Olympic Experimental State Forest Synthesis of Riparian Research and Monitoring

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Executive Summary

The Washington Department of Natural Resources (DNR) has implemented a Habitat Conservation Plan for the Olympic Experimental State Forest (OESF) that specifies riparian protection measures that go beyond the majority of land management plans currently in place in Pacific Northwest forests. Although the riparian buffers on the OESF are wider and more complex than buffers prescribed in the Forest and Fish Agreement for Washington State, DNR wishes to utilize the experimental capacity of the OESF to investigate alternative management options that could result in a forested landscape that more closely resembles the range of conditions produced by a natural disturbance regime, while at the same time continuing to fulfill trust obligations for timber harvest and protecting sensitive stocks of salmon and trout. The opportunity for collaboration between the DNR and the Pacific Northwest Research Station of the USDA Forest Service (PNW) resulted in an agreement for scientists from the PNW to complete a riparian science synthesis that would help to frame future planning efforts and landscape-scale experimentation on the OESF, and perhaps on adjoining national forests and park lands. Furthermore, the forthcoming addition of the OESF to the Forest Service's experimental forest network will enable sustained cooperation between DNR, the USFS, and other research interests.

The DNR has asked that the riparian science synthesis address several questions:

1. What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?

2. What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity? Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?

3. What models/metrics/criteria can be used in forest planning to assess the restoration of riparian functions at the watershed scale? What are the critical assumptions that can be addressed through monitoring?"

In addition to addressing these questions, the content of the science synthesis includes topics that were raised in discussions between DNR and PNW staff members. We wish to emphasize that these questions cannot be answered with scientific certainty. No buffer configurations can satisfy every conservation and commodity production objective in all instances, and no models are ecologically perfect. Our approach is to show what some organizations are currently doing to plan and implement strategies for riparian management that attempt to improve compatibility with watershed processes.

Following the introduction, this report includes (1) a section on riparian functions, indicators, and ecosystem goods and services, (2) a section that addresses questions 1 and 2 as they share common themes, (3) a section that addresses question 3, and (4) a section on metrics for assessing the success of achieving management goals. The authors wish to emphasize that much of the material in these sections originates from studies done elsewhere, but is discussed in this report to provide a broad sampling of recent scientific findings about riparian management and watershed planning in the Pacific Northwest. However, as planning for OESF experimentation proceeds, we anticipate that site-specific information will become more important in designing demonstration projects.

Major conclusions from this report include:

Riparian functions, indicators, and ecosystem goods and services

- Aquatic and riparian metrics in the current HCP emphasize temperature, large wood and sediment. While these are key indicators of habitat for salmonids, it is important to remember that maintaining ecologically functional riparian zones is necessary for a much wider array of benefits.
- Application of new remote sensing technologies such as high resolution LiDAR and Forward Looking Infrared (FLIR) will assist managers in identifying floodplain connections, locating water tables and abandoned river channels, and mapping changes in channel morphology. New technologies will also enable landscape-scale determination of vegetative cover, which can be used to quantify certain aspects of stream shading and inputs of organic matter.
- The relatively static view of aquatic and riparian ecosystems currently reflected in fixed habitat standards in many environmental regulations is beginning to change, in part as a result of having to take a longer term perspective. There is an emerging view that streams and associated riparian areas undergo successional changes similar to upland forests, and that they can experience a wide range of conditions like the terrestrial ecosystems in which they are embedded.
- Resilience of salmon and trout is influenced by watershed processes that supply structural components of the aquatic environment such as coarse sediment and large wood, as well as those that support the transfer of energy and nutrients through aquatic food webs. These processes are linked to riparian forests, and forests in upland portions of the watershed that may erode and contribute large trees and coarse sediment to streams.
- When applied to the management of aquatic ecosystems, the concept of resilience requires us to abandon the idea that any water body not conforming to an idealized notion of optimum habitat needs to be fixed. From this new perspective, resource managers must examine variability in current aquatic conditions and establish the large-scale spatial and temporal context of a watershed, historical changes in the system, and potential threats and expectations.

What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?

What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity? Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?

- We used examples of alternative riparian management strategies that were developed by the Willamette National Forest in Oregon to illustrate how landscape planning based on natural disturbance history could be applied to riparian buffer design. Although these strategies were based primarily on wildfire history – an infrequent disturbance in the OESF area – a similar approach could be applied to the western Olympic Peninsula where windthrow, mass wasting, and flooding are much more common.
- The Blue River Management Plan represents one of the first truly integrated management plans based on natural disturbance regimes. It was also a significant departure from the site-based default management prescriptions in the Northwest Forest Plan. Although the nature of the natural disturbance regime in the Blue River watershed differs somewhat from the disturbance patterns in the OESF planning area (e.g., Blue River experiences more wildfires and fewer windstorms that OESF), the approach is worthy of consideration as an alternative to fixed-width riparian buffer prescriptions.
- The Blue River watershed has been incorporated into an adaptive management area within the Willamette National Forest, and will be monitored over time to determine if the habitat projections are realized. In some ways, the OESF shares important attributes with the Blue River watershed: the OESF contains several drainages (e.g., Clearwater River) that are almost wholly managed by DNR; there are extensive databases on forest stand composition, natural disturbance history, and fish and wildlife habitat; and the OESF planning area has experimentation as an important management objective.
- Research by University of Washington scientists on the lower Queets River within the boundaries of Olympic National Park has focused on scientific characterization of a largely unmanaged coastal rainforest watershed. The Queets River watershed is especially relevant to the OESF because it lies within the OESF planning area and represents a relatively pristine reference site that can be used to identify target habitat conditions.
- Although there will always be uncertainty with respect to the question of how wide riparian management zones should be to protect aquatic ecosystems, recent scientific investigations have revealed patterns of riparian influence that can assist in determining buffer widths. These are generally summarized in Figure 13 of this report. Exceptions to the generalizations are also discussed.
- With respect to the question of whether selective timber harvest can occur in the outer part of the riparian management zone (i.e., the portion of the riparian zone farthest from the stream), we found no evidence that this would impair riparian function with respect to wind firmness. In general, field studies suggest that sharp-edged forest boundaries, buffers whose boundaries face southwest, buffers near exposed ridges, buffers with a shallow water table and rooting depth, and buffers with root rot or other tree diseases that impair root strength are more susceptible to windthrow.

- There is very preliminary evidence from research in British Columbia that wind buffers of about 40 feet will be sufficient to protect the integrity of the interior riparian stand; however, a scientific test of the efficacy of wind buffers of different widths has not yet been conducted. It is likely that wind buffer effectiveness will be influenced by maximum wind velocity, which will be controlled by local topography.
- Provided the riparian forest community adjacent to the stream is sufficiently wide to protect the ecological functions diagrammed in Figure 3 in this report, we found no evidence that timber harvest from an outer riparian management zone would significantly compromise aquatic habitat. We further note that openings caused by natural disturbances do occur in riparian zones in unmanaged watersheds. However, protection of riparian function at the landscape scale requires a broader space and time perspective that examines the condition of riparian forests throughout a watershed.

What models/metrics/criteria can be used in forest planning to assess the restoration of riparian functions at the watershed scale? What are the critical assumptions that can be addressed through monitoring?

- Fully recovering the natural range of states of a habitat element such as large wood in an altered watershed requires landscape-based management strategies that facilitate restoration of both the largely undisturbed median conditions and post-disturbance environmental extremes; otherwise, habitat diversity will be lost.
- Management prescriptions have been written to meet quantitative environmental guidelines and are thereby meant to mitigate the effects of land-use practices on stream habitats and the species that depend on those habitats. These prescriptions remain contentious for a number of reasons, but most significantly because they attempt to force streams to conform to an "idealized" state than cannot be sustained in a regime of natural disturbances.
- Collecting the data needed to calibrate and run habitat models (e.g., stream temperature) is time consuming and expensive, and running a model requires an investment in time to learn the modeling software. Consequently, site-specific analyses of model accuracy are often considered prohibitive in most land management applications – even at the reach scale.
- Growing concern over cumulative effects of individual land management decisions has highlighted the need to analyze and manage watersheds holistically, conducting assessments over large-spatial scales and considering the long-term cumulative effects of all land management activities within entire watersheds. Although single factor effects have been documented at the watershed scale, cumulative, multi-factor effects remain inadequately evaluated at large spatial scales. Lacking direct empirical data, other approaches are needed to "scale up" results of reach-scale studies to entire watersheds. But developing aquatic habitat objectives, even for a single factor like temperature, can be difficult.

- The need for an extensive, well-designed monitoring program cannot be overemphasized. Any landscape-scale land management plan will be experimental in nature and thus face critical uncertainties.
- Response times of forested systems of the western Olympic Peninsula to restoration treatments will be slow, although some treatments may be able to accelerate the development of desired conditions. It will take a long time to grow the large riparian trees needed to maintain critical aquatic and riparian habitats. We expect that it will take decades to centuries to significantly alter the landscape patterns that exist today. It will be possible to use specific silvicultural and restoration treatments to speed up the creation of desired landscape conditions, but even the most optimistic scenarios must approach disturbance-based land management with abundant patience.
- Examples of commonly used metrics for implementation and effectiveness monitoring of aquatic, riparian, and watershed restoration are given in Tables 4 and 5 of this report.

Introduction

This report serves to fulfill the provisions of an agreement between the Washington Department of Natural Resources (DNR) and the USDA Forest Service Pacific Northwest Research Station (PNW). The purpose of this agreement is to provide expert services to assist DNR staff in developing forest management strategies, assessment methodologies, and monitoring programs on DNR-managed lands in meeting riparian conservation objectives on the Olympic Experimental State Forest (OESF).

The primary deliverable of the agreement is a synthesis of the latest scientific findings that may be applicable to OESF management. The following paragraphs from the Statement of Work in the agreement describe the background and objectives of this scientific synthesis:

> "DNR seeks to achieve the conservation objectives of the riparian conservation strategy for the Olympic Experimental State Forest (OESF). These objectives seek to maintain and aid restoration of habitat that is capable of supporting viable populations of salmonid species, as well as for other non-listed and candidate species dependent on in-stream and riparian environments. The riparian conservation objectives also incorporate the OESF mission, that of implementation of a credible program of research, experimentation, and monitoring to aid forest management and the scientific understanding of riparian systems in managed landscapes.
>
> To date, implementation of riparian conservation objectives has been accomplished through a 12-step watershed assessment procedure[1]. Assessments have occurred on an activity-basis to demonstrate that proposed timber management activities do not conflict with the objectives of the riparian conservation strategy. Due to scale and uncertainty underlying these assessments, DNR has been limited in its ability to fully achieve the riparian conservation objectives; i.e., meeting multiple objectives of habitat conservation, commodity production, and information gathering melded across the entire OESF landscape.
>
> Landscape planning provides an opportunity to take an incremental step forward in achieving these OESF conservation objectives. Through landscape planning, implementation of the riparian conservation objectives will be addressed at the watershed-scale. This will allow DNR to evaluate cumulative effects and to schedule of stand-level activities in consideration of multiple landscape-level objectives. It also provides an opportunity to update assessment procedures, providing greater certainty about the effects of proposed activities and greater focus to research and monitoring in addressing remaining critical uncertainties."
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> "Since implementation of the Habitat Conservation Plan, considerable learning has occurred about management of riparian forests along coastal streams in the Pacific Northwest. The DNR seeks the assistance of the PNW in synthesizing

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[1] http://www.dnr.wa.gov/Publications/lm_hcp_ch4e.pdf

learning, which has occurred on and off of DNR-managed lands, in answering three key questions:

4. What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?

5. What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity? Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?

6. What models/metrics/criteria can be used in forest planning to assess the restoration of riparian functions at the watershed scale? What are the critical assumptions that can be addressed through monitoring?”

The Olympic Experimental State Forest occupies approximately 260,000 acres on the northwestern side of Washington’s Olympic Peninsula (Figure 1). Major drainage systems within the OESF include the Hoko R., Lake Ozette, Sol Duc R., Calawah R., Bogachiel R., Hoh R., Clearwater R., and Queets R. The area possesses highly complex geological surfaces consisting of a mixture of marine sediments, volcanic outcroppings, and glacial deposits (Orr 2002). Precipitation falls mostly as rain, although winter snows occur in the Olympic Mountains above 3,000 ft. elevation. The western slopes of the peninsula include some of the wettest areas in the continental U.S., with precipitation averaging about 140 inches per year and some locations receiving more than 200 inches per year. Native tree communities in the coastal lowlands are dominated by spruce-hemlock rain forests (Franklin and Dyrness 1988; Henderson et al. 1989; Bigley and Hull 2001 unpublished), making the west side of the Olympic Peninsula one of the few temperate rainforest zones in the world.

The Olympic Mountains, a northern extension of the Coast Range in Oregon and Washington, form the core of the peninsula. The Olympics are the second highest mountain range in Washington State, with Mt. Olympus at 7,980 ft. being the highest point. Although the eastern side of the Olympic Peninsula was covered by the Puget Lobe of the continental ice sheet during the last major glacial period, montane glaciers eroded many of the major river valleys of the peninsula’s west side in the Olympic Experimental State Forest planning area. The western Olympic Peninsula also contains one of the most diverse assemblages of native salmonid fishes in the Pacific Northwest (Wydoski and Whitney 2003), with various species possessing fluvial (non-migratory stream-dwellers), adfluvial (rear in lakes but spawn in streams), and anadromous (spend most of life in ocean but spawn in streams) life cycles. Unlike many other regions of Washington, rivers in the OESF area have no major dams and are subject to natural (unregulated) flow regimes.

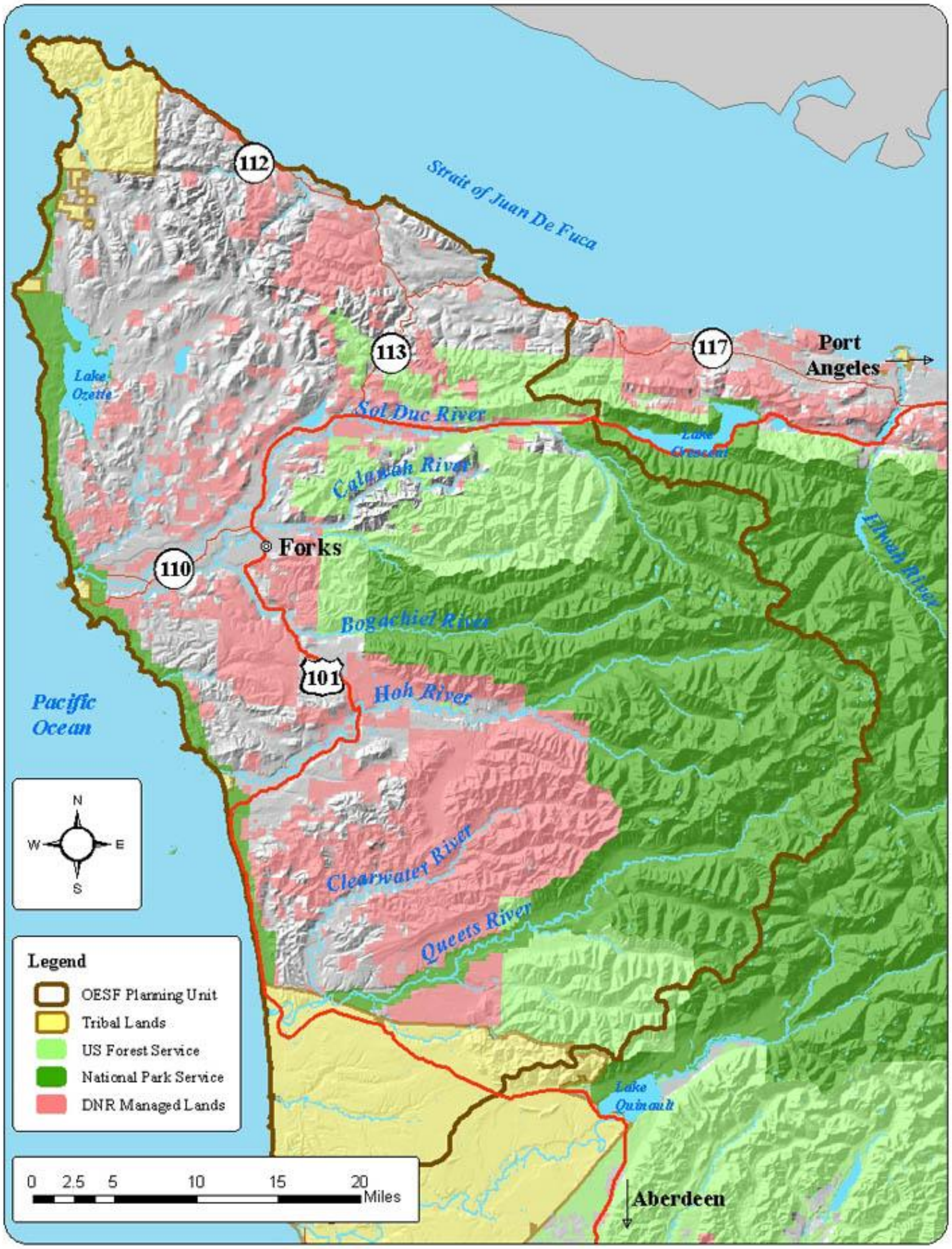

Figure 1. The Olympic Experimental State Forest planning area (bounded by the heavy solid line). DNR managed lands are shown in pink. From http://www.dnr.wa.gov/ResearchScience/Topics/ForestResearch/Pages/lm_oesf_main.aspx

Since implementation of DNR's Habitat Conservation Plan in 1997, additional learning has occurred about watershed management along coastal streams in the Pacific Northwest. The objective of this report is to synthesize this recent learning to aid in answering the three key questions above. Our goal is to assist DNR staff in developing forest management strategies, assessment methodologies, and monitoring programs on DNR-managed lands in order to meet riparian conservation objectives.

Fishes of Concern

As stated in the agreement, DNR seeks "to maintain and aid restoration of habitat that is capable of supporting viable populations of salmonid species, as well as for other non-listed and candidate species dependent on in-stream and riparian environments". The following table lists the notable fish species inhabiting (or believed to inhabit) the OESF area, their federal and state classification with respect to whether they are an "at-risk" species, and their preferred freshwater habitats. The table also lists species that are not currently considered at-risk, but are included because they are of recreational, commercial, or cultural importance, or are believed to be in decline.

Table 1. Native fishes of the OESF planning area. From Wydoski and Whitney (2003), NOAA Fisheries (http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Index.cfm), and Washington Department of Fish and Wildlife (http://wdfw.wa.gov/wlm/diversty/soc/soc.htm).

Species	**Federal ESA status**	**State Species of Concern classification**	**Preferred freshwater habitat**
Pacific lamprey	Not listed	Not listed, but in widespread decline	Rivers and streams
River lamprey	Species of concern	Candidate	Rivers and streams
Coastal cutthroat trout	Species of concern	Not listed	Rivers and streams; can be both anadromous and resident
Chum salmon	Not listed	Not listed	Low gradient rivers and streams
Coho salmon	Not listed	Not listed	Rivers and streams; riverine ponds and wetlands in winter
Rainbow trout (steelhead)	Not listed	Not listed, but in decline on Olympic Peninsula	Rivers and streams; can be both anadromous and resident

Species	**Federal ESA status**	**State Species of Concern classification**	**Preferred freshwater habitat**
Sockeye salmon (Lake Ozette)	Threatened	Candidate	Lake Ozette, but some stream spawning in the lake's tributaries
Chinook salmon	Not listed	Not listed	Rivers; life cycles include <1 yr freshwater rearing ("ocean type") and >1yr freshwater rearing ("freshwater type")
Mountain whitefish	Not listed	Not listed, but possibly in decline on Olympic Peninsula	Rivers
Bull trout*	Threatened	Candidate	Rivers and streams; can be both anadromous and resident
Dolly Varden*	Not listed	Not listed	Rivers and streams; can be both anadromous and resident
Olympic mudminnow	Not listed	Sensitive	Low gradient rivers and streams, wetlands

* Occasionally synonymized, bull trout and Dolly Varden are both native chars considered separate species by Wydoski and Whitney (2003). Although they may interbreed, bull trout on the Olympic Peninsula tend to occupy headwater streams and Dolly Varden tend to occur in lowlands where they often adopt an anadromous life history. The status of Dolly Varden on the Olympic Peninsula is poorly known.

Although the western Olympic Peninsula does contain several federally listed and state sensitive fishes, this area, overall, maintains a greater proportion of robust fish populations than many other locations on the Pacific coast (Huntington et al. 1996). Apart from forest management, human impacts in the OESF planning area have been minor compared with more heavily developed coastal areas in Washington, Oregon, and California. River basins residing mostly within Olympic National Park boundaries, such as the Queets River, are considered the most intact, ecologically healthy systems along the Pacific coast below the Canadian border (Naiman et al. 2000). Because the Washington DNR manages large areas of Olympic Peninsula trust land for both forest commodities and habitat conservation for fish and wildlife (e.g., Pacific salmon, northern spotted owl, and marbled murrelet), it is important that management plans promote compatibility between these two important objectives.

OESF Riparian Conservation Strategy

The Habitat Conservation Plan (HCP) for the OESF emphasizes achieving riparian conservation objectives at the landscape(or watershed) scale, rather than at the scale of individual stands:

> *"The objectives of the OESF riparian conservation strategy are to maintain and aid restoration of riparian functions at the watershed scale, rather than at the site specific level. Implementing these objectives, therefore, requires an evaluation procedure by which the aquatic and streamside conditions at a given site can be assessed in relation to the known influences of physical, biological, and land-use factors throughout the watershed."* [2]

Prior to landscape planning in the 11 landscape planning units in the OESF, watershed conditions have been evaluated and monitored through a 12-step watershed assessment procedure in those drainages not having completed watershed analyses or landscape plans. About half of the watersheds within the OESF planning area have had watershed assessments completed. Figure 2 illustrates the process for scaling down from landscape goals to site-specific management recommendations.

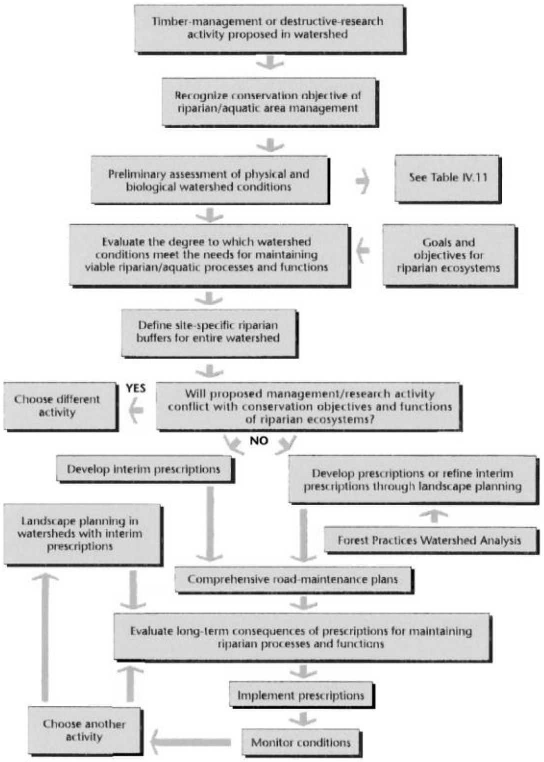

Figure 2. The 12-step watershed assessment process for meeting riparian objectives in the OESF. From the 1997 DNR Habitat Conservation Plan, Chapter 4E, Fig. IV.13.

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[2] http://www.dnr.wa.gov/Publications/lm_hcp_ch4e.pdf

In the Olympic Experimental State Forest, of the many factors affecting habitat for salmonids and riparian-dependent species, mass wasting and windthrow are believed to exert the greatest short- and long-term influences (HCP IV. 106). In addition to the HCP riparian conservation strategy addressing these two factors by creating riparian buffers designed to minimize mass wasting and windthrow, a critical working hypothesis is that buffers designed to minimize mass wasting and blowdown will be sufficient to protect other key physical and biological functions of riparian systems, such as large wood recruitment, stream shade, and streambank stability. Thus, many of the riparian protection requirements in the HCP are meant to ensure adequate shade for temperature control, recruitment of large wood from the streamside forest into the stream for fish habitat, and, to a somewhat lesser extent, to minimize the movement of fine sediment into stream channels – sediment control being primarily regulated by road construction and maintenance requirements. For each of these environmental parameters hazard thresholds have been established that can serve as indicators of potentially deleterious conditions for salmonids. For example, the temperature screening process employs a model that assumes a linear relationship between the elevation of a stream segment and the amount of cover (expressed as % canopy over the water surface) needed to provide adequate shading to keep stream temperatures below thermal tolerance levels for different fish life cycle functions. Riparian buffers are the principal means of achieving the riparian conservation objectives and are based on strips of vegetation adjacent to the stream, in which the innermost strip, usually excluded from timber harvest or heavy equipment entry, serves the purpose of providing shade, large wood, and streambank protection. Beyond this innermost strip, an outer strip may also be present whose purpose is primarily to protect the inner buffer from windthrow. Management options for the outer buffer are most flexible, e.g., commercial thinning may occur there.

Since completing their HCP in the mid-1990s, the DNR has participated in a number of research efforts regarding large wood dynamics, factors influencing stream shading, headwater stream management, and many wildlife studies related to HCP implementation (Tepley and Phifer 2008[3]). They are also aware of simultaneous investigations by other land and water management organizations that address both site-specific and landscape-scale conservation issues. One of the important objectives of this report is to summarize the findings of additional recent scientific studies of riparian research and monitoring, particularly those that may be relevant to watershed-level planning in the OESF. Hopefully this report will help to frame new experiments that will assist managers in making better informed decisions.

Future Planning

As adaptive management proceeds on the OESF, alternatives to the default ("no action") riparian conservation strategies in the HCP will be considered. These will be supported by analytical processes that could lead to changes in riparian management strategies and actions. A corollary objective of this report is to display watershed-level planning processes in managed forests that have been used elsewhere and that could provide viable alternative planning approaches for current DNR planning procedures. Our discussion will include key metrics that could be compiled or estimated from data currently being gathered to meet riparian conservation objectives. We also discuss some of the critical uncertainties underlying these metrics that could be evaluated in field tests accompanied by appropriate monitoring.

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[3] http://www.dnr.wa.gov/ResearchScience/Topics/ForestResearch/Pages/lm_oesf_research.aspx

Watershed Scale

Throughout this report we use terms such as "watershed" without deliberately referencing a geographic scale. We do this because different organizations associate different spatial dimensions with these terms, but we realize that they do have explicit meaning from a regulatory standpoint. With regard to spatial scales that are relevant to DNR planning, we reproduce the following definitions from an internal report "A Discussion of Appropriate Scales for Riparian Forests, Stream Channels and Related Fisheries Assessments" by W. S. Jaross, J. E. Caldwell, and M. Teply (W. Jaross, personal communication). They reflect the scales applicable to forest and riparian management units on state and private lands in the OESF planning area.

> **WRIA:** For the purposes of WAC 173-500-040, the OESF is divided into 3 areas known as Water Resource Inventory Areas (WRIAs); 19 Lyre-Hoko, 20 Soleduck-Hoh, and 21 Queets-Quinault. WRIA
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> **WAU:** Watershed analysis is performed on Watershed Administrative Units (WAUs) - areas defined by hydrology and geomorphology - ranging in size from about 10,000 to 50,000 acres (WAC 222-22-020). WAU's are hierarchically contained within WRIA's. The maintenance of WAU boundaries by DNR Forest Practices is coordinated with the WRIA's as well as federal hydrologic units.
>
> **Watershed**: A watershed (scale ambiguous) is the drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake (DNR-HCP Glossary p. 17)
>
> **Sub-watershed**: A portion of a WAU, typically defined when conducting watershed analysis/assessments. Hypothesized by a hydrologist and a fisheries biologist to be one of the appropriate scales to use when investigating watershed processes and their affect on stream channels and fish habitat. Often, but not always, a named tributary to a larger river system. In some cases, synonymous with sub-basin in Watershed Analysis.[4]
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> **Sub-basin:** A sub-basin (scale ambiguous) is a drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake. Typically used to describe hydrologically defined basins that are both smaller and larger than WAU's. In some cases, synonymous with sub-watersheds in Watershed Analysis; i.e., the watershed is divided into sub-basins (on MAP B-1) usually of the Type 3 streams, and a ground sediment yield is calculated as a function of soil depth, creep rate, stream length.
>
> **Type 3 watershed:** A Type 3 sub-basin is defined as the smallest sub-basin unit containing a Type 3 stream segment**.** (PR 14-004-160). These, in general, comprise smaller areas than the sub-watersheds. A scale used in the Hydrologic Change Assessment of watershed analysis and in the OESF HCP 12-step watershed assessment procedure (DNR-HCP IV. 127-133).

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[4] Note that over time the definition of type 3 waters was updated, and hydrography improved. As a result the scale of basins contributing to a type 3 evolved from 3-10 thousand acres to smaller basins.

Stream segment: The part of a stream extending between designated tributary junctions. Also known as channel segment and stream tributary

Stream tributaries: A tributary (or confluent/affluent) is a stream or river which flows into a mainstem (or parent) river, and which does not flow directly into a sea. In orography, tributaries are ordered from those nearest to the source of the river to those nearest to the mouth of the river. A confluence is where two or more tributaries or rivers flow together.

The descriptive means terms “right tributary” and “left tributary” always apply from the perspective of looking downstream (in the direction the current is going), similarly to the river banks.

The opposite of a tributary is a distributary; a river branch that flows away from the main stream. A river and all its tributaries drain the watershed of the river.

The Strahler Stream Order examines the arrangement of tributaries in a hierarchy of first, second, third and higher orders, with the first order tributary being typically the least in size. For example, a second order tributary is comprised of two or more first order tributaries combining to form the second order stream.

Stream reach: Any specified length of stream (Armantrout 1998). The actual distance will depend on stream size and on the assessment to be conducted.

Stream management unit: Stream segments, reaches, or tributaries, each containing a control station, that are identified on stream reach maps in adopted water resource management program documents as units for defining base flow levels, (WAC 173-500-050).

Riparian Functions, Indicators, and Ecosystem Goods and Services

Before we address DNR’s three questions, it is helpful to summarize recent insights into our understanding of riparian functions and processes. Riparian forests mediate a variety of ecosystem processes that contribute both to the maintenance of productive aquatic habitat and to other ecological “goods and services” that are valued by society, such as protecting biodiversity and buffering the effects of storm flows. Table 2 lists some of the most important riparian functions, their indicators, and benefits to society. Current implementation procedures to achieve HCP objectives for aquatic and riparian conservation in the DNR HCP emphasize temperature, large wood and sediment. While these are key indicators of habitat for salmonids, it is important to remember that maintaining ecologically functional riparian zones is necessary for a much wider array of benefits.

Table 2. Riparian functions, indicators, ecosystem effects, and ecological goods and services (modified from Naiman et al. 2002).

Functions	**Indicators that Functions Exist**	**Effects of Functions**	**Goods and Services Provided**
Hydrology and Sediment Dynamics			
Stores surface water (short term)	Floodplain connected to stream channel	Attenuates downstream flood peaks	Reduces damage from floodwaters
Maintains a high water table	Presence of flood-tolerant and drought-tolerant species	Maintains native riparian vegetation structure	Contributes to regional biodiversity by providing habitat
Accumulates and transports sediments	Riffle-pool sequences, point bars, terraces	Contributes to fluvial geomorphic processes	Creates predictable yet dynamic channels and floodplains
Biogeochemistry and Nutrient Cycling			
Produces organic carbon	A balanced biotic community	Provides energy to maintain aquatic and terrestrial food webs	Supports populations of native organisms
Contributes to overall biodiversity	High species richness of plants and animals	Reservoirs for genetic diversity	Contributes to biocomplexity
Cycles and accumulates chemical constituents	Water quality parameters within normal limits	Intercepts nutrients and toxicants from surface runoff	Clean water
Sequesters carbon in soil	Organic-rich soils	Contributes to nutrient and carbon retention	Helps ameliorate climate change
Habitat and Food Web Maintenance			
Maintains streamside vegetation	Presence of shade-producing forest canopy	Shades streams during warm seasons; moderates temperature at night	Maintains conditions for cool-water species
Supports characteristic terrestrial vertebrate populations	Appropriate species having access to riparian areas	Allows daily and seasonal movements as well as annual migrations	Wildlife viewing and game hunting
Supports characteristic aquatic	Fish migrations and population	Allows migratory fish to complete life cycles	Provides fish for food, cultural use, and

Functions	Indicators that Functions Exist	Effects of Functions	Goods and Services Provided
vertebrate populations	maintenance		recreation

We believe that the application of new remote sensing technologies such as high resolution LiDAR and Forward Looking Infrared (FLIR) will assist managers in identifying floodplain connections, locating water tables and abandoned river channels, and mapping changes in channel morphology. New technologies will also enable landscape-scale determination of vegetative cover, which can be used to quantify certain aspects of stream shading and inputs of organic matter. Although off-the-shelf indicators of riparian functionality at large spatial scales are still in development, we suspect that within the next decade our ability to measure some environmental metrics that were formerly cost-prohibitive to assess over broad areas will become available to land managers at a reasonable cost. New technologies will enable us to extend the range of riparian indicators beyond temperature, shade, large wood, and sediment.

Managing for Resilience Based on Natural Disturbance Regimes

Managing for resilience in an environment where salmon and trout may be at risk will require decisions about habitat that are by necessity relatively short-term and geographically focused. Management plans for the OESF will continue to identify restoration and protection actions at site-specific scales that are consistent with landscape-based strategies. Local spatial and short-term temporal scales are small relative to the distribution and persistence of Pacific salmon as a whole, but they are very important for developing management strategies that promote the local population resilience. In addition to temporal trends and cycles, much recent work has emphasized the importance of acute disturbances resulting from events such as wildfire (Rieman and Clayton 1997; Dunham et al. 2007), volcanism (Bisson et al. 2005), and earthquakes (Hastings 2005). It is important to note that natural variation is expressed differentially over time and space, because watersheds differ in climate, landform, and vegetation – all factors that mediate disturbance and the specific processes that form and maintain freshwater habitat for Pacific salmon (Montgomery 1999; Benda et al. 2004). For the western Olympic Peninsula, important disturbance processes influencing the development of riparian forest communities have been well summarized (Agee 1988; Henderson et al. 1989). These disturbance regimes differ somewhat for forests dominated by Sitka spruce and western hemlock at low elevations and silver fir dominated forests at higher elevations.

Spatial and temporal variability in physical processes is complemented by a remarkable diversity of life histories in salmon and trout (Quinn 2005). For example, some species spend only a few days in fresh water prior to seaward migration and others spend one or more years in a variety of freshwater environments before migration. Still others do not exhibit extensive migrations at any point in their life cycles. Life histories can vary along broad environmental gradients such as from north to south or coastal to interior, and also by sex as males and females face different selective pressures (Groot and Margolis 1991; Hendry and Stearns 2003). In populations having extended freshwater residence, multiple life history patterns may exist, but only one or two of which may be favored at any point in time. These may include both anadromous and fully freshwater life histories within the same breeding population (Jonsson and Jonsson 1993). Evolutionary requirements of survival, growth and reproduction govern the development of life history patterns (Northcote 1978; Hendry and Stearns 2003), but environmental variability leads to certain strategies having better success than others at different times and places. The result is the remarkable variety of life histories we observe in salmon and trout native to the Olympic Peninsula.

In recent years there have been an increased number of studies involving fish and fish habitat centered on the watershed (Benda et al. 1998) and landscape (Reeves et al. 1995) scales. This has required that aquatic ecosystems be considered in the context of time scales of decades to centuries. Time has not previously been a major consideration when considering the behavior of aquatic ecosystems. A consequence of this oversight is that aquatic ecosystems have been assumed to be relatively stable through time, and have been thought to recover relatively quickly if disturbed by natural events. Terrestrial ecosystems, in contrast, have been understood to vary dynamically over long time periods, and forested landscapes have been characterized as a series of patches of different forest ages that gradually change over time.

The relatively static view of aquatic and riparian ecosystems currently reflected in fixed habitat standards in many environmental regulations is beginning to change, in part as a result of having to take a longer term perspective. There is an emerging view that streams and associated riparian areas undergo successional changes similar to upland forests, and that they can experience a wide range of conditions like the terrestrial ecosystems in which they are embedded. For example in the Oregon Coast Range, large wildfire has occurred on average every 250-300 years (Reeves et al. 1995). Extensive landsliding often follows these fires, inundating stream channels with thick deposits of sediment and logs. Habitat conditions are not very favorable for fish in such situations. Primary rearing areas in summer are pools which are often isolated from each other because the flow goes through rather than over the gravel – a condition common to some streams in the OESF that have experienced recent mass erosion events. As the recovery cycle progresses, about 120-140 years after a fire, habitat for fish in Oregon coastal streams becomes diverse and complex. The amount of sediment decreases as fine sand and silt are transported downstream and previously buried wood is exposed. Additionally, as the surrounding forest recovers, wood begins to be recruited from the adjacent riparian zone. Preliminary estimates suggest that these favorable conditions probably exist in 30-60% of the forested landscape along the central Oregon Coast Range (Reeves et al. 1995). Habitat conditions for fish have likely declined as the old-growth forest developed. The amount of large wood in the channel increased because of increased input from the aging forest. However, the rate of transport and erosion of gravel exceeds the input rate, and as result a stream channel now contains large expanses of bedrock, in which pools are infrequent and of low habitat quality.

Wildfire, while infrequent, is an important natural disturbance agent in the western Olympic Peninsula and is often overlooked in understanding the disturbance regime of the area. Within the past century at least two large fires have occurred in the northwestern corner of the peninsula – one in 1907 and the other in 1951. Both fires took place after extended rainless periods when soil moisture levels were exceptionally low. Although wildfires typically burn more severely on hillslopes, alluvial valleys can experience stand-resetting fires during periods of prolonged drought. Greenwald and Brubaker (2001) found evidence of large fires in riparian zones of the

Queets River valley that may have been influenced by long-term changes in the region's climate. The fire disturbance history of the Olympic Peninsula suggests that the erosional cycles that have been studied in the Oregon Coast Range may be applicable to this area as well.

Resilience of Pacific salmon is influenced by watershed processes that supply structural components of the aquatic environment such as coarse sediment and large wood, as well as those that support the transfer of energy and nutrients through aquatic food webs. These processes are linked to riparian forests, and forests in upland portions of the watershed that may erode and contribute large trees and coarse sediment to streams, as described above. Considerable regulatory attention has been given to riparian forest protection, largely to preserve trees for stream shading, streambank stabilization, and as future sources of large wood for fish habitat (Bisson et al. 2006). Contemporary forest practices typically restrict harvest in riparian zones, but are often less focused on the importance of wood recruitment from uplands. In some locations, wood recruited to channels from landslides can constitute a significant portion of the wood load in the stream network (May and Gresswell 2003) and redistribution of hillslope-derived wood through fluvial transport is an important process in habitat formation downstream (Benda et al. 2003).

Resilience of Pacific salmon is also tied to recovery of aquatic and riparian food webs (Bisson and Bilby 1998; Naiman et al. 2002). For example, some projects have attempted to improve freshwater productivity by placing salmon carcasses in streams to restore an important annual source of marine-derived nutrients where salmon runs are depleted (Stockner 2003; Wilzbach et al. 2005). Managing tree species composition in riparian zones can also influence aquatic food webs. For example, conifers in riparian zones may be important contributors of large wood for habitat (see above), but smaller deciduous species such as nitrogen-fixing alders (*Alnus*, sp.) can deliver more energy and nutrients to streams (Karlsson et al. 2005). Most efforts to improve food web productivity for salmon are based on the assumption that trophic support from lower to higher consumer levels (with salmon as apex predators) is important. However, in many aquatic ecosystems, consumer-regulated (top-down) food web dynamics have received inadequate attention (Power and Dietrich 2002). In Pacific salmon streams and lakes, other top predators (e.g., birds) may be present, and even terrestrial consumers may play an important role in regulating food web dynamics (Baxter et al. 2005). A better understanding of the processes influencing the food webs of aquatic ecosystems that support Pacific salmon is needed, as food resources and the presence of competitors and predators will exert a strong influence on population resilience.

Salmon and trout require many different habitats in freshwaters (Groot and Margolis 1991), including those used for egg incubation, juvenile rearing, and migration of adults. In some cases, the value of a particular location may not be obvious, as in the case of localized thermal refugia (Torgersen et al. 1999; Ebersole et al. 2003) or use of ephemeral streams in winter (Wigington et al. 2006). Neighborhood effects may also be important; for example, use of a specific location may be related more to use of nearby habitats than to characteristics of the habitat itself (Isaak et al. 2007; Mull and Wilzbach 2007). Habitat supplementation refers to redundancy in terms of multiple habitats that can provide the same function for fish (Moyle and Sato 1991; Schlosser 1995). The importance of supplementation was illustrated in the recovery of Pacific salmon in the wake of the Mt. St. Helens eruption (Leider 1989; Bisson et al. 2005), where salmon occupied alternative habitats when historically used habitats were temporarily destroyed. At a larger spatial extent, metapopulation (clusters of breeding populations) dynamics such as source-sink relationships may be important factors in habitat use (Schtickzelle and Quinn 2007), but often the distinction between these and other spatial processes such as those described above is unclear (Rieman and Dunham 2000). In a general sense, habitat diversity appears to be essential for supporting salmonids, but understanding more specifically how watershed processes influence population resilience and expression of life histories remains an important information need.

The significance of physical and biotic connectivity in freshwater ecosystems is widely acknowledged to be essential for maintaining habitat dynamics and species responses (Lowe et al. 2006). For salmon and trout, the importance of movement to fulfill life cycle requirements is a hallmark of the species' biology. In fresh water, connectivity includes migratory pathways along rivers and their tributary systems, as well as unimpeded lateral connections between main channels, secondary channels, and floodplains. Ecological connectivity is similarly critical for processes essential to the function of freshwater ecosystems, including a wide variety of complex aquatic and terrestrial interactions that regulate channel dynamics, food webs, and water quality (e.g., Naiman and Bilby 1998; Power and Dietrich 2002). Riparian forests on valley floors and on alluvial terraces adjacent to stream channels play an important role in the dynamics of the water table beneath and adjacent to streams, in moderating discharge during flow extremes, in controlling the concentration of soluble nutrients, in mediating the seasonal input of organic matter and terrestrial food items to aquatic ecosystems, and in regulating microclimate (Naiman et al. 2005; Richardson et al. 2005). Removing barriers to movement and improving natural linkages between terrestrial and aquatic ecosystem processes to recreate normative watershed conditions has become an important conceptual foundation for salmon restoration programs (Williams et al. 2006).

The conceptual basis for aquatic and riparian management is shifting from an equilibrium perspective to one that recognizes dynamic, non-equilibrium conditions and natural variability (Naiman et al. 1992; Wellington et al. 2005). For example, restoration programs in coastal estuaries inhabited by Pacific salmon often acknowledge the importance of re-establishing dynamic physical and biological processes (Simenstad and Cordell 2000). A dynamic view of aquatic ecosystems requires an increased appreciation of infrequent but large events such as physical disturbances (e.g., wind storms, fires, and floods) that create and maintain habitats. This perspective recognizes disturbance and successional processes that do not occur in an orderly or predictable manner (Pahl-Wostl 1995). Within an area affected by a natural disturbance, several transitional states may be expressed over time such that the timing or duration of any particular state may be difficult to predict (Wondzell et al. 2007). Succession from one state to another can occur slowly in response to geomorphic adjustments (i.e., elevation change by an earthquake) or more rapidly in response to large, infrequent events such as floods, fires, and landslides. The signature and legacy of these events can influence local conditions for long time periods (Foster et al. 2003). Stream conditions can thus be viewed as transitory, reflecting local spatial controls, past natural disturbance, and land-use impacts.

Management of the freshwater habitat of Pacific salmon should focus on natural processes and variability rather than attempt to maintain or engineer a desired set of conditions through time

(Lugo et al. 1999; Dale et al. 2000). This does not imply that we should attempt to recreate or re-establish completely pristine conditions everywhere, which would simply not be possible. When applied to the management of aquatic ecosystems, the concept of resilience requires us to abandon the idea that any water body not conforming to an idealized notion of optimum habitat needs to be fixed. From this new perspective, resource managers must examine variability in current aquatic conditions and establish the large-scale spatial and temporal context of a watershed, historical changes in the system, and potential threats and expectations. The fundamental idea is to characterize variation in natural processes within stream networks and ask where we are, where we want to go, and how we get there, in the context of restoring a natural range of habitat conditions.

What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?

What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity? Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?

We discuss these two questions together because they share a common theme and because the alternative approaches that are being tried address both the lateral/longitudinal aspects of riparian zone management and the issue of maintaining riparian forest integrity.

Earlier Conceptual Basis for Establishing Riparian Buffers

State and privately-owned forests in the Pacific Northwest have been regulated by state forest practices rules since the 1970s. During the 1970s, the primary intent of forest practices regulations with respect to fish habitat was to provide adequate shade for temperature protection and enough riparian vegetation to protect streambanks from erosion. During the 1980s the importance of large wood to fish habitat was recognized and riparian buffers expanded, in some cases with specific basal area requirements to ensure sufficient recruitment of tree boles and rootwads to stream channels.

The President's Northwest Forest Conference in 1993 and subsequent development of the Northwest Forest Plan resulted in a thorough re-examination of the ecological functions of riparian zones with consideration given to protecting habitat for entire communities of fish and wildlife, not just salmon and trout. Based on research information available at the time, federal scientists developed presumed relationships concerning the role of different riparian functions at increasing distances from the edge of the stream channel. Those relationships are shown in Figure 3.

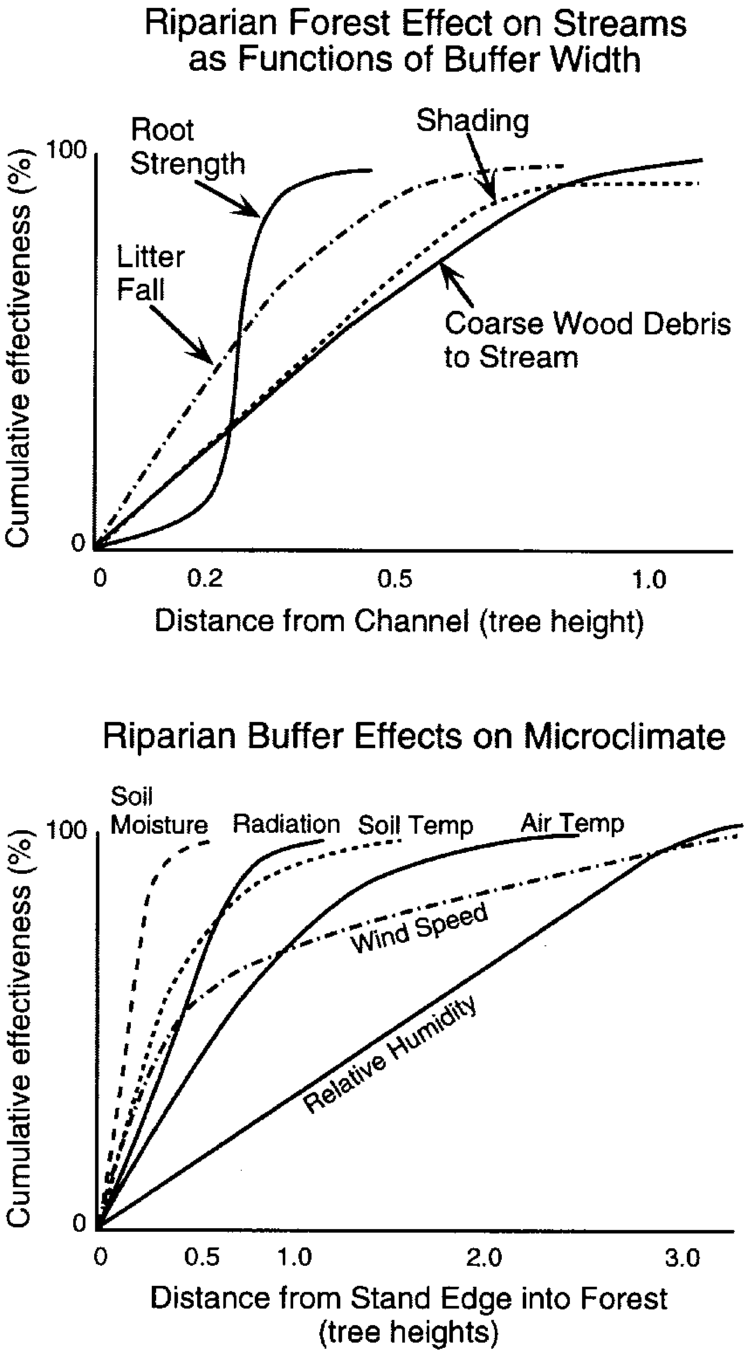


Figure 3. Top: Generalized curves indicating percent of certain functions or processes affecting interactions between streams and adjacent riparian zones achieved with varying distances (as indexed to the height of a dominant tree) from the edge of the stream channel. Bottom: Generalized curves indicating percent of microclimatic attributes achieved within varying distances from the edge of a stream. Source: Forest Ecosystem Management Assessment Team [FEMAT] Report (1993).

Based on the putative relationships shown above, the Northwest Forest Plan established default riparian buffers that were greatly expanded relative to those in which the only considerations were shade, large wood, and sediment. The wide default buffers on federally managed forests were meant to establish conservative boundaries and restrictions on management activities until more detailed site-specific analyses were completed that would give forest planners more options, including the option of integrating riparian treatments such as thinning with upland treatments (Sedell et al. 1994). Nevertheless, a survey of 250 watersheds in which Northwest Forest Plan default actions had been followed showed that 64% had improved watershed conditions 10 years after plan implementation (Reeves et al. 2006).

While it was generally understood in the 1990s that state and private forests would not be held to the same environmental protection standards as those on federal lands, there was a widespread scientific belief that state and private forest practice regulations were not providing sufficient protection to halt the decline in salmon habitat (National Research Council 1996). Because the majority of salmon listings under the Endangered Species Act took place during this time, many land management organizations negotiated Habitat Conservation Plans (HCPs), usually valid for 50 years, which would provide for increased riparian protection while also ensuring regulatory predictability. Nearly all of the new HCPs included provisions for adaptive management, in which new scientific information could be used to adjust forest management activities for habitat conservation as well as commodity production. It has been 10-15 years since many HCPs were negotiated, and land managers are applying adaptive management principles to forest planning.

Landscape Management Based on Natural Disturbance Regimes

Federal land managers have asked the same questions that DNR is asking:

> *What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?*
>
> *What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity? Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?*

An early attempt to develop a landscape-based management plan happened in the Willamette National Forest on the western slopes of the Cascade Mountains in Oregon. There, the Augusta Creek watershed was studied to establish its historical disturbance regime, which was dominated by wildfire and landslides. Based on the patterns of wildfire, erosion and forest recovery in the watershed, Cissel et al. (1998) developed a plan that utilized large planning blocks with different management emphases (Figure 4). The plan represented a marked departure from the complex network of unmanaged riparian reserves that would have been implemented under the Northwest Forest Plan.

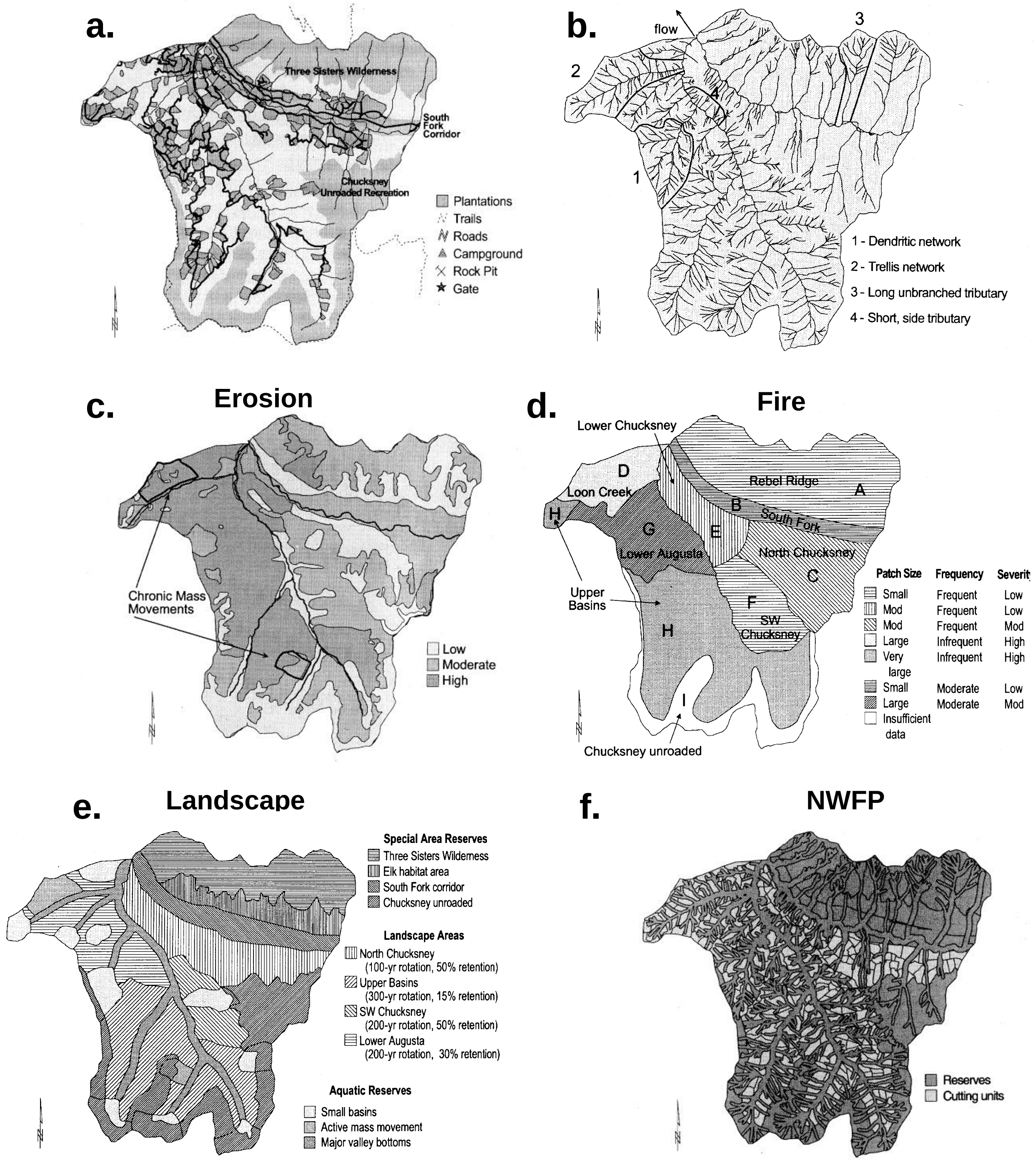


Figure 4. The Augusta Creek watershed. a. current condition showing roads and harvest units, b. stream network, c. historic erosion pattern, d. historic wildfire regime, e. proposed landscape plan, and f. default unmanaged reserves under the Northwest Forest Plan. Modified from Cissel et al. (1998).

The landscape based-management plan for Augusta Creek was not implemented, but forest planners and watershed specialists applied similar principles when developing a new plan for a nearby watershed – Blue River. The Blue River plan was adopted and is currently the subject of long-term investigations of a disturbance-based landscape plan in the western Cascades.

The Blue River, Oregon, Management Plan: A Template for Planning Based on Natural Disturbance Processes

The Blue River Management Plan (Cissel et al. 1999) represents one of the first truly integrated management plans based on natural disturbance regimes. It was also a significant departure from the site-based default management prescriptions in the Northwest Forest Plan. Although the nature of the natural disturbance regime in the Blue River watershed differs somewhat from the disturbance patterns in the OESF planning area (e.g., Blue River experiences more wildfires and fewer windstorms that OESF, and the frequency of landslides at OESF is quite likely much greater than in this region of the western Cascades), the approach is worthy of consideration as an alternative to fixed-width riparian buffers. Figure 5 shows the pattern of fire-related disturbance history in the watershed, and Figure 6 illustrates the configuration of management units under the default prescriptions in the Northwest Forest Plan and the larger, less complex planning units in the disturbance-based plan.

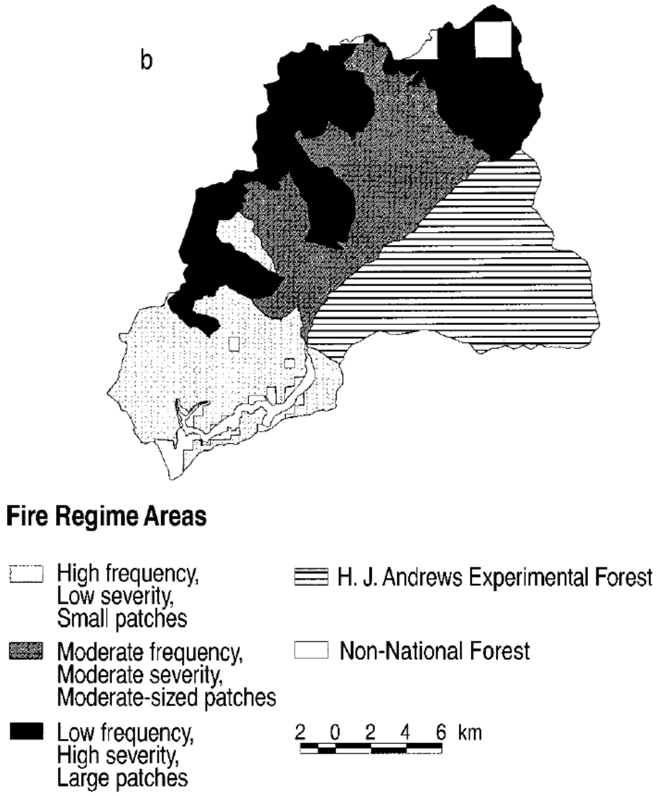


Figure 5. Historical fire patterns in the Blue River watershed. From Cissel et al. (1999).

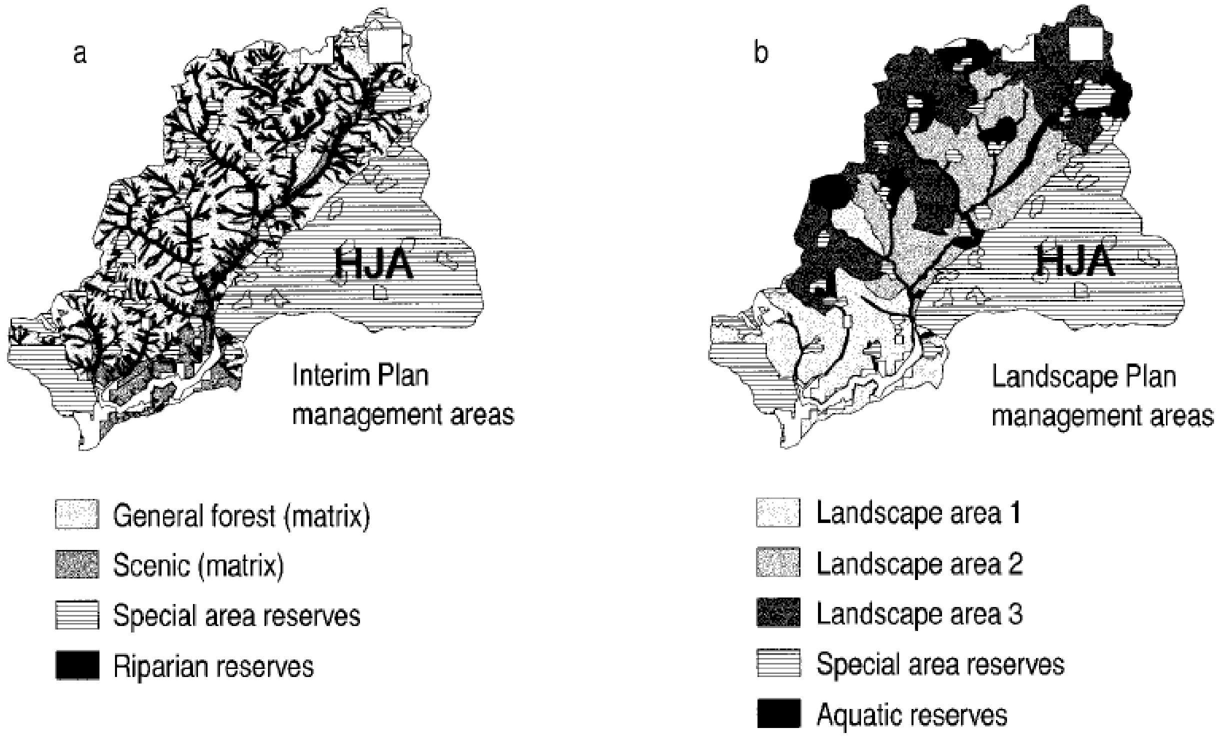
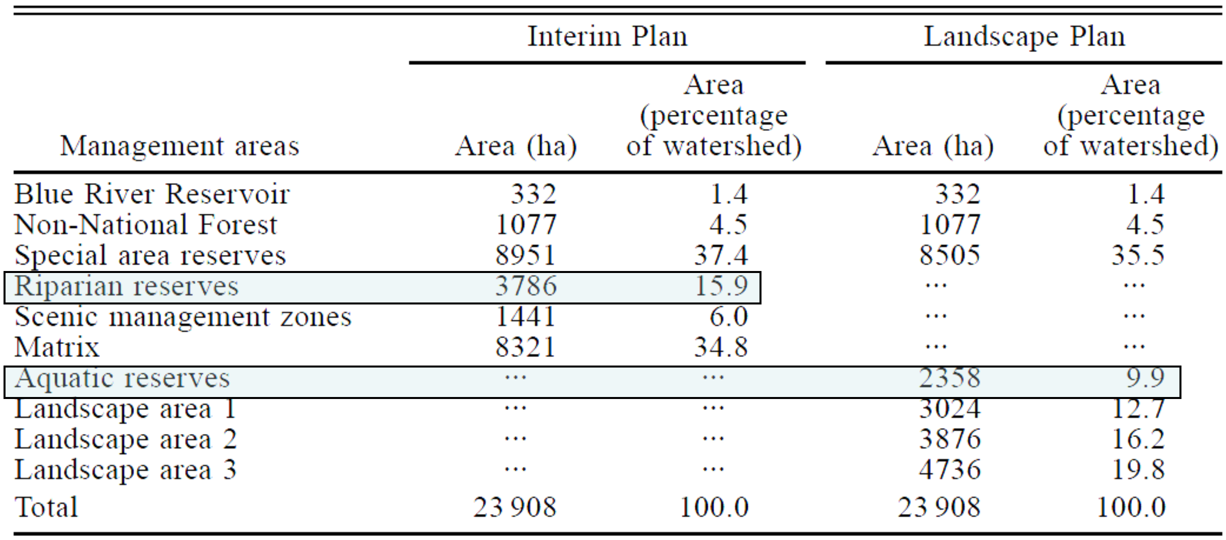


Figure 6. Blue River, Oregon, management areas based on default NWFP guidelines (a) and disturbance-based management areas (b). HJA = H. J. Andrews Experimental Forest, an area set aside for scientific research not included in the Blue River Plan. From Cissel et al. (1999).

Under the interim riparian protection guidelines (default Northwest Forest Plan buffers) in Figure 5a, the network of riparian reserves forms a complex landscape pattern that poses a challenge to implementation of forest management activities, including timber harvest and road building. In Figure 5b, “aquatic” reserves are generally confined primarily to the larger streams in the watershed, with riparian zones on smaller tributaries being managed as part of upland treatments, including large and small openings. The upland treatments are meant to emulate forest structure that resulted from historical fires, i.e., the location, size, and silvicultural treatments are designed based on wildfire mapping interpretations. The “aquatic” reserves are meant to maintain the natural conditions that would result from the fire and erosion patterns near streams in this area. Cissell et al. (1999) state “Riparian corridor reserves were designated along both sides of all fish-bearing streams (~70–200 m slope distance on each side). These linear reserves occupy the entire valley bottom and adjacent lower hillslopes. Corridor reserves connect aquatic and riparian areas throughout the basin and link with the small watershed reserves. Unlike the Interim Plan, no additional reserves were established at the landscape scale for nonfish-bearing perennial and intermittent streams.”

Under the disturbance-based landscape plan, the area of riparian reserves in the Blue River watershed actually declined relative to the amount of land that would have been included under the default ("Interim") guidelines, dropping from about 16% to 10% (Table 3).

Table 3. Area and percentage of land in the Blue River watershed under the interim (default NWFP) guidelines and the disturbance-based landscape plan. From Cissel et al. (1999)



	Interim Plan		Landscape Plan	
Management areas	Area (ha)	Area (percentage of watershed)	Area (ha)	Area (percentage of watershed)
Blue River Reservoir	332	1.4	332	1.4
Non-National Forest	1077	4.5	1077	4.5
Special area reserves	8951	37.4	8505	35.5
Riparian reserves	3786	15.9	...	...
Scenic management zones	1441	6.0	...	...
Matrix	8321	34.8	...	...
Aquatic reserves	...	...	2358	9.9
Landscape area 1	...	...	3024	12.7
Landscape area 2	...	...	3876	16.2
Landscape area 3	...	...	4736	19.8
Total	23 908	100.0	23 908	100.0

Projections of future forest age distribution in the Blue River watershed were carried out based on the two alternative management strategies (Figure 7). These projections showed that the landscape plan would result in a much less fragmented forest structure after 200 years than would occur with the interim plan, in which old forest was confined primarily to riparian reserves. The disturbance-based landscape plan yielded a forest stand composition that was considered more favorable for a variety of fish and wildlife, including salmonid fishes and northern spotted owls, by creating a landscape that would provide improved habitat for interior forest species.

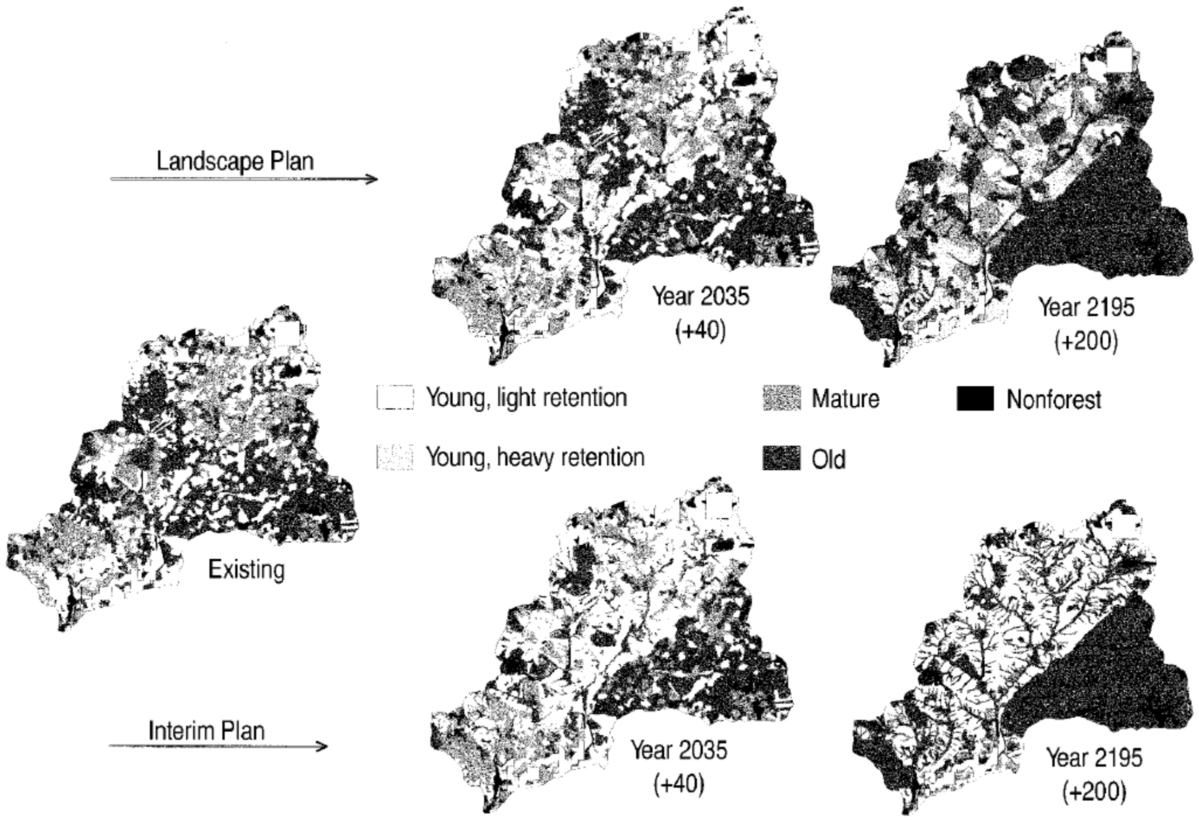


Figure 7. Anticipated forest structure over 200 years in the Blue River watershed under the landscape plan and the interim (default NWFP) plan. From Cissel et al. (1999).

Although, there was less land allocated to aquatic reserves in the landscape plan, harvest rotation age in the three landscape areas (Figure 6; Table 3) was longer, on average, than in the interim plan. This was intentionally done to enhance the amount of old forest conditions which were believed necessary for spotted owls and other interior forest wildlife species. The tradeoffs in terms of commodity production and environmental benefits are summarized in Table 4.

Table 4. Summary of anticipated timber production and watershed effects of the Blue River landscape plan. Quotations (underlined emphasis ours) are from Cissel et al. (1999).

Timber production	"The Landscape Plan produces ~17% less wood volume than the Interim Plan in the long term. Differences in manufactured wood volume and wood value are likely less, because the Landscape Plan produces bigger trees due to longer rotation lengths (mean rotation length of 192 yr, compared to the mean rotation length for the Interim Plan of 88 yr)."

Watershed effects	"Significantly larger patch sizes in the Landscape Plan are expected to favor [wildlife] species associated with interior habitats." "Riparian and adjacent lower slopes along nonfish-bearing streams would experience some partial cutting under the Landscape Plan. The Landscape Plan provides greater flexibility for management in riparian and adjacent lower slope zones by relying, in part, on lower cutting frequencies through long rotation lengths, as well as lower cutting intensities through greater green-tree retention in the uplands. Some disturbance in these zones is accepted as part of the range of historical conditions. Consequences of these treatments include higher light levels leading to potential localized increases in stream productivity and stream temperature and less than maximum large wood input to streams…Channel stability, stream flow, and sediment inputs are expected to be very similar in the two scenarios." "Patches of windthrow in riparian zones are more likely in the sharp-edged landscape of the Interim Plan, but dispersed windthrow may be more common in the Landscape Plan in response to higher densities and greater extent of residual trees in cutting units"

The Blue River watershed has been incorporated into an adaptive management area within the Willamette National Forest, and will be monitored over time to determine if the projections are realized. In some ways, the OESF shares important attributes with the Blue River watershed: the OESF contains several drainages (e.g., Clearwater River) that are almost wholly managed by DNR; there are extensive databases on forest stand composition, natural disturbance history, and fish and wildlife habitat; and the OESF planning area has experimentation as an important management objective. We believe the approach used at Blue River could serve as the template for a similar approach to landscape planning at OESF. This would entail, in some cases, abandoning the HCP riparian buffer guidelines and instead integrating riparian management into upland forest treatments, particularly for non-fish bearing headwater streams, as part of the experimental treatments.

Queets River, Washington: Potential Reference Condition

Research by University of Washington staff and students on the lower Queets River within the boundaries of Olympic National Park (Figure 1) can help shed light on the question:

> *What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula? How can forest management be used to maintain and aid restoration of these forest characteristics?*

This work has focused on scientific characterization of a largely unmanaged coastal rainforest watershed. The Queets River watershed (Figure 8) is especially relevant to the OESF because it lies within the OESF planning area and represents a relatively pristine reference site that can be used to identify target habitat conditions. Geomorphically, the Queets River system is similar to other large, formerly glaciated valleys on the western Olympic Peninsula, including the Quinault R., Clearwater R., Hoh R., Bogachiel R., and Sol Duc River.

Figure 8. The lower Queets River within Olympic National Park. Photo: J. Latterell.

Studies of gallery forests adjacent to the Queets River have shown that floodplain terraces are important sources of large wood recruitment for the mainstem (Fonda 1974). Figure 9 shows the cycle of riverine terrace development that results from channel meandering.

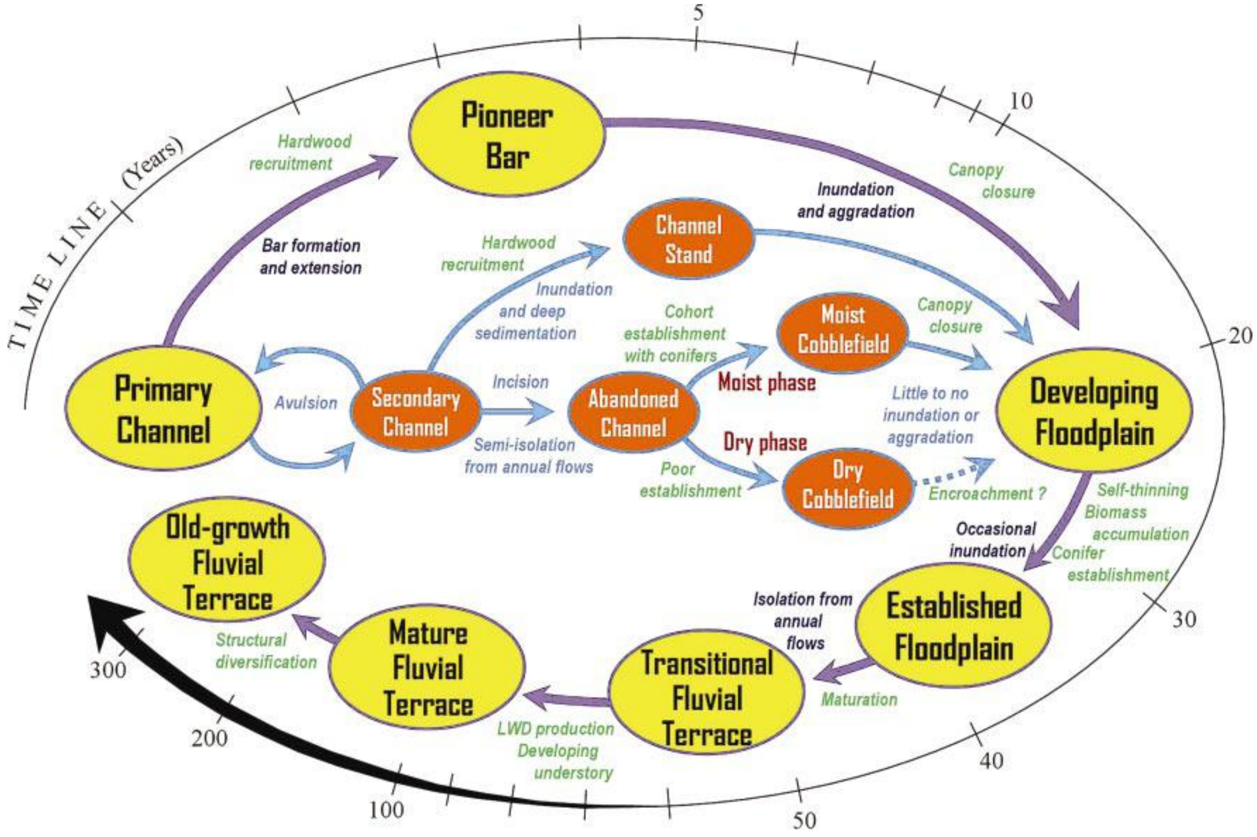


Figure 9. Riverine terrace development in the Queets River valley. From Van Pelt et al. (2006).

In the mainstem Queets River, large trees are recruited to the river from mature fluvial terraces (Latterell 2005) when high winter flow results in channel meandering. Mature conifers serve as “key pieces” that form the core of log jams and create depositional areas that can become mid-channel bars, both of which increase aquatic habitat complexity. Additionally, large down trees in riparian areas serve as important germination sites for some conifers (most notable, western hemlock and Sitka spruce), which have low survival rates in the humus soils of riverine terraces (McKee et al. 1982). Because the river flows through a large unconfined alluvial valley, lateral movements can be considerable and wood recruitment can occur at relatively great distances from the currently active channel when channel avulsions take place. This suggests that nearly the entire alluvial valley bottom can eventually be a direct contributor of large wood to the lower Queets River. In Figure 10, large wood recruitment to the Queets River from 1939 to 2002 (based on archival air photos) is shown as a function of distance from the currently active channel. To achieve protection of 50% of the potentially available key pieces would require a riparian management zone of 100 meters; to achieve 95% protection would require a management zone of 275 meters.

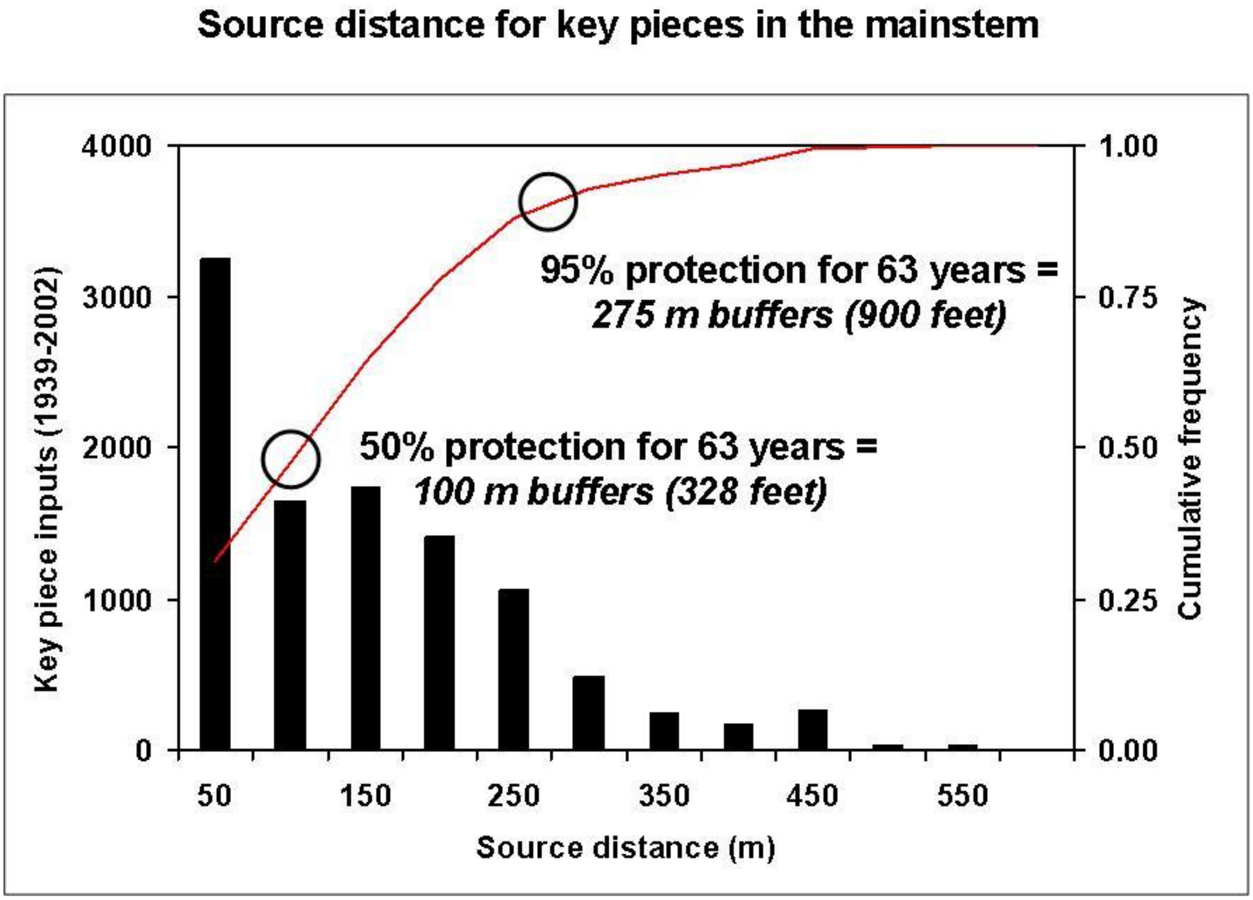


Figure 10. Relationship between large wood ("key piece") inputs and distance from the currently active channel of the Queets River from 1939 to 2002. From J. Latterell (personal communication, based on Latterell (2005)).

The other source of large wood for the lower Queets River is inputs from smaller tributaries and from upstream reaches of the mainstem. Latterell (2005) prepared a wood budget for a typical kilometer in the lower Queets River and estimated that inputs from the upper mainstem and tributaries were about the same as wood inputs from floodplain terraces, and that together these input sources were approximately balanced by large wood exported downstream during high flow events (Figure 11). The close correspondence between wood input and export suggests that the watershed was providing enough large wood to replenish the wood lost to storms without leading to a long-term decline in entrained wood and habitat complexity.

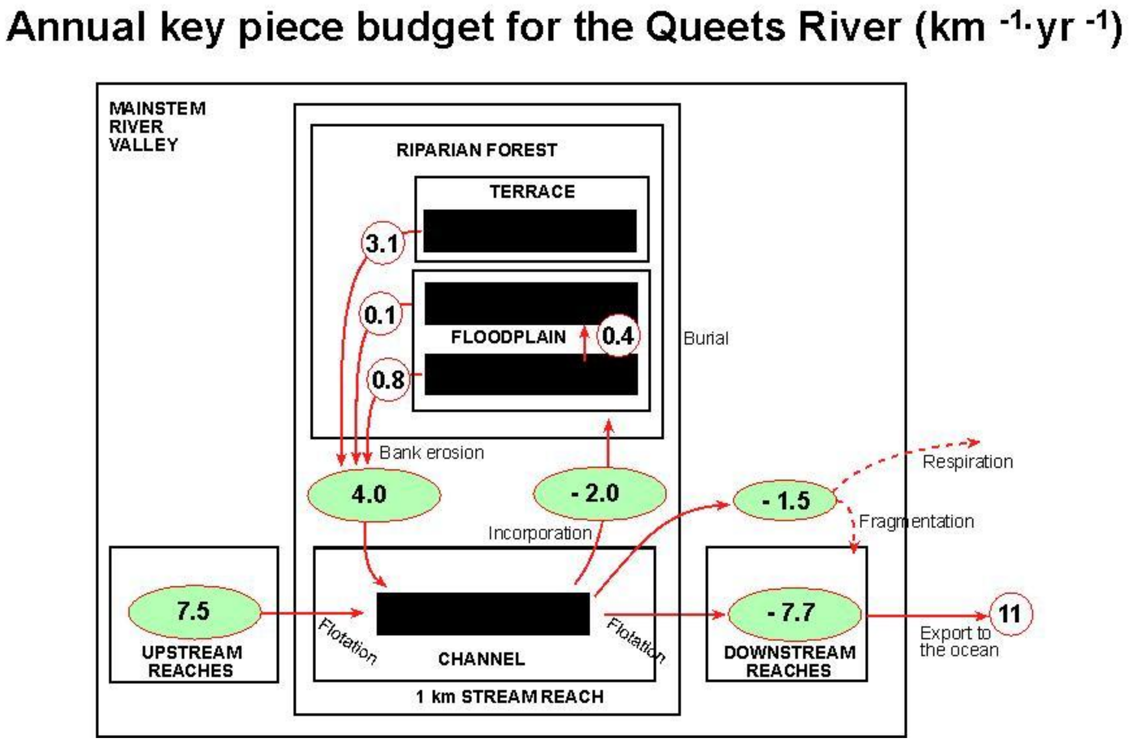


Figure 11. Large wood budget for the lower Queets River. From J. Latterell (personal communication, based on Latterell (2005)).

Research at the Queets River has also examined the relative contribution of conifer and hardwood litter to the aquatic ecosystem. This is important because litter inputs constitute an important source of organic matter for many of the aquatic organisms that become part of the food web supporting salmon and trout (Bisson and Bilby 1998). Although the majority of forest practice regulations pertaining to riparian management and wood in streams stress the importance of conifers for their longevity, resistance to breakage, and contribution to physical habitat, many hardwoods provide litter inputs that have a higher nutrient value and are more labile than conifer litter. This is particularly true for nitrogen-fixing species such as red alder *Alnus rubra*. O'Keefe and Naiman (2006) found that hardwoods dominated riparian vegetation during the first century after riparian stand initiation, and that after about 100 years conifers became dominant. Total litterfall peaked at a riparian stand age of approximately 100 years and both nitrogen and carbon litter inputs to the Queets River also peaked at this stage of riparian stand development.

In terms of wood longevity, however, conifer logs in the river were shown to persist for a longer period of time and affect a longer segment of the river channel than hardwood logs. Latterell (2005) and Latterell et al. (2006) compared the average residence time of conifer boles in the Queets River to the residence time of hardwood boles in a nearby watershed where forest management had removed most of the large riparian conifers. They computed the average "turnover length" of conifer logs – the total distance traveled by a log before it broke up and washed away – as a sum of the number of times it was floated during a storm and came to rest in the channel or at the river's edge (each flotation episode being termed a "spiral"). From the original entry point of a piece or large wood, conifer boles had more than twice the effective turnover length and number of spirals before they lost their function (Figure 12). Thus, while hardwoods contribute litter with relatively high nutrient value, conifers maintain their functionality as aquatic habitat for a greater longitudinal distance from their point of entry.

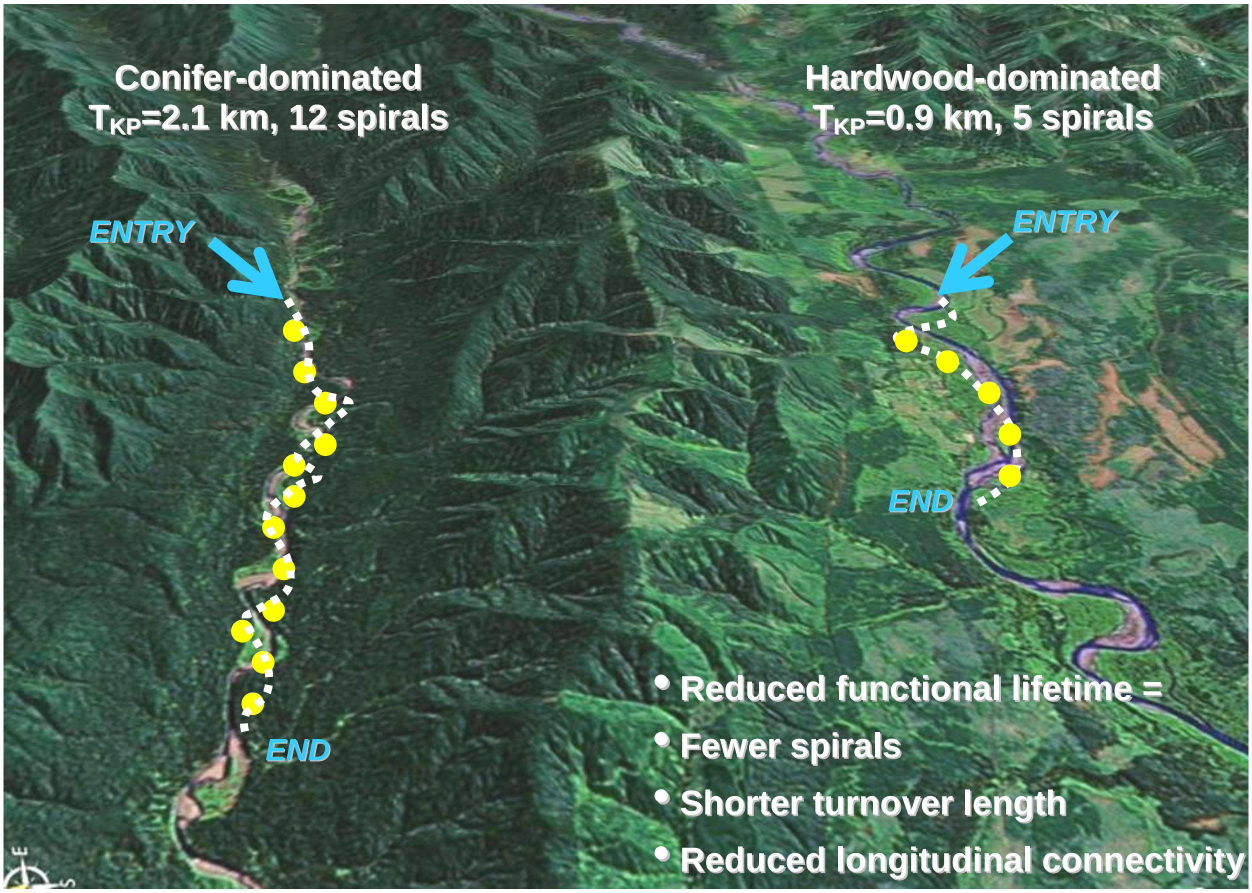
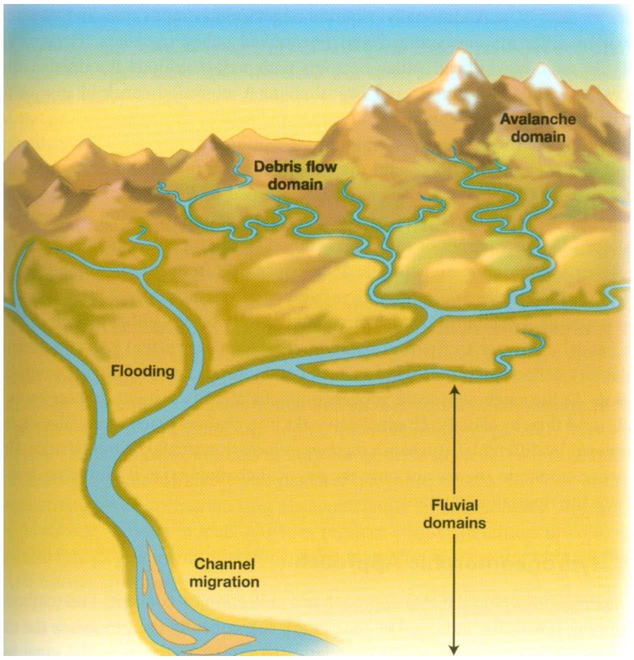


Figure 12. Average turnover length and spiral length of conifer (left) and hardwood boles in the western Olympic Peninsula. From J. Latterell (personal communication, based on Latterell (2005)).

Effective Riparian Zone Width

Although there will always be uncertainty with respect to the question of how wide riparian management zones should be to protect aquatic ecosystems, recent scientific investigations have revealed patterns of riparian influence that can assist in determining buffer widths. These are generally summarized in Figure 13.



Headwaters

- **Unstable headwall areas contribute large wood and coarse sediment to channel network**
- **Riparian zone is usually narrow (≤1 site-potential tree height)**

- **Foothills**
- **Wider riparian zones (can be >1 site-potential tree height) in alluvial stream segments**
- **Tributary junctions serve as nodes of habitat complexity**
- **Swamps and springs are important seasonal habitats**

Coastal lowlands

- **Riparian zone extends to edge of flood plain**
- **Channel migration constantly changes location of key habitats**

Figure 13. Generalized lateral extent of functional riparian zones in forested landscapes. Watershed diagram courtesy of D. Montgomery.

Figure 13 illustrates that the width of riparian zones expands as a stream channel increases in size; however, there are important localized exceptions. Riparian areas may be relatively narrow in geomorphically constrained channels, for example, canyons. Unstable slopes in headwall areas are important sources of wood and coarse sediment for stream habitat through mass erosion processes (Benda et al. 2003), and can be considered part of the functional riparian network (see Figure 4c above). Riparian zones can exceed 1 site-potential tree height where a stream flows through an alluvial valley segment. In these alluvial “flats”, channel meandering, off-channel ponds, and hyporheic flowpaths can produce important aquatic habitats at some distance from the active stream (Stanford and Ward 1992; Cederholm and Scarlett 1982). In reaches of moderate stream gradients, tributary junctions become nodes of habitat complexity where coarse sediment and large wood from debris torrents are deposited (Benda et al. 2004), and these junctions often possess a functionally wide riparian zone. Finally, locations with significant springs and groundwater seeps will also possess riparian characteristics, even though they may not be formally designated as riparian management areas (Naiman et al. 2005). Springs and seeps, especially those that maintain surface water connections to streams, may act as seasonal refugia for fish (Torgerson et al. 1999; Ebersole et al. 2003) and provide cool water for fish-bearing streams. Because of the habitat and water quality benefits they provide, springs and seeps also merit riparian protection.

Windthrow Considerations

The Department of Natural Resources has remained well-informed with regard to windthrow risk to riparian buffers in the OESF planning area (Mitchell and Lanquaye-Opoku 2007). A thoughtful summary of the factors contributing to windthrow is given in the Windthrow Handbook for British Columbia Forests (Stathers et al. 1994[5]). The Windthrow Research Team at the University of British Columbia (http://faculty.forestry.ubc.ca/mitchell/windthrow.htm) under Dr. S. J. Mitchell is an excellent source of recent scientific findings pertaining to windthrow risk and management in coastal forests.

The DNR has also collaborated with the PNW Research Station on a headwater stream investigation in the Capital Forest and Willapa Hills area, where large windstorms are fairly common. In this study (Richard Bigley, Peter Bisson and Martin Raphael were principal investigators), different riparian buffers were applied to adjacent headwater non-fish bearing (Type 5) streams. We found that within five years of timber harvesting, extensive windthrow occurred (Figure 14). Our finding was similar to an unpublished study of windthrow on southern Vancouver Island and Queen Charlotte Islands by Beese et al. (2007[6]), in which wind damage to strips of retained trees averaged 31%. These authors found that tree damage from wind penetration into sharp-edged strips ranged from about 20-40 feet from the outer margin of the strip.

Figure 14. Extensive windthrow in a headwater tributary to the Willapa River where a 50-foot fixed-width buffer had been retained, following the December 3, 2007 storm. Photo: P. Bisson.

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[5] http://www.for.gov.bc.ca/hfd/pubs/docs/Wp/Wp01.pdf

[6] http://faculty.forestry.ubc.ca/mitchell/publications/wind_&_trees_abstracts_combined.pdf, page 15

Although windthrow will vary from site to site, factors that contribute to elevated windthrow risk can be identified (Figure 15).

Windthrow risk

- **Sharp-edged forest boundaries**
- **Aspect and topographic relief**
- **Soil moisture and depth of shallow water table**
- **Tree health**
- **Tree species**
- **Tree height and height:diameter ratio**

Figure 15. Important factors influencing windthrow in riparian areas.

With respect to the question of whether selective timber harvest can occur in the outer part of the riparian management zone, i.e., the exterior wind buffer, we found no evidence that this would impair riparian function with respect to wind firmness. In general, field studies suggest that sharp-edged forest boundaries, buffers whose boundaries face southwest, buffers near exposed ridges, buffers with a shallow water table and rooting depth, and buffers with root rot or other tree diseases that impair root strength are more susceptible to windthrow. Kramer et al. (2001) found that wind disturbance varied with the degree of wind sheltering in southeast Alaska, with sheltered areas experiencing partial blowdown and exposed areas more likely to experience nearly complete blowdown. There is also some preliminary evidence from the CMER Type N

Buffer Characteristics, Integrity and Function study[7] (Schuett-Hames, unpublished) that some tree species are more vulnerable to windthrow than others, possibly as a result of rooting depth and branching characteristics. Selective harvest in the exterior wind buffer could be similar to integrating riparian management prescriptions into upland forest treatments, as is being carried out in the Blue River landscape management plan (Figure 6).

Summary Answers to DNR Questions 1 and 2

The two DNR questions actually contain four queries in total, and we address each of these separately based on the science synthesis above.

What are the extents (lateral and longitudinal) and stand features of riparian forests needed to maintain and aid restoration of habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula?

The lateral extent of the functional riparian zone varies according to location in the watershed (Figure 13). In a broad sense, ecologically functional riparian forests include trees in unstable headwall areas that have a likelihood of being recruited to the channel network through landslides and debris torrents, trees adjacent to seeps and springs (this includes classified wetlands, but may also include smaller unmapped areas where groundwater emerges), and the gallery forests of alluvial river valleys that reside in the floodplain. There is evidence from research in the Queets River watershed that trees entering the active channel network maintain their habitat functions for a length of about 1-2 miles downstream from their origin (Figure 12).

How can forest management be used to maintain and aid restoration of these forest characteristics?

Inventory of the natural disturbance history of a watershed including floods, wildfires, and windstorms enables the construction of maps displaying the dominant disturbance processes in different areas of the landscape (e.g., Figure 4c and 4d). Based on such mapping efforts, silvicultural prescriptions can be designed to emulate, or be compatible with, the effects of natural disturbances at the landscape scale, such as the strategy currently being implemented in the Blue River watershed of Oregon (e.g., Figure 6b). For example, upland management treatments such as thinning can help achieve a forest structure similar to that produced by a low severity fire or wind disturbance regime, and the same prescriptions can be integrated into riparian management plans (Sedell et al. 1994). There may be compelling reasons to leave some riparian areas as unmanaged reserves for wildlife corridors and other environmental considerations, but these areas can also be included in landscape plans. Caution should be used when harvesting timber in floodplains, as trees at some distance from the normally active channel may become buried by flood deposits and subsequently be re-excavated by river meandering. Flexible landscape management plans provide an opportunity to replace a complex (and often unmanageable) network of fixed-width riparian buffers with a riparian strategy that produces a more natural, less fragmented forest structure (Reeves and Bisson 2009).

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[7] http://www.dnr.wa.gov/Publications/fp_am_cmer_typen_bcifww_plan.pdf

What are the extents and stand characteristics of outer (wind) buffers needed to maintain riparian forest integrity?

Vulnerability to wind disturbance will vary according to factors identified in Figure 15. There is very preliminary evidence that wind buffers of about 40 feet will be sufficient to protect the integrity of the interior riparian stand; however, a scientific test of the efficacy of wind buffers of different widths has not yet been conducted. It is likely that wind buffer effectiveness will be influenced by maximum wind velocity, which will be controlled by local topography.

Can timber be harvested in these outer buffers without compromising the ecological functions of the riparian forest?

Provided the riparian forest community adjacent to the stream is sufficiently wide to protect the ecological functions diagrammed in Figure 3, we found no evidence that timber harvest from an outer wind buffer would significantly compromise aquatic habitat. We further note that openings caused by natural disturbances occur in riparian zones in unmanaged watersheds. However, protection of riparian function at the landscape scale requires a broader space and time contextual perspective that examines the condition of riparian forests throughout a watershed. Where the riparian network is currently healthy throughout the drainage system, options for managing outer buffers can increase. Watersheds where much of the riparian network has been significantly altered by a combination of natural and anthropogenic disturbances may require an approach to riparian management that enhances the recovery of large conifers (Sedell et al. 1994), whether this involves conservative levels of timber harvest or active management to accelerate late-seral forest conditions.

In reality there have been relatively few studies of the effects of selective outer buffer timber harvest on riparian function, and more research is needed to properly answer this question. The few studies that have taken place have been short term in nature, and thus cannot address long term changes. For example, an investigation of the effects of riparian zone thinning on litter inputs to streams in the western Cascade Mountains of Washington showed that litter inputs to stream reaches where thinning treatments had been applied increased during the first year post-harvest, but then tended to drop below input levels in control sites during the second post-harvest year (Grady 2001). This was believed to have been caused by litter "flushing" from lower branches of trees left in the riparian zone (and that had increased wind exposure) during the first winter, after which reduced litter sources led to lower input levels. However, studies such as this have tended to be limited to 2-3 years after treatments, so the long term impacts of the treatments on the response variable of interest are poorly understood.

What models/metrics/criteria can be used in forest planning to assess the restoration of riparian functions at the watershed scale? What are the critical assumptions that can be addressed through monitoring?

Reach Scale vs. Watershed Scale Habitat Standards

The notion that there is a certain suite of habitat conditions at the reach scale which are optimal for salmon owes its genesis in part to studies of fish in pristine watersheds with old-growth forests (Reeves and Bisson 2009). We are aware of no evidence supporting the notion that a single optimum habitat configuration exists that will sustain maximum freshwater salmon production, or that such an ideal state could even persist in a dynamic environment. Many fish habitat standards began as hazard thresholds that became federal and state water quality laws after passage of the Clean Water Act and various state-level land and water use laws (Poole et al. 2004). The hazard thresholds (e.g., maximum summer temperatures) represented conditions beyond which further habitat loss would lead to direct or indirect harm to aquatic life. When salmon populations were listed under the Endangered Species Act, environmental standards shifted somewhat from hazard thresholds beyond which survival and reproduction declined to habitat targets that were believed to represent optimum or near-optimum conditions. Water quality parameters such as the maximum daily temperature over a 7-day period have become some of the most common metrics of habitat condition at the reach scale.

Applying fixed habitat standards throughout a drainage network potentially diminishes the range of conditions that occur in a watershed, resulting in a loss of habitat diversity (Figure 16). The natural range of a particular habitat feature, e.g., large wood abundance, is illustrated in the upper left graph where the distribution of values for that feature in a largely pristine watershed might approximate a bell-shaped curve with a relatively wide range (e.g., see Fox 2001). A watershed that has been highly altered by human activity or severe environmental disturbance (Figure 16, upper right) is likely to possess a strongly skewed distribution for the same feature, reflecting a large number of locations in the watershed where the abundance of that particular habitat element has changed in response to a variety of anthropogenic and natural factors. Imposition of a fixed habitat standard essentially forces a universal target on the system (Figure 16, lower left). Although the target is aligned with the median state of the habitat element in the pristine watershed, management actions will attempt to restore depleted areas to the target state and may allow locations with an abundance of the element to dwindle to the same target level. The median will be restored but the range of conditions will be truncated. Fully recovering the natural range of states of the habitat element in an altered watershed (Figure 16, lower right) requires landscape-based management strategies that facilitate restoration of both the median and environmental extremes; otherwise, habitat diversity will be lost (Poole et al. 2004).

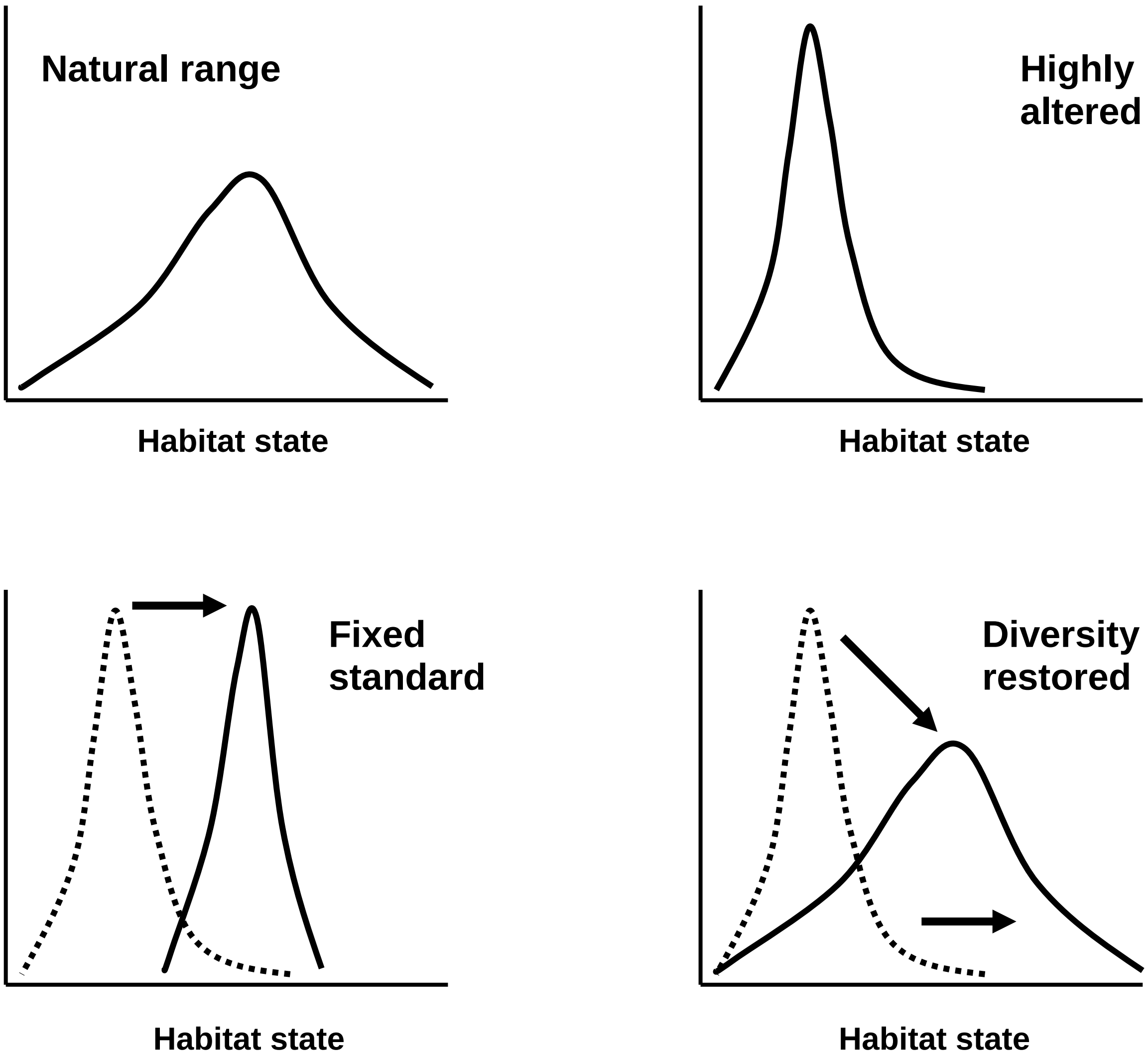

Figure 16. Hypothetical frequency distribution of a habitat element(e.g., maximum temperature, large wood loading, fine sediment level) in a pristine watershed (upper left), highly altered watershed (upper right), watershed where a fixed habitat standard has been applied (lower left), and a watershed where the emphasis has been to restore both the median and natural range of conditions (lower right). The curves represent the distribution of habitat states (abundance, concentration, or some other metric) at various locations throughout the watershed.

A focus on narrow environmental thresholds can come at the expense of recognizing the ecological processes that create and maintain the freshwater habitats of salmon and trout (Beechie and Bolton 1999) and the ecological context in which they evolved (Frissell et al. 1997). Holling and Meffe (1996) referred to the setting of fixed environmental standards as an example of "command and control approach" to natural resource management. This approach fails when it is applied to systems that are complex, non-linear, and poorly understood, and it leads to continued loss of resiliency (Dale et al. 2000; Rieman et al 2006).

Modeling Support for Landscape Planning

Traditionally, management and restoration has focused at the individual project site or reach scale, because the preponderance of scientific studies have been conducted at this scale and because the immediate effects of management activities directly affect streams at this scale. Management guidelines developed at this scale have tended to set specific targets for key attributes shown by various studies to limit productivity of species of concern. In forested watersheds where streams are managed to limit impact of forest harvest on fish species of concern, key attributes typically revolve around stream water temperature (or stream shade), availability of large wood (for structuring in-stream habitat), and also the intrusion of fine sediment into streambed gravels. Mass wasting processes are also of concern in steep forested lands of the coastal Pacific Northwest. A variety of data sources have been used to inform these guidelines, ranging from species-specific laboratory studies to broad-scale comparisons between managed and relatively undisturbed reference sites. Subsequently, management prescriptions have been written to meet these guidelines and thereby mitigate the effects of land-use practices on stream habitat and the species that depend on that habitat. These prescriptions remain contentious, for a number of reasons:

- Underlying natural variability leads to uncertainty in scientific results (Biggs et al., 2009)
- Differences exist between regions (i.e., coastal vs. western vs. eastern Washington)
- Results are confounded by other factors (i.e., 4H's [habitat, harvest, hatcheries, hydroelectric development], climate variability, etc.)
- Laboratory studies may not be directly relevant to field situations (i.e., especially for temperature and fine sediment)
- Results can be unexpected (i.e., less shade = more sunlight = increased aquatic productivity despite increased temperature)
- Species of concern have evolved strategies to cope with sub-optimal habitat that might result in stressed populations and/or small population sizes but reduce the likelihood of local extinction.

Consider stream temperature, for example. The factors that influence stream temperature have been long-studied and are very well known (Johnson 2004; Moore et al. 2005 and references therein); the influence of water temperature on stream fishes and other aquatic organisms are also well known (Acornley 1999; Bear et al. 2007). How then, can this issue remain contentious?

While the factors influencing stream temperature follow well known rules of physics, interactions among these factors in any given stream reach are usually quite complex and some of the processes are difficult, if not impossible, to measure directly. Consequently, accurately quantifying specific effects of each factor in any given stream reach is difficult. Reach-scale stream temperature models have been developed and can be used to examine current stream temperature regimes and project future temperature regimes following a land management activity (Sinokrot and Stefan 1993; Bartholow 2000; Krause, 2002; Boyd and Kaspar 2004). Studies have shown that these models work well, accurately predicting stream water temperature changes along the length of a stream reach following forest harvest activities (Sullivan et al. 1990).

Collecting the data needed to calibrate and run these models, however, is time consuming and expensive; running a model requires an investment in time to learn the modeling software. Consequently, these detailed model analyses are often considered prohibitive in most land management applications – even at the reach scale. As an alternative, Sullivan et al. (1990) developed a temperature sensitivity screen (also known as a shade nomograph; Figure 17) to set shade thresholds necessary to protect streams from adverse water temperature increases after forest harvest. Although rough, these are empirically-based thresholds built from data collected in western Washington and on the Olympic Peninsula. Despite their empirical basis, the nomographs do not account for the variation in local site conditions that might reduce temperature sensitivity in any particular stream reach. Quantifying effective shade for an entire stream reach is also difficult and may not be well characterized by the "view to sky" parameter typically used in these analyses. Finally, the shade nomographs were developed from region-wide datasets and may not accurately reflect sub-regional trends, such as those of the coastal forests of the western Olympic Peninsula.

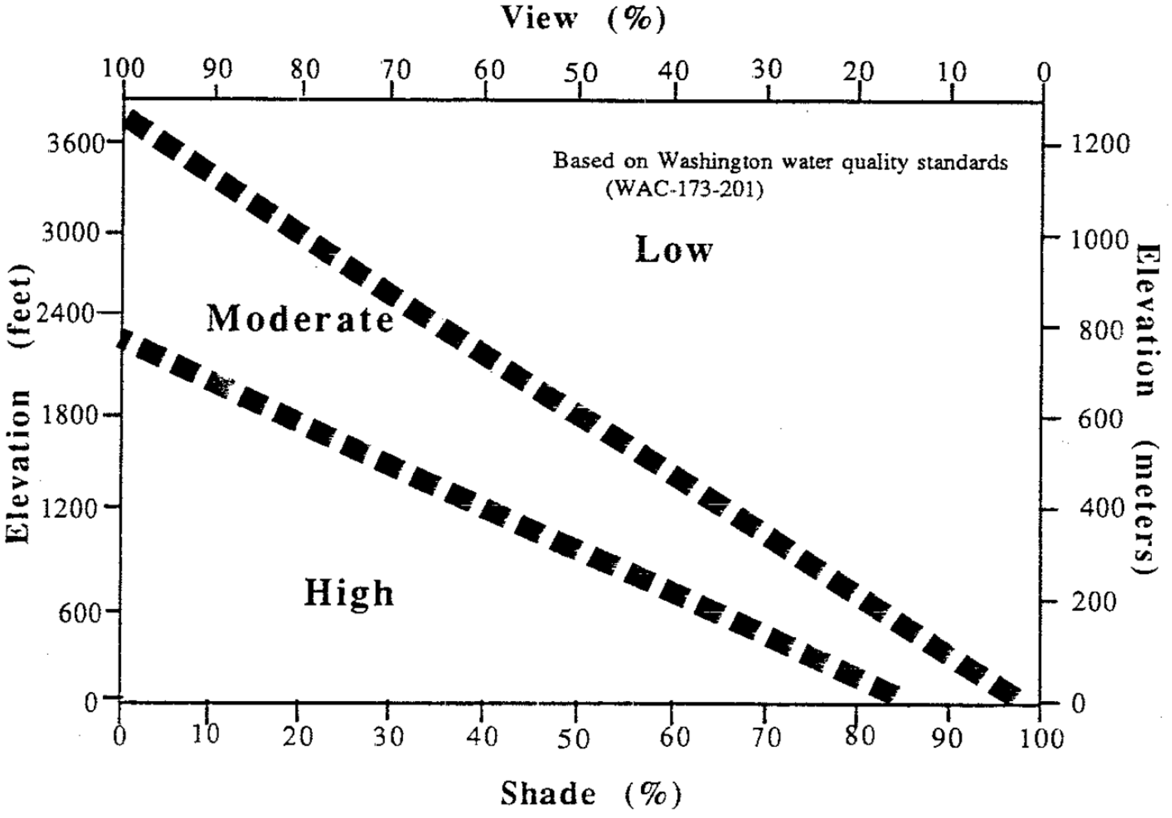

Figure 17. Stream temperature sensitivity screen developed by CMER. Figure reproduced from Sullivan et al. 1990.

In recent decades, growing concern over cumulative effects of individual land management decisions, growing recognition of the role of episodic disturbances, and growing awareness of metapopulation dynamics of species of concern has highlighted the need to analyze and manage watersheds holistically, conducting assessments over large-spatial scales and considering the long-term cumulative effects of all land management activities within entire watersheds. Although single factor effects have been documented at the watershed scale (Beschta and Taylor 1988), cumulative, multi-factor effects remain poorly studied at large spatial scales. Lacking direct empirical data, some other methods is needed to "scale up" results of reach-scale studies to entire watersheds. But developing aquatic habitat objectives, even for a single factor like temperature, can be difficult (see Figure 16 above).

One possible approach is "additive", based on the assumption that if all reaches within the watershed meet or exceed management criteria, the entire watershed meets those criteria. This is the approach used in the State of Washington's Watershed Assessment protocols for shade and stream temperature (Figure 18). This approach is often criticized because it is based on overly simplistic assumptions about how management effects "accumulate" within a stream network, employs a "one-size fits all" approach, and over the long term, will serve to substantially reduce the variability in habitat conditions to some "mean value" resulting in a dramatic departure from the historic range of variability.

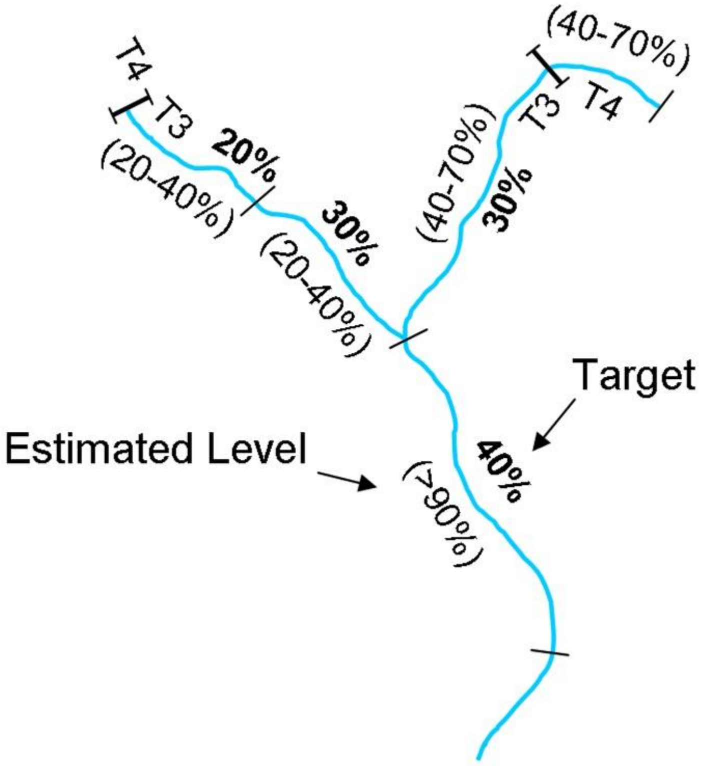

Figure 18. Stream temperature sensitivity screens from Sullivan et al. (1990), applied to a small watershed. Redrawn from Watershed Analysis, Appendix D, Riparian Function, V 4.0, page D-37, from November 1997.

An alternative approach is to use models specifically developed at the network scale such as SHADE-HSPF (Chen et al. 1998), SNTEMP (Bartholow 2000), or BASINTEMP (Douglas et al. 2007). These models avoid the pitfalls of making overly simplistic assumptions or “one-size-fits-all” predictions by attempting to simulate the processes effecting stream temperature over an entire stream network. Unfortunately, these models are far more difficult to use than are reach-scale models, and involve the use of complex simulation algorithms that require vast amounts of spatially distributed data to run (Sullivan et al. 1990). Furthermore, model results may not be sufficiently accurate to guide management assessments. Finally, these network-scale stream temperature models are only single-factor models. Water temperature is not the only issue of concern in watershed management.

Broader scale, multi-factor watershed assessment models have been developed. One such modeling system that is receiving increased attention and application in the Pacific Northwest region is NETMAP (Figure 19, from Benda et al. 2007[8]). NETMAP bundles a collection of smaller (often single factor) models with DEM-based terrain analysis tools to provide multi-factor, watershed-scale planning and assessment. However, all the limitations of single reach-scale and larger network scale models still apply.

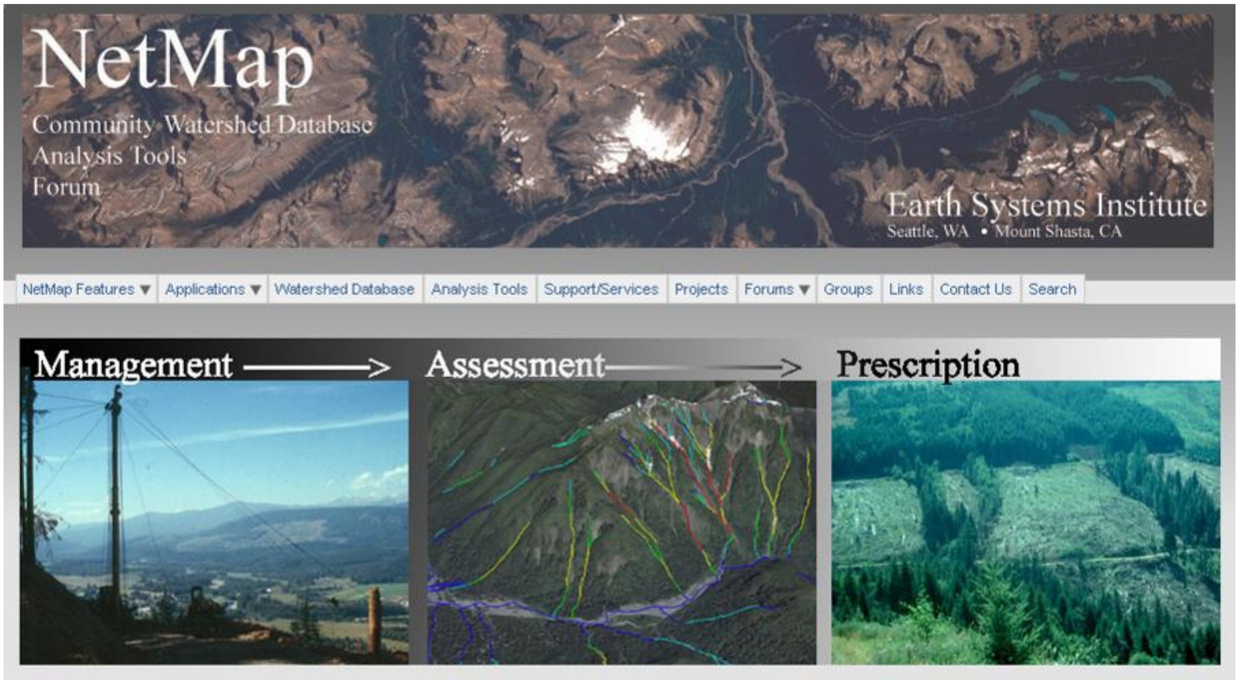

Figure 19. Welcome page for NETMAP[8] showing the clear intended linkages from management through assessment and to specific land-use prescriptions all of which is based on a bundled system of watershed databases, terrain analysis and effects models.

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[8] www.netmaptools.org

In addition:

- The models require calibration and testing,
- Data needs can be extensive,
- Separate model calibrations will likely be required in different regions,
- Models are even more complex often requiring an expert to conduct the model analysis for the end user, and
- Model predictions are always uncertain, and characterizing that uncertainty and conveying it to the end user is difficult.

Currently, NETMAP incorporates the following decision-support tools (http://www.netmaptools.org/):

Basin scale temperature model

Watershed scale road erosion/drainage diversion tool

Flammap, fire risk prediction and WEPP erosion technology integrated into NetMap

Predicting post-fire debris flow risk across the western U.S.

In-stream wood loading tool (winter 2010)

As described above, empirical, stochastic and deterministic models all have serious limitations. In addition, because these are effects models, the models tend not to answer the questions of primary important to land managers, for example:

The models do not answer the question:
How much shade do we need?

Rather, stream temperature models answer the question:
What is likely to happen given a specific harvest treatment?

While these questions are clearly related, models for effects analysis are neither designed nor calibrated to identify thresholds up to which there will be no measurable impact (or impacts smaller than deemed acceptable by regulatory requirement). And even if models could accurately identify acceptable limits from management impacts, there is likely to be an infinitely large combination of potential management activities that can occur (location, type, and timing of all possible activities in a large watershed over a long period of time). Which set of activities will best meet all the goals and objectives set for managing the OESF, including the stream restoration priorities?

Land management plans based on existing statutory guidelines can lead to a fragmented forest structure at the scale of the entire watershed (see Figure 7, “interim plan”). Cissel et al. (1999) reduced the emphasis on riparian reserves, but instead incorporated large contiguous areas, including their streams and riparian zones into simpler management units. The resulting patterns more closely resembled natural forest patterns and presumably are better at providing the mix of forest, riparian, and stream habitats to which the native organisms have evolved.

Our examination of reach-scale, single effects models, network-scale or watershed-scale models, and land management plans based on natural disturbance processes suggests a multi-phased adaptive management approach that might be successfully employed at the OESF:

1) A large-scale, long-term management plan could be developed based on retrospective studies of natural disturbance regimes on the western Olympic Peninsula that, over the long-term, would create landscape patterns that resemble those created by a natural disturbance regime.

2) Both watershed- and reach-scale effects analysis models could be employed to project likely effects of the overall management plan over time, as well as the likely effects of individual projects on important sites for native fishes. Clearly, in order to create landscapes that parallel naturally disturbed landscapes, some areas would have to be managed delicately over extended time periods. Conversely, other areas would be managed much more intensively than is currently allowed under statutory guidelines. However, the larger-scale management plan would set the context for scheduling the type, location, and timing of these management entries.

3) The entire management plan would need to be supported by monitoring. Monitoring efforts would need to be developed and implemented in coordination with all other land management activities. Too often, adaptive management efforts have failed to implement effective monitoring programs. As a consequence, the outcomes of revised management strategies, including those that prioritize restoration efforts, remain difficult or even impossible to evaluate.

Some attributes of the OESF suggest that such an approach could be successful. The OESF lies in close proximity to Olympic National Park, which provides a large area that has been minimally impacted by human development and therefore would provide an ideal template from which to develop a natural disturbance based land management plan. Also, the western Olympic Peninsula is relatively undeveloped compared to Puget Sound or other regions in the state. Thus, disturbance-based management would be less limited by human infrastructure – either from critical infrastructure that would be too at risk from natural disturbance or because of existing infrastructure that would be too difficult to remove. Lastly, the OESF is recognized as an Experimental Forest and in 2009 became part of the USDA Forest Service network of experimental forest sites, with the express intent of facilitating experimental management approaches (http://www.dnr.wa.gov/ResearchScience/News/Pages/nr09_143.aspx).

Developing and implementing an adaptive management strategy for the OESF, where many types of natural disturbances can occur, would likely prove difficult. Cissel et al. (1999) patterned their management plan around a single dominant disturbance process (wildfire) that controlled forest structure over a large contiguous area with spotted owls being a critical focal species for land management planning. Nearly all the land within the watershed was in federal ownership, eliminating the need to coordinate land management activities with multiple land owners. The OESF planning area faces a broader range of natural disturbance factors (especially windthrow and flooding in addition to fire). Windthrow creates a pattern that may not be easily mimicked by commercial logging activities, as it often impacts small areas widely separated in space. Fire regimes in the wet coastal forests are also likely to be much different than in the central western Cascades of Oregon – with much longer fire return intervals, but with rare but severe fires burning very large areas (e.g., Oregon's Tillamook Burn). Also, the OESF area has a long history of timber harvest and the existing forest structure may lie further outside the natural range of variability, making it difficult to develop economically profitable forest management activities in the early phases of implementing a natural disturbance-based management plan. Finally, the OESF does not provide a contiguous, single-ownership block of land that can be managed with a single, over-arching plan.

The need for an extensive, well-designed monitoring program cannot be overemphasized. Any landscape-scale land management plan will be experimental in nature and thus face critical uncertainties, including:

- Most available field-based knowledge has been collected at the reach, site, and project scales. Little empirical information is available to inform watershed-scale planning or the development of watershed-scale monitoring metrics.

- Biological systems (forest, riparian, and stream and associated populations of species of concern) are dynamic, responding to multiple factors, including the legacy of past land use, current land-use practices, short-term climatic variability and longer-term changes in climatic patterns. Partitioning those impacts resulting from management of the OESF is likely to prove impossible.

- Short-term changes are likely to be driven by a combination of favorable and unfavorable events, so that short-term dynamics will not provide accurate information on likely long-term outcomes.

- While the OESF management approach will be experimental in nature, this is not to say that the management plan can be designed as a strictly controlled experiment. The actual results of experimental management conducted in an operational setting over broad areas cannot be supported with the power of standard statistical tests.

Finally, response times of forested systems of the western Olympic Peninsula (including the OESF) will be slow. Simply put, it will take a long time to grow large trees. Historical landscape patterns resulted from centuries of disturbance and plant succession. Similarly, we must expect that it will take decades to centuries to significantly alter the landscape patterns that exist today. It will be possible to use specific silvicultural and restoration treatments to speed up the creation of desired landscape conditions, but even the most optimistic scenarios must approach disturbance-based land management with abundant patience.

Commonly Used Metrics

Many restoration projects have not adequately reported their results and lessons learned, and this is particularly true for some projects that have spanned a decade or more. Monitoring and evaluation procedures deserve to be more than an afterthought in project plans. A recent review of commonly used metrics of restoration success (Independent Scientific Review Panel [ISRP] 2008) included a discussion of the habitat restoration metrics used for monitoring salmon projects in the Columbia River Basin. These included descriptions of work implementation (what was done?) as well as measures of restoration effectiveness (did it work?). The metrics listed below should be considered at the outset of any new project and considered for inclusion in ongoing projects where monitoring and evaluation are deficient. Where several priority metrics are listed for a particular project type, ISRP (2008) did not believe it was necessary to measure all of them for any given project. Some of the metrics apply to situations that occur rarely, if at all, in the OESF, such as grazing in riparian areas; however, they are included here for completeness.

Table 4. Priority metrics for implementation monitoring by habitat project type. Adapted from ISRP (2008).

Project type	**Implementation monitoring priority recommendations**
Riparian fencing; riparian vegetation management	1. Measurements of miles of fence installed, acres of weeds or invasive plants treated, or acres planted with native vegetation. 2. Photo-documentation at pre-determined photo points to provide a basis for changes in the condition of the fence or riparian zone over time.
Erosion control	1. Measurements of the number of acres treated and the types of control measures employed. 2. Photo-documentation at pre-determined photo points of the erosion control treatments applied to a site. The photos should provide a representative sampling of the entire area treated and the range of conditions to which treatments were applied.
Stream habitat improvement; channel realignment; floodplain reconnection	1. Number of rearing habitat structures installed. 2. Length of stream receiving habitat treatments or channel bioengineering. 3. Number of floodplain access points; potential acres of floodplain reconnected with channel. 4. Estimated area of spawning habitat created or rehabilitated. 5. Photo-documentation of the stream or floodplain before and after treatment.

Project type	**Implementation monitoring priority recommendations**
Road improvement, relocation, or decommissioning	1. Miles of road decommissioned. 2. Miles of road relocated away from a riparian zone, floodplain, or unstable slope. 3. Number of road improvements implemented, e.g., # of water bars, ditch relief culverts, improved road crowns, and other sediment control measures. 4. Number of direct entry sediment points (ditches or culverts discharging directly to a stream channel) eliminated.
Fish passage improvement; road crossing replacement; dam removal; trap and haul	1. Photo-documentation of the site before and after treatment. 2. Documentation of steps taken to ensure that site is passable (include description of passability at different flows and by different species/life history stages). 3. In the case of trap and haul projects, the actual number and species of fish captured and relocated above a barrier.
Terrestrial habitat improvement; land leases	1. Number of acres treated or leased. 2. Number of habitat features installed or improved. 3. Photo-documentation of habitat features improved.

Table 5. Effectiveness monitoring metrics. Adapted from ISRP (2008).

Project Type	**Habitat effectiveness monitoring recommendations (it is desirable that at least one metric should be determined for each project)**
Riparian fencing; riparian vegetation management	1. Measurements of changes in ground cover over time (several years, if possible). This can be carried out by standard vegetation survey methods such as transects or regularly spaced vegetation plots. Sampling locations should include the outer riparian zone as well as the streambank. Photopoints can be used if standard vegetation survey methods are not feasible. 2. Quantitative measurements of changes in riparian canopy density over time. This can be accomplished with canopy densiometers, fisheye photography coupled with computer analysis, or an array of light sensing devices (e.g., PAR sensors). Whatever the method, measurements should be

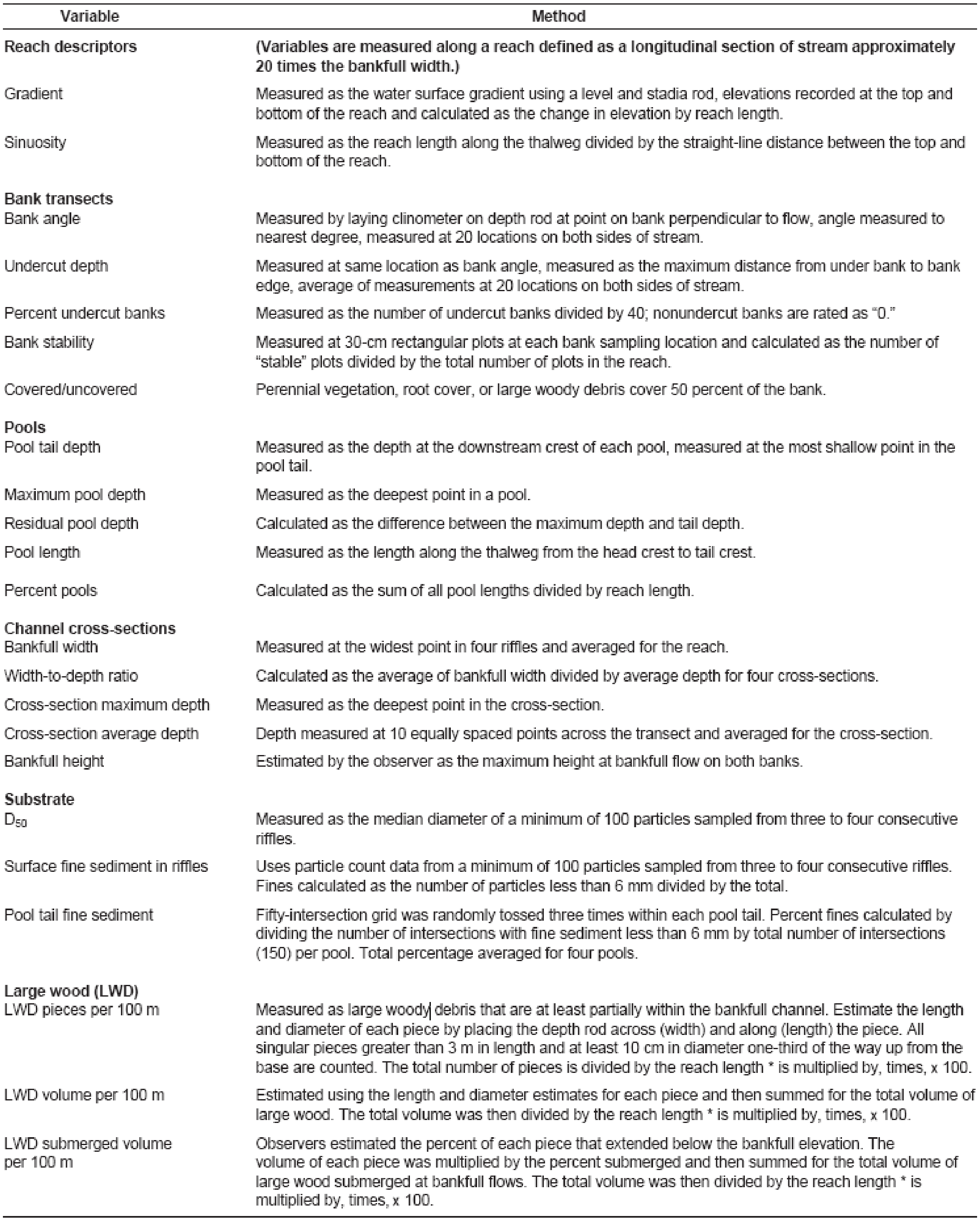
Project Type	**Habitat effectiveness monitoring recommendations (it is desirable that at least one metric should be determined for each project)**
	taken throughout the project area and be replicated over time periods sufficient to capture trends. It is assumed most of the monitoring will occur in summer when shade is most important to aquatic ecosystems. Temperature measurements should accompany shade measurements.
Erosion control	1. Measurements of changes in ground cover over time (several years, if possible). This can be carried out by standard vegetation survey methods such as transects or regularly spaced vegetation plots. Photo documentation can be used if funding is insufficient for actual vegetation surveys. 2. Upstream-downstream and before-after comparisons of stream sedimentation at the project area. Turbidity measurements are much easier to analyze, but sufficient samples must be obtained to capture the range of turbidity variation, so automated samplers may be needed. Deposited sediment is much harder to sample and analyze (e.g., freeze coring), but surrogate measures (e.g., embeddedness) may reveal trends if large changes occur. 3. Measurements of surface erosion over time using sediment collection trenches, erosion pins, or some other erosion study method. This is a difficult undertaking because it is often hard to sample enough sites to be fully representative of the project area, so it is unlikely to be carried out in most cases. It is, however, the most direct method of determining surface erosion.
Stream habitat improvement; channel realignment; floodplain reconnection	1. Inventory of stream habitat composition, preferably using a Before-After-Control-Impact (BACI) design. Above and/or below stream reaches may serve as control sites if they possess similar gradients and other geomorphic features in common with the treated reach. To establish the longevity of instream structures inventories should be repeated over several years or until a major channel-forming flood occurs. 2. Where the goal is to increase channel sinuosity by realigning the channel, monitoring should track sinuosity over time to verify that desired changes have occurred and the stream has not reverted back to its former alignment. This can be done remotely (e.g., air photos). Where the goal is to reconnect the stream with its floodplain, measure the area of floodplain inundated at different flood stages and the time period flooded.

Project Type	**Habitat effectiveness monitoring recommendations (it is desirable that at least one metric should be determined for each project)**
Road improvement, relocation, or decommissioning	1. Upstream-downstream and before-after comparisons of stream sedimentation at the project area. Turbidity measurements are much easier to analyze, but sufficient samples must be obtained to capture the range of turbidity variation, so automated samplers are often needed. Deposited sediment is much harder to sample and analyze (e.g., freeze coring), but surrogate measures (e.g., embeddedness) may reveal trends if large changes occur. 2. Because many road relocation projects aim to get roads out of riparian zones, post-treatment effectiveness monitoring should include surveys of riparian vegetation condition, re-establishment of secondary channels that were cut off by the old road, and reconnection of the stream with off-channel wetlands and other floodplain features that were formerly isolated. Such surveys need not be repeated in multiple years as long as the riparian zone remains intact.
Fish passage improvement; road crossing replacement; dam removal; trap and haul	1. Determination of fish use above the former barrier. This may be accomplished visually, but it is preferable to quantitatively sample fish at established distances above the barrier to determine the extent of new habitat actually utilized.
Terrestrial habitat improvement; land leases	1. Effectiveness monitoring should include measures of the rate at which a site is returning to a desired condition. Quite often the focus will be on restoring a particular type of plant community, so survey techniques appropriate to plant assemblage succession should be used, such as permanent vegetation plots. 2. Remote sensing can be used to track changes in canopy cover, forest composition, and other potentially useful measures of landscape change. Although these techniques can be expensive (e.g., LiDAR), the cost can often be spread among several projects if they are in close proximity.

Considering monitoring at large-scales and long-time frames, there are several excellent examples of monitoring plans that have already been put into place to track stream attributes important for the recovery of habitat supporting salmonids in the Pacific Northwest (Kershner et al. 2004; Reeves et al., 2004). While a detailed analysis of the specific metrics employed (see for example AREMP & PIBO 2004) is beyond the scope of this science synthesis, these plans do provide a template for designing potential monitoring plans for the OESF. For example, Archer et al. (2004) extensively tested a suite of commonly employed metrics for repeatability (Table 6).

That is, each metric was examined to determine the degree to which measured differences among streams resulted from measurement error, observer differences, or real physical differences among the streams examined. Through this testing procedure, Archer et al. (2004) identified a number of robust metrics likely to be useful for long-term monitoring. The appropriate choice of metrics, however, is only one component in a well designed monitoring program. Habitat recovery is likely to be a slow process in which any long term trends may easily be masked by spatio-temporal variability caused by natural disturbance. Therefore, monitoring plans must be capable of detecting subtle trends in habitat quality resulting from changes occurring over decades. Again, the statistical design of such a monitoring program for the OESF is beyond the scope of this science synthesis. However, regional monitoring surveys have been used in the PNW over the last many years. The results of one of these monitoring programs have been examined for its ability to detect trends (Larsen et al., 2004). Based on those analyses, Larsen et al. (2004) concluded that a network of approximately 50 sites, monitored consistently over many years can provide sufficient statistical power to significantly detect trends of 1% to 2% a year within one or two decades. The studies cited above (Archer et al. 2004; Larsen et al. 2004) begin to frame the scope of design likely necessary to monitor long-term changes in stream and riparian habitat conditions on the OESF.

Table 6. List of commonly employed monitoring metrics (reproduced from Archer et al. 2004; Table #3, pg. 4).



Variable	Method
Reach descriptors	**(Variables are measured along a reach defined as a longitudinal section of stream approximately 20 times the bankfull width.)**
Gradient	Measured as the water surface gradient using a level and stadia rod, elevations recorded at the top and bottom of the reach and calculated as the change in elevation by reach length.
Sinuosity	Measured as the reach length along the thalweg divided by the straight-line distance between the top and bottom of the reach.
Bank transects	
Bank angle	Measured by laying clinometer on depth rod at point on bank perpendicular to flow, angle measured to nearest degree, measured at 20 locations on both sides of stream.
Undercut depth	Measured at same location as bank angle, measured as the maximum distance from under bank to bank edge, average of measurements at 20 locations on both sides of stream.
Percent undercut banks	Measured as the number of undercut banks divided by 40; nonundercut banks are rated as "0."
Bank stability	Measured at 30-cm rectangular plots at each bank sampling location and calculated as the number of "stable" plots divided by the total number of plots in the reach.
Covered/uncovered	Perennial vegetation, root cover, or large woody debris cover 50 percent of the bank.
Pools	
Pool tail depth	Measured as the depth at the downstream crest of each pool, measured at the most shallow point in the pool tail.
Maximum pool depth	Measured as the deepest point in a pool.
Residual pool depth	Calculated as the difference between the maximum depth and tail depth.
Pool length	Measured as the length along the thalweg from the head crest to tail crest.
Percent pools	Calculated as the sum of all pool lengths divided by reach length.
Channel cross-sections	
Bankfull width	Measured at the widest point in four riffles and averaged for the reach.
Width-to-depth ratio	Calculated as the average of bankfull width divided by average depth for four cross-sections.
Cross-section maximum depth	Measured as the deepest point in the cross-section.
Cross-section average depth	Depth measured at 10 equally spaced points across the transect and averaged for the cross-section.
Bankfull height	Estimated by the observer as the maximum height at bankfull flow on both banks.
Substrate	
D_{50}	Measured as the median diameter of a minimum of 100 particles sampled from three to four consecutive riffles.
Surface fine sediment in riffles	Uses particle count data from a minimum of 100 particles sampled from three to four consecutive riffles. Fines calculated as the number of particles less than 6 mm divided by the total.
Pool tail fine sediment	Fifty-intersection grid was randomly tossed three times within each pool tail. Percent fines calculated by dividing the number of intersections with fine sediment less than 6 mm by total number of intersections (150) per pool. Total percentage averaged for four pools.
Large wood (LWD)	
LWD pieces per 100 m	Measured as large woody debris that are at least partially within the bankfull channel. Estimate the length and diameter of each piece by placing the depth rod across (width) and along (length) the piece. All singular pieces greater than 3 m in length and at least 10 cm in diameter one-third of the way up from the base are counted. The total number of pieces is divided by the reach length * is multiplied by, times, x 100.
LWD volume per 100 m	Estimated using the length and diameter estimates for each piece and then summed for the total volume of large wood. The total volume was then divided by the reach length * is multiplied by, times, x 100.
LWD submerged volume per 100 m	Observers estimated the percent of each piece that extended below the bankfull elevation. The volume of each piece was multiplied by the percent submerged and then summed for the total volume of large wood submerged at bankfull flows. The total volume was then divided by the reach length * is multiplied by, times, x 100.

Conclusion

Developing a large-scale, natural disturbance based landscape management plan for the OESF planning area holds significant potential to better manage riparian forests to maintain and aid restoration of habitat on the western Olympic Peninsula. There are excellent examples of existing large-scale, natural-disturbance based management plans that can provide a template for the OESF. Further, recent developments in landscape-scale modeling and new technologies are likely to prove helpful in designing such a management plan. However, natural-disturbance based management plans remain experimental in nature and thus face critical uncertainties. To ensure that the management plan simultaneously meets the multiple management objectives of the OESF (habitat conservation and commodity production) it will need to be supported by a well-designed and dedicated monitoring program. Recent advances in large-scale, long-term monitoring, including the identification of robust monitoring metrics and large-scale trend monitoring sampling designs will likely prove helpful in designing such a monitoring program.

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