F				F	F		F	F		F	F		F	F		F	F		F	F		
Eastern Gray Squirrel																										
Opposum	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Black rat																					F/B	F/B				

Forest Structure Classes

Source: Johnson, D.H., and T.A. O'Neil. 2001. Wildlife-habitat relationships in Oregon and Washington. Oregon State University Press, Corvallis, OR. 736 pp.

#	Name	Tree DBH (")	Tree Canopy Cover (%)	Tree Canopy Layers	Comments
1	Grass/Forb - Open	NA	<10	NA	<70% coverage by grasses/forbs
2	Grass/Forb - Closed	NA	<10	NA	>70% coverage by grasses/forbs
3	Shrub/Seedling - Open	<1	<70	1	
4	Shrub/Seedling - Closed	<1	>70	1	
5	Sapling/Pole - Open	1-9	10-39	1	
6	Sapling/Pole - Moderate	1-9	40-69	1	
7	Sapling/Pole - Closed	1-9	>70	1	
8	Small Tree - Single Story - Open	10-14	10-39	1	
9	Small Tree - Single Story - Moderate	10-14	40-69	1	
10	Small Tree - Single Story - Closed	10-14	>70	1	
11	Medium Tree - Single Story - Open	15-19	10-39	1	
12	Medium Tree - Single Story - Moderate	15-19	40-69	1	
13	Medium Tree - Single Story - Closed	15-19	>70	1	
14	Large Tree - Single Story - Open	20-29	10-39	1	
15	Large Tree - Single Story - Moderate	20-29	40-69	1	
16	Large Tree - Single Story - Closed	20-29	>70	1	
17	Small Tree - Multi-story - Open	10-14	10-39	≥2	
18	Small Tree - Multi-story - Moderate	10-14	40-69	≥2	
19	Small Tree - Multi-story - Closed	10-14	>70	≥2	
20	Medium Tree - Multi-story - Open	15-19	10-39	≥2	
21	Medium Tree - Multi-story - Moderate	15-19	40-69	≥2	
22	Medium Tree - Multi-story - Closed	15-19	>70	≥2	
23	Large Tree - Multi-story - Open	20-29	10-39	≥2	
24	Large Tree - Multi-story - Moderate	20-29	40-69	≥2	
25	Large Tree - Multi-story - Closed	20-29	>70	≥2	
26	Giant Tree - Multi-story	≥30	>40	≥2	<40% canopy cover are classified as #23

Appendix G. Site Selection and prioritization criteria for restoration thinning, ecological thinning, and upland planting projects in the CRMW.

The following sections detail the site selection and prioritization criteria for restoration thinning, ecological thinning, and upland planting projects. Criteria are listed in general order of importance and not all prioritization criteria will be applied to all projects.

1.0 Restoration Thinning Projects

Forested areas "that will receive highest priority for restoration thinning will be those that: (1) are most over-stocked, based on age, species, and site characteristics; (2) exhibit signs of severe competition and stress and determined to be at greatest risk of causing catastrophic damage; and (3) have the greatest potential for beneficial results" (CRW-HCP 4.2-36). These areas are likely early in the competitive exclusion stage of forest development. Again, while forest conditions are ecologically contingent upon one another, this section addresses each characteristic separately. Restoration thinning site selection and prioritization criteria are summarized in Table 3.2 of the Upland Plan.

1.1 Stand-level Selection & Prioritization Criteria

Tree Density – Relatively high densities of trees are typical in early stages of competitive exclusion as small trees compete for resources. Restoration thinning will decrease the competition between trees, which will increase or maintain growth rates. Forested areas with more than 1,000 TPA will most benefit from restoration thinning, while areas with 500 to 1,000 TPA will also be considered for thinning.

Tree Diameter – Relatively young and dense forest areas typically have small diameter trees. Restoration thinning will be most appropriate in areas that have trees with less than 8 inches dbh. Areas with more than 300 TPA greater than 7 inches dbh may be more appropriate for ecological thinning, since restoration thinning in these areas will result in large amounts of slash, which serves as wildfire fuel.

Tree Age – Trees in different forest zones reach the early stages of the competitive exclusion stage at different ages based on their differing growth rates that are largely dependent on autecology and site conditions. Forested areas in the western hemlock zone in the CRMW (e.g., less than 3,000 feet asl) will likely reach a size that would benefit from restoration thinning at 15 to 20 year old. Areas in the Pacific silver fir zone (3,000 to 4,500 feet asl), however, may still be an appropriate size for thinning between 20 to 30 years of age, or even as long as 40 years.

2.0 Ecological Thinning Projects

Forested areas "that will receive the highest priority for ecological thinning will be those that are the most overstocked based on size, age, and species and have the least biological and structural diversity and have the greatest potential for beneficial results" (CRW-HCP

4.2-37). These areas are likely in the competitive exclusion stage of forest development. While forest conditions are ecologically linked, this section addresses each criterion separately.

2.1 Stand-level Selection & Prioritization Criteria

Tree Density – The competitive exclusion stage of forest succession exhibits competition among dominant and co-dominant trees, which results in reduced diameter growth rates, and increased stress resulting in competition mortality. Lowering the density of trees in the mid and upper canopy, in areas with greater than 300 trees per acre (TPA), will maintain or increase growth rates of the remaining trees, decreasing the time to achieve the large tree component of late-successional forests, and ultimately increase large snag and downed wood recruitment. Increased light exposure to the understory from thinning is also expected to increase understory plant diversity. While areas with greater than 400 TPA of the targeted age class would benefit most from ecological thinning, areas with greater than 1,000 TPA would be more likely to be an appropriate diameter for restoration thinning.

Tree Diameter – Tree age and tree density directly influence tree diameter. Forest areas with targeted tree ages (30-60+ years) and densities (greater than 400 TPA) typically exhibit mean quadratic diameters greater than 8 inches diameter at breast height (Qdbh). Areas with smaller diameters (less than 8 inches) are likely candidates for restoration thinning (see Section 5.3.1). Areas with large-diameter trees (e.g., greater than 20 inches Qdbh) may be naturally undergoing canopy differentiation in the upper canopy layer, in which case ecological thinning would be of less benefit.

Tree Diameter Distribution – Tree diameter distribution describes the variation of tree sizes within a forest stand. Stands with wide diameter distributions have a wide range of tree sizes, indicating that those stands have differentiated into crown classes and canopy layers. Stands with narrow diameter distributions have a narrow range of tree sizes, indicating poorer differentiation and simple forest structure. Stands with multimodal diameter distributions have distinct classes of larger trees and smaller trees, indicating vertically layerd forest structure, while stands with unimodal diameter distributions may have simpler forest structure. Forest stands that have narrow, unimodal diameter distributions are high priority for restoration intervention, while stands that have wide, multimodal diameter distributions have complex canopy structures and are better candidates for protection.

Stand Density Index and Relative Density – Stand density index (SDI) is a relative measure of stand density that converts a stand's current density into a density at a reference diameter size. Relative density (RD) is based on SDI and is a metric that generally indicates tree competition and growth rate. Competition mortality dominates stand dynamics in areas that have a RD greater than 65, while a stand is considered no longer completely forested with a RD below 20. Vigorously growing stands are typically between 35 and 50.

SDI can be defined as:

$$SDI = TPA\ (Qdbh/10)^{1.605} \qquad (1)$$

where TPA is trees per acre (tree density) and Qdbh is the quadratic mean diameter (Reineke 1933). The Qdbh is the diameter corresponding to the average basal area per tree at breast height. The maximum SDI for 10-inch dbh Douglas fir, for example, is 587 trees per acre (Long 1985).

RD can be defined as:

$$RD = (SDI/SDI_{max}) \times 100 \qquad (2), \text{ or similarly:}$$

$$RD = BA/(Qdbh^{0.5}) \qquad (3)$$

where BA is the basal area per acre (Curtis 1982). Douglas-fir dominated stands with an RD of more than 50 (SDI greater than 290) may have characteristics that would benefit from ecological thinning (e.g., lowering the RD would maintain or increase tree growth rate).

Tree Age – Second-growth forested areas between 30 and 60 years of age, and potentially up to 100 years, typically exhibit characteristics that would most benefit from ecological thinning. These forests are often in the competitive exclusion or biomass accumulation successional stage, depending on tree density. The first 50 years of tree growth largely determines the form of individual trees (Hunter 2001). Ecological thinning in relatively young stands, therefore, is expected to produce more dramatic results than thinning in older stands where tree diameters and crown structures are already established.

Canopy Closure – Higher density forest areas typically result in canopy closures of greater than 70 percent, which often indicates relatively high competition mortality rates, slowed growth, and low understory plant diversity (Franklin et al 2002, Carey et al 1999b). Ecological thinning projects will reduce canopy closure and will be primarily considered for forested areas with greater than 90 percent canopy closure.

Site Class – Though relatively higher site class areas (e.g., high tree growth potential generally based on soil conditions) would likely exhibit a positive response to ecological thinning faster than lower site class areas, higher site class areas will also typically emerge from the competitive exclusion stage without restoration activities faster than lower site class areas (Oliver and Larson 1996). The poorest growing areas (e.g., site class V) may not rapidly, if ever, respond to ecological thinning. Over 80 percent of the CRMW is in site classes III, IV, and

V. Ecological thinning will likely most benefit site class IV, but will also be considered in other site classes.

Live Crown Ratio – The competition for light in high-density forest areas can result in relatively low live crown ratios, or the depth of the live part of the crown as a percentage of the total height of a tree. But trees with higher live crown ratios will likely benefit greater from ecological thinning due to the greater ability to capture increased light energy. Ecological thinning will result in a rapid positive growth response from trees when the live crown ratio is greater then 40 percent and will have a much slower affect when the ratio is less than 30 percent.

Canopy Layering – Forest areas in the competitive exclusion stage typically exhibit one tree canopy layer (the upper canopy), while late-successional forest have more than one layer (main canopy, middle canopy, and understory trees and shrubs). Ecological thinning would most benefit one canopy layer forests by helping to establish understory layers, while multi-canopy layer areas are likely already emerging from the competitive exclusion stage.

Tree Species Diversity – Though tree species diversity in the overstory canopy of forests in the Pacific Northwest is typically relatively low, several species are ecologically suited to most forested areas. Ecological thinning will most benefit areas where one species makes up over 80 percent of the overstory tree abundance, by increasing the relative abundance of the less dominant species. Thinnings will also be considered for areas where the dominant species makes up 45 to 80 percent of overstory tree abundance (e.g., there are three species present with at least 10 percent abundance).

Understory Development – The high canopy closure of forested areas in the competitive exclusion stage typically results in a depauperate understory. Areas with a developed understory, in terms of occurrence and species diversity, likely do not have a closed overstory canopy. Ecological thinning would increase the light energy reaching the forest floor, which would increase the occurrence and diversity of understory plant species. Forested areas with less than 40 percent ground covered by understory would likely benefit from ecological thinning, while areas with less than 10 percent would be primarily targeted for thinning projects.

Understory Species Diversity – The species diversity of vascular plant species (e.g., small trees, shrubs, herbs, and grasses) is typically greater in the understory than in the overstory, though it can still be dominated by a few species in the understory. Ecological thinning will most benefit areas where one understory species represents over 65 percent of the understory ground cover, by providing more growing opportunities to other species. Areas will also be considered for thinning where one species represents 35 to 65 percent of understory ground cover.

Snags – Large standing dead trees (snags) provide a valued habitat component in late-successional forests which is generally lacking from younger forests originating after clearcut harvesting. In these second-growth areas, increasing or maintaining the growth of trees will facilitate the recruitment of large snags in the future. Areas with less than two snags that are greater than 15 inches dbh and over 20 feet tall per acre will most benefit from ecological thinning.

Downed Wood – Large downed wood is also a valued habitat component in late-successional forests that can be lacking from younger forests. Similar to snags, increasing or maintaining tree growth through ecological thinning will shorten the time to the natural recruitment of large downed wood in the future. Areas with less than 500 cubic feet per acre of downed wood with a minimum diameter of 6 inches (e.g., 18 50-foot pieces with an average diameter of 10 inches) will most benefit from ecological thinning.

Horizontal Structural Diversity – Late-successional forests typically exhibit a shifting mosaic of gaps (e.g., canopy openings from individual tree fall) which leads to a relatively high degree of horizontal structural diversity across the landscape. This is characterized by a relatively wide variance in tree densities, mid-canopy branching, and understory distributions. Areas that exhibit homogeneous horizontal structural diversity will benefit most from ecological thinning.

3.0 Upland Restoration Planting Projects

Forested areas "that will receive highest priority for restoration planting will be those that have plant diversity much lower than expected, based on site characteristics, and those with the greatest potential for beneficial results" (CRW-HCP 4.2-35).

3.1 Stand-level Selection & Prioritization Criteria Criteria

Site selection criteria of upland planting projects were not addressed using the coarse- and fine-filters approach, but rather with three objectives of biological diversification. They are addressed separately below:

Improving Tree Stocking Levels - Upland planting of trees will most benefit relatively young forest areas in the initiation stage of forest succession (less than 15 years old) where natural tree regeneration or previous tree planting has not resulted in a tree density of at least 190 trees per acre. These areas are likely to be below 4,500 feet asl and of low growing potential (site class III to V and/or on southwestern-faced slopes). The potential planting sites should also have sufficient plantable spots per acre (e.g., places suitable to plant tree seedlings) to accommodate 190 trees per acre. Areas that continue to be under-stocked after several planting attempts may not warrant additional planting effort, although alternative restoration efforts may be explored.

Improving Tree Species Diversity at Other Restoration Sites - A goal for upland forest restoration projects in the CRMW, including ecological and restoration thinning, is to enhance biological diversity. Upland planting projects will be implemented in conjunction with ecological and restoration thinning projects where the current diversity has not reached its potential. Examples of this include planting shade tolerant species under a canopy of shade-intolerant species, planting shade-intolerant species in created gaps, planting root rot resistant species in areas infected by root rot, planting shade-tolerant conifers under a deciduous canopy, planting deciduous trees and shrubs under a conifer canopy, and planting on decommissioned roads. The suitability of these planting projects will be evaluated during the planning of those other restoration projects.

Improving Diversity of Other Plant Species - The planting of other species (shrubs, herbs, grasses, mosses, and lichens) will also improve the diversity in many upland areas. Planting of non-tree species will be used to enhance ecosystem processes such as the development of specific wildlife habitat structures, soil and soil flora development, epiphytic community succession, and forest structural development. A large focus of planting will include appropriate shrubs and deciduous trees that are rare on a project site but are important to ecological processes. Seedbank dependent forbs may also be planted that, due to past management disturbance, are not regenerating. In addition, some mosses, liverworts, and lichens provide habitat and food sources for arthropods and birds, aid in nutrient cycling, and contribute to organic matter of soil and litter. Planting of vascular species may be augmented by innovative techniques for seeding of lichens and bryophytes. Typically these species have short dispersal distances and past management in the CRMW has further increased the distances between seed sources. Seeding in forests of the appropriate age which lack nearby seed source may help contribute to the development of desired forest characteristics. This work will be done in an experimental context.

Additional upland forest restoration planting will explore opportunities to inoculate with parasites and pathogens. Although forest habitat management has historically attempted to eliminate forest parasites and pathogens, current research suggests that organisms such as dwarf mistletoe (*Arceuthobium spp.*) and tree rots (e.g., *Phellinus weirii*) drive key ecosystem processes in forested ecosystems (Castello et al. 1995). Dwarf mistletoe provides a food source for some wildlife species, creates witches' brooms that serve as nesting and cover habitat, and assists snag creation by weakening trees. Historically, the CRMW likely had patches of trees infected with mistletoe and other patches of mistletoe-free trees. Past management (specifically, clearcut timber harvesting) has probably altered the extent, distribution, and size of the populations of dwarf mistletoe in the CRMW. The extent of dwarf mistletoe in the CRMW needs to be determined. Another unusual species that may be considered for inoculation is heart rot, a pathogen important to the development of hollow trees and trees suitable for cavity excavation (Bull et al 1997). Damaging tops or boles of trees to allow heart rot to establish may be adequate, however it is possible that populations of heart rot fungi have also been lowered by past management and inoculation of selected trees may be required.

ADDITIONAL FACTORS (Table 3.3 in Upland Plan)

Road Access – One of the products of a history of commercial timber harvest in the CRMW is an extensive road network. Though this network provides access to most forest areas that are candidates for ecological and restoration thinning, it also provides a significant source of sediment to streams. Restoration of a more natural water cycle through the decommissioning of non-essential roads is one of the major management goals of the CRW-HCP. The scheduling and location of the decommissioning projects, however, may prioritize thinning projects that are accessible by these non-essential roads to occur before their decommissioning. Also, thinning projects that require the construction or reconstruction of roads will have low priority relative to areas that can be treated using the existing infrastructure. Priority will be given to potential restoration thinning sites where road accessibility may be compromised permanently in the future (e.g., road decommissioning).

Roads that are scheduled for decommissioning under the CRW-HCP will provide access to potential upland planting sites only until they are decommissioned. Therefore, potential planting sites that are accessible by roads scheduled to be decommissioned will have priority over those sites where roads will continue to provide access.

Seasonal Limitations – Though ecological thinning projects can be conducted at lower elevations in the CRMW all year around, access to upper elevations is limited by snow for many months of the year. The limited availability of upper elevation forests may give ecological thinning projects at higher elevations a priority in the snow free portions of the year over lower elevation forests.

Thinning Method – The appropriate methods and equipment required to conduct ecological thinning projects vary with existing road access, slope, soil type, tree size, and whether thinned trees will be removed from the site. A method will be chosen for each project that will minimize damage to the residual trees, soil, snags, and downed wood. The economics of each method varies with time, as does technology itself. Areas that would benefit from ecological thinning may be prioritized based on the types of thinning methods available at a given time. For example, ground-based operations (e.g., processor and forwarder) can currently operate efficiently on slopes less than 35 percent and can result in minimal residual damage. Cable thinning, on the other hand, can operate on steeper slopes but often is accompanied by greater damage. Helicopter thinning, though expensive, will also be investigated as an option.

Likelihood of Re-entry – The prescriptions for each ecological thinning project will be based on achieving the greatest perceived ecological benefits for the site. Areas where this can be accomplished by one entry may be preferred over areas where more than one entry is envisaged to cause further disturbance. In other

words, areas where an appropriate thinning prescription results in a tree density that will not require further thinning in the future may be preferred over multiple thinning disturbances.
Priority will be given to potential upland planting sites where the initial planting effort will likely achieve planting goals. Potential sites where the likelihood of replanting is high, based on the failure of the initial planting effort, will have lower priority. Similarly, priority will be given to potential upland restoration planting sites in which no additional thinning entries are foreseen.

Monitoring Efficiency – Due to cost constraints, not all ecological thinning projects will be monitored for their effectiveness in reaching the management goals (see Section 8). Some projects will be selected for monitoring, however, and in these projects efficiency is a factor in prioritizing selection of thinning projects. In potential thinning areas that would have monitoring as an objective, areas that provide the criteria needed for long-term effectiveness monitoring (e.g., large enough to incorporate suitably sized treatment and control sites, long-term road access) will be prioritized ahead of areas that do not.

Cultural Resources – Areas where ecological thinning does not pose a significant risk to the cultural resources of the CRMW will be prioritized ahead of areas where risks are significant. Additionally, the financial costs of assessing risk (e.g., cultural resource surveys) are a concern in planning for thinning. Areas that would require expensive surveys (e.g., low slopes near open water) to enable ecological thinning may not be as high priority as areas where surveys are not required.

Affordability – Though ecological thinning projects are intended to be conducted on an ecologically beneficial basis, the economic costs of conducting a management action also need to be considered when working with limited budgets. The logistics and costs of planning and implementing a project (e.g., project planning, forest inventory, cultural resources inventory, project layout, thinning costs, contract compliance, monitoring, snag creation) will be weighed against the predicted ecological benefits of completing the project. While ecological thinning project costs cannot exceed annual budgets, we will be working under the goal of achieving the greatest ecological benefit for the least financial cost. Areas which can be treated more economically, or where larger areas can be treated for similar costs, may have priority.

Water Quality Impacts – Potential restoration thinning sites will not be thinned if they pose a significant risk to water quality.

Stand Size – Potential restoration thinning sites generally will have priority for consideration for thinning if they are greater than 10 acres in size. Sites that are smaller could be thinned if they are in close enough proximity to other potential thinning sites to be considered as a single project.

FACTORS THAT AFFECT RESTORATION PROJECT DESIGN

Tree Species Diversity –Upland forest restoration will most benefit forested areas where one tree species makes up over 80 percent of tree abundance, by increasing the relative abundance of less dominant species through thinning and planting. Restoration will also be considered for areas where the dominant species makes up 45 to 80 percent of the tree abundance (e.g., there are three species present with at least 10 percent abundance). Increasing tree species diversity

Proximity to CRMW Boundary – Though the CRMW will generally be managed as a forest reserve over the course of the CRW-HCP, forested lands outside and adjacent to the CRMW, particularly those adjacent to the western portions of the CRMW, will be subject to continued rotation harvest or conversion to other landcover types. Potential forest restoration sites near the CRMW boundary are therefore subject to edge effects associated with both landowner boundaries (trespass, wildfire, exotic species) and ecotones (windthrow). To minimize these effects in forest restoration projects, priority could be given to potential sites away from the CRMW boundary. To maximize habitat connectivity with patches of late-successional habitat outside the CRMW, however, particularly to land owned by the USDA Forest Service (USFS) that is adjacent to eastern portions of the CRMW, priority could be given to potential sites near the boundary. The proximity to the CRMW boundary should guide treatment design relative to possible risks of fire, windthrow, invasive species, and trespass.

Sub-Basin Planning – Landscape and water quality concerns could be addressed by prioritizing forest restoration projects based on their location within watershed sub-basins in the CRMW (e.g., concentrate restoration projects within a basin until a natural functioning basin is restored). Sub-basin prioritization could either be based on the most need (e.g., basins with the most anthropogenic disturbance) or the least effort (e.g., basins with the most intact natural processes), or other criteria.

Appendix H. Outlines of individual project management plans.

Below are examples of outlines of individual project management plans. These outlines are made as suggestions and are expected to evolve over time as specific plans are written and implemented.

1) An example of an ecological thinning plan outline from the table of contents of the 700 Road Forest Restoration Management Plan:

6.0 SPECIFIC THINNING PRESCRIPTIONS

6.1 Data and Scenarios Considered
6.2 Thinning Prescriptions
6.3 Future Silvicultural Treatments

7.0 LOGGING/ ENGINEERING SYSTEM

8.0 RISKS, BENEFITS, AND COSTS

8.1 Risks
8.2 Benefits
8.3 Costs

9.0 MONITORING

9.1 Compliance Monitoring
9.2 Effectiveness Monitoring
9.3 Validation Monitoring

10.0 IMPLEMENTATION AND DOCUMENTATION

10.1 Seattle City Council Ordinance
10.2 Contracts
10.3 Project Completion

11.0 LITERATURE CITED

2) An example of a restoration thinning plan outline from the table of contents of the 2003 Restoration Thinning Management Plan:

EXECUTIVE SUMMARY

1.0 INTRODUCTION

1.1 Background
1.2 Authority
1.3 HCP Upland Forest Goals
1.4 HCP Upland Forest Management Activities
1.5 Site Selection
1.6 Scoping

2.0 ECOLOGICAL PROCESSES

2.1 Forest Development
2.2 Disturbance Effects
2.3 Late-successional Forest Conditions

3.0 ECOLOGICAL OBJECTIVES

3.1 Site Specific Objectives -Landscape, Basin, to Unit Scales
3.8 Desired Future Conditions
3.8.1 Short Term Desired Future Conditions