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NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 7

FORESTRY IMPACTS ON FRESHWATER HABITAT OF ANADROMOUS SALMONIDS IN THE PACIFIC NORTHWEST AND ALASKA-- REQUIREMENTS FOR PROTECTION AND RESTORATION

Michael L. Murphy

October 1995

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Coastal Ocean Office

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Cover photo: Landscape view of private timberlands in southeast Alaska showing a typical mosaic of harvested areas interspersed with patches of uncut forest and buffer zones along streams. (Photo by K Koski, NMFS).

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U.S. DEPARTMENT OF COMMERCE
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Note to Readers

Forestry Impacts on Freshwater Habitat of Anadromous Salmonids in the Pacific Northwest and Alaska--Requirements for Protection and Restoration was developed by Michael L. Murphy of the NOAA National Marine Fisheries Service's Alaska Fisheries Science Center with funding from the NOAA Coastal Ocean Program (COP). The document presents a science overview of the major forest management issues involved in the recovery of anadromous salmonids affected by timber harvest in the Pacific Northwest and Alaska. The synthesis reviews salmonid habitat requirements and potential effects of logging, describes the technical foundation of forest practices and restoration, analyzes current federal and non-federal forest practices, and recommends required elements of comprehensive watershed management for recovery of anadromous salmonids.

COP provides a focal point through which NOAA, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The goals of the program parallel those of the NOAA Strategic Plan.

A specific objective of COP is to provide the highest quality scientific information to coastal managers in time for critical decision making and in a format useful for these decisions. To help achieve this, COP inaugurated a program of developing documents that would synthesize information on issues that were of high priority to coastal managers. A three-step process was used to develop such documents: 1) to compile a list of critical topics in the coastal ocean through a survey of coastal resource managers and to prioritize and select those suitable for the document series through the use of a panel of multidisciplinary technical experts; 2) to solicit proposals to do research on these topics and select principal investigators through a rigorous peer-review process; and 3) to develop peer-reviewed documents based on the winning proposals. Seven topics were selected in the initial round, but the series is expanding because of the suitability of findings from other COP-funded research to appear in this synthesis format. The documents already published are listed on the inside back cover.

As with all of its products, COP is very interested in ascertaining the utility of the Decision Analysis Series particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or E-mail us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our address and telephone and fax numbers are on the inside front cover. My Internet address is DSCAVIA@HQ.NOAA.GOV.

Donald Scavia
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Executive Summary

This synthesis presents a science overview of the major forest management issues involved in the recovery of anadromous salmonids affected by timber harvest in the Pacific Northwest and Alaska. The issues involve the components of ecosystem-based watershed management and how best to implement them, including how to:

- Design buffer zones to protect fish habitat while enabling economic timber production;
- Implement effective Best Management Practices (BMPs) to prevent nonpoint-source pollution;
- Develop watershed-level procedures across property boundaries to prevent cumulative impacts;
- Develop restoration procedures to contribute to recovery of ecosystem processes; and
- Enlist support of private landowners in watershed planning, protection, and restoration.

Buffer zones, BMPs, cumulative impact prevention, and restoration are essential elements of what must be a comprehensive approach to habitat protection and restoration applied at the watershed level within a larger context of resource concerns in the river basin, species status under the Endangered Species Act (ESA), and regional environmental and economic issues (Fig. ES.1).

This synthesis 1) reviews salmonid habitat requirements and potential effects of logging; 2) describes the technical foundation of forest practices and restoration; 3) analyzes current federal and non-federal forest practices; and 4) recommends required elements of comprehensive watershed management for recovery of anadromous salmonids.

HABITAT REQUIREMENTS AND EFFECTS OF LOGGING

The life cycle of anadromous salmonids has several stages, each with its own habitat needs. Among other things, adults returning to spawn require access to spawning gravel; their eggs need cool, oxygenated water; juveniles need adequate food, cover, and temperature; and smolts

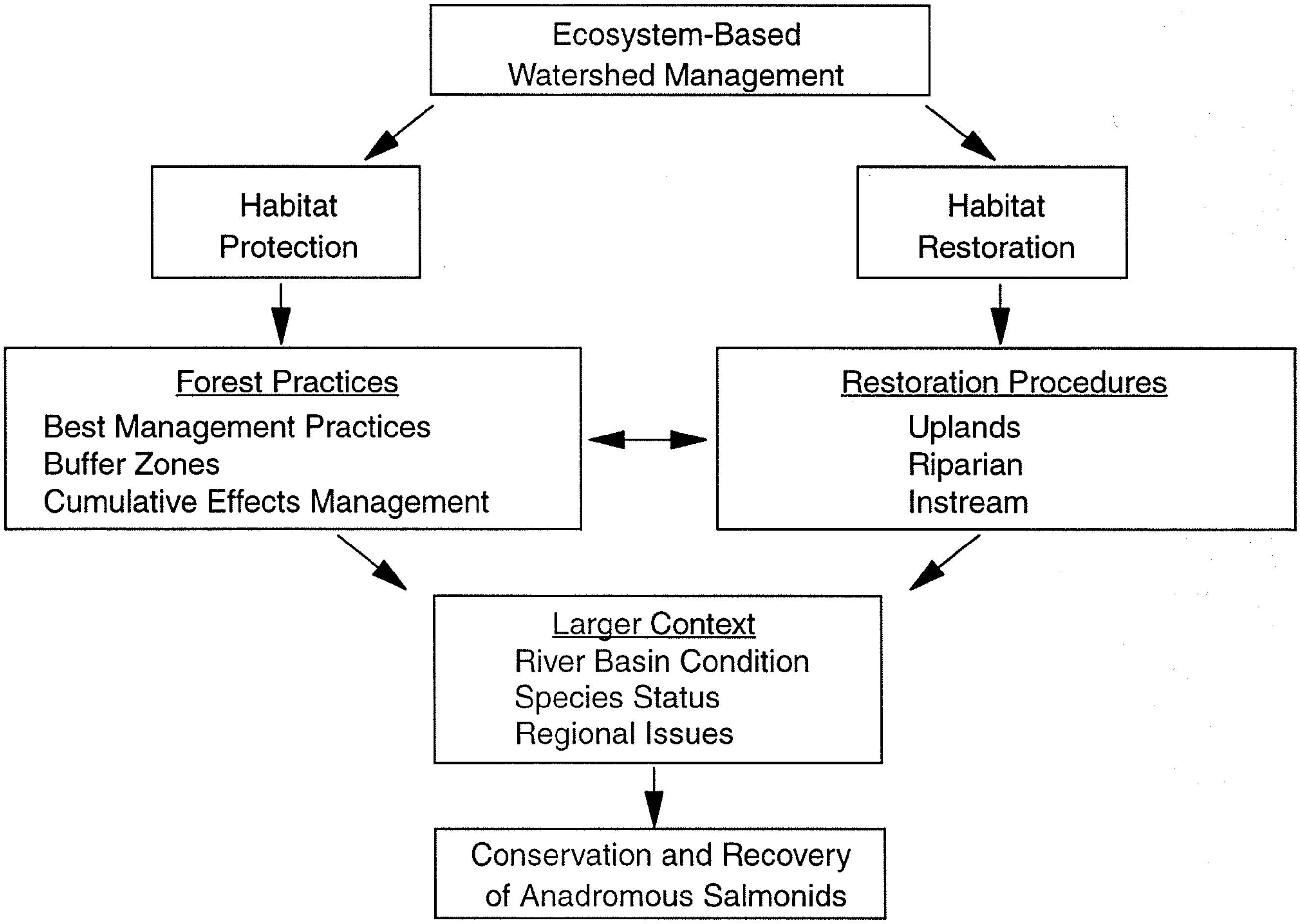


Figure ES.1. Major elements of a strategy for comprehensive, ecosystem-based watershed management.

migrating to sea need adequate streamflow. Because of these diverse habitat requirements, salmonid streams must provide appropriate diverse habitat conditions from the headwaters to the estuary.

Freshwater habitats for anadromous salmonids are created by physical and biological processes affecting the flow of water, sediment, nutrients, and organic matter through the watershed, modified by features such as large woody debris (LWD), and periodically "reset" by natural disturbances.

Small streams are the "backbone" of salmonid habitat. Even when not used because of barriers or steep gradient, small, even intermittent streams are critical to downstream fish habitats because they transport water, sediment, and woody debris from the upper watershed. Intermittent stream channels account for over one-half of the total length of stream channels in many watersheds. Small streams are easily affected by logging and other land uses because they are sensitive to changes in riparian vegetation and condition of the surrounding watershed. Forest practices that alter erosion, runoff, or riparian vegetation can have major impacts on small streams and the rivers into which they flow.

Impacts from over 100 years of logging and other land uses are still evident in streams of the Pacific Northwest and other regions. The most pervasive effect has been reduced habitat complexity due to loss of LWD, causing a widespread reduction in salmonid abundance and diversity. Despite improvements over the last 20 years, logging activities can still have multiple impacts. Effects of timber harvest, road construction, and other activities anywhere in a watershed can be transmitted through hydrologic and erosional processes to affect salmonid habitat. The most important impacts result from changes in sediment, streamflow, temperature, and LWD.

OBJECTIVES OF FOREST PRACTICES REGULATIONS

Forest practices must be designed to protect fish and wildlife habitat while enabling economic timber production. Agencies regulate forest practices through buffer zones, Best Management Practices (BMPs), and cumulative effects management.

Buffer zones are administratively defined areas along streams or erosion hazard areas in which aquatic resources are given highest management priority. The function of buffer zones is to protect streams and riparian areas from disturbance; filter sediment from uplands; and supply food, cover, shade, and LWD. Regulations determine both the width of buffers and activities within them. Buffer zones are not necessarily "lock-out" zones; trees often can be harvested, but with restrictions to protect aquatic resources. Restrictions are generally tighter on public than on private lands. Under the federal Northwest Forest Plan, for example, buffers can be modified only if watershed analysis demonstrates that a modification is needed to attain ecosystem management objectives (USDA and USDI 1994a).

The appropriate design for buffer zones depends on management objectives. The widest buffers with greatest restrictions on activities are used along fish-bearing streams to meet a full range of objectives for fish habitat, as well as for other wildlife (e.g., owls and amphibians) (USDA and USDI 1994a). Leaving large conifers in a sufficiently wide buffer (at least as wide as the height of a mature tree) is particularly important for providing LWD for fish-bearing streams. Narrower, selectively harvested buffers can be used along non-fish streams specifically to protect water quality and prevent downstream impacts.

BMPs are specific rules (e.g., waterbarring skid trails) to prevent nonpoint-source pollution, particularly from fine sediment. The Clean Water Act gives states authority to certify their forest practices rules as approved BMPs, and to certify BMPs of federal agencies for streams under federal jurisdiction. States with regulatory BMP programs impose requirements on forest practices and assess penalties for noncompliance.

Monitoring is conducted primarily by federal and state agencies. Implementation monitoring to determine whether BMPs are applied as specified is the most common type of monitoring. Effectiveness monitoring to determine whether BMPs achieve their intent is important in improving BMP performance. Comprehensive monitoring programs should also determine whether habitat problems are being recognized and appropriate practices specified, determine whether the combined system of BMPs protects water quality for particular projects, and provide for public review for improving BMPs.

Recent assessments indicate that forestry BMPs can protect water quality if they are carefully developed and implemented (Brown and Binkley 1994). Current problems often result from poor BMP implementation, which is generally worse on small private parcels than on public or large industrial holdings. Most state BMPs, furthermore, do not carefully protect small non-fish streams, and BMPs for protecting unstable slopes still need to be developed.

Cumulative effects management is a form of planning for preventing impacts from nonpoint-source pollution that could be overlooked at the project level. Evaluations of potential cumulative effects consider watershed erosion potential, slope stability, current and past disturbances from timber harvest and other land uses (e.g., grazing, agriculture, mining), recovery rate after disturbance, and project area relative to the total watershed. The most comprehensive procedure for analyzing cumulative effects at the watershed scale is "watershed analysis" (Washington Forest Practices Board 1993), a systematic process to describe current watershed conditions and develop prescriptions to prevent undesirable cumulative impacts. The assumption is that undesirable cumulative impacts can be avoided by managing sensitive areas appropriately and applying standard practices in non-sensitive areas.

Planning at the basin, regional, and even larger scales is also necessary for managing cumulative effects on anadromous salmonids because of their wide-ranging migrations. The NMFS Proposed Recovery Plan for Snake River Salmon (USDC 1995) is a good example of the comprehensive planning required to address all potential factors that cumulatively affect salmon populations. In this plan, watershed uses, including timber harvest, are just one of five planning components that also include main-stem and estuarine habitat, fisheries harvest management, hatchery propagation, and changes in institutional structure to improve decision making. These other four components are beyond the scope of this synthesis, but forestry-fisheries issues should properly be considered in this context.

ANALYSIS OF CURRENT FOREST PRACTICES

Federal land management agencies and the five western states with anadromous salmonids (Alaska, California, Idaho, Oregon, and Washington) have recently revised their rules to increase habitat protection. On federal lands, principal direction is given by one of three sources: the Northwest Forest Plan (NFP) within the range of the northern spotted owl (USDA and USDI 1994a); PACFISH, an interim strategy until Environmental Impact Statements can be completed for non-NFP areas (USDA and USDI 1994b); and the Tongass Land Management Plan (TLMP) as supplemented by the Tongass Timber Reform Act (TTRA) in Alaska. On private lands, forest practices follow their state's administrative rules. All these programs provide examples of "state-of-the-art" management for protection of salmonid habitat.

Forest management under NFP, PACFISH, TLMP, and the five states have many common elements, including buffer zones and regulatory BMPs. They differ mainly in how they manage buffer zones and cumulative effects. All classify streams by "beneficial use" (i.e., fish streams vs. non-fish streams) and give fish-bearing streams more protection through buffers and BMPs than small non-fish streams. Buffers along anadromous fish streams range in minimum width from 25 ft (8 m) on private lands in Washington to 300 ft (91 m) on federal NFP and PACFISH lands. Buffer width for perennial non-fish streams can range from 0 ft in Alaska, Oregon, and Washington to 150 ft (46 m) under NFP and PACFISH. Intermittent stream channels routinely have buffers only on NFP and PACFISH lands and in Idaho, but some states may use buffers when warranted by site conditions.

For fish-bearing streams, harvest restrictions within buffers are designed to protect most riparian functions, particularly shade, channel stability, and LWD. Four of the five states require a specific number of "leave trees" in combination with other vegetation requirements for LWD sources. These requirements, however, do not fully provide for future LWD sources, and result in leaving only an estimated 23% to 58% of potential conifer LWD sources compared to the sources present in mature forest.

Non-fish streams and intermittent channels are managed primarily to prevent sediment pollution and downstream impacts. Buffers on these stream channels on private lands are often narrow and heavily harvested, and stream protection relies heavily on BMPs. Three BMPs are particularly important in protecting small non-fish streams from disturbance. They determine 1) whether trees may be felled into stream channels and limbed there, 2) whether cable yarding may cross streams with full or partial log suspension, and 3) whether tractors may operate within streams or their buffer zones.

The states' BMPs for these activities carefully protect fish-bearing streams, but small non-fish streams are not as carefully protected. All states require that trees be felled away from fish-bearing streams, but several allow felling into small non-fish streams. Cable yarding across fish-bearing streams must have full suspension and prior approval in Oregon and Washington, but not for small non-fish streams. Tractor yarding is not allowed across fish-bearing streams except at constructed temporary crossings, but the states do allow tractors in some intermittent non-fish streams.

The agencies differ in how they assess and manage potential cumulative effects. Watershed analysis is a major component of the strategy for preventing cumulative effects on federal lands under NFP and PACFISH, but not currently under TLMP. California, Idaho, and Washington have a formal process for evaluating cumulative effects, but Alaska and Oregon do not. Applying watershed analysis on private lands is hindered because of the difficulty in coordinating resource assessment and management across property boundaries.

HABITAT RESTORATION

Habitat restoration has an important role in the recovery of anadromous salmonids as one element in a comprehensive program of watershed management emphasizing habitat protection. Habitat restoration is used to stabilize deteriorating conditions and speed recovery in key watersheds. Restoration should be regarded as an interim measure until degraded watersheds recover under effective management, not as an exemption from stream protection. Before initiating restoration, land uses that have caused the degradation must be modified to end adverse effects.

Effective habitat restoration has a watershed perspective based on hydrologic principles and is preceded by careful analysis to assess habitat problems and evaluate restoration potential. Habitat restoration includes three components: 1) upland restoration to control erosion, stabilize roads, upgrade culverts, and manage watershed uses; 2) riparian restoration to modify riparian vegetation to provide shade, LWD recruitment, and other functions; and 3) instream restoration using boulders, LWD, or other structures to provide missing habitat features and increase habitat complexity.

The need for habitat restoration is great. More than two-thirds of the riparian areas and one-half of all streams in the Pacific Northwest are degraded. Restoration of key watersheds, those with the best remaining habitat or greatest restoration potential, comprising one-third of federal lands in Oregon, Washington, and northern California, would cost $720 million over 10 years (Pacific Rivers Council 1993a). Although restoration costs are high, the investment return would be considerable because it would generate many jobs, and the recovery of salmon and watershed functions would have many social and economic benefits. Considering the costs, habitat protection is obviously preferable to allowing habitat to degrade to the point of needing restoration.

CONCLUSIONS AND RECOMMENDATIONS

A comprehensive watershed-level approach to habitat protection and restoration is essential for maintaining or restoring salmonid habitat because the watershed is a fundamental unit for both ecological processes and land management. The main technical elements of watershed management are buffer zones, BMPs, watershed analysis, and restoration.

To maintain or restore optimal habitat in fish-bearing streams, buffer zones should be at least as wide as the height of a mature tree, usually 30–40 m, and be managed to attain characteristics of mature native forest. Narrower buffers may not maintain adequate LWD over the long term, and selective harvest within buffers further reduces LWD sources. No-harvest buffers are most appropriate along fish-bearing streams with mature forest, most common in Alaska and in national forests. On private lands in other states, the number and size of leave trees should be increased where additional large conifers are available.

Many previously logged areas have degraded vegetation consisting mostly of hardwoods and brush and lacking large conifers. Restricting harvest would not necessarily improve habitat protection nor help restore riparian functions. Active management of these riparian areas is needed to meet habitat requirements of fish. Selective harvest within these buffers could be used to improve riparian vegetation (i.e., by thinning and conifer planting). Forest practices rules can include incentives for timber operators to actively manage degraded riparian stands to reestablish mature conifers or other appropriate vegetation. Reestablishing conifer forest in riparian areas would benefit both fisheries and timber because trees could be selectively harvested where shown not to harm fish habitat

Buffer zones are also needed along small non-fish streams that affect salmonid habitat. The usually minimal buffers on these streams on private lands means that their protection must rely on BMPs which do not always protect them from disturbance. Monitoring studies have not yet shown that BMPs for non-fish streams are effective in preventing downstream impacts. Buffer width and harvest prescriptions for these areas can be developed specifically to protect headwater sources of temperature control, sediment, and debris for downstream fish habitat.

The BMPs for activities near small non-fish streams need to be closely monitored to ensure they are effective. This is essential because small non-fish streams are particularly important for preventing sediment pollution and because buffer zones along them on private lands are usually narrow and heavily harvested. Effective BMPs may be the only practical means of protecting the numerous non-fish headwater streams in managed timberlands while other activities continue.

Watershed analysis is an important tool for assessing cumulative effects. In mixed-ownership watersheds, agencies can organize and lead landowners in cooperative watershed management across property boundaries. Ultimately, basin-wide planning efforts are needed that include all public and private land managers.

Habitat restoration should have a watershed-level approach and include measures to control erosion, reestablish riparian conifers, and improve instream structure. A priority is to stabilize existing roads to control erosion. Instream projects should be used only as part of a comprehensive watershed management program. Due to limited funds, most degraded habitat must rely on slow natural recovery under effective management. Because of the current depressed condition of many salmonid stocks, as much as possible should be done to speed recovery in key watersheds. The goal is to secure, expand, and link key watersheds in a system of refugia connected by intact migration corridors.

Habitat restoration is not a panacea for recovery of anadromous salmonids. There must also be changes in land and water uses to improve habitat protection and changes in fisheries management to ensure sufficient escapement. Habitat restoration and protection, however, are critical because even with fisheries closures, depressed stocks cannot recover without habitat.

Any conservation strategy will probably fail without community support. Comprehensive watershed management must also include outreach programs to recruit support from landowners and local communities. Tax credits and cost-sharing programs can be expanded to compensate landowners for measures taken to protect public aquatic resources.

The focus of this synthesis is on effects of forest management activities on anadromous fish habitat, but many land and water uses besides forestry have contributed to the decline of anadromous salmonids and therefore must also contribute to their recovery (USDC 1995). Improving forest practices and restoring fish habitat will not, by themselves, guarantee recovery of anadromous salmonids. However, these things are needed if the populations are to recover.

Chapter 1
Introduction

Across much of their range in the Pacific Northwest, anadromous salmonids have declined to the point that many stocks are depleted, federally listed as threatened or endangered, or extinct. Once-productive fisheries have been drastically curtailed or closed. Although habitat damage from timber harvest is not the only cause, it is an important factor in the decline of many stocks (Nehlsen et al. 1991; Botkin et al. 1994). To help reverse this decline, land managers have come to recognize the need for increased protection of stream habitat in areas managed for timber production and increased efforts to restore streams degraded by past timber harvest.

Several trends converged during the last two decades to focus concern on protecting and restoring fish habitats affected by timber management. The great value of fish and wildlife has become apparent, and the public demand has increased for recreational use of the forest (Meehan 1991). The listing of salmonid stocks and other wildlife species under the Endangered Species Act (ESA), with its strong regulatory measures, has brought many forest managers to see the need for a new approach to managing land and water resources. Forest managers of today are moving away from maximizing timber production by high-yield forestry toward managing resource complexes including fish (Meehan 1991). "Ecosystem management" is becoming the forest manager's paradigm for providing long-term maintenance of multi-species biological communities (Franklin 1992; Reeves and Sedell 1992; FEMAT 1993).

Habitat protection and restoration are two key elements in the recovery of anadromous salmonid stocks. Protection of fish habitat should be among every land manager's goals because fish habitat is influenced by uses throughout entire watersheds. Restoration is considered a "band-aid" approach to bridge the interim until habitat recovers enough under good watershed management to contribute to the recovery and sustained natural reproduction of anadromous salmonids. Without restoration, natural recovery of many impaired fish habitats would take decades or centuries (Rhodes and McCullough, in press); salmonid stocks near extinction may not survive that long. Protection of good existing habitats should have the highest priority, but many streams have been damaged and need to be restored (Meehan 1991).

Fortunately, much scientific knowledge is available to help guide resource managers. Salmonid habitat requirements and the effects of timber harvest on fish habitat are basically understood, and the fundamentals of restoration are known. Enough is known to implement land-use practices that prevent further habitat degradation (Chamberlin et al. 1991) and to begin restoring habitats previously degraded (Koski 1992).

In the past, habitat restoration and forest practices were generally treated as separate activities and not related to the watershed as a whole. In the modern paradigm of ecosystem management, however, they are recognized as essential elements of what must be a comprehensive approach to habitat protection and restoration applied at the watershed level (FEMAT 1993; Jensen and Bourgeron 1994). This approach is necessary to account for the way physical and biological processes function and interact in watersheds. A comprehensive watershed-level approach to habitat protection and restoration is essential for maintaining or restoring salmonid habitat.

Numerous publications have reviewed separate issues, such as the effects of timber harvest on fish habitat (e.g., Macdonald et al. 1988; Hicks et al. 1991a), buffer zones (e.g., Belt et al. 1992; Johnson and Ryba 1992), and habitat restoration (Reeves et al. 1991; Koski 1992). However, there are few analyses of all the elements essential to a watershed-level program of forest practices and restoration.

The purpose of this synthesis is to provide an overview of the important management issues involved in a watershed approach to forest practices and habitat restoration relating to protection and recovery of anadromous salmonids. Specific objectives are to

1) review habitat requirements of anadromous salmonids and potential effects of logging on salmonid habitat;

2) describe the function and technical foundation of forest management practices and fish habitat restoration;

3) analyze current forest management practices as examples of "state-of-the-art" watershed management strategies; and

4) recommend required elements of comprehensive watershed management for protection and recovery of anadromous salmonids.

The geographic focus of this synthesis is on forest practices within the range of anadromous salmonids in the Pacific Northwest and Alaska, but the principles also apply to other areas where timber harvest and other land uses affect aquatic habitats.

Chapter 2
Methods

Information for this synthesis was gathered primarily from review of the literature (published and unpublished) and consultations with scientific and technical experts in the forestry and fisheries fields.

Several interdisciplinary site visits were used to review current forest practices and restoration programs in California, Oregon, Washington, and Alaska. Emphasis of these visits was on viewing activities on private lands because forest practices on private lands vary among the states, whereas practices on federal lands are more consistent across the region.

In California, a 2-day tour of ongoing forestry activities was conducted by the California Department of Forestry and Fire Protection (CDF). This tour visited several industrial timber operations, as well as smaller non-industrial landowners. Focus of the tour was on current forest practices regulations and their administration by the CDF. Site visits to habitat restoration activities on private lands were provided by the California Department of Fish and Game (CDFG). Tours of habitat restoration projects on the Six Rivers National Forest were organized by the USDA Forest Service (FS).

In Oregon, the Oregon Department of Forestry (ODF) provided a 2-day tour of forestry activities on private industrial timberlands. Site visits were also used to review restoration research programs conducted by the Oregon Department of Fish and Wildlife (ODFW), Oregon State University, and the FS Pacific Northwest Research Station. Ongoing research programs are investigating both instream and riparian restoration activities.

In Washington, forest practices and restoration on private lands were reviewed during a site visit conducted by Weyerhaeuser Company. Restoration research conducted by the Washington Department of Natural Resources (WDNR) was also reviewed during a site visit.

In Alaska, reviews of forest practices on private lands were jointly conducted by the Alaska Department of Fish and Game (ADFG) and the Department of Natural Resources. Other information on forest practices and related research was provided by the Alaska Working Group on Cooperative Forestry/Fisheries Research.

Chapter 3

Historical Background

THE DECLINE OF ANADROMOUS SALMONIDS

In North America, the native anadromous salmonids occur from mid-California to the Arctic Ocean in the west, and from Connecticut to northern Newfoundland in the east (Fig. 3.1; Meehan and Bjornn 1991). In the west, anadromous salmonids occur in five states: California, Oregon, Washington, Idaho, and Alaska. Anadromous species include five species of Pacific salmon (*Oncorhynchus* spp.), steelhead (*Oncorhynchus mykiss*), sea-run cutthroat trout (*O. clarki*), and Dolly Varden (*Salvelinus malma*). In the east, only Atlantic salmon (*Salmo salar*) and to some degree brook trout (*Salvelinus fontinalis*) are anadromous. Non-anadromous populations of salmonids occur throughout the U.S. and Canada.

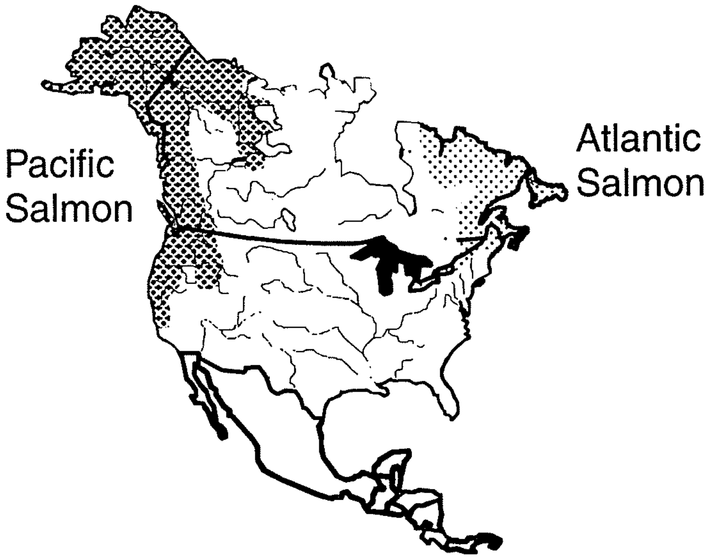


Figure 3.1. Distribution of native anadromous salmonids in North America. (After Meehan and Bjornn 1991.)

Because of their fidelity in homing to natal streams in which they were spawned and reared, anadromous salmonids have become reproductively isolated into hundreds of locally adapted populations, or stocks (Ricker 1972). Any given stream with appropriate habitat can harbor several coexisting species and several different stocks of each species (Fig. 3.2).

Stories of the original abundance of anadromous salmonids in the United States (Netboy 1974) seem like fiction from today's perspective. With the exception of Alaska, existing populations of native anadromous salmonids on both coasts are mere remnants. On the East Coast, Atlantic salmon have been severely depleted for over 100 years. On the West Coast, at least 106 major stocks are extinct, and another 101 are at high risk of extinction (Nehlsen et al. 1991). In California, for example, coho salmon (*Oncorhynchus kisutch*) now occur in only one-half of historic natal streams (CDFG 1994).

Salmon are still the nation's most valuable fisheries (U.S. Dept. Commerce 1990), with anaverage (1985-89) commercial ex-vessel value in the northeastern Pacific of $773 million (Talley 1990). Value for sport, subsistence, and other non-market amenities are also substantial (Huppert and Fight 1991). Because of the depleted condition of the stocks, most fisheries off California, Oregon, and Washington were closed in 1994. The Pacific Coast Federation of Fishermen's Associations estimates that 98% of the jobs dependent on salmon fisheries in the Pacific Northwest have been lost since 1988, and the economic impact of lost salmon fishing is $1.25 billion. Considering the depleted condition of most native stocks, the potential value of the resource if restored would be enormous.

Figure 3.2. Salmonid habitat in a small forested stream in southeast Alaska, showing its complexity and abundance of pools, spawning gravels, and cover provided by large woody debris. (Photo by K Koski, NMFS.)

Three principal factors caused the decline of anadromous salmonids: 1) loss of habitat due to habitat destruction, inadequate passage at dams, and inadequate streamflow; 2) overfishing of weaker stocks in mixed-stock fisheries; and 3) negative interactions with non-native fish, especially from hatcheries (Nehlsen et al. 1991). Belief that hatcheries could mitigate habitat loss also provided an excuse for taking habitat for development. Several factors usually operated in concert. For example, the now-extinct run of coho salmon in Oregon's Grande Ronde River was first reduced by habitat destruction from logging, grazing, and agriculture; then further reduced by dams on the Snake River in the 1960s–1970s; and finally overfished when management agencies decided the stock was too weak to warrant protection in mixed-stock fisheries (Nehlsen et al. 1991). A new paradigm that advances habitat restoration and ecosystem function rather than hatchery production is needed for salmonid stocks to survive and prosper (Nehlsen et al. 1991).

Habitat destruction from logging, mining, grazing, agriculture, and urban development was the factor most commonly associated with the decline of anadromous salmonids (Nehlsen et al. 1991). Unregulated clearcut logging damaged numerous streams, rivers, and estuaries (Sedell et al. 1991). Hydraulic gold mining in California created a giant wave of sediment that progressed from mountain streams to San Francisco Bay (Ritter 1978). Dredge mining for gold in the 1800s dug up streambeds in California and Idaho, leaving tailings piles visible today (McIntosh et al. 1994). Overgrazing by sheep and cattle caused chronic erosion and altered riparian areas, and agriculture converted forests to erosion-prone croplands and withdrew water for irrigation (Wissmar et al. 1994). Construction of housing and highways accompanying explosive population growth in many areas of the West severely impacted numerous watersheds (Netboy 1974).

As of August 1995, the National Marine Fisheries Service (NMFS) has listed four stocks as threatened or endangered under ESA: Snake River spring/summer chinook, Snake River fall chinook, Snake River sockeye, and Sacramento River winter chinook. NMFS has also proposed to list Umpqua River cutthroat trout, Klamath Mountain Province steelhead, and three distinct evolutionarily significant units (ESUs) of coho salmon on the Oregon and California coasts. All other stocks of anadromous salmonids outside Alaska are undergoing status review.

For the first stocks listed under ESA, concerns included big-river problems with fish passage and water management in the Columbia River and Sacramento River Basins, as well as fishing mortality and land management activities, especially in Idaho and eastern Oregon and Washington. The NMFS Proposed Recovery Plan for Snake River Salmon (USDC 1995) has five major planning areas including tributary ecosystems, main-stem river and estuarine ecosystems, fisheries harvest management, hatchery propagation, and changes in institutional structure to improve decision making. As the status of coho salmon, steelhead, and cutthroat trout came under review, concern expanded to a broader geographic area and more emphasis on impacts of land uses and hydro projects on small streams (L. Sullivan, NMFS, pers. comm. 1995).

Small streams are the "backbone" of salmonid habitat. Salmonids occupy streams ranging from tiny first-order tributaries to the main-stem Columbia River (ninth-order; Leopold et al. 1964), but most spawning and rearing, especially for coho salmon, steelhead, Dolly Varden, and cutthroat trout, take place in second- to fourth-order streams (Figs. 3.1 and 3.3). Large rivers can provide important spawning, rearing, and migratory habitat for all species, but small streams greatly outnumber the higher-order rivers. Even when small streams are not used by salmonids because of barriers or steep gradient, they are important to the quality of downstream habitats because they carry water, sediment, nutrients, and woody debris from the upper watershed to downstream reaches.

Small streams are also easily affected by land uses (Meehan 1991). They are intimately associated with their riparian zones and flood plains (Fig. 3.4), and they are highly responsive to changes in riparian vegetation and the condition of the surrounding watershed. Land uses that increase erosion, modify runoff, or alter riparian vegetation have greater effects on small streams than on larger streams.

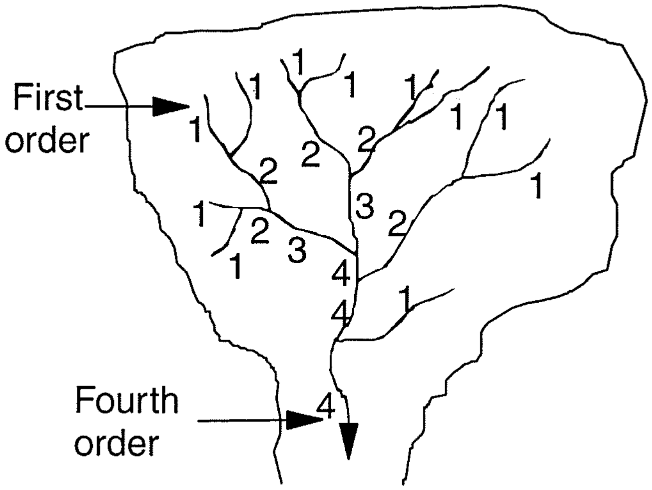


Figure 3.3. Diagram of a watershed's drainage network, showing stream orders according to the Strahler (1957) classification system. First-order streams are headwater streams without tributaries; second-order streams are formed by the confluence of two first-order streams; third-order streams are formed by the confluence of two second-order streams; and so on.

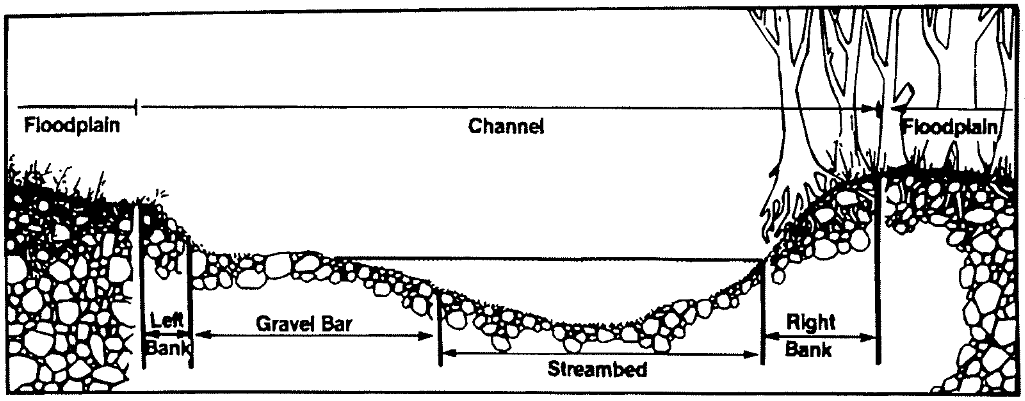


Figure 3.4. Cross-section of a woodland stream, showing association with riparian vegetation and flood plain. (From Sullivan et al. 1987; reprinted with permission from University of Washington, Institute of Forest Resources.)

LEGACY OF PAST LOGGING

Logging and clearing of land historically impacted vast areas of U.S. forests and their salmonid habitats. Over 1 million km^2 of the original forest has been converted to agriculture and other uses (Powell et al. 1993). The greatest rate of forest clearing was between 1850 and 1910, when American farmers cleared 758,000 km^2, averaging 35 km^2 per day for 60 years. Logging began in New England in the 1700s, in the Great Lakes and Gulf Plain in the early 1800s, in the Pacific Northwest in the mid 1800s (FEMAT 1993), and in Alaska about 1950 (Gibbons et al. 1987).

In the early years, streams were used to move logs downstream to accumulation sites. Every stream of sufficient size in western Oregon and Washington was cleared of obstructions for log drives during high water (Sedell et al. 1991). On streams too small for log drives, splash dams of log cribbing were used to raise a head of water for sluicing logs (Fig. 3.5; Sedell and Luchessa 1982). Repeated splash damming caused major long-term damage to fish habitat as torrents of water and logs severely scoured many streams, leaving barren bedrock. By about 1900, over 300 major splash dams and numerous undocumented smaller dams operated in Oregon and Washington.

Even where splash dams were not used, stream channels served as transportation corridors for logging. Railroads were built along the larger drainages, and then logs were yarded down the smaller tributaries to the railbed. In this way, impacts extended to the tiniest intermittent channels. Whole watersheds were logged as convenience dictated, beginning in the lower watershed and progressing upstream until all valuable timber was taken. Logs were yarded downhill, scraping debris and sediment into stream channels.

Logging practices after this early period were improved but still affected salmonid habitat. Streams were protected from being used for yarding in the 1950s. Clearcutting to the streambank, however, was normal practice until the 1980s. Riparian buffer zones were not used much until the late 1980s, and most of these buffers contained only minimal trees (Phinney et al. 1989).

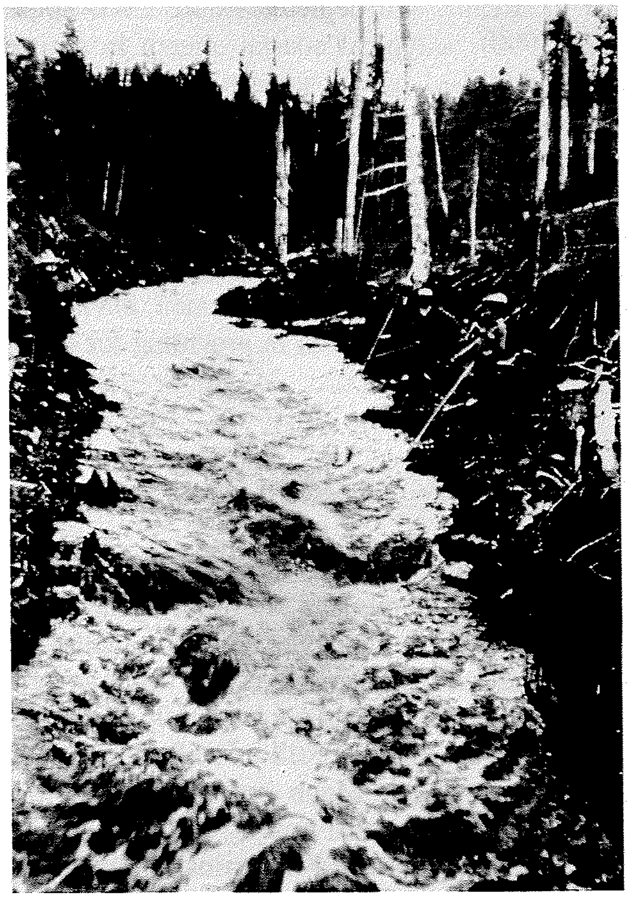


Figure 3.5. Finishing up a log drive after splash damming in western Washington in 1927. (Photo courtesy of J. Sedell, FS.)

Before regulations limited logging slash entering streams, timber harvest often completely buried streams in accumulated limbs and tops (Gibbons and Salo 1973). The small unstable debris often washed downstream within a few years, destabilizing natural debris jams (Bryant 1980). To address this problem, forest practices rules in the 1970s began requiring removal of logging slash from streams after timber harvest. Timber operators did their best to thoroughly clean streams after yarding, often removing every piece of debris from the channel, including beneficial natural debris (Bilby and Ward 1989).

Lack of knowledge about fish habitat requirements also caused mistakes in stream management. In response to the days when logging slash was a major problem, fisheries managers from the 1950s to the 1970s focused on removing large woody debris (LWD) from streams. Woody debris was seen as a detriment to salmon migration, and all along the Pacific coast, logjams were removed with the intention of opening new reaches of stream (Narver 1971; Hall and Baker 1982).

Impacts from over 100 years of logging and debris removal are still evident in most streams of the Pacific Northwest and other areas of the nation (Koski 1992). One of the most damaging long-term effects has been a drastic reduction in LWD (Bisson et al. 1987), extending from the headwaters to the estuary (Sedell et al. 1991). Past logging practices have reduced large, stable LWD in streams and depleted future LWD sources in riparian zones. Depending on geology (Hicks 1990), a typical coastal stream in second-growth forests of the Pacific Northwest has greatly simplified habitat consisting of a single, cobble-bed channel lacking pools and LWD. In other areas, streams may have bedrock channels lacking gravel, woody debris, and other channel features (McIntosh et al. 1994).

Today, forest management is evolving to provide greater protection for salmonid habitat. Improved knowledge of habitat requirements and increased concern for habitat quality by recreational and commercial fishermen, environmental organizations, and the general public have led to this greater emphasis in providing for fish habitat in forest management activities (Brouha 1991).

PRESENT-DAY TIMBERLANDS

Forests in the U.S. now amount to 70% of the area that was forested in 1600 (Powell et al. 1993). Today's landscape, however, generally consists of small patches of forest of mostly middle seral stages interspersed with recently harvested areas. At lower elevations, forests are intermingled with farms and towns, and fragmented by highways and residential developments. Inventories in the 1980s showed only 18% of the original old-growth forest in California, Oregon, and Washington still existed; 85% was on public land and higher elevation (Bolsinger and Waddell 1993). Much has been cut since this last inventory. The more valuable forest types have been the most heavily logged. The ponderosa pine forests in national forests on the east slope of the Cascade Mountains, for example, have only 2-8% climax old growth remaining (Eastside Forests Scientific Society Panel 1993). Generally, forest land at lower elevations is privately owned and has been logged at least once.

About 20% (2 million km^2) of the nation's total land area is classed as "timberland," capable of producing more than 20 cubic ft of industrial wood per acre (1.4 m^3/ha) per year and not withdrawn from timber harvest in parks and other reserves (Powell et al. 1993). Most of the nation's highly productive forest lands, capable of producing more than 120 cubic ft per acre (8.4 m^3/ha) per year are in the South and in the Pacific Northwest. Areas that produce both timber and anadromous salmonids coincide over much of western North America and mostly in Maine in the eastern United States. Composition of U.S. forests is diverse, ranging from pure stands of Ponderosa pine (*Pinus ponderosa*) in the semiarid West to multi-species hardwoods in the Northeast. The most productive timberlands are the loblolly-shortleaf pine forests of the South and the Douglas fir (*Pseudotsuga menziesii*) and redwood (*Sequoia sempervirens*) forests of the Pacific Northwest.

U.S. forests within the range of Pacific anadromous salmonids produce about 17 billion board-feet of sawlogs and other wood products per year—one-quarter of the total U.S. timber production (Powell et al. 1993; Warren 1993; Fig. 3.6). Private lands and national forests account for most timber harvest, with smaller contributions from USDI Bureau of Land Management (BLM) lands in Oregon and state lands in Washington. Most U.S. timber production, however, comes from the South, outside the range of anadromous salmonids. British Columbia, Canada, is also a major producer, about the same as the Pacific Northwest.

These timberlands are owned primarily by the federal government and private firms and individuals (Fig. 3.7). Most federal timberlands are national forests; other public lands include mostly BLM lands in Oregon and state lands in Washington and Alaska. Private lands are about equally divided between the forest products industry and private non-industrial groups and individuals. As the amount of available timber on federal lands declines, more pressure is put on private lands. Conversely, as timber declines on private lands, pressure is put on public lands to provide timber to maintain local economies.

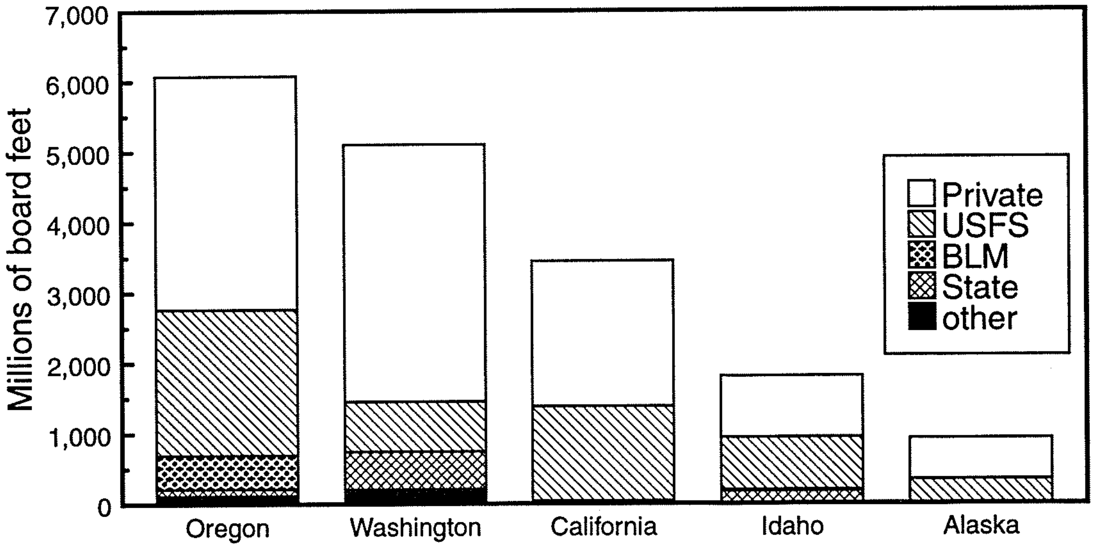


Figure 3.6. Lumber production in states within the range of Pacific anadromous salmonids. (Data are from Warren 1993.)

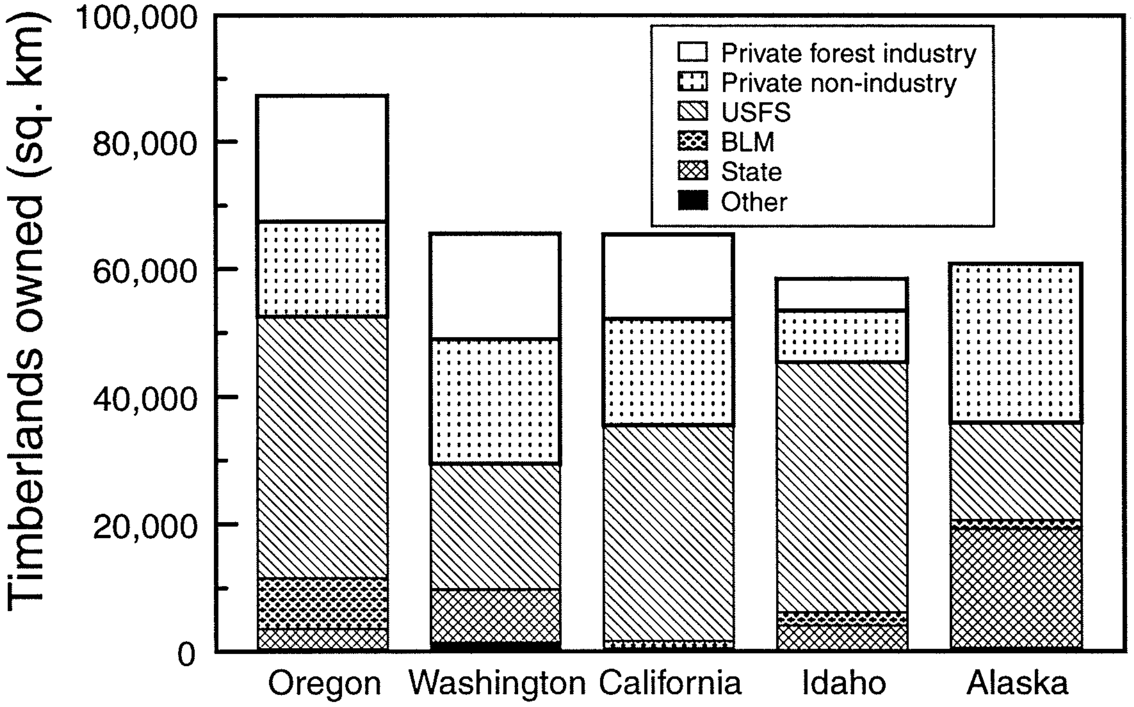


Figure 3.7. Ownership of timberlands in the Pacific Northwest and Alaska. (Data are from Powell et al. 1993.)

Chapter 4
Salmonid Habitat Requirements

The typical life cycle of anadromous salmonids consists of several stages that encompass marine, estuarine, and freshwater environments (Fig. 4.1; Groot and Margolis 1991). Each life stage has different habitat requirements. Adults returning from the sea require access to spawning gravel and cover from predators; eggs and alevins incubating in the streambed require stable, permeable gravel and cool, oxygenated water; juveniles rearing in the stream require food, suitable temperature, and cover; and smolts migrating to sea require adequate streamflow. These multiple factors operate simultaneously and vary seasonally and annually. Their role in salmonid population dynamics also changes with the different stages of the life cycle.

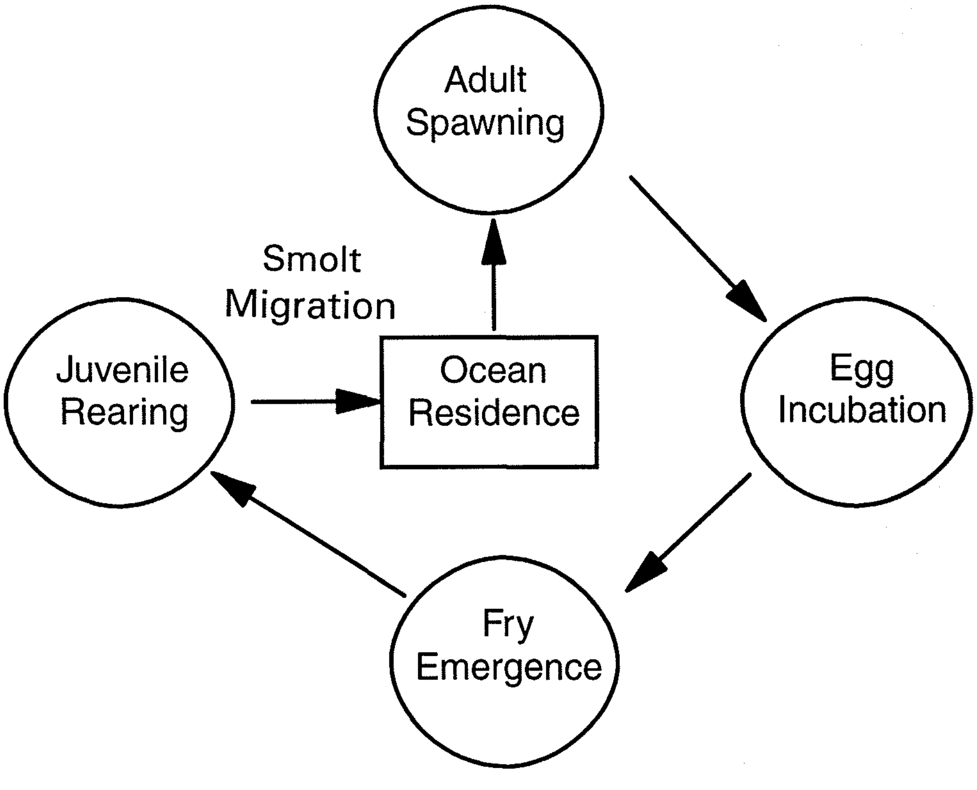


Figure 4.1. Generalized life cycle of anadromous salmonids, involving several distinct freshwater life stages and a period of ocean residence.

Habitat requirements of anadromous salmonids have been thoroughly reviewed (Bjornn and Reiser 1991). This chapter presents the salient habitat requirements that pertain to effects of logging. It follows the life cycle of salmonids, beginning with the habitat requirements of adults as they return to spawn, and ending with the migration of smolts as they leave for the sea.

Although descriptions of habitat requirements are generally species-specific, almost all aquatic habitats used by anadromous fish accommodate complex assemblages of stocks rather than a single stock. Because the various species, stocks, and life stages of salmonids have different habitat requirements, the streams they inhabit must provide appropriate diverse hydraulic and geomorphic conditions from the headwaters to the river mouth.

UPSTREAM MIGRATION OF ADULTS

Adult anadromous salmonids must reach the spawning grounds at the proper time and with enough energy left to spawn (Bjornn and Reiser 1991). Native stocks have migration schedules that are flexible enough to accommodate delays during normal periods of unsuitable conditions. Stocks that migrate up long river systems often arrive in the spawning area several months before spawning, whereas those migrating up short coastal streams often do not move into streams until just before spawning. Some stocks enter streams in fall when streamflow is high and do not spawn until the following spring.

Although the migration schedule is flexible, it has evolved to meet the specific flow and temperature regimes of the natal streams. Temperature during incubation is probably the primary determinant of spawning time (Heggberget 1988). Any given stock spawns mostly during a 3- to 4-week period determined by the temperature regime where the eggs incubate (Meehan and Bjornn 1991). Spawning is timed to allow for egg incubation so that fry emerge at the right time to feed and grow.

For successful migration, conditions must be suitable for at least part of the migration season. Streamflow should be at least 30–70% of the mean annual flow, and water depth should be at least 18–24 cm, depending on the species (Bjornn and Reiser 1991). High turbidity can cause fish to delay migration, but turbidity generally does not affect homing. Fish easily negotiate their way up highly turbid glacial rivers (Eiler et al. 1992). Water temperature can be in a broad range between 3 and 20°C. If streamflow is too high, water velocity may be too fast. Adult salmon can swim at a sustained speed of more than 3 m/s and dart over 6 m/s, but the maximum negotiable water velocity is under 3 m/s in critical stream reaches, usually shallow riffles.

Low dissolved oxygen (DO) can impede migration and even cause fish kills in some situations. Swimming performance declines sharply when DO concentration drops below 7 mg/L, and fish may stop migrating when DO is below 4.5 mg/L (Bjornn and Reiser 1991). Pre-spawn die-offs of adult pink (*O. gorbuscha*) and chum salmon (*O. keta*) can occur during temporary summer droughts when fish become crowded in pools and deplete oxygen (Murphy 1985).

Large pools and abundant cover are important components of migration habitat. Adult salmon often hold for several weeks in large pools as they ascend a stream to spawn (Burger et al. 1985; Thedinga et al. 1993), and some fall-run stocks spend months in fresh water before spawning (Meehan and Bjornn 1991). During this time, the adults are vulnerable to predation and disturbance, and must conserve energy for further upstream migration and spawning. Bears can take a large toll in some areas, but are not significant where their number has been reduced. Human disturbance can be important where salmon holding areas are near recreation sites. Large pools and abundant LWD provide resting habitat and cover needed for successful upstream migration.

Perhaps most important for adult migration is freedom from barriers. Water falls, debris jams, and other obstacles can block upstream passage. Many such barriers are only temporary. Debris jams and beaver dams may be barriers at low flow but become passable at higher flow (Bryant 1984). Salmon and steelhead can jump obstacles up to 3 m high if the pool below the falls is deep enough (Bjornn and Reiser 1991). Salmonids can get past many obstacles that appear to be barriers, given suitable streamflow and obstacle configuration.

SPAWNING

The usable spawning habitat in a stream depends on the stream's size, depth, velocity, temperature, amount of proper-size gravel, and configuration of pools and riffles (Bjornn and Reiser 1991). Streamflow regulates the amount of spawning area in a stream by controlling the area covered by water and its depth and velocity. For each stream, there is an optimum flow that provides the maximum usable spawning area. Salmonids can spawn when water temperature is as low as 1°C and as high as 20°C, but the favorable range is between 4 and 17°C, depending on the stock (Bjornn and Reiser 1991). Suitable gravel substrate is between 1 and 10 cm diameter, depending on fish size, but upwelling groundwater can make substrates finer than 1 cm suitable for spawning (Lorenz and Eiler 1989).

The number of possible redds in a stream depends on the area required per spawning pair and the area of suitable spawning habitat (Bjornn and Reiser 1991). The average redd size of anadromous salmonids ranges from 0.6 m^2 for pink salmon to 10 m^2 for chinook salmon, and the area needed per spawning pair is from 0.6 to 20 m^2 (Table 4.1). The number of possible redds in a stream is roughly equal to the gravel area divided by 4 times the average redd size (Bjornn and Reiser 1991). Suitable spawning habitat, however, is often much less than the area of gravel because suitable habitat also requires proper channel configuration.

The best channel configuration for spawning is often at transition areas between pools and riffles. These areas often have abundant intragravel flow which brings oxygen to the eggs and removes metabolic wastes (Bjornn and Reiser 1991). Downwelling currents at the tails of pools force water into the gravel, and upwelling currents at downstream ends of riffles force water up from below. Structural features of the channel, such as LWD, are important for spawning habitat because they help create these pool-riffle transition areas. In gravel-poor streams, LWD also forms spawning habitat by trapping gravels (Everest and Meehan 1981) and in sediment-rich streams, by scouring silt out of spawning beds (Sedell and Swanson 1984).

Table 4.1. Average redd area and area per spawning pair. (After Bjornn and Reiser 1991.)

Species	Redd area (m^2)	Area per pair (m^2)
Chinook salmon	3–10	13–20
Steelhead	4–5	
Coho salmon	2.8	12
Chum salmon	2.3	9
Sockeye salmon	1.8	7
Pink salmon	0.6–0.9	6
Cutthroat trout	0.1–0.9	

As in upstream migration, cover is also important during spawning, and nearness to cover often determines spawning sites (Bjornn and Reiser 1991). Overhanging and submerged vegetation, undercut banks, deep water, turbulence, and LWD provide shade and protect fish from disturbance.

INCUBATION

Successful incubation depends on numerous variables, such as streamflow, channel stability, and temperature, but usually the most important factor is substrate permeability. Permeable substrate is needed so that water can move freely to bring oxygen to the embryos and carry waste away.

Fine sediment (usually <0.8 mm diameter) is detrimental to embryo survival because it reduces substrate permeability. Permeability of gravel decreases sharply as fine sediment increases from 5 to 20% of the substrate, and embryo survival declines similarly (Fig. 4.2; Chapman 1988). Low DO can kill embryos or cause them to emerge in poor condition (Koski 1975). Fine sediment can also interfere with emergence by blocking interstices in the gravel. Coarser sediment (1–2 mm diameter) can cap the substrate and trap alevins within the gravel.

The spawning activities of adult salmonids can remove fine sediment from the redd and surrounding area (Chapman 1988). New redds contain less fine sediment, especially fine organic particles which are light and easily moved. Where numerous spawners use the same area every year, they help keep the gravel in good condition. If the population declines, the spawning habitat can deteriorate.

Shifting of spawning gravel during periods of high streamflow can cause heavy mortality during incubation (McNeil 1964). Losses can be especially high where stream bedload is excessive because of mass wasting. For example, in the Queen Charlotte Islands, British Columbia, 45–86% of salmon eggs were destroyed by scour in watersheds with severe mass wasting, compared to only 0–14% in more stable areas (Tripp and Poulin 1986).

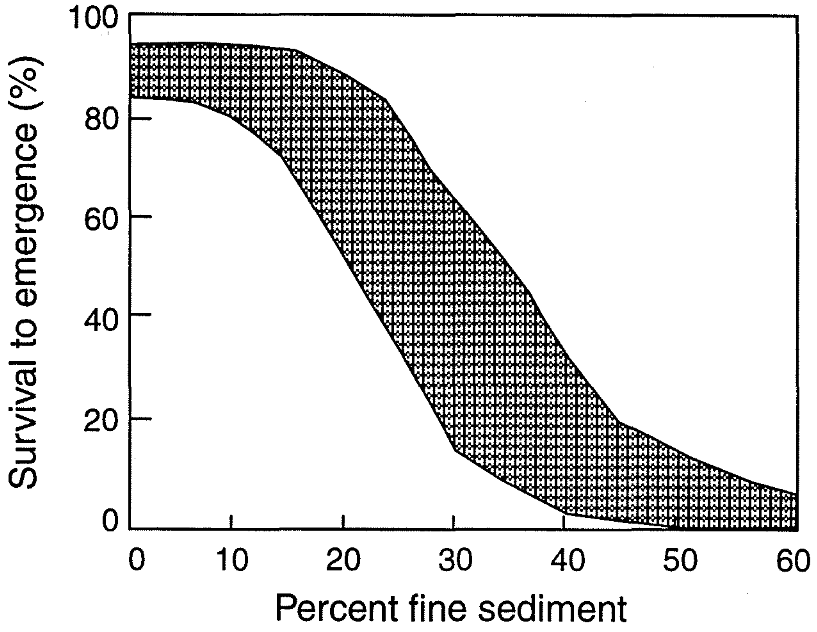


Figure 4.2. Egg-to-fry survival in relation to fine sediment (<2–6.4 mm) in spawning gravel. The stippled area includes data from four separate laboratory studies. (After Bjornn and Reiser 1991.)

The time required for embryos to hatch and for alevins to emerge is sensitive to water temperature and varies by species (Bjornn and Reiser 1991). Steelhead eggs hatch after 85 days at 4°C and after 26 days at 12°C; Pacific salmon eggs hatch after 115–150 days at 4°C, and after 35–60 days at 12°C. After hatching, alevins remain in the gravel for about twice the time it takes eggs to hatch.

The favorable temperature range for incubation is between 4 and 14°C (Bjornn and Reiser 1991). Many salmonid streams are colder than 4°C in winter, but this is generally not a problem if initial development occurs within the suitable range. Because spawning and egg development seldom occur in summer, intragravel water temperature is usually well below lethal or sublethal levels. Eggs of spring spawners, however, may be exposed to high water temperature in late spring.

In northern and high-elevation regions, freezing can cause high mortality during incubation. Direct mortality from freezing is one of the three most important mortality factors (besides low DO and gravel shifting) for pink salmon embryos in southeast Alaska (McNeil 1964). Low temperature also has indirect effects due to formation of anchor ice on the substrate, which can block interchange of water into the redd. Ice dams can destabilize the stream and scour the spawning gravel.

FRESHWATER REARING

The different species and stocks of anadromous salmonids spend different periods of time in fresh water. Pink and chum salmon spend the least time, usually migrating to sea immediately after emergence. Most sockeye salmon (*O. nerka*) spend up to 3 years in lakes, but juveniles of some stocks inhabit riverine sloughs and migrate to sea their first spring or summer (Heifetz et al. 1986; Eiler et al. 1992). Juvenile chinook salmon (*O. tshawytscha*) occur as two general types: "stream type," which inhabit streams for 1 or 2 years (e.g., spring runs), and "ocean type," which migrate to sea their first summer (e.g., fall runs) (Healey 1983). Juvenile coho salmon spend 1 to 3 years, and juvenile steelhead, Atlantic salmon, and cutthroat trout spend 2 or more years in streams.

Stream habitat is obviously more important for species that have extended rearing in streams. For these species, the stream's habitat puts an upper limit, or "carrying capacity," on the number of juveniles (Bjornn and Reiser 1991. At low levels of spawning and fry abundance, carrying capacity does not restrict abundance of juveniles. In such cases, older juvenile populations are directly related to spawner abundance but less than carrying capacity. At higher levels, biological and physical factors cause density-dependent mortality and emigration so that, by late summer, the juvenile population approaches equilibrium with the stream's carrying capacity.

If spawning escapement is adequate, sufficient fry are usually produced to exceed carrying capacity (e.g., Crone and Bond 1976). In two years in Sashin Creek, Alaska, for example, coho spawners and potential egg deposition increased more than fivefold, but the resulting number of yearling juveniles was nearly identical (Table 4.2). This is probably an extreme example because the number of juvenile fish in a stream are unlikely to vary so little. It does, however, illustrate the principle of how rearing habitat can limit populations of coho salmon. Reduced spawning success in such populations would not necessarily reduce smolt yield, as long as

Table 4.2. Number of coho salmon at different life stages in Sashin Creek, Alaska, for two brood years with a large difference in spawner escapement. (Data from Crone and Bond 1976.)

Brood year	Spawning adults	Potential eggs[a]	Pre-emerged fry	Fry	Yearlings
1963	916	1,460,000	214,000	51,852	4,581
1964	162	260,000	58,000	20,355	4,546

[a] Potential number of eggs estimated from number of females and mean fecundity.

sufficient fry continue to be produced to fully seed available habitat (Everest et al. 1987a). However, if spawning escapement is reduced by overfishing or other causes so that the reservoir of surplus juveniles is lacking, the number of smolts is more sensitive to forestry-related impacts (Cederholm and Reid 1987).

Theoretically, carrying capacity of summer habitat sets a density-dependent limit on the juvenile population, which then suffers mortality in proportion to the severity of winter conditions and quality of winter habitat. Unlike in summer, mortality of juvenile salmonids in winter results mainly from density-independent factors (Hunt 1969). Winter mortality in streams is substantial: 46–94% of late-summer populations (Murphy et al. 1984; Hartman et al. 1987), and can usually be attributed to hazardous conditions during floods, stranding by ice dams, and physiological stress from low temperature, oxygen depletion, or progressive starvation (Bryant 1984; Murphy et al. 1984; Harding 1993). Survival factors become more important as latitude increases, because winters are more severe and juveniles stay longer in fresh water. South of Alaska, for example, coho salmon generally spend only one winter in fresh water, whereas in Alaska, most spend two winters (Gray et al. 1981).

The ultimate production of salmon smolts is determined by numerous interacting environmental factors, including food availability, temperature, water quality, streamflow, and cover (Bjornn and Reiser 1991). The importance of each factor varies seasonally: food availability, temperature, and streamflow are most important in summer; cover is key in winter.

Food Availability

In many streams, summer carrying capacity is more related to food supply than to physical factors. Juvenile salmonids will not stay in a stream if the food level is not adequate (Konopacky 1984; Wilzbach 1985). The proof that wild salmon populations in summer are often food-limited is that their number can be increased by supplemental feeding (Mason 1976). Abundant food can increase carrying capacity because more fish can occupy a given area and fewer emigrate (Mason and Chapman 1965). Salmonids can adjust the size of their territories according to food abundance by altering their aggressive behavior (Dill et al. 1981). When food becomes more plentiful, aggression subsides and territories contract.

The period of greatest mortality of juvenile anadromous salmonids is usually during spring and early summer, when newly emerged fry colonize habitat and establish territories, and the population adjusts to carrying capacity. Adults usually spawn in limited parts of a drainage, but the juveniles spread out and colonize most accessible and suitable areas (Leider et al. 1986). Where fry are numerous, their territories cover all suitable parts of the stream, and surplus fry are displaced and emigrate. As fish grow, they require more space, and the population must shrink to accommodate needs.

Stream-rearing salmonids predominantly eat invertebrates that drift downstream (Elliott 1973). Because salmonids are generalist predators, all groups of invertebrates are potential prey, but certain types of immature aquatic insects are eaten most because of their propensity to drift. Common food items include the midges (Chironomidae), mayflies (Ephemeroptera), blackflies (Simuliidae), and net-spinning caddisflies (Hydropsychidae) (Murphy and Meehan 1991). These insects generally are small, and their populations turn over rapidly so that production is often 2–10 times their standing biomass.

Salmonids are usually territorial, and the amount of food they get depends on their territory size and location. Suitable territories have one or more stations with slack water yet close to fast water so that fish can wait for drift while saving energy (Fausch 1984). Such stations are usually limited, so salmonids habitually use only part (often <15%) of the available habitat (Bachman 1984).

To understand food production in streams, one must understand how stream ecosystems operate (Murphy and Meehan 1991). Stream ecosystems have two energy sources: in-stream primary production from aquatic plants (e.g., diatoms) and out-of-stream sources of organic matter (e.g., leaves from riparian plants). The amount of these energy sources depends mainly on riparian vegetation and stream size (Vannote et al. 1980).

Riparian vegetation influences energy sources for the stream by providing shade and dropping organic matter into the stream and flood plain (Meehan et al. 1977). Small streams are often so heavily shaded that aquatic primary production is limited by dim light, and most energy comes from decomposition of the leaves and other organic matter that fall from streamside plants. Besides leaves and other litter, insects falling from riparian vegetation supplement the salmonid diet.

As streams get larger, the influence of riparian vegetation diminishes (Vannote et al. 1980). In the headwaters, small trees and shrubs can provide effective shade, but farther downstream, even large trees may be insignificant. Small streams receive more of their organic matter from local vegetation than do larger streams, although secondary channels of rivers can function like small streams and receive matter directly from local vegetation (Sedell and Froggatt 1984).

The amount of organic matter in a stream is not, by itself, a good measure of stream productivity; more important is food quality (Murphy and Meehan 1991). Almost all forms of organic matter have too high a carbon:nitrogen ratio to be utilized directly by invertebrates, and must first be colonized by fungi and bacteria to enhance food quality. At the low end of the food-quality spectrum are woody debris and the fine particulate residues of already-processed detritus; at the high end are periphyton and deciduous leaves. A large reservoir of decay-resistant organic matter usually is stored in the stream channel throughout the year. Between the fresh inputs from leaf fall and algal blooms, most labile detritus is metabolized, whereas the refractory portions accumulate and steadily decline in nutritional quality.

Large woody debris has a key role in the retention of organic detritus for processing by the stream ecosystem (Bisson et al. 1987). Debris increases the diversity of stream morphology, creating pools, multiple channels, sloughs, and backwaters. Debris dams trap branches that retain leaves and even carcasses of anadromous salmonids (Cederholm and Peterson 1985). Because large logs resist decay and transport, they provide stable storage sites in small streams, where one-half of the streambed may consist of woody debris and detritus. The role of woody debris changes with stream size. In small streams, debris remains where it falls and affects most of the stream. In larger streams, debris is clumped in logjams or floated onto the banks but is still important in creating habitat.

Thus, stream productivity depends on complex interactions between the stream and riparian vegetation. Although energy flow is a key determinant of carrying capacity for juvenile salmonids, the energy must flow within the context of suitable physical habitat.

Temperature

Because salmonids are cold-blooded, water temperature directly influences their physiology and activity. The preferred temperature of juvenile Pacific salmon is 12–14°C, but juvenile salmonids in fresh water have broad tolerance for temperature extremes and readily acclimate to the ambient temperature (Bjornn and Reiser 1991). They seem especially tolerant of high temperature, many degrees higher than they are likely to encounter (Beschta et al. 1987).

Lethal temperature determined in the laboratory depends on the temperature to which the fish is accustomed. Fish acclimated to 5°C survive up to about 22°C; fish acclimated to 15°C survive up to about 25°C (Fig. 4.3; Beschta et al. 1987). The application of such laboratory

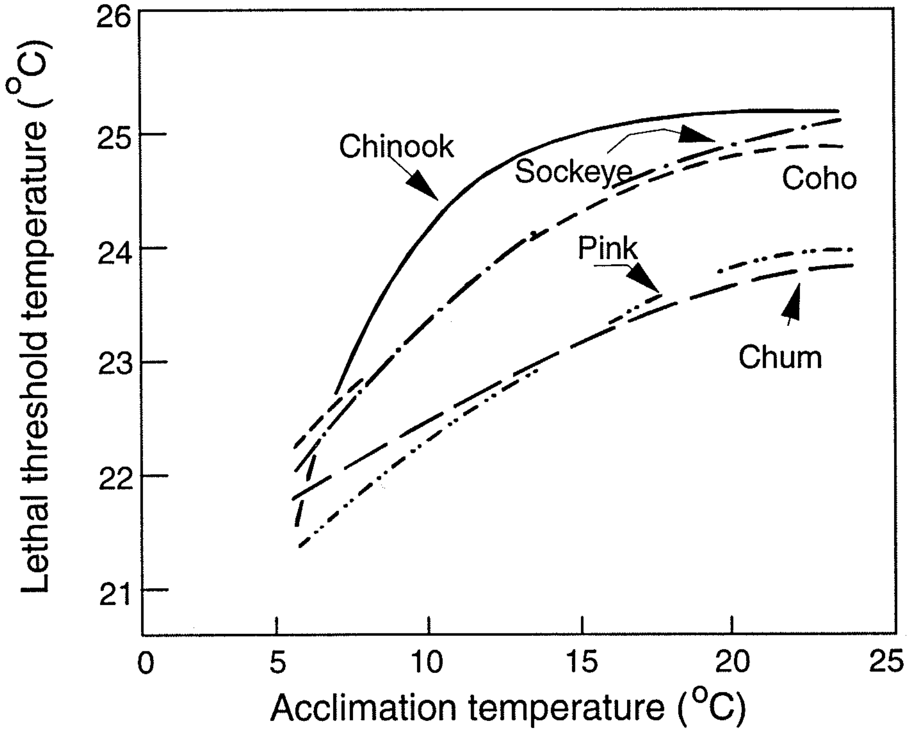


Figure 4.3. Lethal threshold temperature for juvenile salmonids in relation to acclimation temperature. (After Beschta et al. 1987.)

data to natural situations, however, is tenuous because natural streams are complex temperature environments, and wild fish have behavioral and physiological strategies to resist temperature stress. They can seek out localized cool-water sources, such as deep stratified pools and areas with upwelling groundwater (Bilby 1984a), or they can become inactive (Beschta et al. 1987).

The optimum temperature for growth depends on food availability. Fish will not grow until their metabolic requirements are met, and their requirements increase with temperature. Laboratory studies show that growth decreases in situations with high temperature and limited food (Beschta et al. 1987). Growth can be maintained at higher temperature if the food supply increases enough to compensate for increased metabolic needs. Except when fish are starving, growth and activity increase with temperature up to some optimum and then decrease as the optimum is exceeded.

Cold temperature in fall and winter causes juvenile salmonids to become less active, feed less, and hide in the substrate, woody debris, and other cover (Bjornn and Rieser 1991). Hiding behavior begins when temperature drops below about 5°C. If cover is not available as temperature drops, fish may move long distances before finding suitable winter habitat.

Streamflow

Streamflow is a basic habitat determinant for salmonids. The flow regime varies regionally, depending on climate, topography, and vegetation (Swanston 1991). Coastal streams have high flow in fall and winter because of heavy rain and snow, and the largest floods happen during rain-on-snow events. In the interior, flow is high in spring during snowmelt, but rain-on-snow floods can happen in winter. Minimum flow generally occurs in late summer, and in northern and interior regions, a second minimum occurs during winter freeze-up.

The relationship between streamflow and carrying capacity depends on surrounding land forms. It differs, for example, between streams in V-shaped canyons, where flood flows are contained, and streams on broad valleys, where floods can spread out over a wide flood plain. In general, carrying capacity increases as streamflow increases up to a point, and then levels off or declines if water velocity becomes excessive (Bjornn and Reiser 1991). Minimum streamflow in summer can limit carrying capacity on a broad scale. Total commercial catch of coho salmon off Washington and Oregon is directly related to the amount of summer streamflow when the juveniles were in streams 2 years before (Smoker 1955; Mathews and Olson 1980).

Dissolved Oxygen and Turbidity

Dissolved oxygen is normally adequate in most natural streams because turbulence keeps DO near saturation (about 10 mg/L at 10°C). Oxygen can be depleted, however, when streamflow is low and temperature high, and where fine sediment blocks interchange with interstitial water. Local DO depletion to as low as 2 mg/L can occur where upwelling subsurface water enters the stream (Beschta et al. 1987). Juvenile salmonids can survive to as low as 2 mg/L, but growth is reduced at less than 5 mg/L, and swimming performance declines below 8 mg/L (Bjornn and Rieser 1991).

Streams periodically become turbid with suspended sediment during storms and intense snowmelt. Turbidity is an optical property of water wherein suspended materials, such as clay, silt, fine organic matter, and plankton, scatter light. Nephelometric techniques measure this "cloudiness" of water in terms of nephelometric turbidity units (NTU). At about 20 NTU, water first appears cloudy; at 40 NTU, turbidity is highly noticeable; and at 100 NTU, visibility is reduced to a few centimeters. Juvenile salmonids can tolerate moderate, short-term turbidity, and may even benefit from the added cover from predators (Gregory 1993a). High turbidity that occurs in watersheds with excessive erosion, however, can disrupt fish behavior and reduce growth. Juvenile coho salmon stop feeding when turbidity exceeds 60 NTU (Berg and Northcote 1985) and avoid water with 70 NTU (Bisson and Bilby 1982). The turbidity response depends on the species. Juvenile coho salmon avoid glacial rivers with high turbidity, whereas chinook and sockeye salmon feed and grow in glacial rivers with turbidity as high as 200 NTU (Murphy et al. 1989; Brownlee 1990).

Channel Morphology

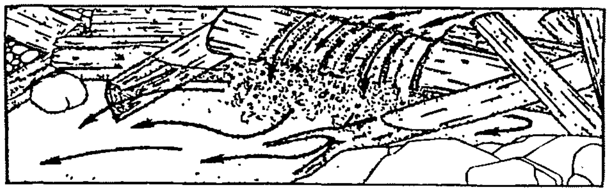
Natural streams contain a diverse mixture of habitats differing in depth, velocity, and cover, arranged in repeating habitat units of pools, riffles, and glides (Bisson et al. 1987). Classification of stream area according to habitat units (Bisson et al. 1982) forms the basis for today's quantitative analysis of salmonid habitat (McCain et al. 1990; Dolloff et al. 1993).

A stream's channel morphology is determined mainly by associated hill slopes and riparian vegetation (Sullivan et al. 1987). The principal factors controlling channel morphology are water discharge, sediment load, bank characteristics, and solid structures, such as LWD, bedrock, and boulders. Stream channels are shaped primarily during storms, when flow is high enough to move sediment lining the channel bed. Stable channels are in dynamic equilibrium where the influx of sediment is balanced by the stream's capacity to carry sediment away. Pools and riffles may change location, but their average balance is maintained.

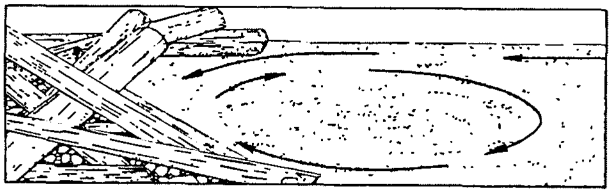
The physical consequences of LWD are particularly important to salmonids (Sullivan et al. 1987). Debris creates pools and undercut banks, deflects streamflow, retains sediment, and stabilizes the stream channel. Debris not only provides cover directly, but also forms 80–90% of pools in typical valley-bottom streams (Fig. 4.4; Heifetz et al. 1986). By forming pools and retaining sediment, LWD also helps maintain water levels in small streams during periods of low streamflow (Lisle 1986). Debris increases the hydraulic complexity of streams, and the slack water around debris offers good opportunities for feeding close to the faster water carrying insect drift.

Water velocity is an important factor determining habitat use for juvenile salmonids (Bjornn and Reiser 1991). The velocity range used by salmonids differs among species and generally increases with fish size. Coho generally use slower water than steelhead and chinook. Complexity of natural stream habitat helps accommodate the diverse needs of the various salmonid species and age groups.

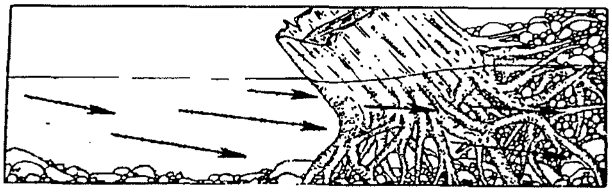
Most stream-dwelling salmonids inhabit pools because of low current velocity. Drifting food, however, is usually more abundant where velocity is high. Although the flow carries drift, the



Plunge pool



Dammed pool



Lateral-scour pool

Figure 4.4. Formation of various pool habitats by large woody debris. (From Bisson et al. 1987; reproduced with permission from University of Washington, Institute of Forest Resources.)

metabolic cost of maintaining position in riffles is too high. Riffles have few suitable feeding stations, usually located behind boulders and debris, and these provide limited vision of passing food (Bisson et al. 1987). Coho salmon avoid riffles almost entirely, preferring pools with ample cover where they can feed on drift as it enters the pool from upstream riffles (Nickelson et al. 1992a).

Cover

Abundant cover can increase a stream's carrying capacity for juvenile salmonids by providing security from predation and floods. Abundant cover also visually isolates fish, reducing aggression and territory size (Dolloff 1986). Cover can include woody debris, overhanging vegetation, undercut banks, cobble and boulder substrate, water depth and turbulence, and aquatic vegetation. The need for cover varies diurnally, seasonally, by species, and by fish size (Bjornn and Reiser 1991).

In winter, the need for cover overrides all other habitat needs. As winter approaches, salmonids feed less and seek cover, particularly in ponds and stream reaches with abundant woody debris or cobble substrate (Peterson 1982; Murphy et al. 1984; Johnson et al. 1986). Pools with LWD and coarse substrate are critical winter habitats of juvenile salmonids (Fig. 4.5). Fine sediment can reduce amount of cover available in the streambed by filling interstitial spaces (Fig. 4.6).

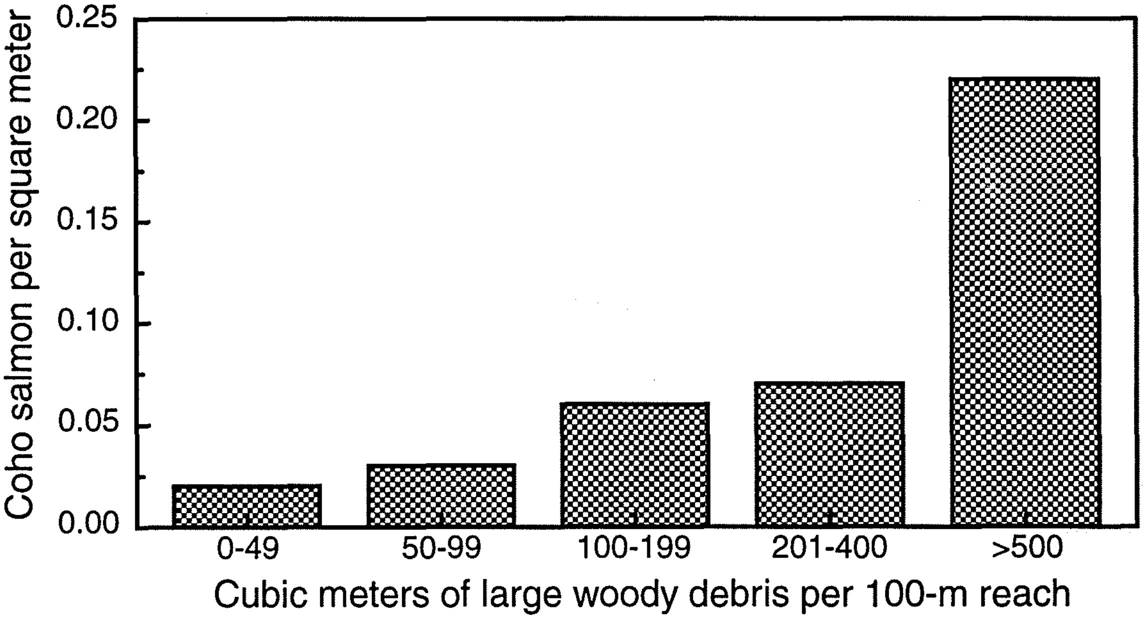


Figure 4.5. Winter density of coho salmon in relation to large woody debris in southeast Alaska. (After Murphy et al. 1984.)

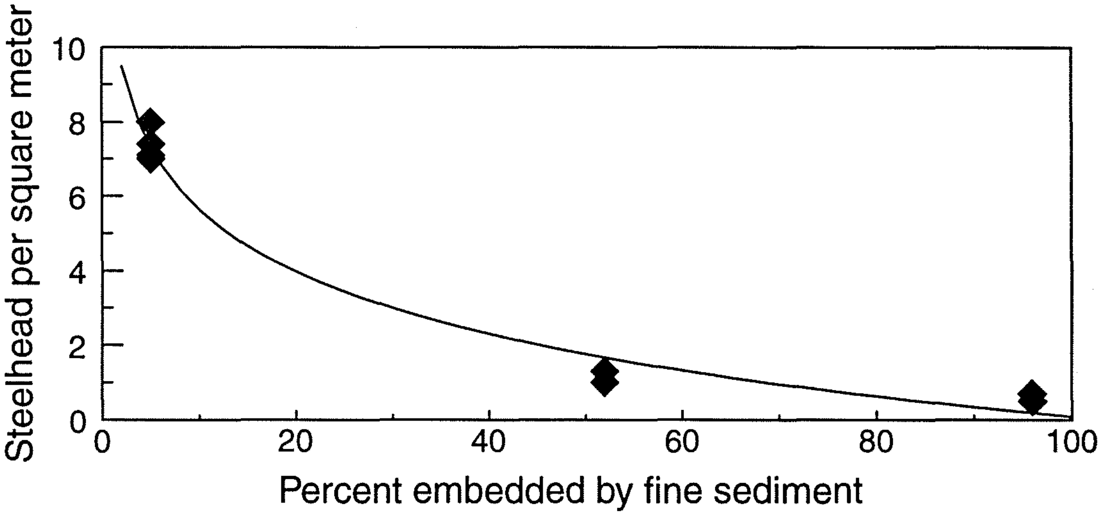


Figure 4.6. Habitat use by juvenile steelhead in winter in relation to embeddedness of the streambed by fine sediment. (After Bjornn and Reiser 1991.)

SEAWARD MIGRATION

The timing of seaward migration of salmonids that spend extended periods in streams is regulated primarily by photoperiod, and is modified by temperature, streamflow, and fish growth (Groot and Margolis 1991). The timing of outmigration is often nearly the same each year and usually peaks during a spring freshet. Migrations of native stocks are timed so that the smolts arrive in the estuary when food is plentiful. Rapid growth during the early period in the estuary is critical to survival because of high size-dependent mortality from predation (Murphy et al. 1988).

The parr-smolt transition is often incomplete when fish begin migration, especially in larger watersheds (Rodgers et al. 1987). "Presmolts" may spend several weeks in the lower parts of rivers until the transition is complete. Stocks of ocean-type chinook exhibit slow "rearing migrations," in which the fish feed and grow while migrating toward lower parts of the drainage system in summer (Johnson et al. 1992). In short coastal streams, migrations tend to be quick, and the parr-smolt transition is nearly complete before migration starts (e.g., Thedinga et al. 1994).

Habitat requirements during seaward migration are similar to those of rearing juveniles, except that smolts tend to be more fragile (Thedinga et al. 1994). They easily lose scales if handled, and are less tolerant of low DO and high temperature. Because most smolt migrations occur during freshets in spring, low oxygen and high temperature are not usually a problem. High streamflow aids their migration by flushing them downstream and reducing their vulnerability to predators.

Migrating smolts are particularly vulnerable to predation because they are concentrated and moving through areas of reduced cover where predators congregate (Larsson 1985). Most predation occurs in certain areas that are predation "hot spots" (Fast et al. 1991). Mortality during seaward migration can exceed 50% and represent a major loss in salmon production (Larsson 1985; Thedinga et al. 1994). In small streams, numerous predators, such as mergansers, otters, and mink, may be drawn to streams during the smolt migration and can take a heavy toll on migrating fish. Woody debris, undercut banks, and moderate turbidity provide important cover for migrating smolts.

Fish can also be serious predators in larger rivers and reservoirs. In the Columbia River, for example, northern squawfish (*Ptychocheilus oregonensis*), walleye (*Stizostedion vitreum*), and smallmouth bass (*Micropterus dolomieu*) took 14% of all migrating salmonids that entered the John Day Reservoir (nearly 3 million fish); 21% of this loss was in a small area at the head of the reservoir (Rieman et al. 1991). The NMFS Proposed Recovery Plan for Snake River Salmon (USDC 1995) proposes actions to control predation by squawfish, birds, marine mammals, and non-native fishes to increase survival during downriver migration.

LIMITING FACTORS

Most analyses of habitat requirements examine the role of specific habitat components in isolation. To assess overall effects of habitat change on salmonids, specific factors that may limit their abundance must be considered in the context of all other factors over the entire freshwater period. This is the province of the analysis of limiting factors.

The objective of limiting factor analysis is to identify the "bottleneck" that restricts overall smolt yield (Fig. 4.7). In this analysis, the salmonid life cycle is divided into different life stages, each dominated by different habitat components (Reeves et al. 1989). The factor that limits overall smolt production from a stream can affect the population at any life stage. For example, the stream may be underseeded and in need of greater escapement of adults. Spawning may be adequate, but summer carrying capacity may be restricted by high temperature or low food production. In many streams damaged by past logging, lack of winter cover is the main "bottleneck" that restricts smolt production.

For anadromous salmonids, river systems should be viewed as interconnected networks which contain habitat for spawning, rearing, and migration in different areas within the network. To provide for long-term maintenance of habitat for all life stages, drainage networks need to be managed on a landscape scale (Naiman 1992; Reeves et al. in press).

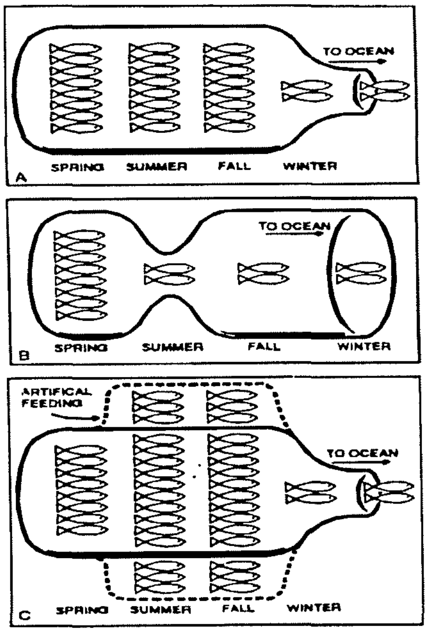


Figure 4.7. Illustration of "bottlenecks" restricting salmonid smolt production. Bottlenecks in winter (A) may be caused by poor cover from flooding and icing; bottlenecks in summer (B) may be caused by poor food production. Panel C illustrates how poor winter cover nullifies increased food availability in summer. (From Reeves et al. 1991; reproduced with permission from the American Fisheries Society.)

Chapter 5

The Potential Effects of Logging

Logging and associated activities can have multiple effects on salmonid habitat. Salmonid habitat is a product of interactions among the stream, floodplain, riparian area, and uplands—in short, the entire watershed. Effects of timber harvest, road construction, and other activities anywhere in the watershed can be transmitted through changes in hydrologic and erosional processes to modify habitat for salmonids (Fig. 5.1; Chamberlin et al. 1991).

Effects of logging on anadromous salmonids have been studied intensively since the 1950s, and have been reviewed comprehensively (Gibbons and Salo 1973; Salo and Cundy 1987; Meehan 1991). Although many details about logging impacts are still unknown, their causes and mechanisms are understood. Impacts on a specific site are usually not predictable quantitatively because of the many interacting factors involved, including random weather events (Sullivan et al. 1987; Chamberlin et al. 1991). However, given information on the logging activity, watershed characteristics, riparian vegetation, stream, and fish populations, one can specify the probable direction and magnitude of habitat changes and effects on salmonid populations.

Studies of effects of logging typically have examined specific habitat components and consequences for different parts of the salmonid life cycle. Most studies attempt to isolate effects of one variable from others that also change after logging. Fewer studies have examined overall cumulative effects of logging and the integrated population response of salmonids in whole basins. Thus, much is known about the potential effects of timber harvest on various habitat components and the response of various salmonid life stages (Table 5.1). Integrating these separate components into an ecosystem model of habitat effects and population response is more theoretical (Hicks et al. 1991a).

In addition to these effects of actual timber harvest and roads, other timber management activities also can affect salmonids adversely. Use of forest chemicals (fertilizers, pesticides, and fire retardants) can affect salmonids directly and indirectly (Norris et al. 1991). The risk of direct toxic effects can be reduced when buffer zones along streams are left untreated and applicators are careful to prevent drift and avoid direct application to surface water. Recreational use of streams and riparian areas usually will have minor negative effects on fish habitats, but recreational activities are highly variable and must be evaluated locally (Clark and Gibbons 1991). Intensive recreational use can damage riparian vegetation and streambanks or disturb spawning adults.

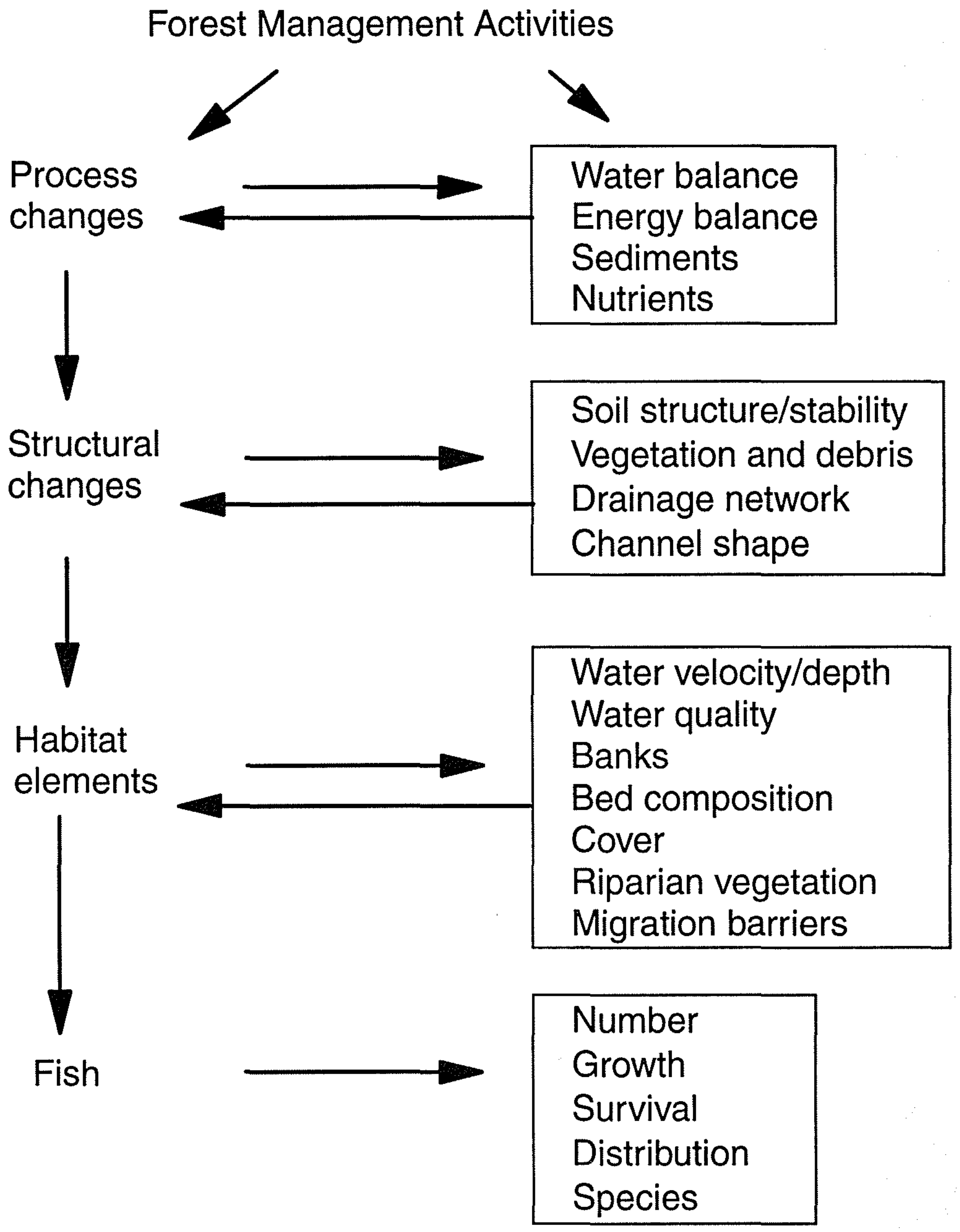


Figure 5.1. Connections between timber harvest, road construction, and other timber management activities in a watershed and effects on salmonid habitat via changes in watershed processes and structures. (After Chamberlin et al. 1991.)

Table 5.1. Influences of timber harvest on physical characteristics of stream environments, potential changes in habitat quality, and resultant consequences for salmonid growth and survival. (After Hicks et al. 1991a.)

Forest practice	Potential change	Potential change in salmonid habitat	Potential effects on salmonid populations
Timber harvest in riparian zones	Decreased shade	Increased summer temperature; more light, more algae, more food production	Changes in growth, age at smolting; early emergence; increased summer carrying capacity
	Decreased supply of large woody debris	Reduced cover, pool habitat, gravel and organic matter storage, hydraulic complexity, and food production	Decreased winter survival, spawning success, and species diversity; increased predation
	Addition of slash (bark, branches)	Increased oxygen demand, organic matter, food, and cover; decreased channel stability	Reduced spawning success; short-term increase in growth
	Streambank erosion	Reduced cover, stream depth	Increased carrying capacity for fry, reduced for older fish; increased predation
		Increased fine sediment in streambed; reduced food supply	Reduced spawning success; slower growth
Timber harvest on hillslopes; forest roads	Altered streamflow	Temporarily increased summer base flow	Temporarily increased survival
		Increased peak flows and bedload shift	Increased embryo mortality

Table 5.1. Continued.

Forest practice	Potential change	Potential change in salmonid habitat	Potential effects on salmonid populations
	Increased erosion	Increased fine sediment in stream gravels; reduced food production and cover	Reduced spawning success, growth, and carrying capacity; increased winter mortality
		Increased supply of coarse sediment	Increased or decreased rearing capacity
		Increased debris torrents; less cover in torrent track; more debris jams	Migration blockages; poor survival in torrent track; better in debris jams
	Increased nutrients	Increased food production	Increased summer carrying capacity
	Stream crossings	Obstructions in stream channel; sediment inputs	Restricted upstream movement; reduced spawning success
Scarification and slash burning	Increased nutrients	Short-term increase in nutrients and food production	Temporarily increased growth and summer carrying capacity
	Inputs of fine organic and inorganic sediment	Increased fine sediment; temporarily increased oxygen demand	Reduced spawning success

STREAM TEMPERATURE

The detrimental increase in summer temperature was one of the first issues identified as environmental awareness about the effects of logging developed in the 1960s (Beschta et al. 1987). These concerns led to changes in FS and BLM national policy and development of state forest practices acts intended to prevent temperature changes in fish-bearing streams.

The principal source of energy for heating streams is direct solar radiation hitting the water surface, whereas heat from convection and conduction are insignificant (Beschta et al. 1987). Streams are heated by reductions in shade, not by warm air, nor do they quickly cool after entering shaded sections. Streams exposed over long reaches do not heat up indefinitely, but reach equilibrium as evaporation, convection, conduction, and inflow of groundwater balance the radiation load.

Canopy removal can increase stream temperature as much as 10°C (Fig. 5.2; Beschta et al. 1987). The increase is directly proportional to the area opened to sunlight and inversely proportional to stream discharge (Beschta et al. 1987). Thus, the increase is greatest on small streams and diminishes as streams get wider because of the lessening influence of tree canopy. Specific stream and watershed conditions cause wide variation in temperature response. Stream gradient, morphology, orientation, latitude, and bed materials are some factors that affect how much temperature will increase after canopy removal.

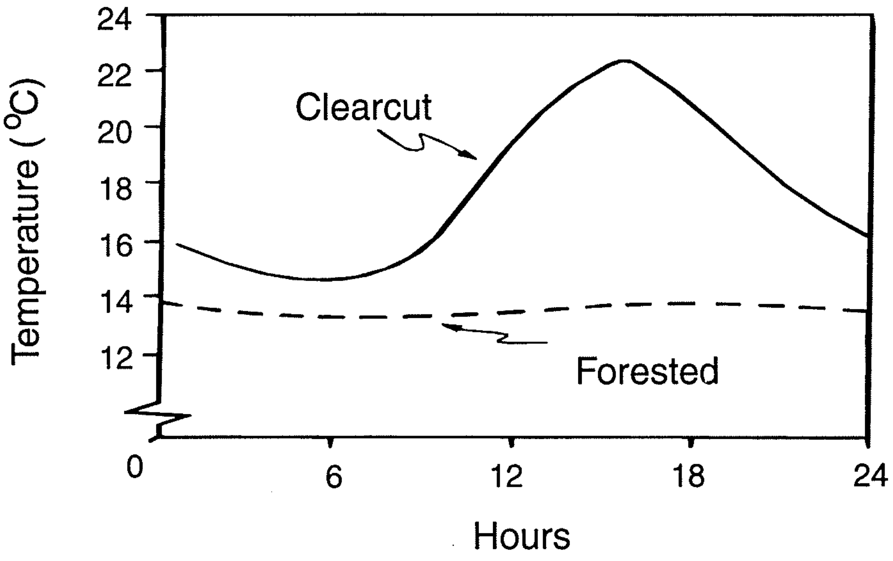


Figure 5.2. Typical daily stream temperature in clearcut and forested streams during clear weather in Oregon's Coast Range. (From Beschta et al. 1987; reprinted with permission from University of Washington, Institute of Forest Resources.)

Changes in stream temperature are considered harmful to salmonids because stocks are adapted to their stream's natural regime, and any change can alter development, growth, survival, and timing of life-history events (Beschta et al. 1987). Increased temperature beyond the preferred range can cause juveniles to leave or grow slower. High temperature can inhibit upstream migrations of adults and increase disease. Increased temperature can exacerbate die-offs of adult pink and chum salmon during temporary summer droughts in small coastal streams (Murphy 1985).

Although increased temperature is a major concern, field studies have generally failed to demonstrate significant temperature impacts on salmonids after clearcut logging (Beschta et al. 1987). On the contrary, streams in clearcuts can have large populations of juvenile salmonids (Murphy and Meehan 1991). The reason for this may be that tolerance limits determined in the laboratory may not apply to the complex thermal environments in streams. Local cool-water sources (e.g., upwelling groundwater) can provide refuge from periodic high temperature (Bilby 1984a). Daily stream temperature in clearcuts fluctuates widely and can briefly exceed the reported lethal threshold. Salmonids apparently can withstand these short-term exposures without detrimental impact (Beschta et al. 1987). These field studies, however, have generally examined streams in small clearcuts where the temperature increase was moderated by upstream forest. Cumulative increases in temperature from numerous small clearcuts could have major impacts on downstream habitat.

Another reason for lack of reported temperature impacts is that most studies have been conducted in regions with moderate temperature regimes in the center of the salmonid distribution (e.g., coastal Oregon, Washington, British Columbia, and Alaska; Hicks et al. 1991a). In other regions with higher ambient temperature, on the margins of their distribution, streams may become too warm for salmonids because of excessive exposure to sunlight (Bjornn and Reiser 1991). In these regions, larger streams, which are naturally more open to sunlight, often become uninhabitable for salmonids in summer. Canopy reductions along these streams or in their headwaters can extend the time and area that temperature is unsuitable.

Long-term warming of streams can cause increased competition and predation. Salmonids may be replaced because of competition from warmwater species (Reeves et al. 1987). Elevated water temperature in the Columbia River Basin allowed introduced smallmouth bass, major predators on juvenile chinook salmon, to expand their range into salmon rearing areas where cold water might have excluded them in the past (Li et al. 1987).

Although timber harvest can change stream temperature in summer, it does not greatly affect stream temperature in winter. Canopy removal can raise winter temperature in low-elevation, coastal drainages; but it can lower it in northern areas and higher elevations because of lost insulating cover and increased radiative cooling (Beschta et al. 1987). Where winter temperature decreases, ice forms more readily and salmonids may die from freezing and icing hazards. Although effects on winter temperature may be slight, caution is warranted because even a small change can affect fish when water temperature is low.

Increased winter temperature can have mixed effects on salmonids. Elevated temperature during egg incubation can speed development and cause fry to emerge early. Early emergence can be beneficial by prolonging the growing season, leading to larger size in fall and winter, which helps overwinter survival (Holtby 1988; Thedinga et al. 1989). Early emergence, however, also exposes fry to late-winter freshets, and fry and smolts may migrate to sea before the spring plankton bloom in the estuary, leading to poor ocean survival (Holtby et al. 1989).

Because of the extensive geographic range of salmonids, potential temperature impacts should be viewed with a regional perspective. In some regions of the Pacific Northwest and Alaska, concern over increased summer temperature may be unwarranted (Beschta et al. 1987). In southeast Alaska, for example, stream temperature in clearcuts rarely exceeds 26°C, except in exposed, intermittent pools (Sheridan and Bloom 1975). Even in southeast Alaska, however, high temperature may be a problem for salmonids in some "temperature-sensitive" streams that are wide, shallow, low gradient, and have lake or muskeg sources (Gibbons et al. 1987). In other regions with comparatively high ambient temperature, such as southern Oregon, California, and the interior Columbia River Basin, increased temperature may have profound negative effects on salmonid populations.

SEDIMENT

The term "sediment" commonly refers to fine particles the size of clay and silt, but in the strict sense, sediment includes all particles from colloids to boulders. Generally, however, it is the fine sediments that are of concern because of possible detrimental effects on salmonid habitat, whereas the coarser gravels, cobbles, and boulders help shape channel morphology and provide substrate for cover and spawning. Logging activities can have major effects on the amount of sediments delivered to streams and their subsequent routing downstream.

In mountainous terrain, sediments of all sizes are delivered to streams primarily by landslides (Swanston 1991). These occur as slow-moving slumps and earthflows or as episodic debris torrents and avalanches which happen during heavy rainfall when saturated soils trigger slope failures. Undisturbed forest soils normally resist surface erosion because their coarse texture and thick surface layer of duff and moss prevent overland flow.

Surface erosion in forested sites usually occurs only after the soil is bared by landslides, fire, overgrazing, or logging (Swanston 1991). Compaction of soils by logging equipment increases surface erosion by reducing soil infiltration and causing overland flow. Surface erosion is greatly increased where disturbed or compacted soils are exposed to rainfall. Road surfaces, landings, skid trails, ditches, and disturbed clearcut areas can contribute large quantities of fine sediments to streams (Chamberlin et al. 1991). Nearly all forest operations disturb soil to some degree. Road construction and maintenance, log hauling, tree felling, yarding, slash disposal, and site preparation for replanting are all potential nonpoint sources of fine sediment pollution.

Construction of roads in steep terrain can substantially increase all types of soil erosion (Furniss et al. 1991). Landsliding associated with roads can be more than 300 times more frequent than in undisturbed forest, and because the landslides are relatively large, the amount of sediment produced from roads greatly exceeds the sediment from forests and clearcuts (Fig. 5.3; Furniss et al. 1991). The increase in landslides caused by roads depends on soil and bedrock type,

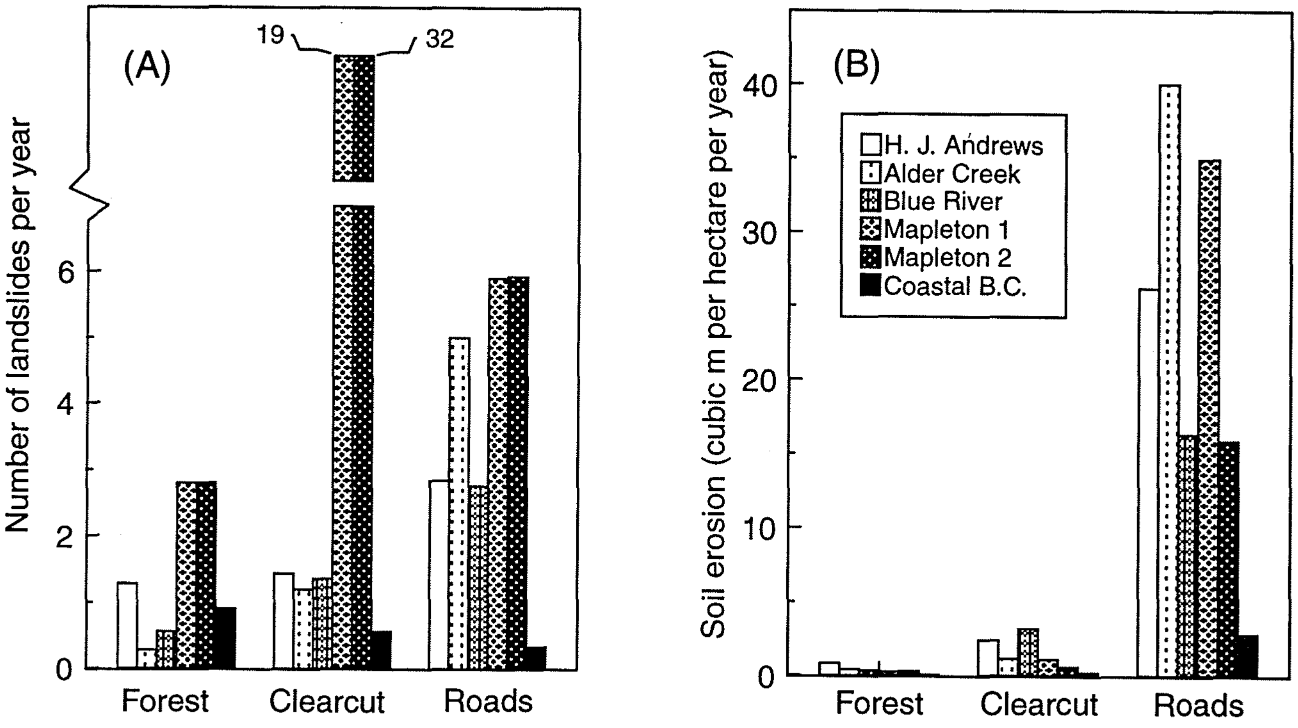


Figure 5.3. Comparison of the rate of landsliding (A) and mass soil erosion (B) associated with forests, clearcuts, and roads as measured by six long-term studies of more than 10 years. (Data are from Furniss et al. 1991: H.J. Andrews, Alder Creek, and Blue River are in western Cascade Range, Oregon; Mapleton 1 and 2 are in the Oregon Coast Range.)

steepness, and especially road location. Landsliding can continue for decades after the roads are built.

Road failure is a concomitant risk of building roads in mountainous terrain (Furniss et al. 1991). Landslides and severe gullying can result where roads intercept runoff and route it onto hillslopes. The most common causes of landslides are improper placement of road fills, inadequate maintenance, inadequate culverts, overly steep hillslopes, improper sidecasting, poor road location, undercutting of slope support, and interception of surface and subsurface water. Water intercepted by ditches can carry eroded sediment directly to streams (Fig. 5.4).

Culverts and bridges pose the greatest risk to fish of any road feature (Furniss et al. 1991). When a culvert becomes plugged by debris or overtopped by high streamflow, the stream can be diverted, causing severe sedimentation. The risk of failure of a crossing structure depends on its size compared to flood events (Fig. 5.5), and culverts should be sized to accommodate

Figure 5.4. Surface runoff being intercepted by a logging road and flowing down the road's ditch after heavy rain in southeast Alaska. (Photo by B. Baker.)

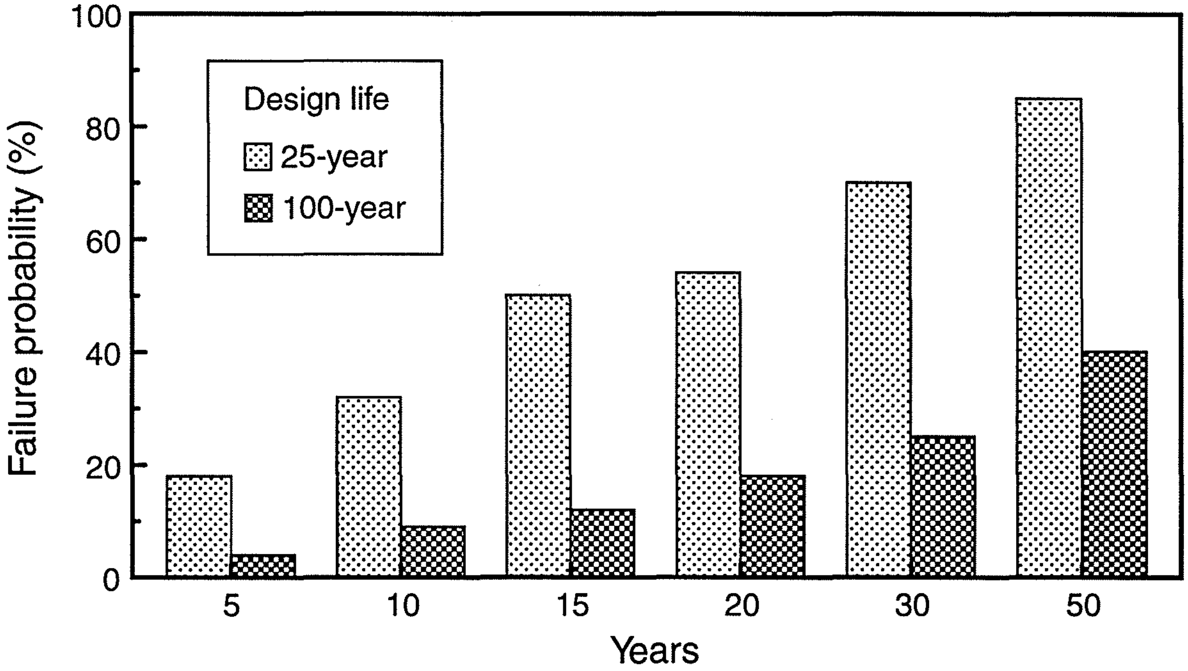


Figure 5.5. The failure probability of culverts designed for 25-year and 100-year flood events. (Data are from FEMAT 1993.)

at least a 50-year flood (Furniss et al. 1991). Whatever the design life, any crossing structure is virtually certain to fail if not maintained or removed when the road is abandoned.

Regular road use can cause chronic sediment inputs to streams nearly as great as during road construction. The road surface can break down with repeated heavy wheel loads of hauling trucks, particularly under wet conditions, resulting in a continual source of fine sediment (Fig. 5.6). In the Clearwater River, Washington, for example, the amount of sediment that washed off roads equaled the amount from landslides (Reid and Dunne 1984).

Although most large landslides are associated with roads, many small landslides originate on clearcut slopes as the root strength which holds soils together is lost within 2–10 years after trees are cut (Burroughs and Thomas 1977; Ziemer and Swanston 1977). The increase in landslides in clearcuts varies widely, depending on slope stability (Fig. 5.3). Because landslides tend to be small, the amount of soil erosion is much lower than the erosion associated with roads, but the greater total area of clearcuts makes this a substantial source of sediment (Swanston 1991).

Yarding operations can disturb ground over large areas (Everest et al. 1987a). Cable yarding and helicopter systems that suspend logs generally cause minimal soil disturbance, but tractor yarding can disturb and compact soils considerably (Fig. 5.7; Chamberlin et al. 1991). The bare and compacted soil associated with tractor yarding can cause landsliding and surface erosion. Effects of compaction and overturn of topsoil are also important because of potential long-term reduction in soil permeability and productivity (Froehlich and McNabb 1984).

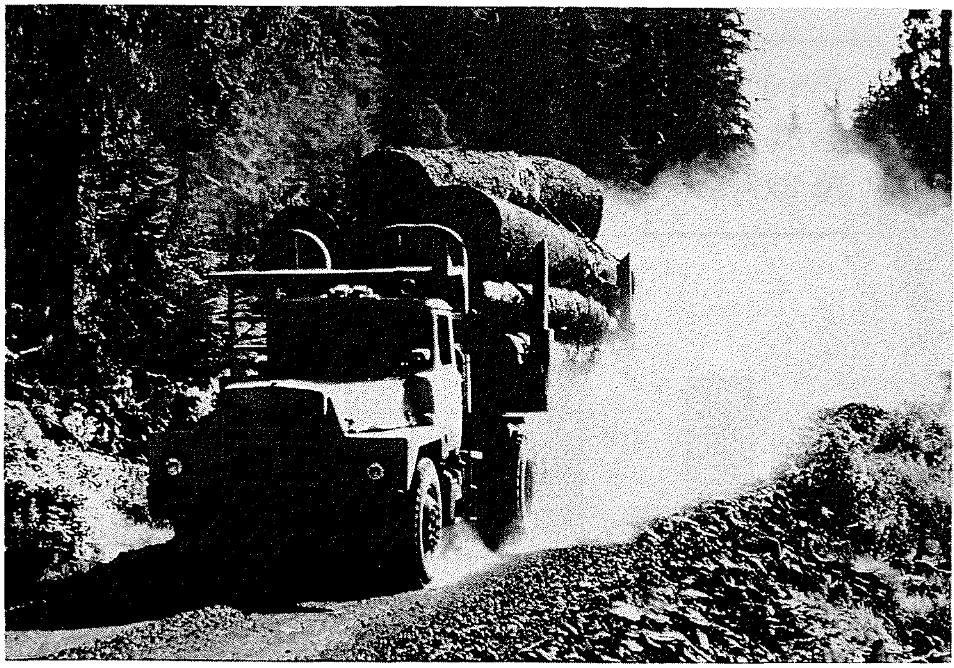


Figure 5.6. Fine sediment produced by logging truck in southeast Alaska. (Photo by T. R. Merrell, Jr.)

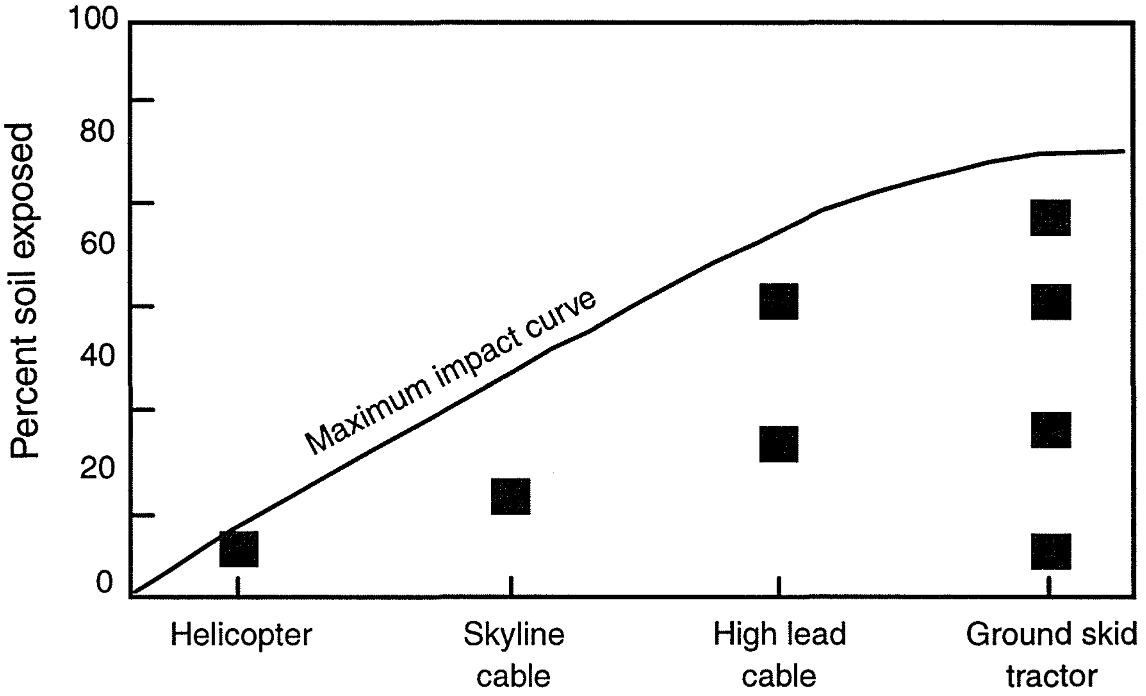


Figure 5.7. Soil disturbance caused by different yarding methods. Each point represents findings of a separate study. (After Chamberlin et al. 1991.)

For almost all forestry activities, as hillslope gradient increases, so does the potential for delivering sediment into streams. Hence, forest practices need to be tailored to site conditions to minimize effects on slope stability. Unstable areas in watersheds should be identified, and special precautions should be used to avoid impacts in these areas.

Once delivered to streams, fine and coarse sediments move downstream by different routes. Fine sediment moves suspended in the water column, and coarse sediment moves as "bedload," rolling and bouncing along the stream bottom. Suspended sediment generally consists of clay and silt which move rapidly downstream and deposit in slack-water areas and on flood plains, or infiltrate coarser substrate of the streambed (Beschta and Jackson 1979). Bedload sediment consists of coarse sand, cobble, and larger particles which move sporadically during floods and are deposited as "wedges" behind structural features such as LWD (Fig. 5.8) and at channel bends (Swanston 1991). Coarse sediment is sorted and arranged by streamflow to form an "armor" layer on the streambed, preventing bedload transport except for only a few days each year during "flushing" streamflows (Swanston 1991). Overturn of the upper layers of the streambed at these times flushes fine sediments, redistributes bedload to form new pools and riffles, and causes local accumulation of sediment deposits behind obstructions and at points of reduced gradient.

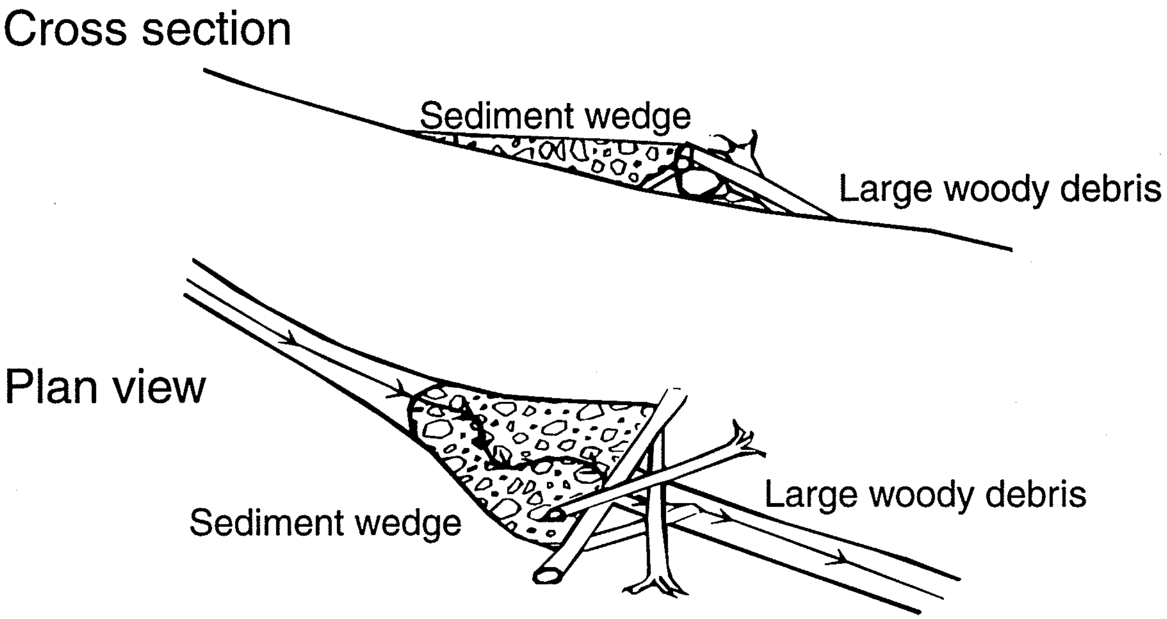


Figure 5.8. Diagram showing storage of bedload sediment "wedges" behind large woody debris. (After Swanston 1991.)

Undisturbed streams maintain a dynamic equilibrium between sediment delivery and routing, and have abundant sediment stored in their channels (Everest et al. 1987a). Most streams, however, do not remain undisturbed, even without human influence, but operate in context of natural long-term disturbance cycles. Streams periodically receive large pulses of sediment and woody debris during large storms, wildfire, and other watershed disturbances (Reeves et al. in press). Thus, sediment delivery, routing, and storage are not static, and streams pass through natural long-term cycles of excessive as well as depauperate amounts of sediment.

Past forest practices have changed the sediment equilibrium and storage in streams by increasing hillslope erosion and causing a loss of structural channel features (Everest et al. 1987a). The loss of structural features reduces storage and accelerates routing of bedload sediment downstream (Fig. 5.9). Aggraded downstream reaches become wider, shallower, and more prone to lateral migration and bank erosion (Sullivan et al. 1987).

The response of salmonid populations to increased sediment from logging is often difficult to assess because of natural variability and the multiple effects of logging on stream ecosystems. Much of the knowledge about sediment impacts is extrapolated from controlled laboratory experiments (Everest et al. 1987a) and from field studies examining egg-to-fry survival under natural conditions (e.g., Koski 1966; Tagart 1976).

Several field studies, however, have demonstrated significant adverse effects of sediment from logging. In Carnation Creek, British Columbia, increased fine sediment after timber harvest

Figure 5.9. Disturbance and loss of channel structures caused downcutting and export of stored sediment from a headwater stream in southeast Alaska. (Photo by T. R. Merrell, Jr.)

reduced chum salmon escapement by 25% (Holtby and Scrivener 1989), and logging sediment probably contributed to the general decline in chum salmon in the last 40 years in west Vancouver Island (Scrivener 1991). Sediment from extensive logging in the South Fork Salmon River basin in Idaho buried spawning and rearing habitats. A logging moratorium was begun in 1966 which allowed conditions to begin to improve (Platts and Megahan 1975). By 1979, the percentage of fine sediment in spawning areas had decreased from 30% to 8% and gravel increased from 32% to 68% (Sullivan et al. 1987). In the Queen Charlotte Islands, British Columbia, 45–86% of salmon eggs were destroyed by scour in watersheds with severe mass wasting, compared to only 0–14% in more stable areas (Tripp and Poulin 1986). In a tributary of the Clearwater River, Washington, sediment from a debris torrent and streamside salvage logging aggraded the stream channel to the point that the stream dried up in summer because the water level dropped below the level of deposited sediment; coho smolt yield decreased 60–86% (Cederholm and Reid 1987).

These examples indicate the range of direct adverse effects that increased fine sediment can have on salmonid populations. Fine sediment can directly reduce egg-to-fry survival, food production, summer rearing area, and winter survival (see Chapter 4). Less-direct effects include changes in stream channel morphology and stability, causing long-term reductions in carrying capacity and survival.

STREAMFLOW

Cutting trees and building roads can alter the watershed's water balance and accelerate movement of water from hillsides to stream channels (Chamberlin et al. 1991). Of greatest concern are the changes in low flow (base flow) in summer and peak flow during rainstorms and snowmelt.

Base flow increases after timber harvest because removing trees increases soil moisture and groundwater as less vegetation results in less transpiration and interception on foliage. Base flow usually increases most in summer when transpiration has the greatest effect on soil moisture. In fall and winter, the soil is usually saturated, and runoff is similar in both clearcuts and forests. Increases in base flow are short lived, decreasing as vegetation recovers (Fig. 5.10). After 10–30 years, base flow may return to normal or decrease below pre-harvest levels because rapidly growing second-growth hardwoods transpire more water than mature trees (Fig. 5.11; Hicks et al. 1991b). Increased base flow can benefit salmonids by maintaining higher water levels (Hetherington 1988), but decreased base flow can shrink available habitat, especially at critical low-flow periods in late summer.

Peak flows increase after logging because water is routed more quickly to stream channels (McIntosh et al. 1994). Activities that disturb and compact the soil increase surface runoff which reaches streams faster than subsurface flow. Ditches along roads collect runoff and intercept subsurface flow and route it quickly to streams (Fig. 5.4). Roads act as first-order streams and channel more water directly into larger streams (Wemple 1994). More snow accumulates in clearcuts and melts earlier and faster, causing more severe rain-on-snow events and higher and earlier peaks during spring snowmelt (Harr 1986; Golding 1987). Increased peak

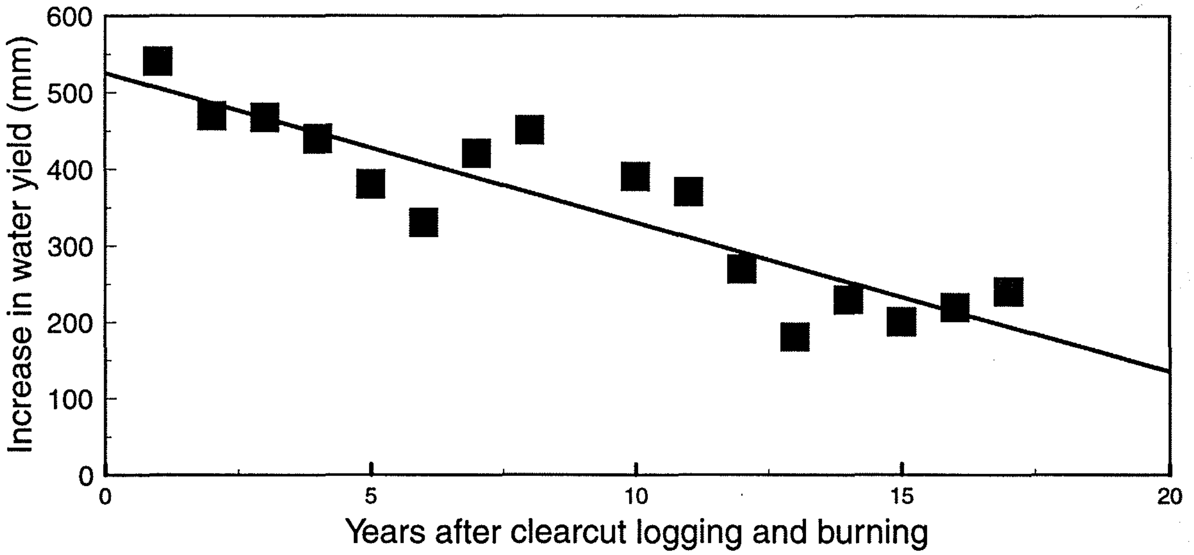


Figure 5.10. Diminishing increase in water yield after timber harvest in southwest Oregon. (After Harr 1983.)

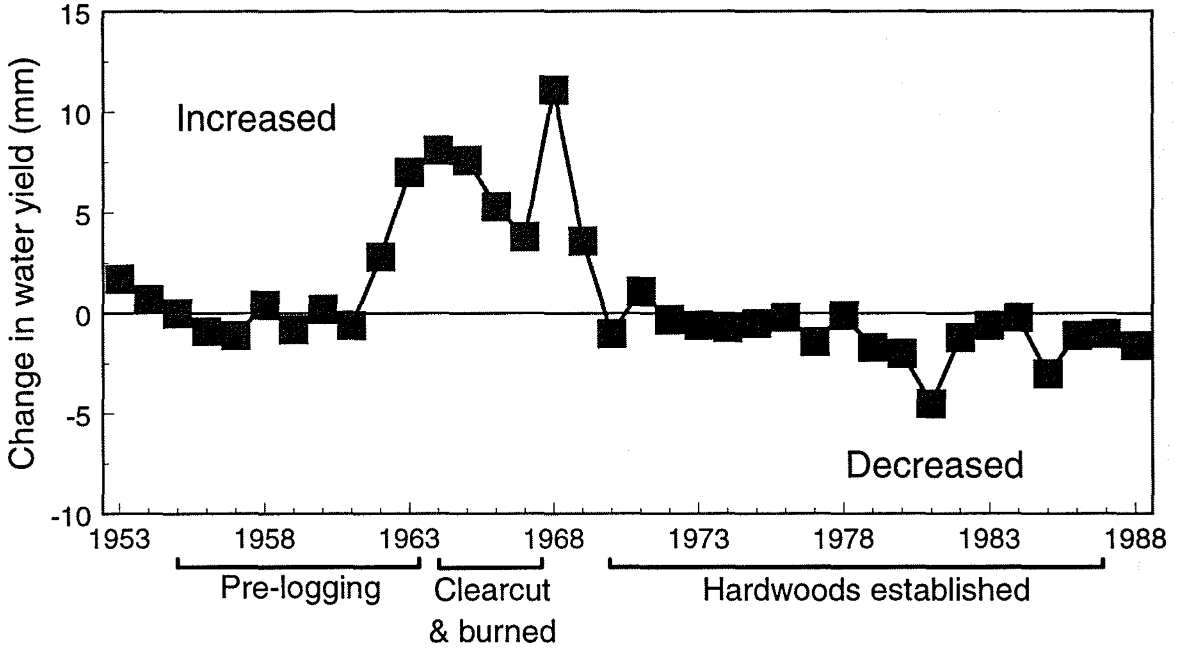


Figure 5.11. Change in August water yield from a western Oregon watershed after logging. Water yield initially increased after the watershed was clearcut and burned, but decreased after dense second-growth hardwoods became established. (After Hicks et al. 1991b.)

flow is detrimental for fish habitat because the resulting bedload overturn can scour stream channels, kill incubating eggs (McNeil 1964), and displace juvenile salmonids from winter cover (Tschaplinski and Hartman 1983).

LARGE WOODY DEBRIS

Large woody debris is an integral part of streams in forested watersheds, providing structure to the stream ecosystem and important habitat for salmonids (Bisson et al. 1987). It plays important roles in controlling stream morphology, regulating storage of sediment and particulate organic matter, and creating and maintaining fish habitat. Removal of LWD results in immediate loss of important habitat features and a decline in salmonid abundance (Hicks et al. 1991a). Debris removal destabilizes the stream channel and eliminates pools and cover. The increased riffles may favor underyearling steelhead and cutthroat trout, which prefer riffle habitat, but the loss of pools harms coho salmon and older steelhead and cutthroat trout (Bisson and Sedell 1984; Murphy et al. 1986).

Logging activities can reduce LWD in several ways (Bisson et al. 1987). Existing LWD can be destabilized during tree felling and yarding, and later exported downstream or onto the floodplain. Salvage of downed merchantable logs from the stream channel and floodplain removes LWD and destabilizes what is left. Cleaning of stream channels after yarding also removes LWD and destabilizes channels (Bilby and Ward 1989). Even if left undisturbed, LWD declines over time if riparian trees are cut because second-growth vegetation provides insufficient new conifer debris to replace the key pieces as they decay or wash downstream (Andrus et al. 1988; Murphy and Koski 1989). The "key pieces" of debris that create stable habitat in streams have been hard hit by past logging. Many streams in second-growth forest become progressively debris-poor as total LWD declines and changes to mostly small pieces of alder (*Alnus* spp.).

Woody debris in streams is depleted by decay, fragmentation, and export to downstream reaches and floodplains (Bisson et al. 1987). The depletion rate depends mostly on size and species of wood and type of stream. Woody debris from Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) in southeast Alaska is naturally depleted by about 1–3% per year in valley-bottom streams (Murphy and Koski 1989). Some species, such as redwood and western red cedar (*Thuja plicata*), last much longer.

Removal of trees from the riparian area during logging causes a long-term reduction in the recruitment of new LWD (Bisson et al. 1987). After clearcutting in riparian areas, second-growth trees are the principal source of new woody debris. In young forest stands, inputs of debris large enough to provide stable habitat is low for the first 50–75 years (Grette 1985; Andrus et al. 1988; Murphy and Koski 1989), and could remain low much longer if riparian areas are converted to non-conifer species (Chan 1993). Accumulations of LWD continue to decrease (Bryant 1985) as large key pieces are depleted.

Effects of timber harvest in riparian areas can last hundreds of years. If all sources of new LWD are removed by clearcutting, the key pieces of large LWD in the stream will disappear over a period of about 250 years (Murphy and Koski 1989). Because new key pieces from second growth do not begin to enter the stream for 60–80 years after logging, LWD begins a long-term decline that may not bottom for nearly 100 years and not recover for more than 250 years. Timber harvest rotations of less than 100 years will permanently eliminate large LWD unless streams are protected by adequate buffer zones.

A model of LWD input and depletion was used to demonstrate long-term effects of clearcutting without buffer zones in southeast Alaska (Murphy and Koski 1989). The model showed that if trees were not left along streams during timber harvest, the LWD in a stream would be reduced by 70% after 90 years, and would take more than 250 years to recover (Fig. 5.12). An uncut 30-m buffer zone would maintain LWD over the long term, whereas narrower buffers or partially harvested buffers would cause LWD to decline. This model needs to be adjusted to apply to regions outside southeast Alaska, but the principle applies elsewhere.

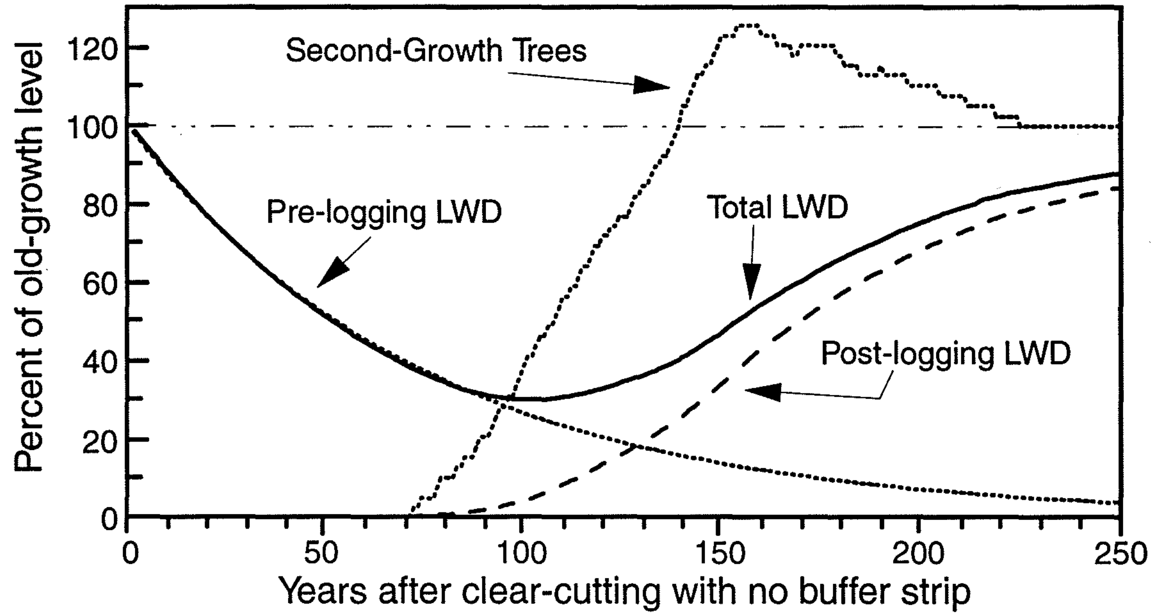


Figure 5.12. A model of the changes in large woody debris after clearcut logging without a riparian buffer zone in southeastern Alaska. (After Murphy and Koski 1989.)

MIGRATION HABITAT

Changes in stream channels after road construction and timber harvest can interfere with fish migration by blocking passage through culverts at stream crossings, causing logjams, decreasing cover from predators, decreasing the frequency of large pools used for resting, and adversely affecting temperature and DO.

Decreases in large pools and cover because of the loss of LWD can expose migrating adults to predation and deprive them of resting habitat. Suitable large pools are usually in limited supply along a stream, so that each is important and often will hold large numbers of migrating adults. Logging activities can decrease the frequency of large pools by decreasing the frequency of "key" pieces of LWD. In Oregon and Washington, frequency of large pools decreased by nearly two-thirds between the 1930s and the late 1980s (Fig. 5.13).

Culverts can be a barrier to upstream fish migration, especially if installed above the grade of a stream (Furniss et al. 1991). Poorly installed culverts not only block migrations of adult salmon returning to spawn but also impede seasonal movements of juvenile fish between summer and winter rearing areas within a watershed. Culvert conditions that block fish passage include too high a water velocity, too shallow a water depth, lack of a resting pool below the culvert, and too high a jump to the culvert (Furniss et al. 1991). A single poorly installed culvert can eliminate the fish population of an entire stream system.

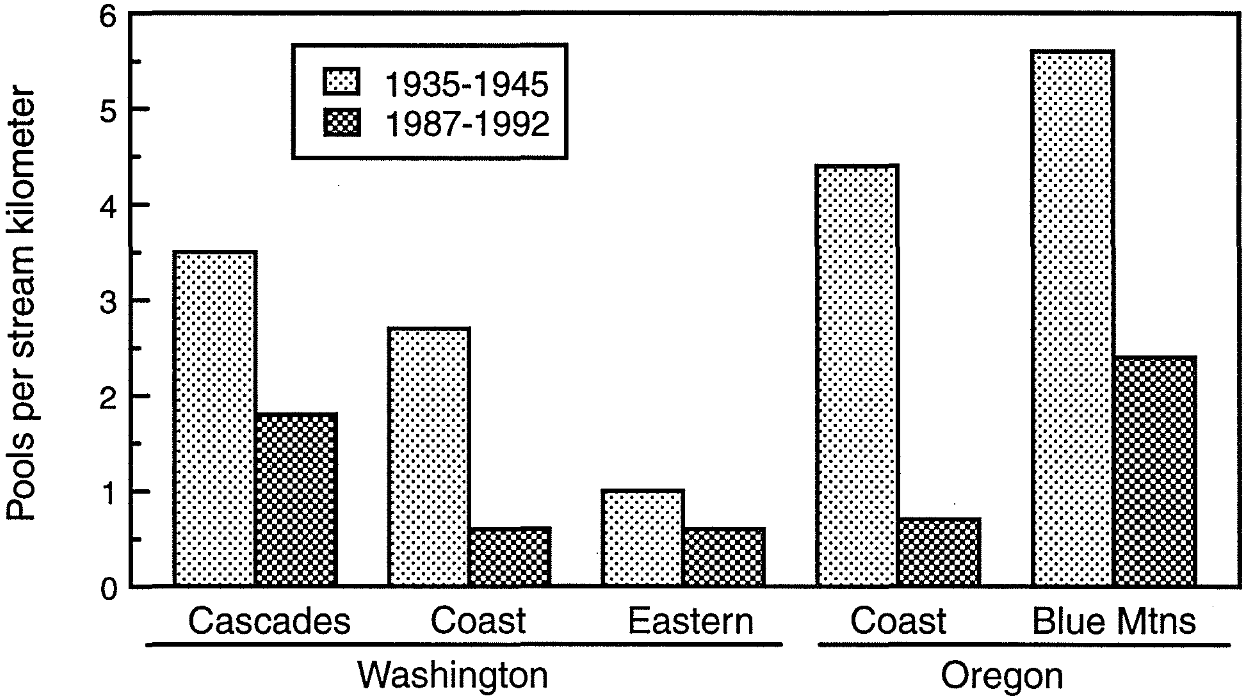


Figure 5.13. Changes in pool frequency between 1935 and 1992 in Oregon and Washington. (Data are from FEMAT 1993 and McIntosh et al. 1994.)

FOOD AVAILABILITY

A potential benefit of timber harvest results from the increased light when forest canopy over the stream is opened up. This can stimulate aquatic primary production and increase food for fish (Murphy and Meehan 1991). Forest streams are often light limited, and studies from California to Alaska have shown increased algal production after canopy removal. The increased algal production results in more abundant benthic invertebrates which juvenile salmonids eat.

Although energy sources change after timber harvest, the dominant macroinvertebrates and functional feeding groups usually remain unchanged (Hawkins et al. 1982; Duncan and Brusven 1985). Insects that feed by collecting fine detritus particles dominate in both shaded and open stream reaches. This is because the increased algal production in open reaches is used mostly as organic detritus after the algae sloughs from rocks (Murphy et al. 1981). The algae-derived detritus is more nutritious than detritus from forest litter. Thus, canopy removal can increase the abundance of invertebrates by enhancing the food quality of detritus.

Summer density of fry of some salmonid species often increases during the first 10–15 years after timber harvest because of increased production of invertebrates (Murphy and Meehan 1991). Where food is limiting and other habitat factors are suitable, density of coho salmon fry in summer is directly related to the abundance of algae (Fig. 5.14) because increased algal production increases energy flow through the food web. The higher density of coho salmon fry probably results from smaller feeding territories (Dill et al. 1981). Other habitat features, however, must also be suitable for fry density to respond favorably to increased food. Other salmonids, furthermore, may not respond the same way as coho. In Carnation Creek, B.C., for example, juvenile coho increased after logging, but steelhead, cutthroat trout, and chum salmon decreased (Hartman 1988; Holtby 1988; Scrivener and Brownlee 1989).

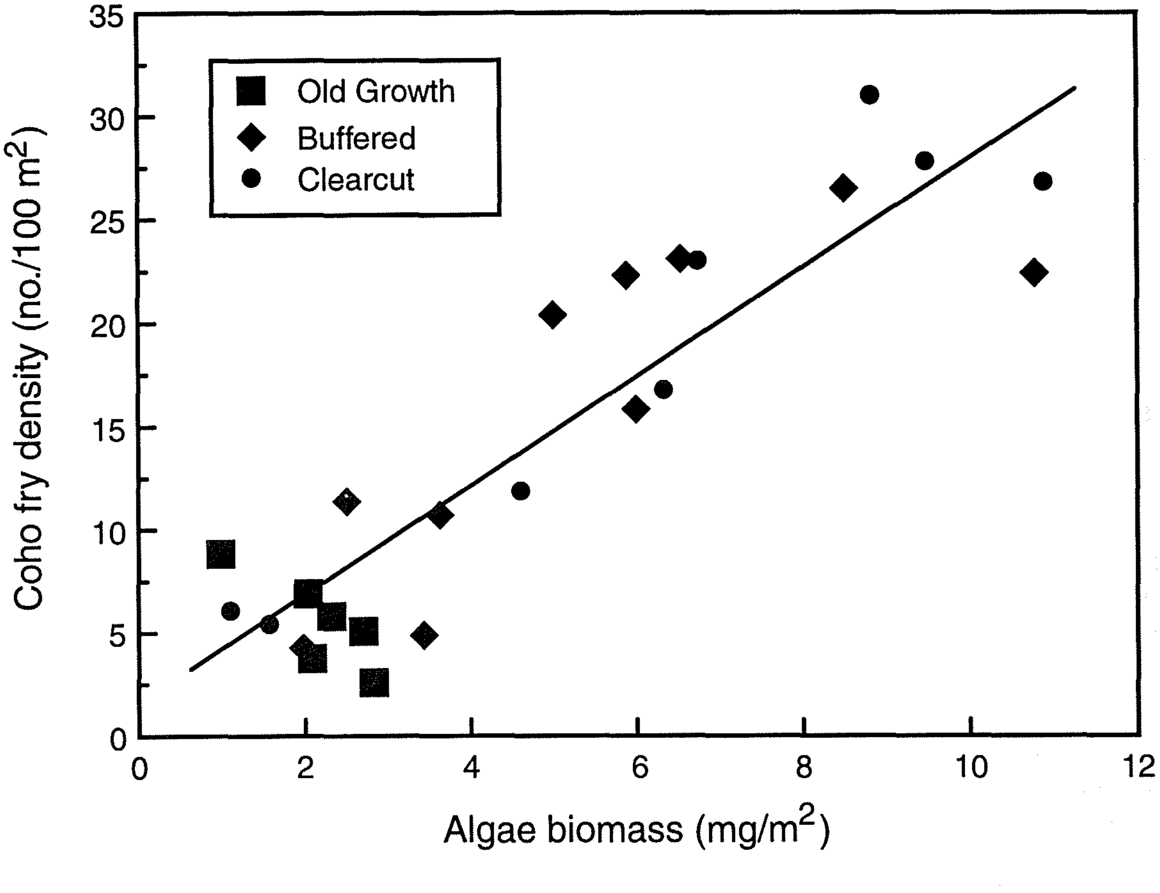


Figure 5.14. Relationship between density of coho salmon fry and algae biomass in old-growth, buffered, and clearcut reaches of streams in southeast Alaska in summer. (After Murphy et al. 1994.)

Timber harvest can affect availability of leaf detritus by altering riparian vegetation and physical conditions in the stream (Gregory et al. 1987). Effects vary as the riparian plant community passes through stages of recovery. Litterfall from streamside vegetation decreases by 75% immediately after riparian timber harvest, but recovers quickly with the growth of deciduous shrubs. Loss of debris dams because of decreased LWD reduces the channel's storage capacity for organic matter, resulting in reduced food resources and habitat for aquatic invertebrates. Increased temperature accelerates microbial decomposition of organic matter, which can promote increased invertebrate production and lead to more fish food (Warren et al. 1964).

An important long-term effect of clearcut logging is potential overshading from second-growth canopy (Murphy and Hall 1981; Sedell and Swanson 1984). Second-growth vegetation produces a denser shade and lacks the canopy gaps that are common in old-growth forest (Bjornn et al. 1992). Thus, increased stream production in the first 20 years after timber harvest may be followed by a much longer period of depressed production.

CUMULATIVE EFFECTS

Cumulative effects result from the combined effects of separate management activities through time and space (Burns 1991). Although individual management activities by themselves may not cause significant harm, incrementally and collectively they may degrade habitat and cause long-term declines in fish abundance (Bisson et al. 1992). Effects of individual actions, such as dispersed, separate harvest units and road building, should be considered in the context of all other previous and ongoing activities in the watershed.

Changes in sediment dynamics, streamflow, and water temperature are not just local problems restricted to a particular reach of stream, but problems that can have adverse cumulative effects throughout the entire downstream basin (Sedell and Swanson 1984; Grant 1988). For example, increased erosion in headwaters combined with reduced sediment storage capacity in small streams can overwhelm larger streams with sediment (Bisson et al. 1992; Fig. 5.15). Likewise, increased water temperature in headwater streams may not harm salmonids there but can make water too warm downstream (Bjornn and Reiser 1991).

Cumulative effects on sediment and hydrology worsen as the area affected by timber harvest increases (Rhodes and McCullough, in press). The amount of sediment delivered to streams and fine sediment in pools increase with increasing timber harvest and road construction (Chen 1992; Lisle and Hilton 1992; Fig. 5.16). Water yield increases in proportion to the area devegetated (Harr 1983), and peak flows increase in proportion to roads and soil compaction (Harr et al. 1979; Fig. 5.17). Pool depth and frequency, LWD, and channel complexity decrease with increased logging (Fig. 5.18; Bisson et al. 1992; Reeves et al. 1993).

Figure 5.15. Fine sediment derived from upstream timber harvest being carried by a headwater stream into downstream fish habitat in foreground. (Photo by T. R. Merrell, Jr.)

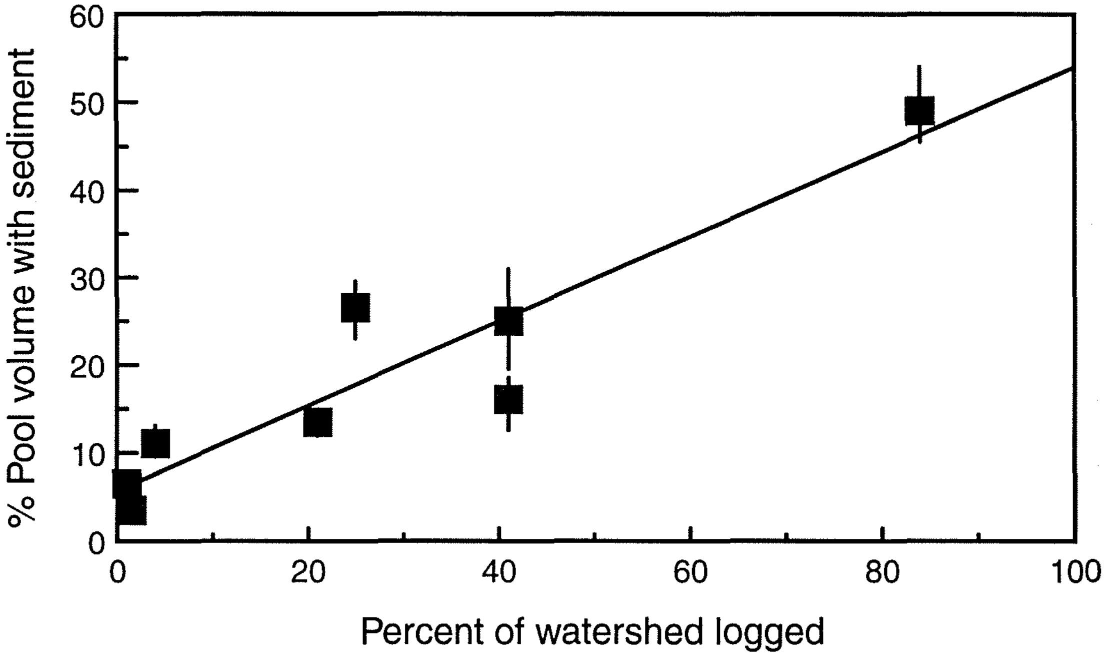


Figure 5.16. The relationship between amount of fine sediment in pools and level of timber harvest and road construction in several northern California watersheds. Vertical bars are ± one standard error. (After Lisle and Hilton 1992.)

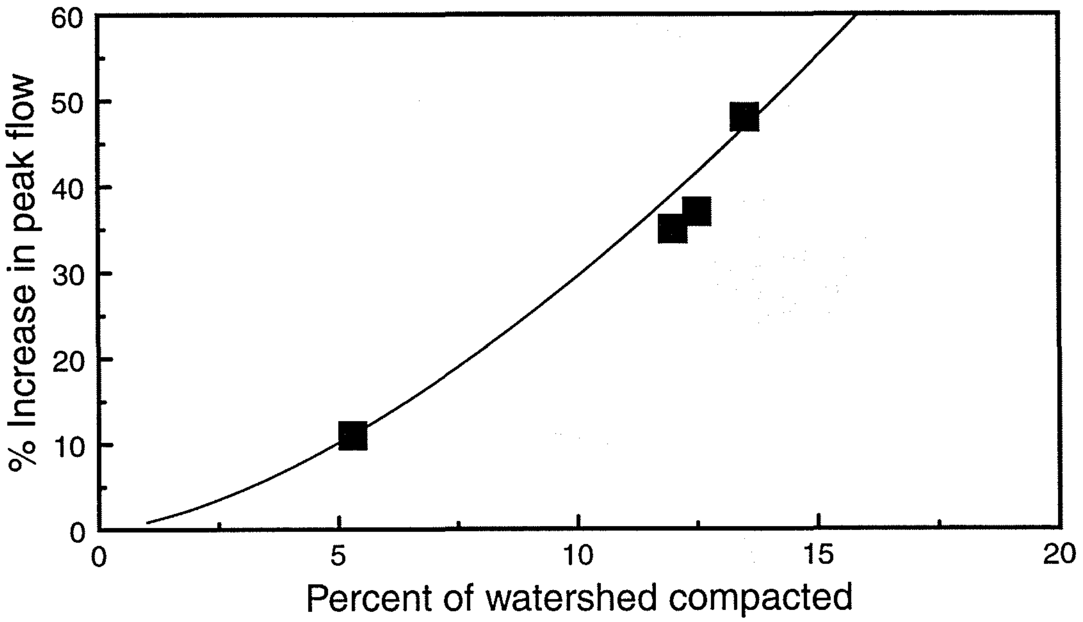


Figure 5.17. The relationship between peak streamflow and the area of a watershed affected by roads and soil compaction in western Oregon. (After Harr et al. 1979.)

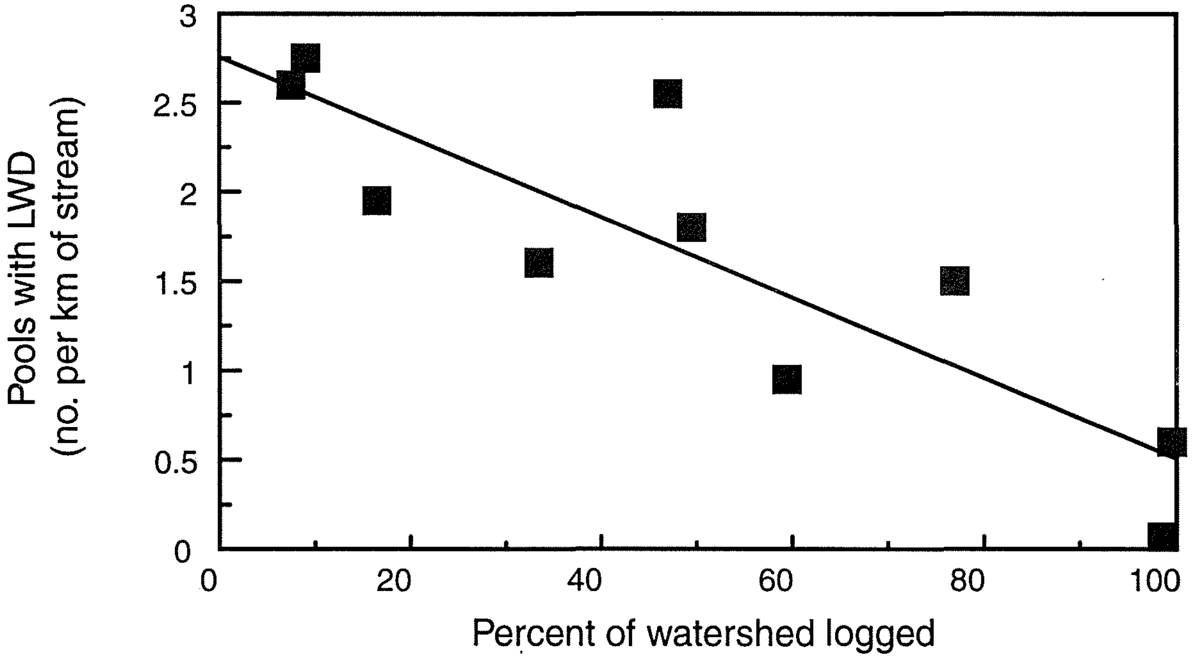


Figure 5.18. Frequency of pools associated with large woody debris in ten Oregon coastal streams with different levels of logging. (After Bisson et al. 1992.)

The most pervasive cumulative effect of past forest practices has been an overall reduction in habitat complexity (Bisson et al. 1992). Habitat complexity has declined principally because of reduced size and frequency of pools due to filling with sediment and loss of LWD (Fig. 5.19; Reeves et al. 1993; Ralph et al. 1994). This cumulative habitat simplification has caused a widespread reduction in salmonid diversity (Fig. 5.20). A few fish species were favored by the changes in habitat, whereas others declined or disappeared (Reeves et al. 1993). A similar pattern of decreased diversity of fish communities has been observed in streams altered by other human activities, such as agriculture (Schlosser 1982; Berkman and Rabini 1987) and urbanization (Leidy 1984; Scott et al. 1986).

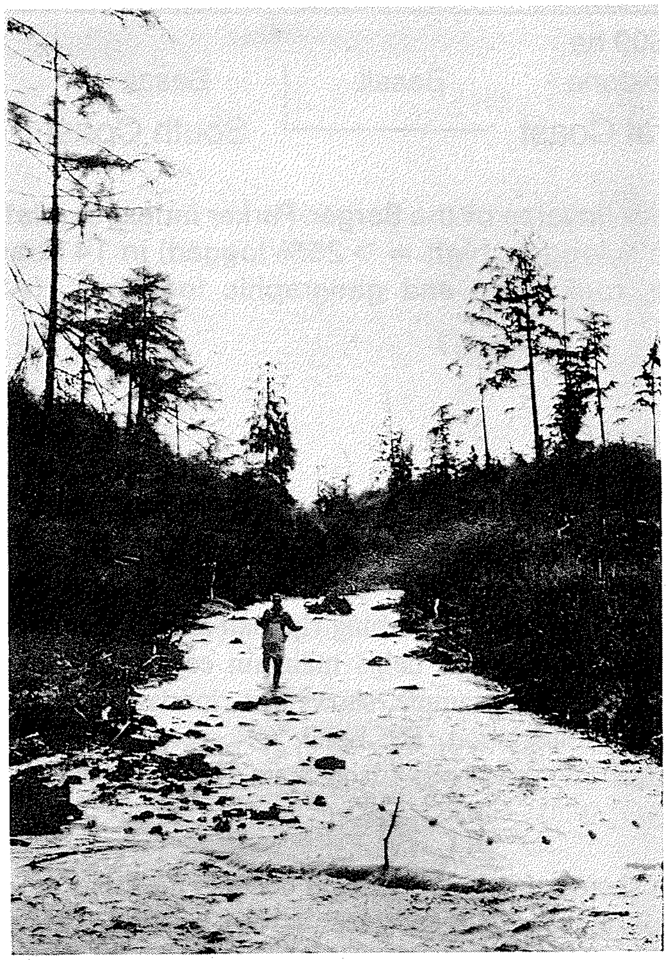


Figure 5.19. A stream in southeast Alaska 15 years after timber harvest without a buffer zone, showing extreme reduction in pools and habitat complexity due to loss of large woody debris. (Photo by M. Murphy, NMFS.)

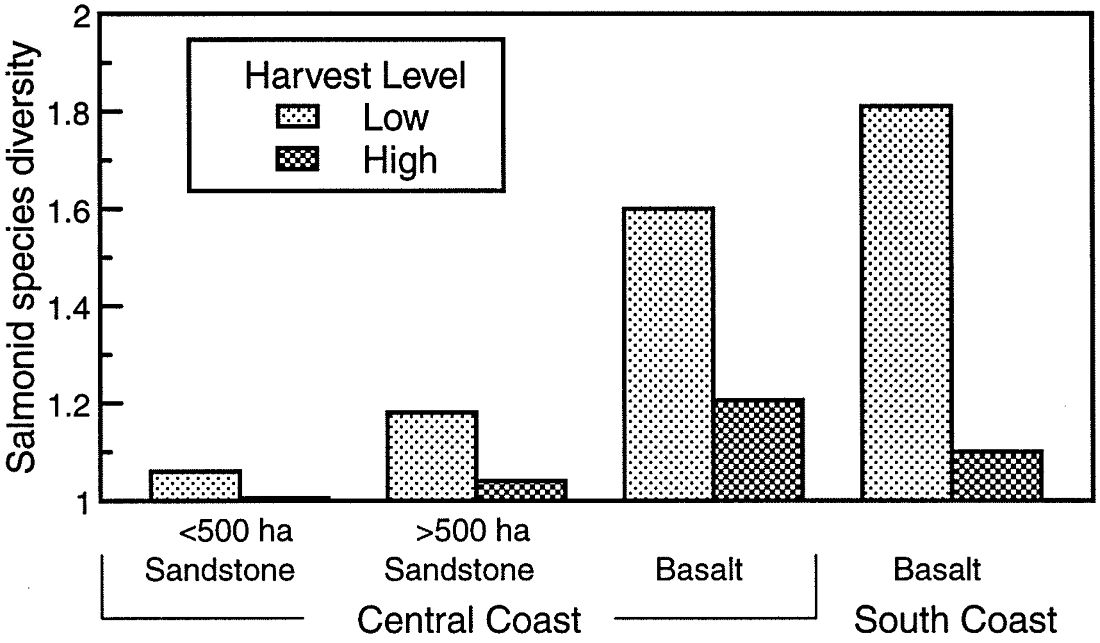


Figure 5.20. Salmonid species diversity (inverse of the Berger-Parker index) in relation to level of timber harvest (low = <25% logged; high = >25% logged) in 14 coastal Oregon watersheds of different size, rock type, and geographic location. (After Reeves et al. 1993.)

SALVAGE LOGGING

Salvage logging after catastrophic events, such as wildfire, windthrow, flooding, or insect damage, is often detrimental for salmonid habitat because of the importance of large woody debris for fish habitat and the possible harmful effects of disturbing riparian areas. Catastrophic events are part of the natural disturbance regime which helps maintain ecosystem diversity (Everett et al. 1994). Research on effects of fire, for example, shows that riparian areas are the first to recover from catastrophic events (A. Youngblood, FS, Bend, OR, pers. comm. 1994) and may actually benefit from being burned (W. Minshall, Idaho State University, Pocatello, ID, pers. comm. 1994).

Salvage logging in riparian areas after fire should usually be avoided because the areas are then extremely fragile and can not withstand roading, yarding, and other salvage activities (Minshall et al. 1989; Minshall et al. 1990; Minshall and Brock 1991). Wildfire dramatically increases runoff and fine sediment while decreasing shading and cover from undercut banks and woody vegetation. Salvage logging can exacerbate these impacts. Under postfire salvage conditions on the east slope of the Cascade Mountains, traditional logging systems, such as tractor skidding over bare ground and cable skidding, cause more severe soil disturbance and erosion than advanced systems, such as skyline, helicopter, and tractor skidding over snow (Klock 1975).

A likely impact of timber salvage after wildfire is an increase in water runoff, erosion, and landslides because of increased snow accumulation and faster snowmelt where trees (even dead ones) have been removed (Megahan 1983). Factors influencing snow accumulation and melt, rather than evapotranspiration, dominate the spring hydrologic regime in interior areas (Swanston 1991). This is because the moisture deficit from evapotranspiration is satisfied by rain in fall and early winter. Salvaging dead trees increases snow accumulation because of changes in winter snowmelt, reduced interception in standing trees, and especially, aerodynamic factors affecting snow deposition (Megahan 1983). The increased snow pack results in increased soil saturation which can trigger landslides, increase runoff intercepted by roads, and exacerbate the scour of stream channels and downstream sediment transport common after wildfires (Minshall et al. 1989, 1990).

A study of the effects of helicopter logging (Megahan 1983) shows the potential effects of timber salvage after wildfire. Megahan (1983) compared two headwater drainages in the Idaho Batholith: one was clearcut and yarded by helicopter; one was an unharvested control; and both were burned by a hot wildfire. In the logged-and-burned watershed, snow accumulation increased 41%, spring melt rate increased 30%, the subsurface flow intercepted by roadcuts increased 96%, and peak flows increased 27%. None of these effects were detectable in the burned-only watershed.

The implication of Megahan's (1983) study is that even helicopter salvage of standing dead trees after wildfire can increase the risk of landslides. Landslide hazard is directly proportional to the depth of the saturated zone relative to soil depth, and most landslides begin after intense rain or rapid snowmelt creates a temporary water table and high pore-water pressure in the soil (Swanston 1991). In Megahan's (1983) study, soil moisture and subsurface flow increased much more in the logged-and-burned watershed than in the burned-only watershed. Coupled with the declining cohesive strength of decaying tree roots, increased soil saturation after timber salvage can seriously increase landsliding (Megahan 1983).

Besides potential problems with sediment production, salvage logging can also retard attainment of riparian management objectives by removing trees that are sources of LWD for the stream. In fire-climax ecosystems on the east slope of the Cascade Mountains, new debris principally enters the stream in pulses after fire, rather than by slow continuous recruitment (Minshall et al. 1990). Cutting and removing trees from the riparian area would leave fewer trees to replace the stream's debris as it is depleted by decay, fragmentation, and transport.

New sources of large woody debris are critical to the stream's post-fire recovery (Minshall et al. 1989, 1990). After fire, existing woody debris in the stream channel is often removed by high stream discharge and exported downstream or deposited along the floodplain. The export of woody debris reduces storage capacity of the stream channel for sediment. As a result, stored sediment is exported and the stream channel becomes deeper and streambed becomes coarser. The sediment exported downstream comes from both increased hillslope erosion and erosion of stream channels. Beginning after about 2 years, new woody debris gradually begins to accumulate in stream channels from the undercutting and blowdown of fire-killed trees. This large debris serves as accumulation points for sticks and fine detritus, forms pool habitat, and creates new storage sites for sediment, helping to slow the downstream transport of fine sediment.

Large woody debris from fire-killed trees has important roles in sediment routing, not only in streams, but also on hillslopes (Wilford 1984). As the fire-killed trees fall or blow down across the slope, they form cross-slope obstructions. Sediments and small debris from upslope mass movements are deposited behind these obstructions, forming a series of terraces which delay the delivery of sediments to stream channels. Salvage of fire-killed trees could reduce the formation of these beneficial sediment-storage elements on hillslopes, resulting in gully erosion and transport of previously stored sediments into stream channels.

Although salvage logging can have adverse effects on stream ecosystems, it might be warranted in some situations. Effects of wildfire and insect outbreaks under current forest conditions can be more severe than in natural landscapes because of years of fire suppression (Arno and Ottmar 1994; Mason and Wickman 1994). Therefore, some management activities, including salvage logging, might help to ease the transition to a more natural disturbance regime (S. Chan, FS. Corvallis, OR, pers. comm. 1994).

Salvage of insect-killed trees in riparian areas can be justified in some situations to protect integrity of riparian vegetation from further insect damage (Daterman 1994). Removal of infested trees from riparian areas, however, would probably be unsuccessful in stopping insect damage because 1) not all infested trees can be found and removed; 2) infested trees are usually removed after the beetles have emerged in spring; and 3) pest management on a "stand level" is ineffective because of the beetle's strong flight capability. To improve success in controlling insect epidemics, a watershed-scale pest management plan for the ecosystem must be implemented on a landscape scale (Daterman 1994).

Salvage to reduce fuel loads might also be justified in some situations. Fish may be killed when riparian areas along small streams burn in high-intensity fires (Minshall and Brock 1991). Salvage of a proportion of insect-killed trees may be beneficial in reducing risk of high-intensity fires in some riparian areas.

Chapter 6

Technical Foundation of Forest Practices

The challenge for watershed management is to sustain all forest resources, processes, and ecosystem linkages while enabling economic timber production. Forest practices rules for protecting fish habitat fall into three basic categories (Belt et al. 1992): 1) buffer zones; 2) Best Management Practices (BMPs); and 3) cumulative effects management. This chapter examines these rules and their technical foundation.

BUFFER ZONES

Buffer zones (also called riparian management areas, stream protection zones, etc.) are lands immediately adjacent to streams or lakes designated to protect aquatic resources (Fig. 6.1).

Figure 6.1. A riparian buffer zone along an anadromous fish stream in the Tongass National Forest, southeast Alaska. (Photo by K Koski, NMFS.)

These areas receive special management consideration, but are not necessarily "lock-out" zones; timber harvest and road crossings are often permitted but with restrictions to protect aquatic resources. Restrictions are generally tighter on public than on private lands. Under the federal Northwest Forest Plan, for example, buffers can only be modified if watershed analysis demonstrates that a modification is needed to attain ecosystem management objectives (USDA and USDI 1994a).

Buffer zones are administratively defined as the area within some distance from the stream channel in which protection of water quality and fish habitat is given highest management priority. The emphasis in defining riparian buffers for fish habitat is on ecological functions from the perspective of the stream, not on botanically defined riparian plant communities. Thus, a riparian buffer zone usually includes both upland forest and distinct riparian vegetation. Buffers may also be designed to benefit wildlife and other non-fish aquatic species in addition to anadromous fish.

An understanding of the influence of riparian vegetation on streams is fundamental to understanding the function and effectiveness of riparian buffer zones. Small streams are intricately connected physically, chemically, and biologically to their riparian zones (Meehan et al. 1977; Murphy and Meehan 1991). Roots of streamside vegetation stabilize stream banks, retard erosion, affect nutrients in groundwater, and create overhanging cover. Vegetation and downed woody debris dissipate stream energy during floods and obstruct movement of sediment and organic matter. The canopy provides leaves and other organic matter that are part of the energy base for the stream ecosystem, and its shade limits algal production and moderates stream temperature. The trees and other LWD that fall into the stream channel provide the principal structural features that shape the stream's morphology, linkages to the flood plain, habitat complexity, streambed materials, and other characteristics (Sullivan et al. 1987; Beschta 1991).

Small perennial and intermittent non-fish streams are especially important in routing water, sediment, and nutrients to downstream fish habitats (Reid and Ziemer 1994a). Intermittent streams account for more than one-half of the total channel length in many watersheds in the Pacific Northwest and Alaska, so they strongly influence the input of materials to the rest of the channel system. These small channels store large volumes of hillslope materials and release them over long periods. Much of the sediment eroded from hillslopes during a major storm may be stored in the smallest channels and released gradually, thereby lessening the harm on downstream habitats. These sites can be particularly important as potential sediment sources because they are often susceptible to gullying and debris flows. Intermittent channels and unchanneled swales associated with them often are areas of considerable potential instability.

Many functions of riparian vegetation decrease with increasing distance from the streambank (FEMAT 1993). The point where the graph of cumulative effectiveness reaches 100% indicates the distance over which a function operates (Fig. 6.2). A standard way of measuring functional distance is by considering the height of mature trees growing along the stream. For example, the contribution of root strength to maintaining streambanks operates within a distance of 0.5 tree height. Inputs of leaves and particulate organic matter come mainly from the area within 0.6 tree height. Shading and large woody debris are derived from a distance of about 1 tree height.

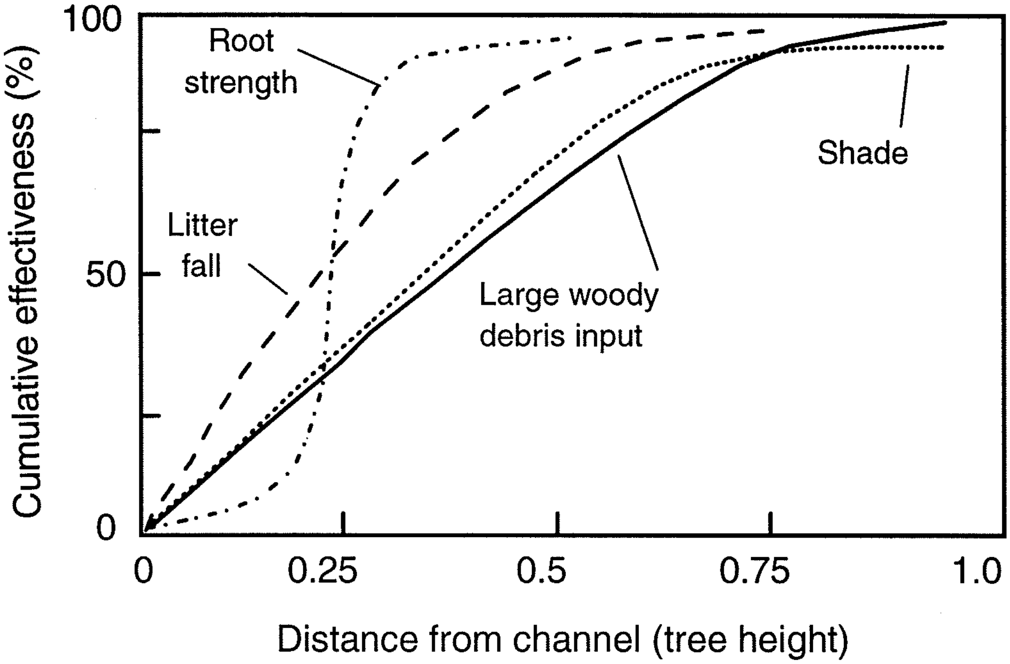


Figure 6.2. The cumulative effectiveness of various functions of riparian vegetation in relation to distance from the streambank in western Oregon. (After FEMAT 1993.)

The same types of relationship also determine the buffer width needed to attenuate changes in microclimate from the adjacent logging unit (Fig. 6.3). The width needed to buffer changes in solar radiation, for example, is less than 1 tree height, whereas the width needed to attenuate changes in wind speed and relative humidity is about 3 tree heights. Such changes in microclimate may be important in determining the long-term viability of the buffer and in determining the suitability of the buffer for riparian-dependent plants and wildlife (Hibbs et al. 1991; FEMAT 1993).

The concept of "site-potential tree height" (the average maximum height possible given site conditions) can be used to adjust buffer width for differences in site productivity (FEMAT 1993). Tree height depends on local growing conditions, and tree height largely determines the distance over which ecological functions operate (FEMAT 1993). This height can be determined from the location's site index and silvicultural data on mature forests that develop on that type of site. The site-potential tree height provides a standard measure of the way many riparian functions, such as providing woody debris, decrease away from the stream bank in different areas.

The area of influence of riparian vegetation also depends on channel constraint and floodplain development (Sparks et al. 1990). Streams constrained within bedrock channels with minor flood plains have a restricted zone of interaction with riparian vegetation (Gregory and Ashkenas 1990). In contrast, unconstrained, valley-bottom streams with extensive flood plains interact with riparian vegetation over a much broader area.

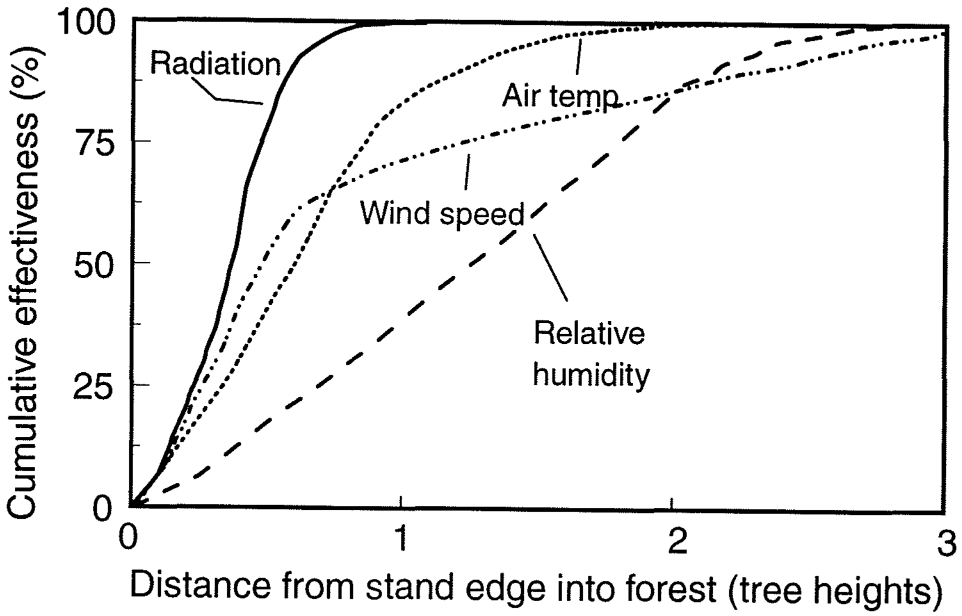


Figure 6.3. The cumulative effectiveness of various functions of forest vegetation in relation to distance from the edge of adjacent clearcuts in western Oregon. (After FEMAT 1993.)

Buffer Design

Forest practices rules regulate two features of buffer zones: their width and timber harvest within them. In general, there is little controversy about using buffers to maintain aquatic resources, but there is some controversy about how wide buffers should be and how they should be managed (Johnson and Ryba 1992).

The recommended width for buffer zones depends on management objectives (Johnson and Ryba 1992). If a specific function is targeted for protection, the width can be determined by that requirement. If several functions are targeted, the function with the widest requirement can decide buffer width. In practice, the narrowest buffers are used along non-fish streams where management objectives are primarily to maintain water quality. The widest buffers are used along fish-bearing streams to not only protect the stream, but also to maintain integrity of the riparian vegetation (i.e.,"to put a buffer on the buffer;" Cederholm 1994).

Buffer width can be fixed or variable (Belt et al. 1992). Fixed-width buffers are more easily enforced and require fewer specialized staff, whereas variable-width buffers allow tailoring of forest practices to site-specific conditions (Bisson et al. 1987; Bradley 1988). Fixed prescriptions may be less effective than management techniques adapted to local topography and natural disturbance regimes (Naiman et al. 1991). In practice, agencies use a hybrid system of fixed-width buffers where the required width varies across a small number of categories, based on beneficial use, stream width, or hillslope gradient. Some rules (e.g., Oregon's) also allow buffer width to vary along a given stream, as long as it averages above the required minimum (ODF 1994).

Prescriptions for timber harvest within buffer zones range from complete no-harvest to complete harvest. As with buffer width, the amount of timber harvest allowed within buffer zones depends on management objectives. More harvest is allowed along small, non-fish streams managed for water quality than along streams managed for fish habitat. Buffers can be managed to achieve objectives or left as unmanaged, no-harvest zones. Managed buffers are more flexible to account for local conditions and better able to implement restoration in degraded areas. No-harvest unmanaged buffers are more easily administered and less costly in time and personnel.

Factors Affecting Buffer Effectiveness

Effectiveness of buffer zones has been evaluated primarily for four basic functions: 1) filtering sediment, 2) providing shade, 3) providing LWD, and 4) overall protection of fish habitat.

SEDIMENT FILTERING

Effectiveness of vegetation in filtering sediment has mainly been evaluated for filter strips below roads, which are generally the largest source of sediment (Belt et al. 1992). These evaluations are particularly relevant because roads are often located next to streams with intervening buffer strips. For example, a survey of Idaho forest practices (Idaho Water Quality Bureau 1988) found that existing roads near stream channels were the most important factor contributing to degradation of water quality.

The key factors controlling sediment filtering are slope and density of obstructions (i.e., woody debris and ground vegetation). The steeper the side slope, the wider the buffer should be to filter sediment. Belt et al. (1992) and Johnson and Ryba (1992) reviewed numerous studies whose recommendations ranged from 25 ft (7.6 m) for 0% slopes to 200 ft (61 m) for steep (>50%) slopes. Johnson and Ryba (1992) recommended a 100-ft (30-m) buffer to filter sediment. Regardless of width, buffers are ineffective at stopping sediment that moves through them in gullies and small stream channels (Duncan et al. 1987).

SHADING

The shade-producing canopy is a key function of riparian vegetation in moderating stream temperature (Beschta et al. 1987). Other factors that affect shading include stream size, orientation, local topography, tree species, stand age, and stand density. The relationship between canopy density and buffer width is variable (Fig. 6.4), but buffers that are 30 m wide provide about the same shade as in old-growth forest.

Shade for the stream can be provided by unmerchantable trees and, along small streams, even streamside shrubs. Thus, buffers can be selectively harvested and still function effectively as shade. This may be adequate for non-fish streams managed only for water quality, but it would be inadequate for fish-bearing streams. Early riparian buffers used in the 1970s and 1980s were

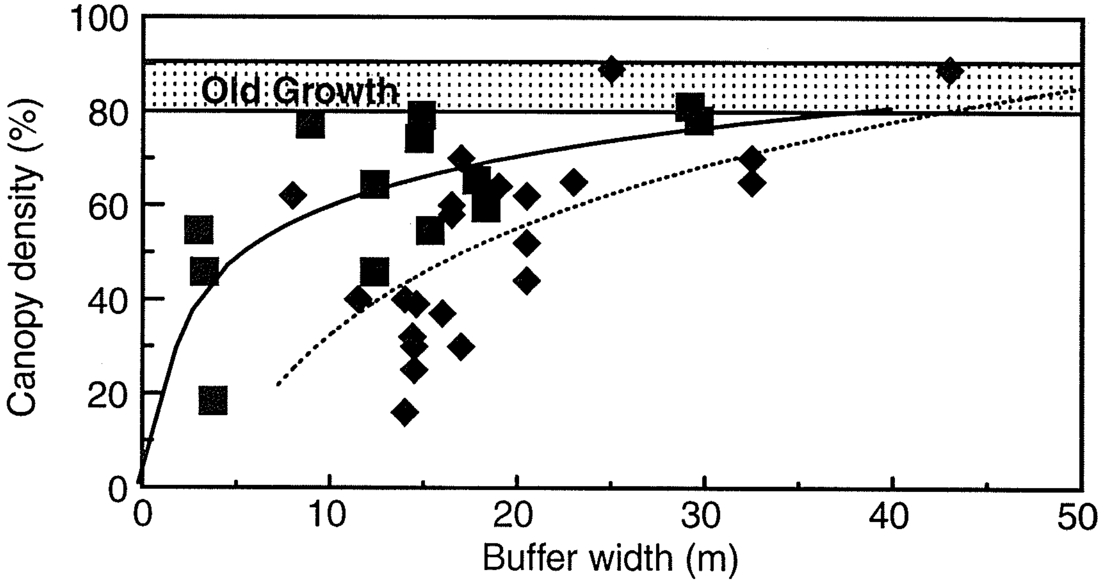


Figure 6.4. The relationship between canopy density and buffer width (uncut buffers) in western Oregon. Square symbols and solid line represent data from (A) Brazier and Brown (1973); diamond symbols and dotted line represent data from Steinblums et al. (1984). (After Beschta et al. 1987.)

mainly designed to prevent adverse increases in temperature (Beschta et al. 1987). Little consideration was given to other important features of fish habitat; consequently, these buffers failed to adequately protect fish habitat (Phinney et al. 1989).

PROVIDING LARGE WOODY DEBRIS

After the importance of LWD was recognized in the 1980s, efforts were made to design buffers to provide for long-term maintenance of LWD in streams. Studies focused on determining where LWD comes from (i.e., LWD recruitment) and how long it lasts in streams.

The basis for determining width of buffer zones for maintaining LWD was the "source distance" measured from the streambank to the spot where the tree once stood. The probability of a tree's falling into a stream decreases rapidly with increasing distance from the stream (Robison and Beschta 1990). In southeast Alaska, 99% of LWD is recruited from up to 30 m (100 ft) away from the stream (Fig. 6.5; Murphy and Koski 1989). The NMFS Alaska Region issued a policy statement in 1988 calling for 30-m, no-harvest buffer zones along streams in Alaska to protect LWD sources (USDC 1988). In western Oregon and Washington, LWD can be recruited from up to 55 m (180 ft) away (McDade et al. 1990). Thus, a wider buffer is needed in western Oregon and Washington than in Alaska to provide the same protection for LWD sources.

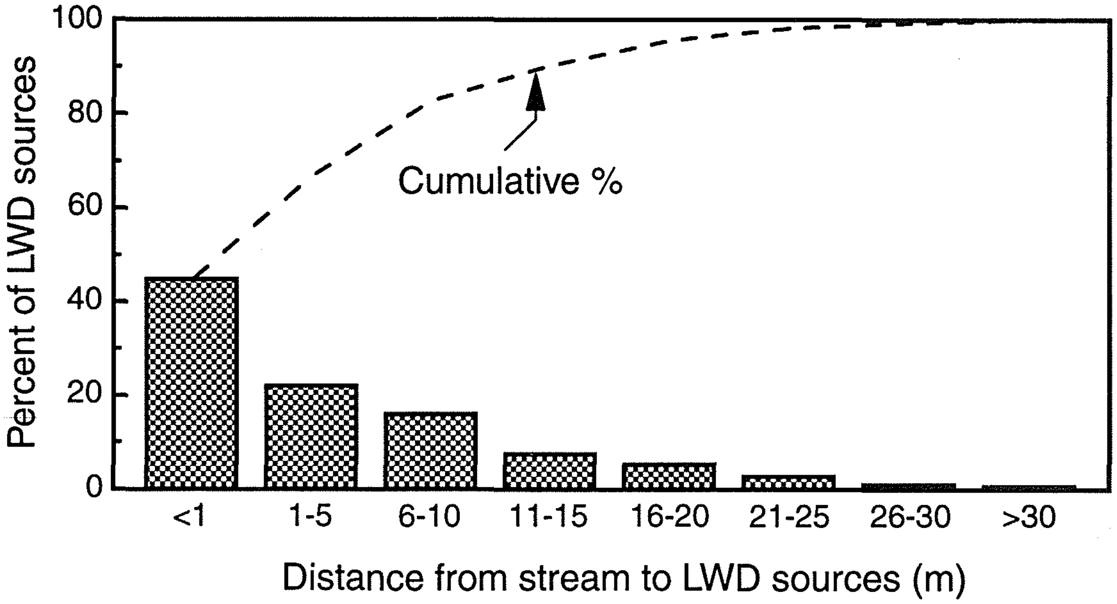


Figure 6.5. Source distance for large woody debris (LWD) in southeast Alaska. (After Murphy and Koski 1989.)

Source distance of LWD also depends on the type of stream (Lienkaemper and Swanson 1987; Murphy et al. 1987). Valley-bottom streams in unconstrained channels receive much of their LWD from the immediate streambank because the stream can undercut trees lining its banks. Over the long term, an unconstrained stream can wander across its flood plain and undercut trees growing far from its present channel. A constrained stream's channel consists of bedrock and is therefore more stable, and trees along the banks are safer from undercutting. Constrained streams, however, often have steep adjacent slopes, and LWD can slide into the stream from far away.

Selective harvest possibly could be used to harvest valuable trees within buffer zones without decreasing LWD sources if selected trees are unlikely to fall into the stream (Robison and Beschta 1990). Such harvest, however, must be done carefully to avoid damaging remaining trees. Further, too much harvest can open up buffers to wind damage and exacerbate potential succession to shrub vegetation (Hibbs et al. 1990). The most stable buffers have a dense stand of trees rather than individual trees protruding above an understory (Johnson and Ryba 1992).

Selective harvest needs to leave trees that are large enough to provide stable LWD. The size of LWD needed to form stable habitat depends on stream size (Fig. 6.6; Bisson et al. 1987). Small streams less than 5 m wide need LWD that is at least 30 cm in diameter and 5 m long; large streams more than 20 m wide need LWD that is at least 60 cm diameter and 12 m long. These "key pieces" of LWD serve as "anchors" to trap and stabilize other smaller pieces. Loss of such large "key pieces" of LWD reduces stability of LWD accumulations and diminishes the

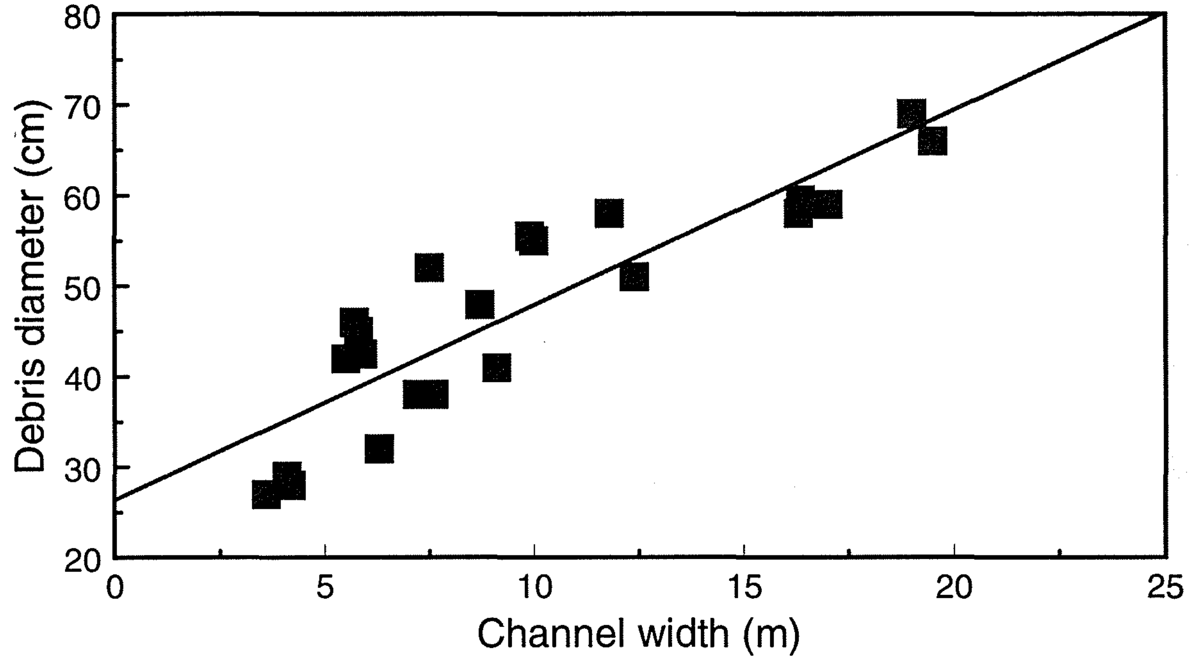


Figure 6.6. The diameter of stable large woody debris as a function of channel width. (After Bisson et al. 1987.)

beneficial functions of LWD in the stream (Heimann 1988). Once the key pieces are gone, the smaller LWD will not remain in place for long.

Selective harvest within buffers offers an opportunity to restore degraded riparian vegetation in second-growth areas (Bilby and Bisson 1991). Degraded riparian areas can be improved by appropriate silviculture if rules allow entry into buffer zones during timber harvest (T. O'Dell, Simpson Timber Company, Korbel, CA, pers. comm. 1994). By using silvicultural treatments, such as patch cutting, thinning, and conifer planting, alder-dominated riparian areas can be treated to restore vegetative diversity and provide LWD for recovery of productive stream habitat (Bilby and Bisson 1991). Active management of riparian areas may be necessary to meet the long-term needs of fish habitat (Sedell et al. 1989). Reestablishing conifers in riparian areas offers potential long-term benefits for both fisheries and timber managers.

OVERALL EFFECTIVENESS OF BUFFER ZONES

Evaluating the overall effectiveness of riparian buffer zones is difficult because of the long time periods involved for impacts to occur and for ecosystems to recover. Full impacts on LWD, for example, may take 100 years to occur, and habitat may take centuries to recover (Murphy and Koski 1989). Evaluation of the long-term effectiveness of riparian buffers relies heavily on modeling and extrapolation of data into the future.

Although one of the major functions of riparian buffer zones is to provide LWD for the stream, blowdown of trees in buffers sometimes results in a more abrupt loading of debris than intended. Blowdown is more likely in areas of poorly drained soil, where buffers are perpendicular to prevailing wind, and where the trees are conifers (C. Andrus, ODF, Salem, OR, unpublished manuscript; DeWalle 1983; Steinblums et al. 1984). Blowdown is not highly correlated with buffer width; however, wider buffers may still provide greater protection for the stream because blowdown is often concentrated at the buffer edge. Blanket prescriptions for buffer width and feathering edges may be ineffective in reducing blowdown (Boughton 1993). The risk of blowdown, however, can be reduced by adjusting the buffer layout so that boundaries take advantage of local windbreaks, such as mature forest, ridge lines, and rock outcrops (Gregory and Ashkenas 1990; Boughton 1993).

Blowdown in buffer zones is not considered a management failure nor a major problem for the stream (Murphy et al. 1986; C. Andrus, ODF, Salem, OR, unpublished). Blowdown accelerates LWD recruitment faster than in natural stands, but it is not an ecological disaster (Gregory et al. 1990). In southeast Alaska, where wind is a major ecological factor, only 10–15% of trees in buffers blow down (S. Paustian, FS, Sitka, AK, pers. comm. 1995). Upturning of roots can contribute sediment, but this not usually a problem (C. Andrus, ODF, Salem, OR, unpublished manuscript). Blowdown can also eliminate undercut banks, but this loss is offset by added cover from LWD (Heifetz et al. 1986). In specific cases where blowdown creates a problem, such as a barrier to fish migration, debris accumulations can be modified, but as little as possible to achieve desired results.

Physical exposure of the riparian community to increased light and wind could cause the buffer to deteriorate. When timber is harvested to the outer limit of the riparian zone, an edge is created that affects the interior microclimate of the riparian forest (Fig. 6.3). Relative humidity within the buffer declines, air temperature varies more, and windthrow and tree breakage increase. Increased side light accelerates shrub development which reduces herbaceous cover and tree regeneration (Hibbs et al. 1991). These factors may accelerate senescence of overstory trees and succession to shrub-dominated communities. Thus, wider riparian buffer zones may be needed to not only protect the stream but to ensure the long-term viability of riparian functions (Cederholm 1994).

Natural disturbance regimes that operate over long cycles could be important in the long-term effectiveness of buffer zones for maintaining habitat quality and diversity. The size of buffer zones generally does not account for natural disturbances that involve larger landscape scales (Everett et al. 1993). Attempts to maintain stable buffer zones against the natural tendency for disturbances in dynamic forest ecosystems may be ineffective or even counterproductive because stream productivity, unique habitats, or sensitive species often require disturbance events for long-term sustainability (Everett et al. 1993).

Over the long term, habitat formation in streams may depend on infrequent catastrophic disturbance events, such as major floods and landslides occurring after wildfire (Reeves et al., in press). The most significant outcome of natural disturbances was the episodic delivery of large quantities of mixed sediment and LWD into fish-bearing streams from hillslope failures and debris torrents triggered along headwater stream channels (Swanson et al. 1987; Hogan and

Schwab 1991). This material provided complex and productive fish habitat during subsequent decades as the stream reworked and exported the material downstream. During later stages of the disturbance cycle, fish habitat becomes less productive after most of this LWD and sediment has been exported or decayed.

Disturbances from timber harvest differ from natural disturbances in frequency, severity, and legacy of changes in the watershed (Reeves et al., in press). On the natural landscape, wildfires and major hillslope failures were less frequent, covered less area, and left large amounts of standing and downed wood in upslope areas. Modern timber harvest leaves much less large wood, except in riparian areas along fish-bearing streams. Hillslope failures after timber harvest deliver mostly sediment without the large quantities of LWD that accompanied natural disturbances. Because of the reduced LWD, stream channels that develop in watersheds managed for timber will be simpler than the complex channels that developed after natural disturbances.

Thus, disturbance is not necessarily negative, but is needed to provide productive fish habitat over the long term (Marcot et al. 1994; Everett et al. 1993; Reeves et al., in press). The challenge is to develop management regimes that put timber harvest in the context of disturbance regimes so that human patterns of land use do not substantially exacerbate natural disturbance mechanisms and leave the necessary legacy for the development of required habitat conditions. For the long-term development of productive fish habitat, the legacy of timber harvest needs to include more large wood in upslope areas, particularly in buffer zones along headwater streams and channels with the greatest potential for delivering this material to fish-bearing streams (Reeves et al., in press). In critical watershed areas, such as riparian zones and unstable soils, natural disturbance regimes allowed to predominate can provide the necessary habitat-forming amounts of sediment and LWD.

BEST MANAGEMENT PRACTICES

Best Management Practices are specific rules designed to prevent nonpoint-source pollution, particularly from fine sediment (Lynch and Corbett 1990). They are measures used by agencies to meet pollution control needs under the Clean Water Act (MacDonald et al. 1991). Best Management Practices can also refer to forest practices in general (Bisson et al. 1992). In this synthesis, BMPs are used in the stricter sense related to the Clean Water Act.

Most BMPs address activities within buffer zones, harvest activities on hillslopes, road construction and maintenance, and silvicultural practices (Boyette 1993). The Pacific Northwest states generally have several categories of BMPs that pertain directly to streams: 1) directional felling of trees and bucking and limbing of logs within streams and buffer zones; 2) yarding of logs across streams and buffers by either cable or tractor methods; 3) treatment of soil and slash deposited in stream channels; 4) prevention of erosion during tractor logging on hillslopes, including construction and maintenance of skid trails; 5) mechanical site preparation in buffer zones for replanting; and 7) road design, construction, maintenance, and obliteration. Usually, BMPs are applied as a system of practices rather than a single practice.

BMP Programs

The Clean Water Act gives state water-quality agencies authority to certify their state forest practices rules as approved BMPs for controlling pollution. Nationwide, 12 states had or were developing a forest practices act as of 1992, and in 10 of these states, the act required implementation of water quality BMPs (Boyette 1993). A state agency may certify BMPs of federal agencies and delegate responsibility for streams under federal jurisdiction. Sixteen states have a formal arrangement with the FS, and 5 states have an arrangement with the BLM (Boyette 1993).

The most frequent barriers to implementation of the forestry nonpoint-source management program under the Clean Water Act are lack of adequate funding, staffing constraints, and lack of technical personnel (Boyette 1993). As of 1992, 42 states had revised or developed BMPs for forestry, and five states used federal cost-share programs to develop their BMPs (Boyette 1993). Complexity of the concept itself adds to the problem.

State approaches to controlling nonpoint-source pollution from forestry activities can be regulatory or voluntary (Brown and Binkley 1994). States with regulatory programs impose requirements on forest practices and assess penalties for noncompliance. They usually require approval of harvest and road construction plans, inspection of projects in progress to improve compliance, and final inspections to determine the need to assess penalties. States with voluntary programs emphasize education, training, and on-site inspections if requested. Nationwide in 1992, 23 states had voluntary programs, 13 had regulatory programs, 5 had a combination of regulatory and voluntary measures, and 9 still lacked any formal program (Brown and Binkley 1994). All the Pacific Northwest states and Alaska have a regulatory program and monitor implementation and effectiveness to a limited degree.

BMP Monitoring

Monitoring is an important and required component of BMP programs. Monitoring for implementation and effectiveness are most common, but a comprehensive BMP monitoring program should include seven objectives (California Board of Forestry 1993):

1. Determine whether critical problem areas are recognized and appropriate practices are specified;

2. Determine whether BMPs are adequately applied (implementation monitoring);

3. Determine whether BMPS are effective in meeting their intent (effectiveness monitoring);

4. Determine whether properly implemented BMPs meet water quality standards (compliance monitoring);

5. Determine whether BMPs for given projects protect the stream's beneficial uses (project monitoring);

6. Provide results to the regulatory agency and public for review; and

7. Provide means for improving monitoring procedures and BMPs.

Nationwide, at least 40 states have some program for monitoring BMP implementation (Brown and Binkley 1994). Eleven states have a monitoring program for BMP effectiveness, and most of these states have published reports (Boyette 1993). As of 1992, 22 states had monitoring programs for BMP compliance, and 15 states have published results of compliance monitoring (Boyette 1993). Nine states used results of BMP effectiveness monitoring to modify BMPs (Boyette 1993).

Implementation monitoring should be the first priority because BMP effectiveness can not be evaluated unless the BMPs are actually implemented as specified. The most important aspect of implementation monitoring is sample design [e.g., which timber harvest units or roads should be included in the sample (Ferguson 1995)]. Ideally, all units would be measured, but constraints on time, personnel, and funds usually necessitate visiting only a representative sample of ongoing activities. A numerical rating system is also needed in determining whether or to what extent practices have been implemented (Ferguson 1995).

Effectiveness of BMPs can be monitored individually or collectively (MacDonald et al. 1991). Monitoring individual BMPs, such as the spacing of water bars on skid trails, is important in controlling nonpoint-source pollution, but this is different from monitoring to determine whether the BMPs protect water quality (Dissmeyer, in press). Individual BMPs are often best evaluated at the site of the practice, such as a skid trail, which may be far away from the stream and riparian zone. Legally, however, sediment generated from roads may not be a concern until it enters a stream. Thus, there should be a clear linkage between the upslope measurements and water quality (MacDonald and Smart 1994). In contrast, overall effectiveness of combined BMPs for a project is usually evaluated by directly measuring water or other stream characteristics. Such instream measurements may be difficult to relate to individual BMPs. The states evaluate BMP effectiveness from a variety of perspectives. Parameters monitored most often include turbidity, suspended solids, bioassessments, macroinvertebrates, and cobble embeddedness (Boyette 1993).

Monitoring of BMP implementation and effectiveness is conducted by numerous entities, including federal and state agencies, tribes, and private landowners (e.g., TFW 1992; California Board of Forestry 1993; Hoelscher et al. 1993; Simpson Timber Company 1994). Such a decentralized approach allows monitoring to be tailored to individual land-use activities, but disadvantages are that monitoring methods vary and data are not easily aggregated and compared (Boyette 1993; Brown and Binkley 1994).

One example of a recent BMP monitoring project is Hoelscher et al.'s (1993) audit of Idaho's BMPs. As with many projects of this type, objectives were to inspect the level of compliance with forest practices rules and judge whether BMPs were effective in preventing sediment pollution in streams. Over 1,000 activities were evaluated, and methods included assessment of upland erosion, sediment pathways, and instream sedimentation. In this audit, BMPs were implemented 92% of the time. Where BMPs were not implemented, sediment pollution occurred in 75% of the cases, which emphasized the importance of enforcement. More than one-half of the projects, however, were judged to have an adverse cumulative effect by causing sediment pollution. Recommendations were made to the Idaho Land Board to modify the forest practices rules to improve BMP effectiveness, and new rules were approved in 1995 (J. Colla, IDL, Coeur d'Alene, ID, pers. comm. 1995).

In general, recent assessments of BMPs indicate that forest practices can protect water quality if BMPs are carefully developed and implemented (Brown and Binkley 1994). Most state BMPs, however, do not carefully protect small perennial and intermittent streams from disturbance, and BMPs for minimizing erosion on unstable slopes are still being developed.

The BMPs for protecting small perennial and intermittent streams must be effective because such BMPs are the only practical means for protecting these headwater streams while other resource activities continue. These BMPs prescribe whether trees can be felled into stream channels, whether felled trees can be bucked and limbed there, and whether logging slash must be removed from the channels after yarding. Certain BMPs also determine whether logs can be dragged or yarded across stream channels, and whether tractors and other logging equipment can enter and cross them. Present state BMPs often allow trees to be felled, bucked, and limbed in small perennial and intermittent streams, with few restrictions on yarding. These activities can destabilize small stream channels, causing the release of large amounts of sediment to downstream fish habitats (Toews and Moore 1982; Bilby 1984b).

Many current problems with water quality also result from poor BMP implementation (Brown and Binkley 1994). Compliance is generally lower for small private holdings than for public or industrial lands (Brown and Binkley 1994). Having qualified field personnel available to provide site-specific BMP recommendations is probably the most efficient way to improve implementation (Brown and Binkley 1994).

Ongoing changes in forest practices regulations should consider effects on profitability of timber companies because decreased profitability could cause large land holdings to be subdivided or converted to other land uses (R. Bettis, Pacific Lumber Company, Scotia, CA, pers. comm. 1994). This change would make implementing watershed management more difficult and lessen habitat protection because the larger holdings are generally better at implementing BMPs and often have experienced technical personnel. Watershed management is easier to implement on watersheds with single owners than in watersheds with many small parcels with different owners.

CUMULATIVE EFFECTS MANAGEMENT

The analysis and management of cumulative effects are means of controlling non-point source pollution that might be missed by planning at the project level (Cobourn 1989). Forest managers can reduce or prevent undesirable cumulative effects on fish habitat by effective planning at the watershed level (Klock 1985). The National Environmental Policy Act (NEPA), Clean Water Act, and laws of several states require that effects of past, present, and future management activities be considered to prevent undesirable cumulative impacts.

Evaluations of potential cumulative effects of a given project should consider watershed erosion potential; slope stability; current disturbances from roads, timber harvest, and other land uses; rate of recovery after disturbance; and project area compared to the total watershed (Bach 1993). More comprehensive methods for assessing cumulative watershed effects rely on interpreting watershed condition and stream dynamics. Patterns of disturbance visible on aerial photographs can be used to evaluate changes in channel conditions and to link such changes to upstream causes (Grant 1988).

In evaluating cumulative effects, land managers need to account for land uses other than forestry. Grazing, mining, agriculture, water development projects, recreation usage, and urbanization can all cause incremental cumulative impacts on a watershed and its fish populations (Clark and Gibbons 1991; Nelson et al. 1991; Platts 1991). Forest management must be considered in the context of these other activities and may need to be more conservative because of their cumulative impacts. An example would be watersheds where livestock grazing has damaged riparian vegetation and streambanks (Platts 1991), warranting greater protection of riparian areas along streams during timber harvest to compensate for grazing impacts.

Watershed Analysis

Watershed analysis is the newest tool for assessing watershed features and providing the information needed by planning bodies charged with managing cumulative effects. Watershed analysis is a systematic procedure for describing current conditions and hazard areas in a watershed to provide a basis for prescribing appropriate precautionary measures (FEMAT 1993). It assumes that managers can protect the overall condition of the watershed by managing sensitive areas appropriately and applying standard practices in less-sensitive areas (Washington Forest Practices Board 1993). Watershed analysis, in itself, does not result in decisions regarding management of cumulative effects, although the overall watershed analysis process can include both resource assessment and decision-making modules (e.g., Washington Forest Practices Board 1993). Usually, however, watershed analysis is merely a management tool that provides part of the basis for management decisions. Watershed analysis is currently being developed, and several approaches are being tried on both public and private lands (Grant et al. 1994).

With information from watershed analysis, managers should be better able to avoid cumulative impacts. Because watershed analysis is a new methodology, its efficacy in promoting better habitat protection has not been widely tested. One evaluation on the Tongass National Forest, Alaska, found that several impacts resulting from logging activities could have been avoided if watershed analysis had been conducted (USDA 1995).

A comprehensive cumulative effects assessment process should be 1) systematic, the same steps used to assess each watershed; 2) structured, each step supported by a written guide with decision criteria; 3) reproducible, different observers obtaining the same conclusions; 4) defensible, supported by established scientific principles of watershed management; and 5) adaptive, periodically revised to reflect new science and technology (IDL 1994).

Besides watershed analysis, other approaches to analyzing cumulative effects rely on stream surveys to identify possible problems in a watershed, but these methods are less able to identify management-sensitive landforms. Problems with roads and erosion-hazards would be more readily identified by watershed analysis than by stream surveys.

The concept of Equivalent Clearcut Area (ECA) provides a method for setting threshold levels of concern for cumulative effects (Belt 1980; King 1989). This method monitors areas in young seral stages resulting from clearcutting, fire, or other disturbances, and establishes ECA levels at which cumulative effects begin to show. Exceeding these levels indicates a need for caution before additional activities. For example, an ECA level of 15% of forest stands <30 years old confers a low risk of impacts, whereas risks increase above the 15% ECA level (McCammon 1993).

The ECA approach has potential drawbacks that can limit its application (Rhodes and McCullough, in press). It does not represent factors that modify impacts from disturbance, such as proximity to streams and soil hazard. Timber harvest in riparian areas, for example, has greater impacts than in uplands. The recovery time (15–30 years) for hydrologic processes does not reflect recovery time for other habitat functions (200 years to recover LWD; Minshall et al. 1989). The ECA approach also omits other causes of degradation, particularly grazing.

Despite its drawbacks, the ECA approach is useful in establishing thresholds of concern for the level of timber harvest in watersheds where harvest in riparian areas is closely controlled. In determining ECA level, coefficients based on amount of tree crown cover can be used to relate harvest prescriptions other than clearcutting (e.g., shelterwood cuts) to equivalent clearcut area (L. Bailey, Payette National Forest, pers. comm. 1994; N. Gerhardt, Nez Perce National Forest, pers. comm. 1994). Such conversion coefficients may need to be adjusted to fit local watershed conditions.

Habitat Conservation Plans

Management cooperation across property boundaries is essential for effective watershed management (Trout Unlimited 1994). Habitat protection and restoration on a watershed basis will require integrating federal land management with other regulatory programs that affect aquatic habitats, particularly through the Clean Water Act and Endangered Species Act (Williams 1993). Habitat Conservation Plans developed under the ESA have an important role in watershed planning on private lands.

Under Section 10 of the ESA, non-federal landowners can voluntarily develop Habitat Conservation Plans (HCPs) in consultation with NMFS and the U.S. Fish and Wildlife Service (FWS). The HCPs outline long-term (>50 years) plans for land management and show how critical habitat of a listed species will be managed to mitigate or prevent its "taking" through adverse modifications to habitat falling under the "harass and harm" definitions of the ESA. The plans can include various measures, such as extended rotation cycles for timber harvest in critical habitat, watershed analysis to prevent cumulative effects, habitat restoration, and monitoring. Landowners can also address biotic communities rather than individual species through "multi-species" HCPs that cover listed or non-listed species other than fish and foster conservation of biodiversity.

Once HCPs are approved by NMFS/FWS, the landowners are assured that management of their lands will not be disrupted by new regulations or restrictions for those species. In issuing an incidental take permit, NMFS/FWS accept the applicant's proposed package of conservation measures and agree that the number of fish that would be taken during an otherwise lawful activity (e.g., land management) would not jeopardize the species' existence.

General provisions considered in an HCP include 1) streamside buffers that provide the full range of riparian functions (LWD, shade, nutrients, sediment filtering, and bank stability); 2) planning for road systems to minimize road density; 3) road maintenance to reduce sediment delivery; 4) avoidance of erosion-prone areas; 5) restoration projects for riparian or fish habitats that are integrated with comprehensive watershed management; 6) consideration of natural disturbance regimes; 7) removal of artificial barriers to restore fish passage to natural habitats; 8) measures to provide optimum quantity and quality of water for fish resources; 9) monitoring programs; and 10) planning for adaptive management (R. Baker, NMFS, Portland, OR, pers. comm. 1995).

Because of the wide-ranging migrations of anadromous salmonids, planning at the basin, regional, and even larger scales is also necessary for managing cumulative effects from activities in addition to timber management. The NMFS Proposed Recovery Plan for Snake River Salmon (USDC 1995) is a good example of the comprehensive planning needed to address all factors that can cumulatively affect salmon stocks. In this comprehensive plan, timber management and other watershed uses are just one of five major planning areas that also include main-stem river and estuarine habitat, fisheries harvest management, hatchery propagation, and changes in institutional structure to improve decision making. These other four components are beyond the scope of this synthesis, but forestry-fisheries issues should properly be considered in this larger context.

Comprehensive watershed management must involve more than improved scientific understanding; it also must encompass economic, social, and political concerns (Shepard 1994). Watershed management needs to involve all stakeholders, including landowners, industries, environmental groups, and local citizens, in formulating and implementing watershed management. The challenge is to develop a broad base of support and participation representing a wide spectrum of interests (Brouha 1991; Daniels et al. 1994).

Working groups consisting of government agencies, industry, and citizen groups can be instrumental in obtaining consensus on forest practices issues (AWGCFFR 1991) and watershed management for entire river basins (Doppelt et al. 1993). Working groups provide forums for complete discussion of alternative viewpoints and their supporting rationale as they strive for consensus on scientific, technical, and management recommendations. The NMFS Proposed Recovery Plan for Snake River Salmon (USDC 1995) recognizes that such working groups must be integrated into decision making processes.

Economic incentives can be provided for local communities and landowners to support and participate in habitat protection and restoration. On public lands, contracts awarded by competitive bidding can provide effective habitat protection and restoration while offsetting some employment losses in timber-dependent communities (Lippke and Oliver 1994). Using restoration funds to create local jobs encourages support for habitat restoration (Pacific Rivers Council 1993b; Weigand 1994). Tax credits and cost-sharing programs can be expanded to compensate private landowners for measures taken to protect public aquatic resources (Henly and Ellefson 1987). On private lands, the desire to conserve public fish and wildlife competes with the landowner's rights of private property. Thus, economic impacts on landowners from new regulations requiring expanded buffer zones or retention of additional leave trees along streams should be offset through public funds. Compensation would help to ease resistance to new regulations.

Chapter 7
Current Forest Practices

Forest practices are constantly being revised in light of new scientific information, political compromises, and changing public awareness and demands for forest and water resources. On federal timberlands, forest practices are generally consistent across the Pacific Northwest, with management direction from the Northwest Forest Plan (NFP) and PACFISH aquatic conservation strategies (USDA and USDI 1994a, 1994b). Management direction for federal timberlands in Alaska comes from the Tongass Land Management Plan as amended to include the 1990 Tongass Timber Reform Act. Forest practices on private and state lands are governed by their respective laws, and forest practices vary from state to state.

Regulations governing forest practices are developed through a public process with comments sought from the public on proposed regulations (Brouha 1991). Federal rules are developed and implemented with public review according to NEPA. State rules are written by the responsible resource agency, usually the forestry agency with input from the water quality agency and fish and wildlife agency, to implement intent of forest practices acts passed by state legislatures and rulings by state boards of forestry.

This chapter describes current forest practices on both federal and private lands in the Pacific Northwest and Alaska. These areas have recently revised their forest practices toward ecosystem management aimed at protecting and restoring habitat for anadromous salmonids.

FEDERAL LANDS

Northwest Forest Plan and PACFISH

Considering that aquatic and riparian habitats on federal lands are critical for anadromous salmonids and other species, the President's Forest Ecosystem Management Assessment Team (FEMAT) proposed an Aquatic Conservation Strategy to maintain and restore aquatic ecosystems in the range of the northern spotted owl (FEMAT 1993). The FEMAT (1993) report provided the scientific basis for adopting the strategy in the Northwest Forest Plan. A similar strategy has since been adopted to include areas not covered by the NFP over the entire range of Pacific anadromous salmonids from California to Alaska, and has been termed PACFISH (for Pacific Anadromous Fish Habitat Management Strategy).

Both the NFP and PACFISH strategies are new and not yet wholly implemented, and application of PACFISH in Alaska is on hold pending further study (USDA 1995). The NFP has been adopted through the NEPA process and a Record of Decision (USDA and USDI 1994a). The PACFISH strategy is interim until the FS and BLM complete formal NEPA Environmental Impact Statements (EISs) for the non-NFP areas. In 1994, the FS and BLM initiated EISs to develop and adopt coordinated ecosystem management strategies for the interior Columbia River Basin. This effort is supported by a biological, social, and economic assessment known as the Eastside Ecosystem Management Project (USDA and USDI 1994c). The PACFISH interim direction for the region will be replaced by new management direction when the EISs are completed and the selected alternatives result in revision of national forest and BLM management plans.

The NFP and PACFISH strategies have four principal components:

1. Riparian Reserves (in NFP) and Riparian Habitat Conservation Areas (in PACFISH): Lands along streams and unstable areas where special rules govern land use;

2. Key watersheds: A system of priority watersheds critical to at-risk fish stocks;

3. Watershed Analysis: An evaluation of watershed processes, functions, conditions, and capabilities to enable planning and informed decision making; and

4. Restoration: Programs to restore watershed conditions, riparian functions, and fish habitats.

The NFP and PACFISH strategies, however, are not identical. In the region covered by NFP, riparian reserve boundaries can be modified and management activities can continue in key watersheds only *after* watershed analysis, and no new roads can be built in roadless areas of key watersheds. For PACFISH, watershed analysis is required before authorization to build roads in or across RHCAs can be granted, but it is not required before other management activities. The PACFISH strategy also does not address the construction of new roads in roadless areas. Key watersheds have been identified for NFP areas, and in the Snake River Basin, all watersheds are designated as key watersheds. For other areas outside the Snake River Basin, but within the PACFISH range, key watersheds have not yet been identified (R. Baker, NMFS, Portland, OR, pers. comm. 1995).

Riparian Reserves and Riparian Habitat Conservation Areas (RHCAs) are similar to riparian buffer zones but are more comprehensive. They generally follow the stream network but also include unstable hillslopes and other areas necessary to maintain stream ecosystem processes. They are also designed to maintain wildlife habitat in addition to fish habitat.

The NFP and PACFISH strategies prescribe buffer widths for three categories of streams:

1. Fish-bearing streams: Riparian reserves or RHCAs include either the stream's inner gorge, the 100-year floodplain, the extent of riparian vegetation, the area within two site-

potential tree heights (the average maximum height given site conditions), or within 300 ft (91 m), whichever is greatest.

2. Perennial non-fish streams: Riparian reserves or RHCAs include either the stream's inner gorge, the 100-year floodplain, the extent of riparian vegetation, the area within one site-potential tree height, or within 150 ft (46 m), whichever is greatest.

3. Intermittent streams, wetlands less than 1 acre, and unstable areas: Riparian reserves under NFP include the stream's inner gorge, unstable areas and riparian vegetation, the area within one site-potential tree heights, or within 100 ft (30 m), whichever is greatest. Width of RHCAs under PACFISH in key watersheds is similar to NFP's riparian reserves, but may be narrower (50 ft or 15 m) in non-key watersheds.

Key watersheds are a system of watersheds where habitat for anadromous fish and other at-risk fish species, particularly bull trout (*Salvelinus confluentus*), receive special attention and treatment. Key watersheds can include those with ESA-listed stocks, excellent habitat for mixed salmonid assemblages, and degraded watersheds with good restoration potential. Watersheds in good condition serve as "anchors" for the potential recovery of depressed stocks and provide colonists for adjacent degraded areas. Those in poor condition can provide good habitat after restoration. Key watersheds should not be in isolated blocks, but should be linked by connective corridors (Payne and Bryant 1994) to allow recolonization and expansion of populations during recovery.

Watershed analysis provides information for use in planning and other decision-making processes. It describes conditions and ecosystem processes in a watershed so that project planning can focus on site-specific environmental issues (Reid et al. 1994). Watershed analysis, however, is not a decision-making process, and it does not develop alternatives or limit management options.

Principal aquatic objectives of watershed analysis are to 1) determine ecosystem processes affecting the flow of water, sediment, and organic matter through a watershed; 2) identify areas that are sensitive or critical to beneficial uses; and 3) determine the distribution, abundance, habitat requirements, and limiting factors of critical species. The size of watersheds analyzed is from 20 to 200 square miles (50–500 km^2), which is smaller than regional and basin assessments, but larger than project analyses (Reid and Ziemer 1994b).

Information from watershed analysis provides a basis for general land use planning (Benda 1993), including transportation planning, cumulative effects assessments, and monitoring. Watershed analysis also identifies beneficial uses, environmental issues, and societal concerns, and it may develop recommendations for management options based on physical and biological conditions. It is an iterative process. As activities are conducted, as new data become available, and as habitat recovers, analyses can be kept current for the next planning cycle.

Tongass Land Management Plan

The Tongass Land Management Plan (TLMP) was adopted in 1979 following the 1976 National Forest Management Act to provide guidelines for managing natural resources on the Tongass National Forest of southeast Alaska (USDA 1989). As with forest plans for other national forests, TLMP addresses fish and wildlife, recreation, timber, soil and water, and other multiple-use values. The TLMP is currently undergoing revision and NEPA review, which began in 1989. In 1990, congress passed the Tongass Timber Reform Act (TTRA), reforming forest practices on federal lands in the Tongass National Forest. The Act amended the Alaska National Interest Lands Conservation Act "to protect certain lands in the Tongass National Forest in perpetuity, to modify certain long-term contracts, to provide for protection of riparian habitat, and for other purposes." Management under TLMP was changed to reflect requirements in TTRA.

The TTRA requires buffer zones at least 100 ft (30 m) wide on each side of all Class I streams (i.e., those with anadromous fish) and on those Class II streams (i.e., those with resident fish only) that flow directly into a Class I stream. Timber harvest is prohibited within these buffer zones. No buffer zones are required along Class III streams (i.e., those without fish), but BMPs must be followed to protect water quality and prevent downstream sedimentation and excessive increases in temperature. The TTRA does not specifically classify or address intermittent channels.

The NFP concepts of riparian reserves, watershed analysis, and key watersheds were developed after TTRA was passed. Hence, they were not considered under TTRA. The TLMP, however, does have aquatic habitat management units analogous to riparian reserves and many other similarities with NFP concepts. The PACFISH strategy was intended to include Alaska to bring habitat protection on the Tongass National Forest up to the same level employed on other federal lands with anadromous salmonids. Because of the generally healthy status of anadromous salmonids in Alaska and other reasons, application of PACFISH to Alaska was postponed until further study of the need for the additional protection (USDA 1995).

STATE AND PRIVATE LANDS

Alaska

The Alaska Legislature amended the Alaska Forest Resources and Practices Act in 1990 to reform forest practices on state and private lands (ADNR 1993). On state lands, timber harvest is prohibited within 100 ft (30 m) of anadromous fish streams, and timber harvest must be consistent with the maintenance of fish and wildlife habitat between 100 and 300 ft (30–100 m). On private lands, streams have a lower level of protection, and riparian buffer zones depend on stream type and size.

Streams on private lands in coastal forests of southern Alaska are classified into three types:

Type A. Streams with anadromous fish; unconstrained channels; banks held in place by vegetation.

Type B. Streams also with anadromous fish; channels constrained by bedrock not vegetation.

Type C. Streams without anadromous fish; perennial streams or intermittent channels incised more than 28 degrees.

Other streams and less-incised intermittent channels are not specifically classified.

Standards for management within buffer zones on private lands differ according to stream type. Along Type A streams, no timber can be harvested within 66 ft (22 m) of the streambank (Fig. 7.1). Along Type B streams, all trees may be harvested, but timber harvest within 100 ft (30 m) of the stream or to the slope break (whichever is smaller) must comply with BMPs. Along Type C streams, timber harvest within 50 ft (15 m) of the stream or to the slope break must comply with BMPs.

The BMPs used within buffer zones are designed to protect stream channels from disturbance and prevent sediment and small debris from entering streams during felling and yarding. Trees must be felled away from streams in "V-notches," and operators must achieve at least partial suspension of logs while yarding within buffer zones. Trees felled into fish-bearing streams must be removed immediately, and trees felled into non-fish streams must be removed as soon as feasible to prevent destabilizing the channel and downstream impacts. Alaska's BMPs also cover other forestry

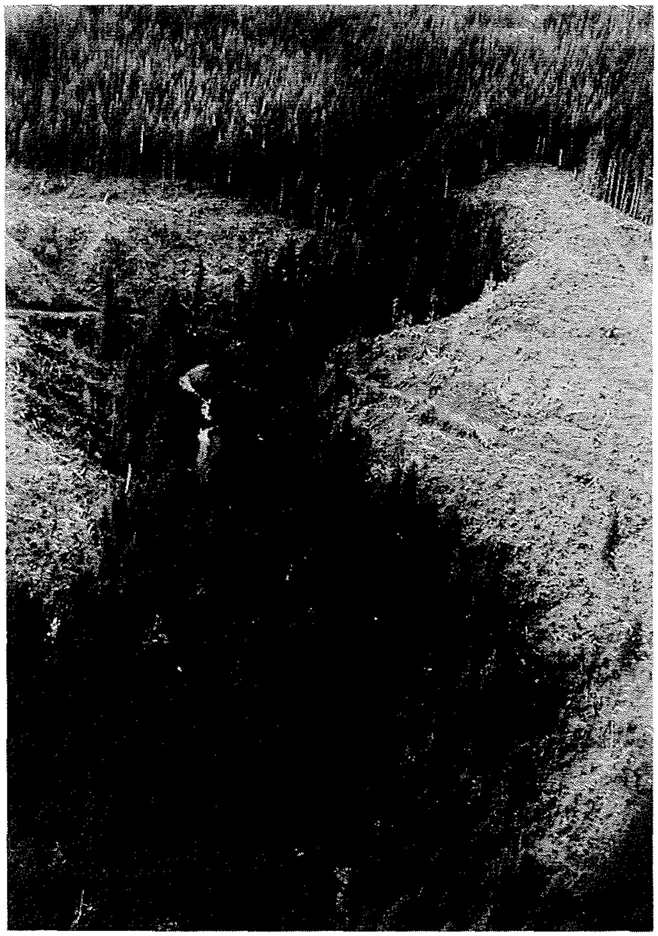


Figure 7.1. A 66-ft no-harvest buffer on both sides of a Type A anadromous fish stream on private land in southeast Alaska. (Photo by R. Harris, Sealaska Corporation.)

activities including slash disposal, harvest unit layout, rehabilitation of mass wasting, road construction and maintenance, and reforestation.

The Alaska rules also grant "variations" from requirements in some cases, such as selective harvest of specific trees within the buffer zone. A landowner may propose a variation to the State Forester, and the Department of Fish and Game has due deference in such requests concerning fish and wildlife habitat. The variation is approved if the State Forester determines that the activity is not likely to cause significant harm to fish habitat because of site-specific circumstances. An automatic variation is granted for small streams [<5 ft (1.5 m) wide], allowing harvest of 25% of the trees between 25 ft (7.6 m) and 66 ft (20 m) from the stream.

The only opportunity for evaluating possible cumulative effects is during review of a "detailed plan of operations" which timber operators must file before beginning work. The plan showing locations of water bodies, stream crossings, road layout, unstable slopes, and other information can be reviewed by affected agencies, coastal districts, and the public. The review results in either allowing forest practices to proceed with standard BMPs or designing new management prescriptions to prevent impacts.

California

The California Department of Forestry and Fire Protection (CDF) enforces the state's forest practices rules which are promulgated through the Board of Forestry. Rules relating to protection of water quality and other resources were revised in 1994 (CDF 1994).

California's waters are grouped into four classes:

Class I. Fish always or seasonally present or a supply of domestic water.

Class II. Fish always or seasonally present within 1,000 ft (304 m) downstream or habitat for non-fish aquatic species.

Class III. No aquatic life present; channel has definite bed and banks and is capable of transporting sediment to Class I or II streams.

Class IV. Artificial watercourses with established beneficial uses.

The width of riparian buffer zones (called Watercourse and Lake Protection Zones; WLPZs) depends on stream class, side slope, and yarding method (Table 7.1). For Class I (fish-bearing) streams, the WLPZ width ranges from 75 ft (23 m) where side slopes are less than 30% to 150 ft (46 m) where side slopes exceed 50%. For Class II (non-fish) streams, the WLPZ width ranges from 50 ft (15 m) where side slopes are less than 30% to 100 ft (30 m) where side slopes exceed 50%. The WLPZ along Class I and II streams in areas of steep side slopes can be reduced if cable yarding is used instead of tractor yarding. The need for and width of WLPZs along Class III (no aquatic life) and IV (artificial) watercourses are determined by on-site inspection.

Table 7.1. California's requirements for width of Watercourse and Lake Protection Zones (WLPZs) by slope class and stream class.

Slope	Class I (fish-bearing)	Class II (non-fish)	Class III (no aquatic life)
<30%	75	50	Site specific[1]
30–50%	100	75	Site specific[1]
>50%	150[2]	100[3]	Site specific[1]

[1] The need for and width of WLPZ is determined by on-site inspection.

[2] Subtract 50 ft for cable yarding.

[3] Subtract 25 ft for cable yarding.

Within the WLPZ, harvest prescriptions depend on stream class and side slope. For Class I streams, at least 50% of the overstory and 50% of the understory canopy must be left representative of the preharvest stand, and the residual overstory canopy must be composed of at least 25% of the preharvest conifers. For Class II streams, at least 50% of the total canopy must be left representative of the preharvest stand and composed of at least 25% of the preharvest overstory conifers. Where less than 50% canopy exists along Class I and II streams before harvest, only salvage that protects riparian functions is allowed. To provide LWD, at least two living conifers [≥16 inch (≥41 cm) dbh and 50 ft (15 m) tall] must be retained per acre within 50 ft of all Class I and II streams. When WLPZs are required along Class III channels, at least 50% of the preharvest understory vegetation must be left living and well distributed.

Activities within the WLPZ and adjacent slopes are regulated by BMPs designed to protect channel stability and prevent sediment and small debris from entering the stream channel. These BMPs direct the operator to fell trees away from streams and to avoid damaging residual vegetation. Yarding operations are also regulated by BMPs that prohibit use of tractors on unstable soils, during winter wet periods, on slopes greater than 65%, and on slopes greater than 50% that do not flatten to Class I or II streams. A prepared structure (e.g., temporary log culvert) must be used when crossing any watercourse that may carry water during the life of the crossing structure. When necessary to protect beneficial uses, a WLPZ or equipment limitation zone may be required for Class III watercourses. Regulations require that, when needed, the width and protection of WLPZs on Class III and IV watercourses prevent degradation of downstream beneficial uses.

Soil and debris that accidentally enter Class I, II, and IV watercourses must be removed immediately to prevent destabilizing the channel. Soil and debris deposited in Class III watercourses must be removed before ending operations or before October 15, and constructed temporary stream crossings there must be removed before winter. Continuous areas of disturbed soil >800 square ft (>74 square m) along Class I and II streams must be treated to reduce soil loss. Within the WLPZ, at least 75% of the ground cover must remain undisturbed for sediment filtering. Where necessary, WLPZs are seeded and mulched to maintain or improve ground cover for sediment filtering. Other BMPs regulate road construction and maintenance, landings, and silvicultural operations.

The required review process begins with filing of timber harvest plans prepared by registered professional foresters and submitted to CDF for approval. As part of a field examination, the forester evaluates riparian areas for erodible streambanks, debris jam potential, overflow channels, flood-prone areas, and other sensitive areas. The forester proposes WLPZ widths and protection measures. The CDF conducts on-site inspections as part of the plan review.

Cumulative impacts must be assessed in the timber harvest plan, based on the Board of Forestry's Cumulative Impacts Assessment Process. The forester preparing the plan must consult sources that are reasonably available, but the forester's duties are limited to closely related past, present, and probable future projects. State agencies can supplement this information. Factors considered in the Cumulative Impacts Assessment include sediment, water temperature, organic debris, peak flows, and watercourse condition (gravel embeddedness, pool filling, channel aggradation, bank cutting). The CDF makes the final determination regarding sufficiency of the assessment and presence of cumulative impacts.

California's rules also include provisions for a form of watershed planning in which the landowner may submit an optional "Sustained Yield Plan." This plan is intended to provide a means for addressing long-term issues of sustained timber production and cumulative effects on fish and wildlife on a landscape basis. This plan analyzes potential cumulative impacts on water quality and fish habitat, includes maps of unstable soils and planned roads, and discusses feasible measures to avoid impacts. The rules encourage landowners in watersheds with multiple owners to cooperate in these watershed assessments.

Certain watersheds that are particularly sensitive to impacts from further timber harvest can be classified as "sensitive" after public hearings and given additional protection. Justification for sensitive status can include ongoing impacts on fish habitat from erosion problems related to past or ongoing land-use activities and potential impacts from accelerated proposed road construction and timber harvest. For all such watersheds, the Board of Forestry identifies specific mitigation measures that will protect sensitive resources.

Idaho

The Idaho Legislature enacted a forest practices act in 1974 and amended it seven times since 1980 (IDL 1992). Forest practices rules are developed by the Idaho Land Board, enacted by the legislature, and enforced by the Idaho Department of Lands (IDL). The Idaho Land Board has recently approved new changes in the forest practices rules which will likely become effective in 1996 (J. Colla, IDL, Coeur d'Alene, ID, pers. comm. 1995). The rules incorporating these changes are described here.

Idaho recognizes only two stream classes:

Class I. Streams important for fish or domestic water supply.

Class II. Minor drainages with perceptible streambed and banks, used by few if any fish; principal value is influence on water quality or quantity downstream.

Buffer zones (called Stream Protection Zones; SPZs) depend on stream class. For Class I streams, the minimum SPZ is 75 ft (23 m) on both sides of the stream. For Class II streams, the minimum SPZ is 30 ft (9 m) on both sides of the stream if it contributes surface flow into a Class I stream; other Class II streams have a 5-ft (1.5-m) SPZ. The number of leave trees required differs by stream class and stream width (Table 7.2). More leave trees are required for large streams [>20 ft (6 m) wide] than for smaller streams. In addition, 75% of the existing shade canopy over Class I streams must be left intact.

Idaho's BMPs establish enforceable standards for all forestry activities, including felling, yarding, slash disposal, road construction and maintenance, and silvicultural treatments (Almas et al. 1993). Trees must be felled, bucked, and limbed away from Class I streams (but not Class II streams) wherever possible. Slash deposited in Class I streams must be removed during operations; slash in Class II streams must be removed after yarding if accumulations could block the stream or be transported downstream. Removing felled timber from the SPZ must be done carefully to avoid damaging shade and sediment filtering functions. Cable yarding across or

Table 7.2. Idaho's requirements for width of Stream Protection Zones (SPZs) and leave trees within SPZs per 1,000 ft (304 m) along each side of streams by diameter breast height (dbh).

	Class I stream width			
	<10 ft	10–20 ft	>20 ft	Class II
SPZ width (ft)	75	75	75	30[1]
Tree diameter (inches dbh)				
3–7.9	200	200	200	140[1]
8–11	42	42	42	0
12–19.9	0	21	21	0
≥20	0	0	4	0

[1] SPZ width is 5 ft and no standing trees are required for Class II streams that do not contribute surface flow into Class I streams.

within SPZs must minimize disturbance to vegetation and the stream channel. Log skidding across streams is prohibited, and tractors and other ground-based equipment are prohibited within SPZs or in streams except at constructed temporary crossings. Log skidding next to SPZs on slopes $>45\%$ needs an approved variance. Operators also must avoid conducting operations along non-classified waters (i.e., without definite bed and bank), such as "wet draws" where the presence of water is indicated.

Cumulative effects are managed with an approach analogous to federal watershed analysis (IDL 1994). Its purpose is to give trained evaluators an understanding of current watershed condition, hydrologic processes, and disturbance history. The process assesses streambed sediment, channel stability, sediment delivery, water temperature, shade, nutrients, and hydrology. It provides a key to determine whether cumulative effects exist, and guidance for landowners to design practices to correct adverse conditions and prevent future cumulative effects.

The cumulative effects assessments are conducted by a committee of forest landowners in the watershed. This committee selects certified evaluators who prepare an assessment report identifying problem conditions and guidelines for forest practices. The committee develops management prescriptions based on the assessment report. The IDL reviews the assessment and prescriptions for consistency, completeness, and compliance with the Forest Practices Act. The process results in either allowing forest practices to proceed with standard BMPs, or designing new management prescriptions to prevent problems.

Monitoring is conducted by the IDL to evaluate implementation and effectiveness. Audits of forest practices determine compliance with approved prescriptions, and effectiveness monitoring is conducted through standard assessment techniques by the landowner committee every 5 years and filed with the IDL. More detailed monitoring is done in some cases by other state agencies.

Oregon

Oregon recently revised its forest practices rules, taking an innovative approach to provide for long-term productivity of stream and riparian habitats (ODF 1994). Innovative aspects include incentives for timber operators to actively manage riparian stands to develop desired future conditions characteristic of mature streamside forests.

Oregon classifies streams according to beneficial use and stream size into three types:

Type F.	Fish-bearing streams.
Type D.	Domestic water supply.
Type N.	Non-fish streams, including intermittent streams with well-defined channels.

Each type is subdivided according to mean annual streamflow (in cubic ft per second [cfs]) into three size categories: large [≥ 10 cfs (≥ 0.28 m^3/s)]; medium [2–10 cfs (0.06–0.028 m^3/s)]; and small [≤ 2 cfs (≤ 0.06 m^3/s)]. Timber operators are required to submit written plans for approval by the Department of Forestry (ODF) if operations are within 100 ft (30 m) of a Type F or D stream.

Riparian buffer zones (called Riparian Management Areas; RMAs) depend on stream class and size (Table 7.3). Width of RMAs ranges from 50 to 100 ft (15–30 m) for Type F streams; 20 to 70 ft (6–21 m) for Type D streams, and 0 to 70 ft (0–21 m) for Type N streams. Small perennial Type N streams have RMAs in some regions (eastern Cascades, Blue Mountains) but not in others (Coast Range and Western Cascades). Intermittent Type N streams do not have RMAs. Non-classified areas without defined channels, such as ephemeral overland flow and seeps, also do not have RMAs, but operators must protect soil and vegetation from disturbances that could affect beneficial uses, and operators are encouraged to leave green trees and snags in these areas.

The rules are designed to move RMAs toward desired future conditions. For Type F streams, the desired future condition for RMAs is to grow and retain riparian vegetation so that, over time, average conditions across the landscape become similar to those of mature streamside stands. Requirements for leave trees are based on objectives for tree basal area that would emulate an average mature streamside stand 120 years old halfway through a 50-year timber rotation. For Type N streams, the desired future condition is to have sufficient streamside vegetation to support functions that are important to downstream fish use and supplement wildlife habitat.

Management goals distinguish between areas with different native forests. Where the native forest would be conifers, the rules aim to retain a sufficient number of conifers to attain a mature conifer stand along large and medium streams by halfway through the next timber

Table 7.3. Oregon's requirements for width (in ft) of riparian management areas by stream size.

Stream size[1]	Type F (fish-bearing)	Type D (domestic water)	Type N (non-fish)
Large ≥10 cfs	100	70	70
Medium 2–10 cfs	70	50	50
Small ≤2 cfs	50	20	0–10[2]

[1] Size based on mean annual streamflow in cubic ft per second (cfs).
[2] 10 ft in some regions if stream is perennial; 0 ft in other regions and if stream is intermittent.

rotation. Where the native community is hardwood dominated, site-specific prescriptions are used so that regrowth replaces older trees. Where the riparian forest was historically conifers but currently dominated by hardwoods, the desired action is to manipulate the RMA during timber harvest to create conditions for reestablishing conifers.

Vegetation retention for Type F streams includes all trees within 20 ft (6 m) of the stream, all downed wood and snags not safety or fire hazards, and at least 40 live conifers [>11 inches (>28 cm) dbh] per 1,000 ft (304 m) along large streams and 30 live conifers (>8 in dbh) along medium streams (Table 7.4). Requirements for Type D and large and medium Type N streams are similar to Type F streams, except that the number of live conifers to be retained is lower (Table 7.4). For small perennial Type N streams, only understory and unmerchantable trees within 10 ft (3 m) of the stream are required in some regions of the state. No retention is required along small perennial Type N streams in western Oregon or any small intermittent Type N stream, but operations are subject to BMPs.

Enough conifers must also be left to meet standard basal area targets (Table 7.5). These targets are designed to produce a mature conifer stand halfway through a timber rotation. They are calculated based on normal yield of a Douglas-fir forest at 120 years of age after adjusting for incomplete stocking of riparian areas, tree mortality, and tree growth during the rotation. The target is also reduced because of the 20-ft no-harvest zone next to the stream, which is not managed. The basal area target of 230 square ft for large Type F streams equals about 350 11-inch-diameter trees. If the preharvest basal area is less than standard targets, no harvest is allowed and the operator must retain additional conifers or other trees.

An innovative aspect of Oregon's rules is that they provide incentives for private landowners to take advantage of restoration opportunities during timber harvest. Timber owners can earn a basal area credit for trees that they place into Type F streams during operations. The basal area

Table 7.4. Oregon's minimum requirements for conifer leave trees [in number per 1,000 ft (304 m) along each side of the stream] in riparian management areas by stream size.

Stream size[1]	Type F (fish-bearing)	Type D (domestic water)	Type N (non-fish)
Large[2]	40	30	30
Medium[3]	30	10	10
Small	0	0	0

[1] Size based on mean annual streamflow in cubic ft per second (cfs; see Table 7.3).
[2] Retained conifers must be at least 11 inches (28 cm) diameter breast height (dbh).
[3] Retained conifers must be at least 8 inches (20 cm) dbh.

Table 7.5. Oregon's standard targets for conifer basal area in riparian management areas each side of Type F streams by stream size class in selected regions.

Region	Normal basal area yield[1]	Standard basal area target (square ft per 1,000 ft) Large (RMA = 100 ft)	Medium (RMA = 70 ft)	Small (RMA = 50 ft)
Coast Range	457	230	120	40
Western Cascades	473	270	140	40
Siskiyou	411	220	110	40

[1] Theoretical normal basal area (square ft per 1,000 ft of stream) in a 100-ft RMA with 120-year-old Douglas-fir forest after adjusting for incomplete stocking and tree mortality (T. Lorensen, ODF, Salem, OR, pers. comm. 1994).

credit is twice the basal area of each conifer log or tree placed in a large or medium Type F stream, or equal to the basal area of logs and trees placed in small Type F streams. These credits can be used to reduce the basal area requirement of live conifers in RMAs. The conifer basal area, however, must not be reduced below "active management" targets, which range from about 50 to 80% of the standard targets. Specific guidelines and requirements for placing logs in streams for basal area credit are given by ODF and ODFW (1995).

Activities near streams or within RMAs are regulated by BMPs to protect water quality. Operators must fell trees away from streams (including small intermittent Type N streams), except for approved restoration projects. Logging slash must be removed from Type F and D streams during harvest operations and must not accumulate in Type N streams in amounts that threaten water quality. Except for small Type N streams, cable yarding across streams must have prior ODF approval and must achieve full suspension. Cable yarding across small Type N streams must minimize disturbance to the stream. Tractors and other ground-based yarders may not enter flowing streams except at constructed temporary crossings. Such crossing structures are not required for crossing dry streambeds if the disturbance is no greater than would be caused by construction of the crossing. Mechanical site preparation for tree planting is not allowed in RMAs on slopes >35%, except for certain equipment during dry periods, and not where soil compaction and erosion are likely. Other BMPs cover all other forestry activities including road construction and maintenance, landings, skid trails, and silvicultural practices.

Oregon's rules do not provide for analysis of cumulative effects. There is no watershed analysis, but instead, Oregon takes a "bottom up" approach based on stream surveys. The ODFW has surveyed most of the streams in Oregon to support forest practices regulation (M. Solazzi, ODFW, Corvallis, OR, pers. comm. 1994). This approach relies on the ability to identify potential problems with cumulative effects by looking at conditions in stream channels and riparian areas.

Washington

The Washington State Forest Practices Act of 1974 created a Forest Practices Board composed of state agencies, county governments, industry, and the public. The Board promulgates the forest practices rules. The first rules did not adequately address fish habitat (Phinney et al. 1989) because no consideration was given to habitat except for temperature. All riparian trees could be cut, sparing only the understory on certain temperature-sensitive streams. In 1987, a group of concerned parties including state agencies, corporations, tribes, citizens, and technical experts undertook negotiations and reached an agreement on new forest practices rules (the Timber Fish Wildlife Agreement, or TFW). The rules were again revised to further address environmental concerns in 1992.

Washington's rules recognize five types of waters:

Type 1.	Special "Inventoried Shorelines."
Type 2.	High value for fish, wildlife, and human use.
Type 3.	Moderate-to-slight fish use.
Type 4.	No fish but are important for water quality and have channels >2 ft (0.6 m) wide.
Type 5.	Other waters including perennial and intermittent streams with or without defined channels.

Riparian management zones (RMZs) are required on Type 1, 2, and 3 streams but not on Type 4 and 5 streams unless warranted by site conditions (Table 7.6). In western Washington, the minimum RMZ width is 25 ft (8 m), and the maximum width depends on stream type and width, ranging from 100 ft (30 m) on Type 1 and 2 streams over 75 ft (23 m) wide, down to 25 ft (8 m) on small (<5 ft wide) Type 3 streams. For each type, buffer width can vary between the minimum and maximum values, depending on extent of wetland vegetation or the width needed for shade.

Prescriptions for the number of leave trees in RMZs in western Washington depends on stream type and streambed substrate (Table 7.6). Fewer leave trees are required for streams with boulder-bedrock channels than streams with gravel-cobble channels. The number of leave trees is greatest [100 trees per 1,000 ft (304 m) of stream on each side] for Type 2 streams with gravel-cobble channels. Leave trees for Type 1 and 2 streams must represent the preharvest stand. For large Type 3 streams, leave trees must be larger than 12 inches (>30 cm) dbh and consist of two conifers per deciduous tree. For small Type 3 streams, leave trees must be larger than 6 inches (>15 cm) dbh and equally conifer and deciduous. Leave trees can be required for Type 4 and 5 streams for site-specific reasons.

Table 7.6. Washington's requirements for width and leave trees per 1,000 ft (304 m) in Riparian Management Zones (RMZs) in western Washington under the 1992 forest practices rules.

Stream Class	RMZ width (ft)	Type/size of leave trees	Trees/1,000 ft, each side Gravel-cobble	 Boulder-bedrock
1 and 2 (≥75 ft wide)	25–100[1]	Representative of stand	50	25
1 and 2 (<75 ft wide)	25–75[1]	Representative of stand	100	50
3 (≥5 ft wide)	25–50[1]	Two 12-inch conifers per deciduous tree	75	25
3 (<5 ft wide)	25	One 6-inch conifer per deciduous tree	25	25
4 & 5	0–25[2]	Site specific	0–25	0–25

[1] Width can vary within the range shown, depending on extent of wetland vegetation.
[2] An RMZ is used only if deemed needed due to site-specific conditions.

Rules for eastern Washington are generally similar to those for western Washington. The RMZ width for Type 1, 2, and 3 streams is 30 to 50 ft (9–15 m) on each side of the stream for areas of partial harvest, and must average 50 ft (15 m) for clearcutting. The minimum leave tree requirements [trees ≥4 inches (≥10 cm) dbh] are 75 trees per acre (185 trees/hectare) for boulder-bedrock streams, and 135 trees per acre (334 trees/hectare) for gravel-cobble streams.

Washington's BMPs comprehensively cover all forestry activities including activities within RMZs, road construction, skid trails, slash disposal, landings, and silvicultural practices. Within RMZs, trees must be felled away from Type 1, 2, and 3 waters except where impractical or unsafe. If felled trees get into streams, they must be removed promptly, and bucking is allowed only as needed to remove the tree from the water. Trees may be felled into Type 4 waters and bucked and limbed within the stream channel provided it is done carefully to minimize accumulation of slash. Downed logs imbedded in channels (except Type 5) must be left undisturbed.

The BMPs also regulate yarding activities. Cable yarding across Type 1, 2, and 3 waters is prohibited, except where the logs will not damage the stream channel or the RMZ. Reasonable care must be taken to avoid damaging residual vegetation. Tractors and wheeled skidders are not permitted in Type 1, 2, and 3 waters without Department of Natural Resources (WDNR) approval and approval by the Departments of Fisheries or Wildlife. Log skidding is not permitted within RMZs without WDNR approval, and skid trails are not permitted within the 50-year flood plain. Tractors are not allowed on slopes where, in WDNR's opinion, they would cause unnecessary damage to public resources. Log skidding across flowing Type 4 waters must be minimized or employ constructed temporary stream crossings. No such restrictions apply for Type 5 waters without RMZs.

Washington's forest practices rules address cumulative effects through watershed analysis. The process is meant to assess watershed problems and sensitivities and be a basis for developing appropriate prescriptions (Washington Forest Practices Board 1993). Watershed analysis is divided into seven modules that separately address mass wasting, surface erosion, hydrology, riparian function, fish habitat, water quality, and public capital improvements (e.g., roads and bridges). The process is collaborative, involving scientists and managers representing landowners, agencies, tribes, and interested public. The desired outcome is a management plan for the watershed that responds to the resource concerns identified by scientific assessment.

Watershed analysis has four phases: startup, resource assessment, prescription writing, and wrap-up. The startup phase forms teams, collects data, defines responsibilities, distributes notifications, and develops a plan for watershed evaluations. During resource assessment, an interdisciplinary team locates sensitive areas and assesses existing and potential impacts by implementing the seven inventory modules. During prescription writing, a team of managers and analysts identifies forest practices to prevent or minimize impacts. During wrap-up, the team develops a monitoring plan to measure effectiveness of the prescriptions.

Other States

Forest practices rules of other states are generally not as comprehensive or restrictive as those of the Pacific Northwest and Alaska. In most states, compliance with streamside protection requirements is voluntary, and no monitoring is done (Brown and Binkley 1994).

Chapter 8
Analysis of Current Forest Practices

The rules for federal lands and for the five states described above have many elements in common. They all have stream classification, regulatory BMPs, and riparian buffer zones. They differ mainly in the size and management of buffer zones and in the assessment of cumulative effects.

All agencies classify streams according to beneficial use (Table 8.1). They fall into three classes:

1. Fish-bearing and domestic water supplies;
2. Non-fish perennial streams; and
3. Non-fish intermittent stream channels.

Non-fish intermittent streams generally include streams that show signs of flowing water and have definite bed and banks. Areas without defined channels (e.g., ephemeral overland flow, seeps, wet draws) are not classified, except in NFP/PACFISH and Washington. Agencies primarily use stream classes to modify their requirements for buffer zones and BMPs. Greatest protection is given to fish-bearing streams and least protection is given to non-fish intermittent streams.

BUFFER DESIGNS

Forest practices rules affect two parameters of buffer zone design: buffer width and management prescriptions within them. These parameters together determine how effective a buffer will be in protecting fish habitat. A wide unharvested buffer obviously provides more protection than a narrow, heavily harvested buffer. Most buffer zone designs, however, are between these extremes.

Streams with anadromous fish have the widest buffer zones (Table 8.2). Minimum width ranges from 25 ft (7.6 m) in Washington to 300 ft (91 m) on federal lands managed under the NFP or PACFISH. Streams with lesser fish values (i.e., non-anadromous species) receive narrower buffers in Alaska and Washington, but the others have similar buffers for all fish streams. Non-fish perennial streams have narrower buffers than the fish-bearing streams or no buffers in some cases. Non-fish intermittent streams, except on federal lands managed under NFP and PACFISH or in Idaho, usually do not have buffers.

Table 8.1. Definitions of stream classes for federal and private lands in five states.

Regulator	Stream Class	Characteristics
Federal (NFP & PACFISH)	1.	Fish-bearing
	2.	Perennial non-fish
	3.	Intermittent non-fish
Federal (TLMP in Alaska)	I.	Anadromous fish stream
	II.	Non-anadromous fish stream
	III.	Non-fish stream
Alaska (southern coastal)	A.	Anadromous fish stream, unconstrained channel
	B.	Anadromous fish stream, constrained channel
	C.	Tributary to anadromous fish stream
California	I.	Fish-bearing or domestic water supply
	II.	Non-fish stream; fish present within 1,000 ft downstream
	III.	No aquatic life; capable of sediment transport
	IV.	Artificial watercourse
Idaho	I.	Fish-bearing or domestic water supply
	II.	Headwater stream with few if any fish
Oregon	F.	Fish-bearing
	D.	Domestic water supply
	N.	Non-fish stream
Washington	1.	"Inventoried Shorelines"
	2.	High fish, wildlife, or human use
	3.	Low-moderate fish, wildlife, or human use
	4.	Non-fish perennial or intermittent streams
	5.	Intermittent stream having periods of spring or storm runoff

All agencies use additional site-specific factors to refine buffer requirements to fit local conditions. On federal lands, riparian reserves and RHCAs can be adjusted for site-specific conditions after watershed analysis. On private lands, four of the five states adjust buffer width depending on hillslope gradient, yarding method, stream size, extent of wetland vegetation, or streambed materials (Table 8.2). Idaho's buffer widths are set without regard to such site-specific factors.

Table 8.2. Width requirements (in feet) for riparian buffer zones on federal [Northwest Forest Plan (NFP) and Tongass Land Management Plan (TLMP) as amended by the Tongass Timber Reform Act] and private lands in five states for the three common stream classes. Buffer width on private lands is measured as horizontal distance in Washington and as slope distance in the other states; therefore, buffers of the same nominal width can be wider in Washington than in the other states, depending on the slope. Reasons for ranges are in footnotes.

Stream	Federal		Private Lands				
Class	NFP[1]	TTRA	AK	CA	ID	OR	WA
Fish-bearing	300	100	66–100[2]	75–150[3]	75	50–100[4]	25–100[5]
Non-fish perennial	150	0	50[6]	50–100[3]	30	0–70[4]	0–25[7]
Non-fish Intermittent[8]	100	0	0	Site[7] Specific	30	0	0–25[7]

[1] Riparian reserve width can be increased to include 100-year flood plain or other factors.

[2] Anadromous fish streams: 66-ft no-cut buffer for non-bedrock streams; 100-ft harvested zone for bedrock-constrained streams.

[3] Depends on adjacent hill slope and yarding method: wider buffers on steeper slopes and for tractor yarding.

[4] Depends on stream size and region; no buffers for small perennial non-fish streams in western Oregon.

[5] Depends on extent of wetland vegetation and stream width.

[6] 50 ft or to the slope break, whichever is smaller.

[7] Buffer zone used only if deemed necessary by site-specific conditions determined during preharvest planning.

[8] Non-fish stream channels with definite bed and banks that carry water part of the year.

California requires a wider buffer in areas with steep slopes and further increases buffer width up to a total of 150 ft (46 m) for tractor yarding. These adjustments respond to two concerns about erosion and sediment production: buffers need to be wider to effectively filter sediment in areas of steep slopes (Johnson and Ryba 1992) and tractor yarding causes more erosion than cable yarding (Chamberlin et al. 1991).

Oregon and Washington adjust buffer width depending on stream size, giving larger streams wider buffers. The assumption is that small streams do not need as wide a buffer as larger streams. Compared to small streams, large streams are usually associated with a wider floodplain (Sullivan et al. 1987) and, therefore, require a wider buffer for floodplain protection. Large streams also have greater total energy for bank cutting and transporting sediment and debris. Although this appears justified, the specific widths needed to protect different stream sizes have not been identified by research; hence, the adjustments in buffer width are based only on professional judgement.

Alaska and Washington adjust buffer width depending on streambed materials. The rationale is that stream channels that are constrained by bedrock are less dependent on LWD and vegetation for providing fish habitat than are unconstrained channels with gravel/cobble substrate. Alaska increases the width of the buffer from 66 ft (20 m) for gravel/cobble channels to 100 ft (30 m) for bedrock-constrained channels but allows complete harvest within the wider zone.

Washington adjusts buffer widths for fish-bearing streams according to wetland vegetation. This approach, however, may not provide long-term protection even to those wetlands. If adequate sources of LWD are not provided by a streamside buffer, the stream can downcut, which would lower the local water table and cause wet areas to dry up (Beschta 1991). A more appropriate approach in defining buffer zones is from an analysis of functions provided by streamside areas to the stream/riparian ecosystem (Belt et al. 1992).

The different prescriptions for minimum amounts of vegetation to be retained in buffers are difficult to compare. Each state has a different approach. These include requiring no-harvest zones (Alaska), retaining a percentage of overstory canopy (California), retaining a specified number and size of trees (Idaho), setting targets for tree basal area (Oregon), and retaining a percentage of preharvest trees (Washington). Usually, a combination of approaches is used. Oregon, for example, has a no-harvest zone and specifies a number of conifers in addition to its targets for basal area.

BUFFER EFFECTIVENESS

Based on review of 38 separate investigations, Johnson and Ryba (1992) concluded that, for most riparian functions, buffers greater than 30 m (100 ft) are adequate, buffers 15–30 m (50–100 ft) are minimal, and buffers less than 10 m (30 ft) are inadequate. With these recommendations as a general guide, buffers on federal lands under NFP and PACFISH are adequate for all riparian functions plus a safety margin to offset risks to habitat from unknown or uncontrollable factors (Table 8.2). Buffer widths on private lands are barely adequate for fish-bearing streams but minimal or inadequate for non-fish streams. This reduced protection for non-fish streams is understandable and appropriate given that management objectives for non-fish streams on private lands do not include most riparian functions, but specifically target sediment control for protection of downstream beneficial uses.

Shade Protection

States usually require a minimum level of shade-producing vegetation to be left along fish-bearing streams. Washington, for example, determines minimum requirements for shade by modeling predicted temperature increases based on expected changes in forest canopy. Idaho requires retention of 75% of shading vegetation, California requires retention of 50% of the canopy, and Oregon retains all trees within 20 ft of the stream.

Adequate shade usually can be provided by leaving a strip of trees next to the stream in a width of about 25 m (80 ft) (Johnson and Ryba 1992). Trees for shade can consist of unmerchantable hardwoods and conifers. Buffer widths for fish-bearing streams on private lands average near the recommended width (Table 8.2) and should be adequate for shade if not harvested too heavily. Idaho's 75% shade requirement, for example, is close to the 80–90% canopy of old-growth forest (Beschta et al. 1987). California's requirement of only 50% canopy retention, however, appears too low, especially because California is on the southern margin of the range of several species, including coho salmon, and increased temperature could make some streams uninhabitable. These prescriptions for shade retention on fish-bearing streams need to be closely monitored to ensure adequate control of stream temperature.

Shade requirements for non-fish perennial streams may be inadequate in some states, particularly Idaho, Oregon, and Washington. In these states, buffers on non-fish streams can be less than one-half the 80-ft recommended buffer width for shade protection (Table 8.2; Johnson and Ryba 1992) and substantial harvest is allowed within the buffers. In Alaska, both federal and private lands have minimal buffers on non-fish streams, but a cooler climate probably helps mitigate potential increases in temperature. Because of their usual small size, non-fish streams may be adequately shaded by shrubs and other understory vegetation, and narrow, harvested buffers may suffice for shade protection. Effectiveness monitoring is required to determine whether these narrow buffers prevent cumulative increases in temperature in downstream fish habitats.

LWD Recruitment

Providing for LWD is more expensive than providing shade because it requires leaving merchantable conifers. Four of the five states have specific requirements for the number of leave trees in riparian buffer zones, whereas federal rules and Alaska use no-harvest prescriptions (Table 8.3). For high-value fish-bearing streams, the number of leave trees per 1,000 ft (304 m) of stream varies widely by state. For example, Idaho requires about 250 trees ranging down to 3 inch (8 cm) dbh. Oregon's prescriptions are the most comprehensive. For large fish streams, Oregon requires 40 trees >11 inch (>28 cm) dbh per 1,000 ft of stream, a 20-ft no-harvest streamside zone, and a standard target for tree basal area of 230 square ft per 1,000 ft of stream. This basal area is equivalent to nearly 350 11-inch-diameter trees.

The approximate level of protection for LWD recruitment can be estimated based on buffer width and prescriptions for leave trees within the buffer. Buffer width determines the area from

Table 8.3. Required leave trees [per 1,000 ft (304 m), each side of stream] within riparian buffer zones on federal and private lands in five states. NH = no harvest.

Stream		Private Lands				
Class	Federal	AK	CA	ID	OR	WA
Fish-bearing	NH[1]	NH[2]	2[3]	242–267[4]	0–40[5]	25–100[6]
Non-fish perennial	0–NH[7]	0	2[3]	140[8]	0–30[9]	0–25[10]
Non-fish intermittent	0–NH[7]	0	0	140[8]	0	0–25[10]

[1] No harvest until after watershed analysis under NFP and PACFISH.

[2] No harvest for unconstrained channels; complete harvest for constrained channels and streams with non-anadromous fish. Within no-harvest buffers, selective harvest permitted through variations.

[3] Retain 50% overstory canopy, including 25% of preharvest overstory conifers and two conifers >16 inch (41 cm) dbh per acre within 50 ft of stream (2.3 trees per 1,000 ft).

[4] Number of leave trees depends on stream width, includes both hardwoods and conifers, and ranges down to 3 inch (8 cm) dbh.

[5] All trees within 20 ft (6 m) of the stream are retained; buffer must meet basal area targets and include from 0 to 40 conifers (minimum 8–11 inches dbh) per 1,000 ft of stream, depending on stream size.

[6] Depends on stream size and streambed materials; hardwood/conifers representatiave of stand.

[7] No-harvest buffers under NFP and PACFISH; complete harvest allowed under TLMP.

[8] Size of retained trees: 3–8 inches (8–20 cm) dbh; includes both hardwoods and conifers.

[9] Leave trees not required on small Type N streams.

[10] Leave trees (conifers and hardwoods) required only for site-specific conditions.

which potential source trees can contribute LWD (Murphy and Koski 1989; McDade et al. 1990), and prescriptions determine how much of this potential material remains after timber harvest.

Considering buffer width for fish-bearing streams, federal NFP and PACFISH buffers provide full protection of LWD sources because the buffers are at least two site-potential tree heights in width. Buffers on private lands, however, are generally not wide enough to fully provide for long-term LWD recruitment. Most prescribed buffers on private lands are narrower than a single site-potential tree height [usually 100–120 ft (30–40 m)]. The exceptions are streams in

California where side slopes exceed 30% (100–150-ft buffers); large streams (mean discharge >10 cfs) in Oregon (100-ft buffers); and certain large streams in Washington where buffer zones are extended to include the wetland plant community (up to 100-ft buffers). All other fish-bearing streams have narrower buffers with reduced potential sources of LWD, and all buffers on private lands have some allowable timber harvest.

Based on buffer width, the buffers for representative fish-bearing streams on private lands in the five states could provide approximately 90% of LWD sources present in mature conifer stands if the buffers were unharvested and if they contained mature conifer forest or were restored to that condition (Table 8.4). Timber harvest within the buffers, however, reduces LWD sources to the minimum requirements for leave trees and other vegetation. These requirements are lowest in California, where only 25% of the conifer overstory including two large conifers per acre must be left, and is highest in Alaska, where a variance must be approved to remove individual trees. The resulting overall protection of conifer LWD sources on private lands ranges from only 23% in California to 82% in Alaska (Table 8.4).

Growth of trees during the timber rotation increases the trees for potential LWD. In Oregon, for example, targets for conifer basal area for leave trees are set so that trees will achieve desired future conditions halfway through a 50-year rotation. Oregon's rules are based on the expectation that basal area will grow 59% within 25 years, thereby achieving the level of LWD sources in a mature Douglas-fir streamside forest (T. Lorensen, ODF, Salem, OR, pers. comm. 1994). Assuming a similar growth rate (59% per 0.5 rotation period) in the other states, the resulting LWD sources at mid-rotation would exceed 90% of the level in mature forest in Alaska and Oregon, but would still be far below that level in California and Washington (Fig. 8.1).

These comparisons of LWD recruitment depend on estimates of average or normal mature forest. The value for Washington, in particular, depends on how many trees occur in an average mature streamside stand. Basal area and density of trees varies widely, and a single value for the percentage leave trees in Table 8.4 fails to portray the large variation that occurs in the field. Nevertheless, the values give a perspective of the relative level of protection for LWD sources under similar hypothetical conditions.

For comparison purposes, this evaluation of buffer effectiveness for LWD recruitment assumed that streamside areas contained mature forest. Many riparian areas in the Pacific Northwest, however, have second-growth vegetation consisting of hardwoods and brush (Gregory et al. 1990). In such cases, leaving a higher percentage of existing trees may not increase conifer LWD for the stream nor help reestablish conifers in the riparian area (Bilby and Bisson 1991). In these cases, regulations should encourage activities that modify riparian vegetation leading to desired future conditions of appropriate mature native forest species.

Oregon's approach provides a prototype model for managing second-growth riparian areas to achieve desired future conditions for both fish and timber. If the buffer lacks enough conifers to meet targets, no harvest is allowed. Monitoring data in Oregon indicate that because of the current condition of riparian forests, minimal tree harvest occurs in buffers on private lands (T. Lorensen, ODF, Salem, OR, pers. comm. 1995). To reestablish conifer stands along streams,

Table 8.4. Comparison of minimum level of protection for conifer LWD sources for representative anadromous fish streams in federal (NFP) and private lands in five states. For comparisons, preharvest buffers are assumed to have mature conifer forest.

	Federal NFP Class 1	AK Type A	CA Class I 40% slopes	ID Class I 15 ft wide	OR Type F >10 cfs[1]	WA Type 2 <75 ft wide
Buffer width (ft)	300	66	100	75	100	25–75
% LWD source trees in unharvested buffer[2]	100%	96%	92%	85%	92%	40–85%
% Prescribed leave trees	100%	85%[3]	25%[4]	58%[5]	63%[6]	38%[7]
% LWD sources after timber harvest[8]	**100%**	**82%**	**23%**	**49%**	**58%**	**32%**

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[1] Mean annual streamflow in cubic ft per second.

[2] Values obtained from graphs in Murphy and Koski (1989) for Alaska and in McDade et al.(1990; model for mature conifers) for the other states. Buffers are assumed to have mature conifer forest.

[3] Value based on 15% harvest rate (R. Harris, Sealaska Corp., Juneau, AK, pers. comm. 1993).

[4] Value based on 25% retention of overstory conifers.

[5] Value obtained by comparing estimated basal area of prescribed leave trees (87 sq. ft per 1,000 ft) to estimated basal area in mature streamside stands on private lands in eastern Oregon (150 sq. ft/1,000 ft; T. Lorensen, ODF, pers. comm. 1994).

[6] Example for Coast Range. Value obtained by comparing standard basal area target to the normal yield of mature Douglas-fir forest adjusted for incomplete stocking and tree mortality (T. Lorensen, ODF, Salem, OR, pers. comm. 1994).

[7] Example for western Washington. Value obtained by comparing the 100-leave-tree requirement to the mean number of trees in mature streamside forest in the Western Cascades, corresponding to the maximum 75-ft buffer (263 trees/1,000 ft; T. Lorensen, ODF, Salem, OR, pers. comm. 1994).

[8] Value calculated by multiplying the % source trees in an unharvested, mature-conifer buffer times the % prescribed leave trees.

Oregon allows alternative prescriptions, such as increased harvest followed by conifer planting in "conversion blocks" alternating with "retention blocks" with lesser harvest (Newton et al. 1995). Oregon further ensures some immediate LWD recruitment by providing basal area credits when operators add trees to streams.

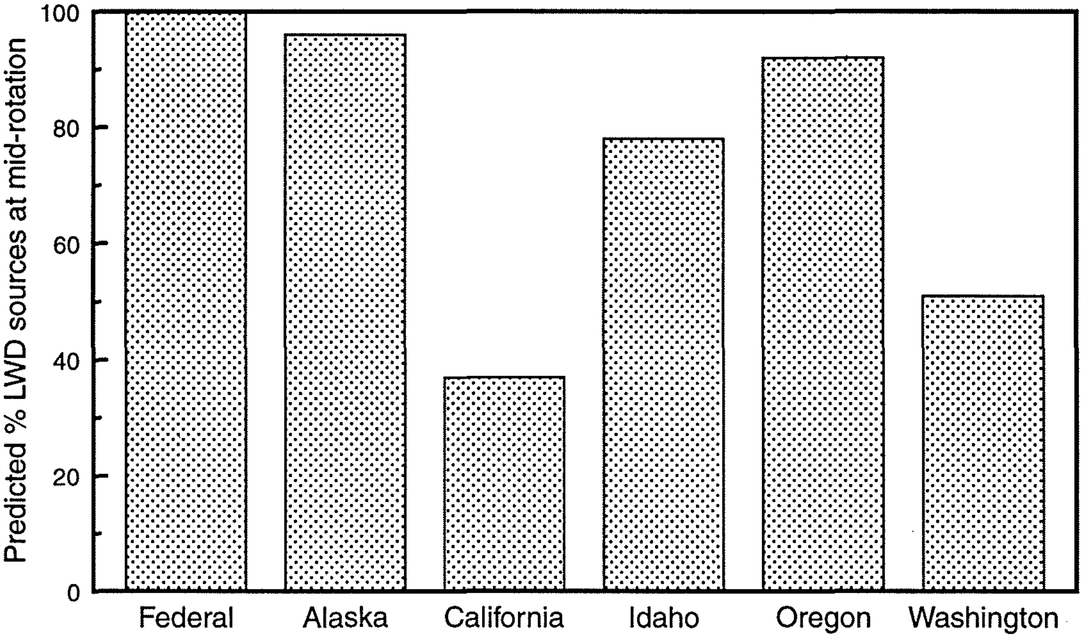

Figure 8.1. Predicted sources of conifer LWD in buffer zones at mid-rotation for representative fish-bearing streams as a percentage of LWD sources present in mature conifer stands. Values are based on federal and state requirements for buffer width and leave trees and assumes mature conifer forest in preharvest buffers and a 59% increase in LWD sources during the first one-half of a timber rotation (see text for explanation).

Prescriptions for buffers in other states, such as Washington's requirement for leave trees that are representative of the existing stand, do not encourage the desired result of improving riparian stands. Oregon's and California's rules also directly address the need for conifer LWD by specifying that leave trees consist of conifers, whereas Idaho and Washington allow both conifers and hardwoods to qualify as leave trees.

A no-harvest buffer zone is most appropriate along fish-bearing streams where streamside areas consist of mature native forest. Where riparian forests are degraded by past logging, a no-harvest prescription limits options for silvicultural treatments for restoring riparian functions for fish habitat (Bilby and Bisson 1991). A no-harvest prescription, unless it provides for "variations," also does not allow landowners to harvest valuable timber from the stand in site-specific cases as long as habitat is protected.

Alaska's approach illustrates the use of no-harvest buffers in mature forest, with "variations" allowing selective harvest. A 66-ft, no-harvest buffer zone is used along unconstrained anadromous fish streams to leave over 90% of LWD source trees present before harvest. Variations can be granted to landowners to harvest additional specific trees whose removal is unlikely to adversely affect fish habitat. State habitat biologists and landowners debate the harvest of individual trees, and about 80% of variation requests are approved. The variation process results in about 15% of trees >12 inch (>30 cm) dbh within the buffer zone being harvested (R. Harris, Sealaska Corporation, Juneau, AK, pers. comm. 1993; Resource Development Council 1994). The state resource commissioners have found that the process generally works satisfactorily (ADFG 1994 Memorandum), but effectiveness of resulting buffers has not been evaluated.

Specifying a number of leave trees in buffers is a common way to set a minimum level of protection for LWD recruitment. Four of the five states require leave trees for fish-bearing streams, and three states require leave trees for perennial non-fish streams. Usually leave trees include many small trees [e.g., down to 3 inch (8 cm) dbh in Idaho] and only a few large trees. The size of these largest trees [>11 inch (28–50 cm) dbh] is generally appropriate to provide stable LWD in streams, but the smaller trees are probably ineffective for LWD (Bilby and Wasserman 1989). Current requirements in the four states are to leave only an estimated 23% to 58% of potential LWD compared to the sources present in mature conifer forest (Table 8.4). To provide optimal fish habitat, the number and size of leave trees need to be increased where additional large conifers are available.

Buffers on small non-fish streams, except for federal lands managed under NFP and PACFISH, are generally not adequate to provide LWD for the stream. All states except Alaska require leave trees along some non-fish perennial streams, but not enough to fully maintain LWD. Only Idaho routinely requires leave trees along intermittent channels (Table 8.3).

Longer term, the lack of LWD sources along small headwater streams can adversely affect downstream habitat in several ways. Reduced sources of LWD can reduce sediment storage in small headwater streams, resulting in more rapid sediment delivery to downstream reaches (Sullivan et al. 1987). Headwalls of small headwater streams can be important sources of LWD to downstream reaches via debris torrents (Swanson et al. 1987); lack of a buffer zone in these areas eliminates this function.

Sediment Control

Controlling sediment delivery is most important along small non-fish streams and intermittent channels because of their dense distribution [accounting for more than 50% of the total length of stream channels in a watershed (Reid and Ziemer 1994a)] and their capacity to transport sediment to downstream reaches. These streams, however, except on federal lands managed under NFP and PACFISH, generally have minimal buffers (Table 8.2). Perennial non-fish streams do have buffers in Idaho and California, and they sometimes have buffers in Washington if deemed needed by site-specific conditions. Perennial non-fish streams do not have buffers on federal lands managed under TLMP, nor along small Type N streams in western Oregon. Where buffers are left on perennial non-fish streams, they are usually heavily harvested (Table 8.3). Intermittent non-fish streams (with definite bed and banks) consistently have a buffer zone only on NFP/PACFISH lands and in Idaho; California and Washington sometimes provide a buffer for site-specific conditions.

The buffers for small non-fish streams appear to be minimal or inadequate for sediment control. The recommended buffer width for sediment filtering ranges from about 26 to 150 ft (8–46 m), depending on hillslope (Johnson and Ryba 1992), whereas the average buffer width on private lands is 40 ft (12 m) for perennial non-fish streams and usually 0 ft for intermittent non-fish streams (Table 8.2). California is closest to the recommended width by requiring 50–100-ft buffers on perennial non-fish streams. A high level of timber harvest within the buffers, however, probably compromises their effectiveness as sediment filters. Because of the narrow buffers and high level of harvest allowed along small non-fish streams, preventing sediment pollution relies heavily on BMPs that restrict felling and yarding practices along streambanks.

BEST MANAGEMENT PRACTICES

The BMPs used in the five states are generally similar in that their principal objective is to prevent sediment pollution. Each state has a suite of BMPs for felling, yarding, slash disposal, site preparation, road construction and maintenance, and other activities designed to prevent disturbances to stream channels, riparian areas, and unstable soils, and minimize sediment runoff from roads and skid trails. Each state monitors effectiveness of its BMPs, but monitoring programs are only recently being developed, and current BMPs have not yet been fully evaluated.

Three BMPs pertaining to buffer zones are particularly important in protecting streams from disturbance and preventing downstream sediment impacts from timber harvest along small non-fish streams. These BMPs determine 1) whether trees can be felled into and limbed within stream channels, 2) whether cable yarding can cross streams with full or partial log suspension, and 3) whether tractors and other ground-based yarders can operate within streams or their buffer zones.

The states' BMPs for these activities carefully protect fish-bearing streams, but small non-fish streams are not as carefully protected. All states require that trees be felled away from and not bucked and limbed in fish-bearing streams; however, several states allow felling, bucking, and limbing in small non-fish streams. Washington and Idaho, for example, allow felling, bucking, and limbing in perennial non-fish streams as long as care is taken to minimize accumulation of slash. Cable yarding across fish-bearing streams must have full suspension and prior approval in Oregon and Washington, except for small non-fish streams. Tractor yarding is generally not allowed across fish-bearing streams and not allowed in most perennial non-fish streams except at constructed temporary crossings; however, all the states allow some log skidding across intermittent non-fish channels. For example, Oregon allows log skidding across dry streambeds where the disturbance is less than it would be to construct temporary crossings. Washington and California allow log skidding across intermittent non-fish stream channels unless a buffer zone is deemed necessary by on-site inspection.

Because small non-fish streams are particularly important for controlling sediment delivery and because buffer zones along them are usually narrow and heavily harvested, BMPs for felling and yarding must be closely monitored to ensure that they are effective. Effective BMPs are essential because they may be the only practical means of protecting the numerous non-fish headwater streams in managed timberlands while other resource activities continue.

Differences in BMPs among the five states and among regions within the states are due to different emphasis in addressing different logging practices, forest types, and watershed conditions. For example, tractor yarding is probably the most widely used method in California, but it is used much less in the other states. Selective tree harvest is also used extensively in drier regions, such as in eastern Oregon, whereas clearcutting predominates in coastal regions. The BMPs in the different states must also contend with very different potential for soil erosion. Watersheds in different geologic provinces in the five states produce vastly different amounts of sediment. Streams in Oregon's Coast Range, for example, annually export 53–102 metric tonnes per km^2 compared to 2,600 tonnes per km^2 in northern California's Coast Range (Hawkins et al. 1983).

The BMPs in regions with high erosion potential need to be more restrictive to prevent sediment pollution, yet tractor yarding, the most disruptive yarding method, is allowed on steeper slopes in California (up to 65% slope) than in the other states (e.g., up to 45% in Idaho and 35% in Oregon). Preventing sediment pollution in northern California presents a major challenge to watershed managers because of the combination of extensive tractor yarding on steep slopes in one of the most erosive landscapes in the world.

CUMULATIVE EFFECTS MANAGEMENT

Both federal and state programs consider cumulative effects. The FS and BLM are devoting effort to watershed analysis in the Pacific Northwest, but the FS has tried watershed analysis on only three watersheds in the Tongass National Forest in Alaska. Washington has a watershed analysis program, and California and Idaho have analogous systems for analyzing watershed condition and prescribing precautionary BMPs to help avoid cumulative effects. The states of Oregon and Alaska do not conduct watershed analysis nor have a process for evaluating cumulative effects.

Applying watershed analysis on private land is difficult for several reasons. The cost of watershed analysis adds a burden to landowners. Most landowners do not have the personnel to do the analysis and must look outside their companies for certified analysts. Getting cooperation and coordination among different landowners in a watershed is often difficult.

Current programs address these difficulties in different ways. In Washington, watershed analysis is conducted by the State Department of Natural Resources in cooperation with landowners. In California and Idaho, the cumulative effects analysis is done by private certified foresters and evaluators. Idaho coordinates its cumulative effects analysis by forming committees of landowners. In watersheds with mixed federal and private ownerships, the FS and BLM can reach out to form cooperative arrangements with private landowners.

Watershed analysis is probably most effective if it provides managers with information necessary to write management prescriptions that address site-specific concerns identified in the analysis.

Federal watershed analysis does not provide prescriptions or alternatives, but is only a process to gather and analyze data for input into decision processes. The Washington or Idaho methods of doing watershed analyses may be the best prototype models to use for prescriptive watershed analysis on private lands with mixed ownerships. Watershed analysis, however, is in its infancy, and more experience is needed to develop its potential for increasing the effectiveness of habitat protection on private timberlands.

Chapter 9
Habitat Restoration

Habitat restoration is one element in a comprehensive program of watershed management that emphasizes habitat protection. The FS and BLM, for example, recognize watershed restoration as one of four components in their Aquatic Conservation Strategy which also includes key watersheds, riparian reserves, and watershed analysis (FEMAT 1993). Habitat restoration is an interim measure until watersheds recover under good management, not a mitigation or an exemption from stream protection.

Stream restoration science is founded on hydrologic principles, stream ecosystem theory, fish-habitat relationships, the concept of limiting factors, and a growing awareness of human impacts on stream ecosystems (Koski 1992). Although the term "restoration" infers returning to an original state, restoration of heavily impacted streams to original condition is generally not practical (Herricks and Osborne 1985). **Habitat restoration is really a pragmatic mix of protection and rehabilitation to some improved level consistent with multiple use of the watershed.**

The approach to habitat restoration described here applies principally to forest lands affected by past timber harvest practices. The approach and techniques may need to be modified to apply to lands affected by mining, grazing, agriculture, urban development, and other uses where considerations in restoring fish habitat may be different than for streams in altered forests (e.g., Ferguson 1991). Numerous reports, workshops, and training sessions have covered the topic of stream restoration (e.g., Gore 1985; Hunter 1991; Reeves et al. 1991; Koski 1992). This chapter briefly reviews the procedures for restoration, presents examples of ongoing restoration programs, and discusses the role of restoration in an overall watershed management program.

RESTORATION PROCEDURES

To be successful, stream habitat restoration requires a holistic approach directed at the entire watershed to ensure that it addresses all major environmental factors affecting the stream ecosystem (Koski 1992). Resource analysis at the scale of the river basin should precede restoration of individual watersheds composing the basin to provide a broad context. Watershed analysis should be used to determine how the watershed functions, which parameters are outside the range of natural variability, and what the restoration potential is (Kershner 1993). Any restoration project should be nested within a larger program of landscape management that protects, maintains, and restores ecosystem structure and function (Gregory 1993b).

Sound restoration requires a solid foundation on ecological principles and a clear recognition of the dynamic nature of streams and adjacent forests (Gregory 1993b). The goal is to reestablish the ability of the watershed to maintain its functions and organization without continued human intervention. Most importantly, practices that caused degradation need to be changed before attempting restoration.

The most important technical elements of a holistic restoration program are 1) upland restoration to control erosion, 2) riparian restoration to restore functions of streamside vegetation, and 3) instream restoration to improve habitat structure by physically modifying stream channels or their flood plains.

Upland Restoration

A first step in restoration is to initiate "upland restoration" to begin recovery of watershed hydrologic and erosional processes. This is a broad-based program to control erosion from roads and bare soils, restore natural streamflow regimes, and manage all uses of the stream and watershed.

A high priority in upland restoration is to address problems with roads (Pacific Rivers Council 1993a). Existing needed roads should be stabilized, and abandoned and unneeded roads should be closed and shaped to stable contours and to drain properly without maintenance (Furniss et al. 1991). Dirt roads should be surfaced with gravel or asphalt to reduce sediment production from road usage (J. Anderson, FS, Baker City, OR, pers. comm. 1994). Road obliteration can prevent most future erosion if road surfaces are backfilled, stream crossings are removed, stream channels are reconstructed to stable configurations, and all bare surfaces are revegetated (Fig. 9.1).

Another first step in restoration is to provide access for fish to suitable habitat where blocked by road crossings. Culverts should be improved or replaced with bridges when necessary to allow upstream fish passage. Restoration work should also address migration blockages caused by other watershed impacts. Fishways can be constructed to provide access where sediment from landslides or excessive erosion deposited in the stream blocks upstream migration (Flosi and Reynolds 1991). Where the sediment forms thick alluvial fans at tributary mouths, boulder fishways can take advantage of scour from the main stem during high streamflow to maintain the fishway (S. Downey, CDFG, Redway, CA, pers. comm. 1994).

Riparian Restoration

Restoration of riparian areas promotes long-term recovery of numerous important riparian functions that strongly influence fish habitat in streams (Beschta 1991; Chan 1993; Everett et al. 1994). Past riparian harvest combined with other watershed impacts have left many riparian areas in degraded condition with poor prospects for recovery (Chan 1993). Impacts from homesteading, grazing, and logging along streams in western Oregon and Washington resulted in development of homogeneous alder and salmonberry (*Rubus spectabilis*) communities in nearly all riparian areas (Gregory et al. 1990; FEMAT 1993). In this region, riparian areas have few

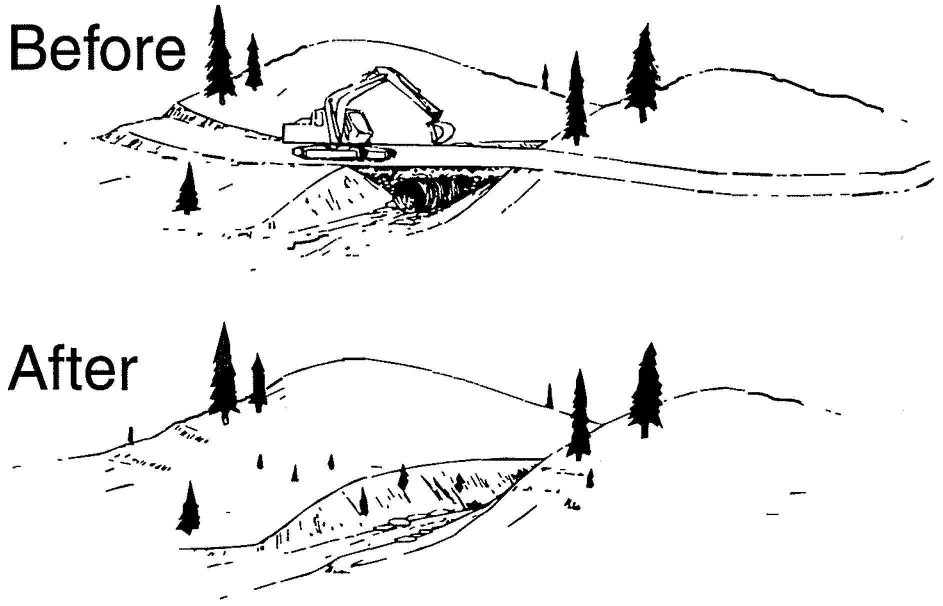

Figure 9.1. Unused and unneeded roads should be "put to bed" by removing culverts and outsloping road surfaces to drain properly without maintenance. (After Furniss et al. 1991.)

trees larger than 10 inches (>25 cm) diameter growing within 100–200 ft (30–60 m) of the stream, and recruitment of large wood may be deficient for decades (FEMAT 1993).

Loss of large conifers from riparian areas worsens the effects of floods on fish habitat. Alder-dominated flood plains do not have the structural integrity to resist damage from excessive scour during high water and debris torrents, whereas large conifers naturally could withstand high flows, hold debris jams, and reduce scouring of the flood plain (Chan 1993). Once large conifers are removed, continual floodplain scouring may prevent their natural reestablishment without restoration to stabilize the stream channel (J. Barnes, FS, Arcata CA, pers. comm. 1994).

In other situation, absence of LWD derived from large conifers can result in channel erosion and downcutting during high streamflow because LWD from alder and other hardwoods is inadequate for structuring the stream channel (Andrus et al. 1988; Heimann 1988). This downcutting lowers local water tables and breaks the linkages between the stream and its flood plain because the lower channel prevents the stream from overflowing its banks (Beschta 1991). Off-channel moisture recharge and storage are reduced and base streamflow declines, which is particularly troublesome in regions with summer droughts. A prime objective of adding LWD, boulders, and other "roughness elements" in bedrock channels is to rebuild the stream's aquifer (L. Hood and L. Burton, FS, Mapleton, OR, pers. comm. 1994). Downcutting also reduces the natural disturbance of the flood plain during peak streamflows. This natural disturbance is needed for the establishment of conifers, and lack of floodplain disturbance encourages the succession of riparian areas to shrub vegetation (S. Chan, FS, Corvallis, OR, pers. comm. 1994).

Silvicultural treatments have potential long-term benefits in restoring habitat functions of riparian areas. A treatment being used and tested extensively in western Oregon is underplanting and thinning to reestablish native conifers (Emmingham et al. 1989; Chan 1993). Because the streams have been downcut, boulders and LWD structures are also added to the stream in conjunction with this riparian restoration to reestablish stream-floodplain linkages (L. Burton, FS, Mapleton, OR, pers. comm. 1994). Thinning of overdense stands also helps reduce fire risks. Caution is warranted, however, because few studies have been completed from which to judge effectiveness.

Under suitable conditions, conifers can naturally become dominant over alder (J. Henderson, FS, Seattle, WA, pers. comm. 1995). If Douglas-fir begins to grow at the same time that alder becomes established, it may compete successfully and develop a dominant canopy well before alder becomes senescent. Western hemlock and western red cedar are shade tolerant and can grow slowly under alder and become dominant as the alders begin maturing and dying. On cool, wet sites, Sitka spruce grows steadily in either openings or beneath alder canopy, and may dominate over alder after 60–90 years (Henderson et al. 1989).

In many cases, however, degraded riparian vegetation may not recover without active management intervention (Sedell et al. 1989). Alder-dominated riparian areas are especially susceptible to poor conifer regeneration due to low light, lack of a conifer seed source, and lack of downed wood or mineral soil needed for a suitable seedbed. The relatively short life of alder, scarcity of conifer seedlings, dense shrub understories, and lack of natural floodplain disturbance because of stream downcutting indicate that many areas would eventually succeed to shrubs without management intervention (Hibbs et al. 1991).

Although some floodplain disturbance is desirable for the establishment of conifers, excessive flooding and severe scouring of the floodplain may prevent conifer establishment (Henderson 1978). Excessive scouring could result from upland disturbances in the watershed and a lack of large conifers in the riparian area. Large conifers help protect the floodplain from scour because they can withstand flood damage better than alder and can trap flood-entrained debris. Until large conifers can become established, floodplain biological communities are more susceptible to flood damage and may be kept in an early successional stage dominated by alder and salmonberry.

Successful restoration of riparian areas must involve active management for a long time (Chan 1993). Because of strong competition, simply planting trees in alder and salmonberry without at least partially removing the overstory and understory is unlikely to succeed. Managers will have to monitor tree growth and survival, and periodically remove understory shrubs to ensure the reestablishment of conifers. Enlightened management policies and practices are needed that will provide the maximum beneficial effects of riparian vegetation on stream hydrology and channel morphology (Beschta 1991). Managers should move toward policies that protect, reestablish, and encourage the functional attributes of riparian vegetation.

Instream Restoration

After upland and riparian problems have been addressed, the third restoration step is to improve instream habitats to increase carrying capacity and fish survival. This is an interim "fix" until the natural long-term recovery of the watershed has begun (Koski 1992). In this step, the primary focus is on using instream structures to alleviate limiting factors, such as to retain spawning gravel or create additional rearing pools. Success of instream structures depends on condition of upslope areas and the continuing hydrologic response to past and ongoing watershed disturbance. Thus, instream structures are recommended only as part of a comprehensive watershed program (Koski 1992).

Though an interim measure, instream restoration may be crucial as part of a program to recover anadromous salmonids while long-term restoration measures have time to become effective (Koski 1992). Attaining desired levels of channel complexity and other habitat conditions may best be achieved in the short term with instream structures until the recovery of watershed hydrologic processes and riparian forests provide for long-term maintenance of the stream channel.

Instream restoration has been criticized as ineffective (Frissell and Nawa 1992). In the past, many instream restoration projects proceeded without adequate planning and evaluation, and commonly prescribed structures were often inappropriate or counterproductive (J. Anderson, FS, Baker City, OR, pers. comm. 1994). Many projects failed or did not demonstrate their effectiveness. Conversely, instream restoration projects that were accompanied by careful planning, monitoring and evaluation, and constructed by experienced biologists have been successful in improving fish habitat (House et al. 1991; Crispin et al. 1993).

Instream projects have mainly targeted one species (coho salmon) although associated species may also have benefitted. Generally, however, restoration efforts should take a "community approach" which emphasizes recovery of native biological communities with their full diversity of aquatic and riparian-dependent species (Sedell and Beschta 1991). Care must be taken to avoid negative effects on other species when altering instream habitat for salmonids. Species like the foothill yellow-legged frog (*Rana boylii*), which has declined alarmingly in California (Welsh et al. 1991), can be adversely affected by instream structures (Fuller and Lind 1994). Similarly, altering habitat to favor one salmonid species may negatively affect another. Adding LWD for coho rearing, for example, may decrease spawning habitat for pink salmon. The goal of the community approach is to restore ecosystem structures and functions that support diverse biological communities including healthy salmonid populations. This approach provides for continued viability of coexisting salmonid stocks, as well as other fish and wildlife species.

Not taking a watershed perspective has been one of the main reasons for failure of instream structures. Frissell and Nawa (1992) evaluated instream structures in 15 streams in western Oregon and Washington after a flood. Damage to structures was widespread in streams with recent watershed disturbance, high sediment loads, and unstable channels. Many structures failed because of altered flow regimes, increased sedimentation, or debris torrents from upslope activities.

Instream structures are most appropriate where upslope portions of the watershed have stabilized and the major habitat problem is lack of physical structure in the stream channel. In such cases, instream structures can provide great benefits. For example, after 8 years, 86% of 812 structures on 10 streams were fully successful in restructuring stream reaches by increasing gravel substrate, instream cover, pool habitat, and total usable habitat (House et al. 1989). In another evaluation, 98% of 200 instream structures were still functioning after 1-4 years, and they had increased pool area and off-channel habitat for coho salmon nearly five fold (Crispin et al. 1993). Addition of conifer logs to debris-poor streams and construction of off-channel alcove habitats can increase salmonid smolt production several fold (Fig. 9.2; Solazzi and Johnson 1994).

An important benefit of instream structures is that they can help reestablish linkages between the stream and its flood plain (House et al. 1991). By trapping sediments and increasing channel complexity, instream structures can raise the water table and expand the stream's flood plain, thus reversing the downcutting that occurred historically from the loss of LWD (J. Cederholm, WDNR, Olympia, WA, pers. comm. 1994). The expanded floodplain also helps reduce adverse effects of peak streamflows because flood waters can spread out over a broader area. This also increases water storage capacity, which helps augment streamflow during droughts (Beschta 1991).

Most instream restoration projects have been directed at improving migration, spawning, or rearing habitat. Instream projects usually attempt to mimic factors that shape and stabilize the stream channel, store sediment, create pools, dissipate stream energy, and provide diverse habitat for either spawning or rearing (Fig. 9.3; Koski 1992). Barriers have been removed and fishways constructed to provide access to habitat. Stream gravel has been cleaned or trapped to improve spawning, and spawning channels have been constructed to increase spawning area. Diverse structures have been added to stream channels to provide summer and winter rearing habitat, and streambanks have been protected to deepen streams and reduce floodplain scour and channel erosion.

Many types of instream structures have been used in stream restoration projects (Koski 1992). In the Pacific Northwest, most structures have been installed in streams of fourth to fifth order with normal peak flows about 6-60 m^3 s^{-1} and with channel gradients of 1 to 3%. In large streams, boulders, whole trees, or cabled logs are used for main-channel structures, instream cover, and bank protection.

Restoration practitioners use a variety of techniques and structures, including:

Dams formed by cross-stream structures simulate natural debris jams or boulder dams in natural streams. Dams are used to create plunge pools downstream and dammed pools upstream, to collect gravel, or sort sediments.

Deflectors, also called wing dams or jetties, have been one of the most commonly used structures to improve fish habitat. Deflectors simulate obstructions that divert streamflow and are used to create pools and cover by narrowing and deepening the stream.

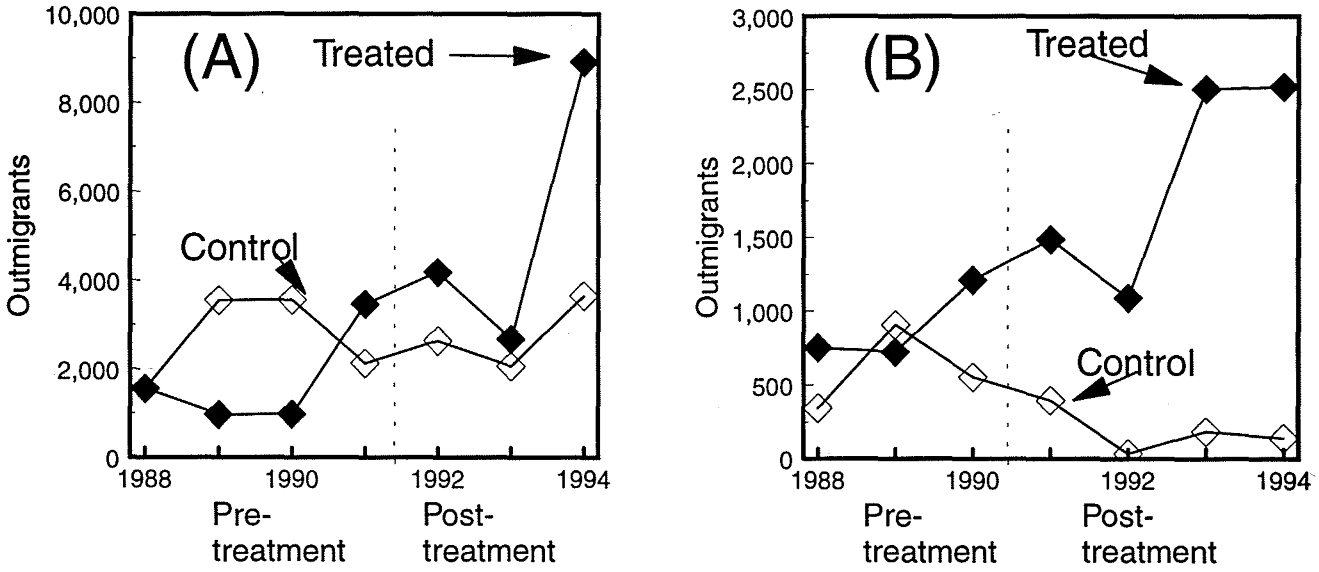

Figure 9.2. Increases in number of outmigrant coho salmon smolts after experimental addition of large woody debris to debris-poor streams in the Alsea River basin (A) and Nestucca R. basin (B) in western Oregon. Treatment occurred in summer 1990. (Data are from Solazzi and Johnson 1994.)

Cover consists of overhead or instream features, such as overhanging vegetation, woody debris, brush bundles, root wads, boulders, substrate interstices, turbulence, and depth. Adding cover combined with other instream structures makes structures more usable by fish. The objective in adding cover is usually to reduce predation and increase fish survival during peak flows.

Stream banks are sometimes protected from scour with revetments or riprap of boulders, woody debris, or brush bundles. Planting shrubs and trees also helps establish root systems that stabilize the bank and provide overhanging cover for fish. Riprap combined with other instream structures stabilizes the created habitat. Riprapping can be used to armor streambanks to protect the toe of unstable hillslopes (Flosi and Reynolds 1991). Excessive riprapping, however, can be detrimental by eliminating side channels, pools, and other complex features (Andrus 1991).

Off-channel habitat, such as pools and alcoves, are constructed or blasted into flood plains along low-gradient streams to provide cover for rearing juvenile salmonids. Protected from peak streamflows, these areas can provide important overwinter habitat (Cederholm et al. 1988; Nickelson et al. 1992b).

Beavers can be introduced or encouraged to colonize an area by planting aspen and other food trees (Andrus 1991). Beaver ponds provide important winter habitat for juvenile coho salmon (Nickelson et al. 1992a), as well as provide other beneficial hydrologic functions for stream ecosystems (Beschta 1991).

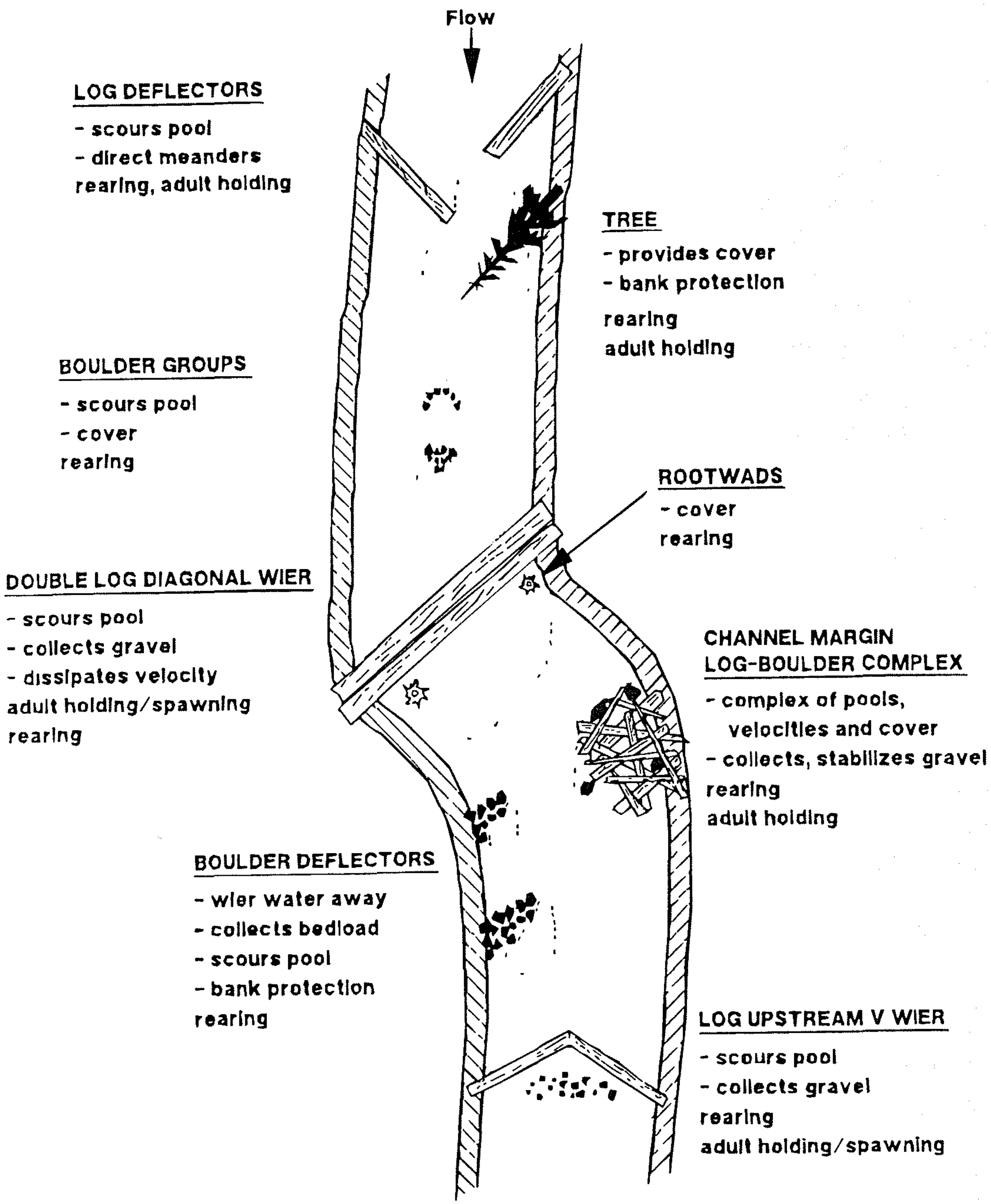

Figure 9.3. Diagram showing variety of instream projects that shape and stabilize the stream channel, store sediment, create pools, dissipate stream energy, and provide diverse habitat for either spawning or rearing. (From Koski 1992; reprinted with permission from Maryland Sea Grant College.)

Restoration Planning and Evaluation

Planning for habitat restoration has two levels: program planning and project planning (Everest et al. 1991). At the program level, managers should consider coordination of financial and personnel resources and priorities for watersheds and species. The target species and the proposed methodology should be carefully considered so that one species is not emphasized at the expense of others. An ecosystem approach to restoration targets habitat complexity to benefit a diversity of species and life stages (Sedell and Beschta 1991). Interdisciplinary consultations are needed to ensure success, and projects should be designed by professionals from as many relevant disciplines as possible (Gregory 1993b).

Project-level planning considers specific details of proposed projects, including the size of the area and the time allotted for inventory of fish and habitat. The project watershed should be larger than 50 km^2 to account for seasonal changes in fish distribution (Everest et al. 1991). Ideally, data on fish distribution and habitat should be available for at least 1 year for analysis of limiting factors (Koski 1992). Project planning is closely coordinated with program planning and follows a stepwise sequence: 1) pre-improvement inventory, 2) limiting factor analysis, 3) site selection, 4) techniques and materials selection, 5) implementation plan, and 6) project evaluation.

The pre-improvement inventory is a crucial step in which watershed attributes are inventoried to identify habitat problems. Surveys of hillslope erosion, riparian vegetation, stream channels, and fish populations provide a basis for analyzing limiting factors and baselines for later evaluations (M. Solazzi, ODFW, Corvallis, OR, pers. comm. 1994).

An analysis of limiting factors must be completed before any habitat enhancement is begun (Reeves et al. 1989). Although the limiting factor concept is useful in identifying limitations to salmonid production, it can oversimplify complex ecological processes (Hall and Baker 1982). As many as 73 factors could potentially limit fish production in a hypothetical stream with three or more salmonid species, each with different age classes and habitat requirements (Everest and Sedell 1984). Historical logging affected multiple habitat factors in streams, and one or more of the factors could be limiting to fish production. A thorough knowledge of habitat requirements and life histories of the endemic stocks in a stream can help in identifying limiting factors and indicating approaches for restoration.

The emphasis in choosing materials and techniques should be to simulate natural habitat. If woody debris is the dominant feature, log structures are used; if bedrock or boulders dominate, boulder structures are used. Particularly in areas of heavy use by sport angling, the project should appear natural. Conifer logs are more effective and persist longer than alder logs. Adding alder logs to a stream is inexpensive, but has only limited value, as effects diminish after several years (C. J. Cederholm, WDNR, pers. comm. 1995). Experienced practitioners use observations of stable materials in the stream to guide them in choosing appropriate size and type of materials to use (S. Downie, CDFG, Redway, CA, pers. comm. 1994).

Evaluating effectiveness of habitat restoration has been neglected but is important in improving restoration technology and demonstrating the benefits of restoration (Hall 1984; Koski 1992).

The most meaningful evaluations simultaneously examine habitat, fish production, and cost effectiveness (Everest et al. 1991). Habitat indicates whether the project attained the desired changes; fish production indicates whether the habitat changes produced the desired effect on the target species. Cost effectiveness shows whether the increased benefits were worth the expense.

Effectiveness monitoring can be conducted for both specific restoration practices and for the cumulative effects of the set of practices applied in the watershed (MacDonald et al. 1991). Monitoring of a specific practice, such as planting vegetation to prevent erosion, indicates whether that practice was successful in a specific situation. Monitoring the entire set of practices determines whether the cumulative effect of all the individual practices was successful in attaining objectives. Effectiveness evaluations are not needed for every individual project, and they are actually outlawed by some appropriation legislation (e.g., California's restoration program), but evaluations should be done for a representative sample of projects across a range of stream types, and for the overall program. Many worthwhile evaluations can be based on professional judgement and unpublished observations of experienced professional practitioners. However, formal scientific studies that fully evaluate projects are needed for at least representative restoration projects.

Cost effectiveness should include the costs of planning, implementation, and maintenance, and the benefits derived from the increased fish production and other attributes in the basin over the longevity of the project. The benefit-cost ratio and present net worth of habitat improvement projects can be assessed (Everest and Talhelm 1982; Everest and Sedell 1984; Everest et al. 1987b). However, this is rarely done because of the time required to thoroughly evaluate changes in habitat and fish production. Almost no literature exists that treats appropriate economic monitoring for ecosystem restoration (Weigand 1994). Evaluating benefits is also difficult because the widespread depressed level of fish populations causes underutilization of improved habitats (J. Barnes, FS, Arcata, CA, pers. comm. 1994).

Evaluations of over 1,200 stream improvement projects in Oregon (Andrus 1991) resulted in nine recommendations for increasing effectiveness: 1) allocate more funds for examining limiting factors and for monitoring results; 2) consolidate smaller projects and treat long channel segments in a few watersheds rather than dispersing projects among many watersheds; 3) exploit the potential of beaver in enhancing channel structure; 4) explore less costly methods for improving channel structure; 5) prioritize funding for areas with important fisheries resources; 6) increase funding for demonstration projects on urban streams to promote public awareness; 7) reevaluate the practice of riprapping streambanks (consider the loss of fish habitat that occurs when riprapping results in a channelized stream); 8) identify streams where high temperature limits production and restore riparian vegetation before using instream structures; and 9) continue to archive information on completed projects so that results can be evaluated.

RESTORATION PLANNING ON PRIVATE LANDS

Restoration opportunities on private lands depend on providing incentives and obtaining access. Some of the best potential fish habitat is located in the low-elevation watersheds that have been intensively managed for timber. To effect restoration on private lands, landowners must be given incentives to conduct restoration or cooperate with federal and state efforts.

Although restoration projects should generally undergo extensive planning and evaluation, these types of reviews are most appropriate for programs on public lands or large projects. For smaller projects on private lands, such rigorous reviews are not easily accomplished nor always necessary. Addition of LWD during timber harvest to restore stream habitat complexity is an example of a small project not requiring extensive planning and evaluation (C. Andrus, ODF, Salem, OR, pers. comm. 1994). A representative sample of such projects, however, must be evaluated for effectiveness, and the projects must address known limiting factors.

A streamlined permitting and design process is needed to take better advantage of restoration opportunities on private lands (T. O'Dell and L. Diller, Simpson Timber Company, Korbel, CA, pers. comm. 1994). Opportunities for adding LWD or boulders to debris-poor streams on private lands often arise during timber harvest when equipment, materials, and labor are on site. To help willing landowners to contribute and to ensure proper design of instream structures, trained agency personnel should be available to help companies obtain permits and advise them on placing instream structures so that the work can be done cost-effectively without delay.

CURRENT RESTORATION PROGRAMS

Many federal, state, and local agencies, tribes, and private interests are actively involved in habitat restoration. On federal lands, the FS and BLM have large programs aimed at all aspects of habitat restoration, including watershed, riparian, and instream restoration.

Restoration on National Forests

The restoration program on the Six Rivers National Forest in northern California provides an example of ongoing restoration on federal lands (J. Barnes, FS, Arcata, CA, pers. comm. 1994). Streams in this region were heavily impacted by landslides during a 100-year flood in 1964. The stream channels have aggraded and become wide and shallow, lacking pools and habitat complexity. Changed logging practices and road improvements have stabilized watershed processes, allowing instream restoration to be effective. Funds for restoration come mainly from the State of California restoration program through its Wildlife Conservation Board.

The primary restoration objective for streams on the Six Rivers National Forest is to provide rearing habitat for juvenile steelhead by the addition of instream structures to narrow and deepen stream channels, create pools and winter cover, and stabilize channels to allow reestablishment of riparian vegetation (Fig. 9.4). Although steelhead are the target species, fall chinook and cutthroat trout are also of concern (Fuller 1990; McCain 1992), as well as other aquatic non-fish species (Fuller and Lind 1994). Although some early mistakes were made in boulder placement, updated techniques effectively increase salmonid carrying capacity in treated reaches (J. Barnes, FS, Arcata, CA, pers. comm. 1994).

Other funds for restoration on national forests can come from the Knutson-Vandenberg Act (1930, amended 1976) which provides money out of timber sale receipts for improving productivity of renewable resources on Forest lands. Use of these "K-V" funds for restoration, however, is hampered because they must be spent within the boundaries of the specific timber sale, which frequently does not coincide with restoration needs.

California's Habitat Restoration Program

California has an active program of habitat restoration for private lands administered by the CDFG. The total budget for the restoration program is about $5 million per year (J. Steele, CDFG, Sacramento, CA, pers. comm. 1994). Funding can come from sales of commercial fishing stamps, angling licenses, permit fees, statewide initiatives, and other sources. Private-sector cooperation, involving matching funds, in-kind contributions, and volunteer efforts, is growing strongly.

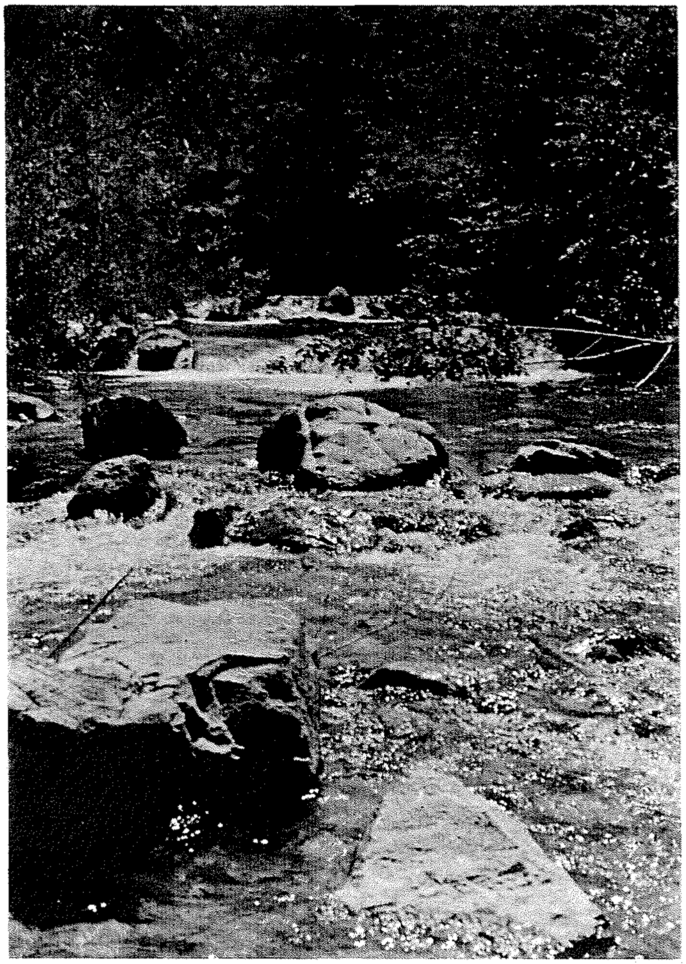

Figure 9.4. Boulders and logs used to form pools and provide complex cover in Redcap Creek, Six Rivers National Forest, California. The stream was heavily impacted by landslides and resulting sedimentation and scour. Before instream structures were added, the channel was stabilized by riprapping to allow establishment of the dense riparian vegetation shown in the photo. (Photo courtesy of J. Barnes, FS.)

A cottage industry of restoration companies has developed in California to conduct restoration activities in cooperation with CDFG. Proposals are submitted by the companies and evaluated by CDFG, and a restoration manual (Flosi and Reynolds 1991) gives specific direction for preliminary watershed assessments, habitat inventories, project planning, and implementation. Research on effectiveness evaluations, however, are prohibited by the legislation establishing the program. Since 1981, nearly 3,000 restoration projects administered by CDFG have been completed to control erosion, improve fish passage, stabilize stream banks, and improve instream habitat (Fig. 9.5). California's restoration program also supports supplemental hatchery and educational programs.

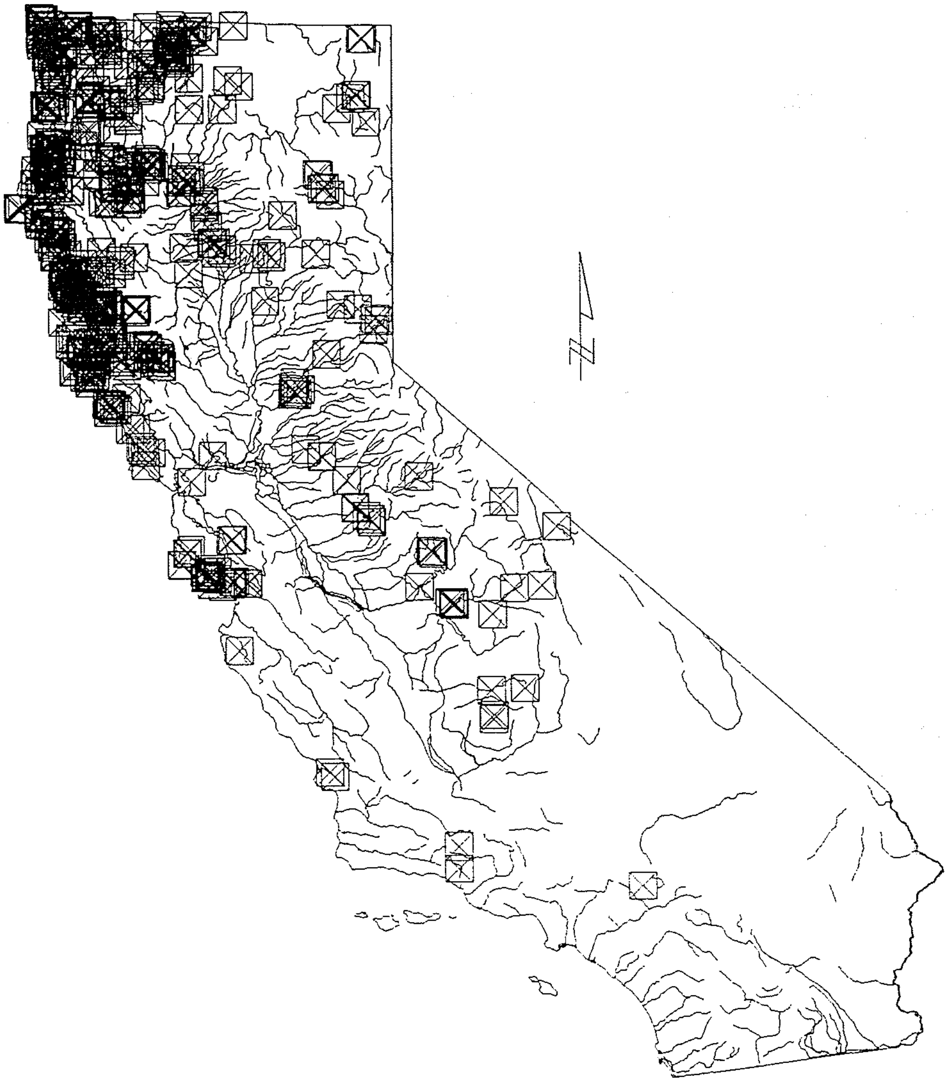

Figure 9.5. Distribution of nearly 3,000 restoration projects administered by California Department of Fish and Game done to control erosion, improve fish passage, stabilize stream banks, and improve instream habitat. (Figure courtesy of J. Hopelain, California Department of Fish and Game.)

Oregon's Basal Area Credits

Oregon incorporated incentives for habitat restoration into its new forest practices rules that provide credits for instream or other restoration projects conducted by landowners during timber harvest (ODF 1994; ODF and ODFW 1995). Other aspects of Oregon's rules encourage active silvicultural management of riparian areas to reestablish mature conifers, an important objective of riparian restoration. The principal objective of the credit for instream restoration is to improve fish habitat in streams that lack LWD. The credits provide incentives for operators to place logs in streams or take other actions to immediately improve fish habitat.

Subject to prior approval of the State Forester, operators may place conifer logs or downed trees in fish-bearing streams and receive "basal area credit" toward meeting the requirement for retaining live trees in a stream's riparian management area. Basal area is determined by measuring cross-sectional area of the large end of the log or at the spot on a downed tree that would be equivalent to breast height. For large and medium Type F streams, the credit is twice the basal area of the placed log (i.e., for every log placed in a stream, approximately two trees can be harvested from the RMA). For small Type F streams, the credit is equal to the basal area of the placed log. The basal area credit, however, can not reduce the standing tree retention below "active management" targets specified in the rules. These active-management targets are usually about 75% of the standard targets.

In placing logs, operators must follow prescriptions from the State Forester (ODF and ODFW 1995). Operators may also propose other enhancement projects for basal area credit, such as creation of off-channel alcoves and fencing to exclude cattle. Such enhancement projects are reviewed by ODFW, and the basal area credit is negotiated among the operator, ODF, and ODFW.

The advantages of this program are that it costs much less than other instream restoration practices, and it encourages landowners to participate in restoration on private lands. Possible disadvantages include the lack of careful pre-project evaluations and the current lack of research on the program's effectiveness and possible unintentional adverse effects. "Credit trees" usually do not include the rootwad, which makes them potentially less stable and less effective than natural LWD. "Credit trees" are placed without anchoring or cabling to stabilize the logs in place, which could cause problems with channel instability. In addition, Oregon does not use watershed analysis in evaluating timber harvest plans. Thus, the projects may not address the actual factors limiting fish production. They target mainly coho salmon, and other species may be adversely affected. The "credit-tree" projects are being monitored (C. Andrus, ODF, Salem, OR, pers. comm. 1994), but results are not yet available. Another potential problem is that future LWD recruitment could be reduced because an operator can take two trees from the RMA for each one placed in the stream. Maintaining "active-management" targets for standing trees in the RMA establishes a minimum level for basal area, which should prevent excessive harvest.

The benefits may outweigh the potential disadvantages. The "credit-tree" projects directly address the lack of LWD in streams, which is widespread, well documented (e.g., Beschta 1991), and recognized as the most common limiting factor for coho salmon (Nickelson et al. 1992a). Although the logs are not anchored or cabled, movement alone should not be considered a failure. In many respects, effective redistribution of wood by the stream may be ecologically more desirable than if it remained in an original fixed position (Gregory and Wildman 1994).

THE ROLE OF RESTORATION IN WATERSHED MANAGEMENT

Watershed restoration is an integral part of a comprehensive program to recover anadromous fish habitat that emphasizes habitat protection and uses restoration to stabilize deteriorating conditions and accelerate recovery in key watersheds. Before initiating restoration, land uses that have caused the degradation need to be modified to end adverse effects.

Considering the cost of restoration, habitat protection is obviously preferable to allowing habitat to degrade to the point of needing restoration. Costs of restoration vary depending on limiting factors, stream size, restoration methods, project objectives, and other factors. Projects that used mostly instream structures cost an average $24,000 per stream km and ranged up to $1.2 million per stream km (House et al. 1989; Hunter 1991). Costs of stabilizing watershed slopes and existing roads, obliterating abandoned roads, and replanting riparian areas are also high (Koski 1992). Restoration practitioners are attempting to find less expensive ways to improve habitat (Cederholm et al. 1988; Cederholm and Scarlett 1991; Flosi and Reynolds 1991), but costs remain high.

The need for restoration is great. For example, more than two-thirds of the riparian areas in the Pacific Northwest are substantially degraded and need reforestation (Pacific Rivers Council 1993a), and 50–85% of all streams in the region need restoration (McMahon 1989). Cost of upland, riparian, and instream restoration in key watersheds comprising about one-third of federal lands in Oregon, Washington, and northern California would exceed $700 million (Pacific Rivers Council 1993a). Political will and commitment will be indispensable to formulating and implementing restoration that would be significant in light of this great need (Wiegand 1994).

Restoration costs money, but its return on investment can be considerable. The return of salmon and recovery of watershed functions have many social and economic benefits, and the direct restoration work would generate many jobs (Pacific Rivers Council 1993a). Due to limited funds and the large amount of degraded habitat, most habitat will have to rely on slow recovery under effective watershed management. Much can be done, however, to speed recovery in priority areas of heavy human use or severely depressed stocks. Major goals should be to maintain existing wild stocks and promote recovery of stocks listed under the Endangered Species Act.

Priorities for restoration should be key watersheds that remain healthy, rather than the most degraded areas (FEMAT 1993). The most urgent restoration task is protection of key watersheds and riparian areas and immediate prevention of imminent road-related sedimentation (Pacific Rivers Council 1993a). The goal should be to secure, expand, and link the healthier areas in a system of refugia watersheds connected by intact migration corridors (Frissell et al. 1993). This approach would yield a quicker, more widespread, and more cost-effective response.

Along with habitat restoration, small supplemental rearing programs may help to speed recovery of wild stocks (e.g., Pacific Lumber Company 1993). Supplemental rearing programs operate small hatcheries and utilize stocks native to the watershed being restored. Their purpose is to speed recovery of the native stock to take full advantage of the restored habitat. Such hatchery programs can be discontinued once recovery is achieved, to minimize potential genetic effects on the wild stock.

Restoration programs should also include an educational component to inform the public about the value of watershed resources and the importance of habitat protection (Koski 1992). Education offers the best possibility of increasing public awareness of environmental issues and instilling a conservation ethic needed to ensure long-term sustainability of salmonid habitats.

Restoring habitat alone can not guarantee recovery of anadromous salmonids. Fisheries management and hydropower also need to contribute (Palmisano et al. 1993; Botkin et al. 1994; USDC 1995). Concurrent with habitat restoration, fisheries management needs to ensure adequate spawner escapements to fully seed the restored habitat. Many depressed wild stocks can not recover without coordinated fisheries management to curtail harvest (C. J. Cederholm, WDNR, Olympia, WA, pers. comm. 1994). Operation of hydropower facilities on river main stems needs to provide upstream passage for adult salmonids and adequate survival of downstream migrant juveniles.

Habitat restoration is not a panacea for habitat recovery (Koski 1992). Habitat restoration and protection, however, are critical because even with fisheries closures, depressed stocks can not recover without habitat.

Chapter 10
Conclusions and Recommendations

A comprehensive watershed-level approach is essential for maintaining and restoring salmonid habitat because the watershed is a fundamental unit for both ecological processes and land management. The failure of past piecework forest management to prevent habitat degradation or to accomplish restoration of stream reaches shows the need for an ecosystem-based, watershed-level management strategy.

The main technical elements of the watershed approach are buffer zones, BMPs, watershed analysis, and restoration. Because any conservation strategy will probably fail without community support, watershed management also includes outreach programs to recruit support from local citizens and enlist cooperation from private landowners.

BUFFER ZONES

Buffer zones are probably the most important tool for protecting critical riparian and aquatic processes. Buffer zones along streams, however, can not maintain fish habitat unless sensitive watershed areas and hydrologic processes are also protected by effective watershed management.

Buffer zones do not need to be "lock-out" zones if management activities within them maintain or restore critical riparian processes. The appropriate design for buffer zones depends on management objectives. The widest buffers with greatest restrictions on activities are used along fish-bearing streams to meet the full range of objectives for fish habitat, as well as for other wildlife (e.g., owls and amphibians). Narrower buffers with fewer restrictions can be used along non-fish streams to protect water quality and downstream fish habitat.

To fully protect fish-bearing streams, buffers need to provide all processes that create and maintain fish habitat, particularly shade, streambank integrity, and recruitment of large woody debris. Buffer zones need to be wide enough to fully protect the stream and floodplain and to ensure the long-term viability of the buffer itself. Buffers wider than one site-potential tree height (average maximum height given site conditions) may be needed to protect the floodplain and riparian vegetation where exposure to light and wind could cause succession to shrub communities. Blowdown in buffer zones, however, is usually not a problem for fish habitat, and where it does cause a problem, such as a stream blockage, it can be minimally altered to restore fish passage while leaving most fallen trees in place.

Current requirements for buffer width and leave trees on private lands do not fully protect LWD sources for fish-bearing streams. Four of the five states require leaving only an estimated 23% to 58% of potential LWD sources compared to the sources present in mature conifer forest. More and larger leave trees are needed to provide optimal fish habitat over the long term.

Many areas in the Pacific Northwest, however, have degraded riparian vegetation dominated by hardwood and shrubs, and lack additional large conifers for leave trees. In these degraded areas, buffer zones can be actively managed to improve degraded riparian functions. Reestablishing conifers offers potential long-term benefits for both fisheries and timber managers. In riparian areas restored to mature conifers, buffers could be selectively harvested if monitoring shows it would not harm fish habitat.

Buffer zones are also needed along non-fish streams to protect water quality and provide LWD for downstream fish habitat. Except for federal lands under NFP and PACFISH, buffers on small non-fish streams (both perennial and intermittent) are often inadequate or lacking. Reliance on BMPs alone may be inadequate to protect these headwater areas, and monitoring studies have not yet shown that BMPs are effective in preventing downstream impacts. The width and harvest activities within these buffers can be designed specifically to protect headwater sources of temperature control, sediment, and woody debris.

Management regimes are needed that will put timber harvest in the context of natural disturbance regimes. Disturbance to streams and flood plains is not necessarily negative, and may be needed for productive fish habitat over the long term. Unnatural disturbances, however, should be minimized, and patterns of land use should mimic the natural disturbance process and leave the necessary legacy for the long-term development of required habitat. Specifically, more large wood is needed in buffers along headwater channels with the greatest potential for delivery to fish-bearing streams.

BEST MANAGEMENT PRACTICES

Generally, BMPs can be effective at controlling nonpoint source pollution but need to be closely monitored for implementation and effectiveness to identify needed improvements. All the Pacific Northwest states and Alaska have a regulatory BMP program and monitor for implementation and effectiveness. Monitoring programs are mostly new, however, and BMPs have not been fully evaluated.

Many current forestry-related problems with water quality result from inadequate BMP implementation, which is generally worse on small private parcels than on public or large industrial holdings. On-site inspections are needed to identify sensitive areas and to design harvest and transportation plans to suit local conditions. Having well-qualified field personnel available to provide site-specific BMP recommendations, particularly for small private landowners, is probably the best way to improve BMP implementation.

Because small non-fish streams are particularly important for preventing sediment pollution and because buffer zones along them are usually narrow and heavily harvested, BMPs for activities near them need to be closely monitored to ensure that they are effective. State BMPs do not fully protect small non-fish streams, intermittent channels, and unstable slopes from logging disturbance. The BMPs pertaining to felling and yarding that apply to fish-bearing streams generally do not apply to small non-fish streams (particularly intermittent channels) and unstable slopes. Monitoring with feedback for adaptive management is needed to develop, evaluate, and improve BMPs for these areas.

WATERSHED ANALYSIS

A watershed program must have some process for analysis and planning at the watershed level. Watershed analysis is the most thorough method for understanding potential effects of land uses at the watershed scale. Watershed analysis can be used to describe current conditions, identify sensitive areas and risks, determine factors limiting salmonid production, and develop prescriptions to prevent cumulative effects.

Watershed analysis should be instituted wherever possible to provide information for watershed planning. State agencies can organize and lead working groups of concerned landowners in cooperative watershed analysis in watersheds with mixed ownerships. The watershed analysis efforts in Washington and Idaho provide good prototype models for developing prescriptive watershed analysis for private lands.

RESTORATION

Restoration is an integral part of comprehensive watershed management and is used to stabilize deteriorating conditions and speed recovery in key watersheds. Effective restoration has a watershed-level approach and includes upland, riparian, and instream components. The upland component is used to control erosion, stabilize roads, upgrade culverts for fish passage, and manage watershed uses. The riparian component restores functions of riparian vegetation by reestablishing mature conifers or other appropriate vegetation. The instream component, using woody debris and other structures to retain spawning gravel and create pools or other features, should be conducted only after watershed problems have been addressed and limiting factors identified.

Effectiveness evaluations are a critical part of restoration because they help improve technology and demonstrate the benefits of restoration. A representative sample of projects needs to be evaluated over a range of watershed and stream classes for each type of restoration technique.

Although restoration projects should undergo rigorous planning and evaluation, a streamlined process is needed to take advantage of opportunities arising during timber harvest on private lands when equipment, materials, and labor are on site. Trained agency personnel are needed to advise willing companies on obtaining permits and designing projects so that the work can be done without delay. Monitoring can be used to develop and evaluate standard techniques for such cases, and incentives can be incorporated in forest practices rules to encourage such projects. Prototype models for this are the Oregon incentives for riparian and instream restoration.

Priorities for restoration are key watersheds with the best remaining habitat, rather than the most degraded areas. The goal is to secure, expand, and link key watersheds in a system of refugia connected by intact migration corridors. Restoration activities for the best watersheds should focus on reducing risks to these habitats by obliterating unneeded roads and revegetating upland and riparian areas. The expectation is that all watersheds, not just key watersheds, will improve over time, but key watersheds will recover fastest because of their high level of habitat protection and priority for restoration. Other watersheds are expected to recover as a result of improved land management.

The best form of restoration is habitat protection. There is no guarantee that restoration efforts will succeed, and the cost of restoration is much greater than the cost of habitat protection. The most prudent approach is to minimize the risk to habitat by ensuring adequate habitat protection.

COMMUNITY OUTREACH

Comprehensive watershed management involves more than improved scientific understanding; it also encompasses economic, social, and political concerns. In the ideal situation, all stakeholders, including landowners, industries, and citizen groups, are partners in planning and implementing watershed management. Working groups of government agencies, industry, and citizen groups can provide the necessary consensus on forest practices and watershed management issues.

Habitat protection and restoration on a watershed basis will require integrating federal land management with other regulatory programs that affect aquatic habitats, particularly the Clean Water Act and Endangered Species Act. Habitat Conservation Plans developed under the ESA have an important role in watershed planning on private lands. Ultimately, basin-wide planning efforts are needed that include all public and private land managers.

Economic incentives can be provided for local communities and landowners to support habitat protection and restoration. On public lands, contracts awarded by competitive bidding can provide effective habitat protection and restoration while providing local employment. Tax credits and cost-sharing programs can be expanded to compensate private landowners for measures taken to protect public aquatic resources, such as expanded buffer zones or retention of additional leave trees along streams.

Although scientific information will always be incomplete and possibly wrong, current knowledge is adequate to design comprehensive watershed management to reduce risks to salmonid habitat and to restore degraded habitat. Scientific information can provide the basis for evaluating trade-offs between timber harvest and habitat protection, but whether society should take actions needed to recover anadromous salmonids is a political decision.

Glossary

Alevin: Larval salmonid that has hatched but has not fully absorbed its yolk sac, and generally has not yet emerged from the spawning gravel.

Anadromous salmonids: Members of the family Salmonidae (especially salmon, trout, and char) that move from the sea to fresh water for reproduction.

Basal area: The cross-sectional area of a log or tree measured at breast height.

Bedload sediment: That part of a stream's total sediment load moved along the bottom by running water, in contrast to suspended sediment which is carried in the water column.

Beneficial use: The designated resource value of a stream, such as domestic water supply or anadromous fish habitat.

Best Management Practices (BMPs): Methods, measures, or practices designed to prevent or reduce water pollution.

Blowdown (also windthrow): The uprooting and felling of trees by strong gusts of wind.

Buffer zone: An administratively defined area established along a stream, lake, wetland, or erosion hazard to provide protection for aquatic resources during land-use activities.

Carrying capacity: Maximum average number of organisms that can be sustained in a habitat.

Clearcutting: Removal of the entire standing crop of trees from an area; in practice, much unsalable material may be left standing.

Coarse sediment: Sediment with particle sizes generally greater than 2 mm, including gravel, cobbles, and boulders.

Compliance monitoring: Sampling of stream water to determine whether properly implemented Best Management Practices meet applicable water quality standards.

Culvert: Buried pipe structure that allows streamflow or road drainage to pass under a road.

Cut and fill: Construction of a road on hilly terrain that is partly excavated and partly filled.

Cumulative effects: Effects that result incrementally and collectively from the combined effects of separate management activities through time and space.

Debris torrent: Deluge of water charged with soil, rock, and woody debris down a steep stream channel.

Density: Number of organisms per unit area or volume.

Dewatering: Lowering of the water table in stream channel deposits caused by a channel shift, flow reduction, or channel downcutting.

Diversity index: Numerical value derived from the number of individuals per taxon and the number of taxa present.

Ecosystem management: Management of watershed land and aquatic resources based on perspective of forest and stream ecosystem structure, function, and dynamics aimed at long-term sustainability of watershed productivity. Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term. Although managing an entire ecosystem can positively affect a listed species, incorporating an ecosystem approach into recovery efforts means protecting the processes and functions of ecosystems important for the conservation of listed, proposed, or candidate species (Grumbine 1994).

Embeddedness: Degree to which coarse sediment (boulders, rubble, gravel) are surrounded or covered by fine sediment, usually measured in classes according to percent coverage.

Effectiveness monitoring: Sampling of soil erosion, streams, and other features to determine whether properly implemented Best Management Practices are effective in meeting their intent.

Emergence: Departure of fry from the incubation gravel into the water column.

Escapement: That portion of an anadromous fish population that escapes fisheries and reaches the freshwater spawning grounds.

Evapotranspiration: Loss of water by evaporation from the soil and transpiration from plants.

Fine sediment: Sediment with particle size of 2 mm or less, including sand, silt, and clay.

Flood plain: Level lowland bordering a stream onto which the stream spreads at flood stage.

Forest practices: The full range of forest management activities employed in silviculture and harvest of timber.

Freshet: Rapid temporary rise in stream discharge caused by heavy rains or rapid melting of snow or ice.

Fry: Life stage of a salmonid between full absorption of the yolk sac and the fingerling or parr stage, which generally is reached by the end of the first summer.

Gradient (topographic slope): Average change in vertical elevation per unit of horizontal distance.

Groundwater: That part of the subsurface water that is in the zone of saturation, including underground streams.

Gullying: Formation or extension of gullies by surface runoff water.

High-lead yarding: Method of powered cable logging in which the mainline blocks are fastened high on a spar so logs can be skidded with one end off the ground.

Landing: Place where felled trees are accumulated for further transport.

Large woody debris (LWD): Any piece of woody material that intrudes into a stream channel, whose smallest diameter is greater than 10 cm, and whose length is greater than 1 m.

Limiting factor: Environmental factor that limits the growth or activities of an organism or that restricts the size of a population or its geographical range.

Implementation monitoring: Sampling of management activities to determine whether practices are adequately applied as specified.

Instream restoration: Activities conducted to improve physical structure of stream channels, such as to provide spawning habitat or create pools.

Intermittent channel: A stream channel that carries water only part of the year during snowmelt or after rain storms.

Main stem: Principal stream or channel of a drainage system.

Mass movement: Downslope transport of soil and rocks due to gravitational stress.

Monitoring: The process of collecting information to evaluate whether anticipated or assumed results of a management plan are being realized or whether implementation is proceeding as planned.

Nephelometric turbidity unit (NTU): Measure of the concentration or size of suspended particles (cloudiness) based on the scattering of light transmitted or reflected by the medium.

Nonpoint-source pollution: Pollution from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, and construction.

Old growth: Forest stand dominated by large old trees reaching natural senescence; the last stage in forest succession. Characters of old-growth forest include 1) storied canopy including different tree species in the lower levels; 2) openings that allow light into the forest floor where dense vegetation thrives; 3) presence of snags and downed logs; and absence of major stand-altering disturbance by humans (Bolsinger and Waddell 1993).

Parr: Young salmonid in the stage between alevin and smolt, which has developed distinctive dark marks on its sides and is actively feeding in fresh water.

Perennial stream: A stream with flowing water all year long.

Permeability: A measure of the rate at which a substrate can pass water, the rate depending on substrate composition and compaction.

Pool: Portion of a stream with reduced current velocity, often with deeper water than surrounding areas and with a smooth surface.

Presmolt: Juvenile salmonid during the parr-smolt transformation, with intermediate coloration and body form.

Primary production: Production of organic substances by photosynthesis.

Redd: Nest made in gravel, consisting of a depression dug by a fish for egg deposition and then filled.

Riffle: Shallow section of a stream or river with rapid current and a surface broken by gravel, rubble, or boulders.

Riparian restoration: Management activities aimed at changing the size, density, species composition, or other characteristics of riparian vegetation to improve ecosystem functions.

Riparian area: Area between a stream or other body of water and the adjacent uplands.

Riprap: Layer of large, durable materials (usually boulders), used to protect a stream bank or lake shore from erosion.

Runoff: The part of precipitation and snowmelt that reaches streams by flowing over the ground.

Second growth: Forest stand that has come up after some drastic interference such as logging, fire, or insect attack.

Sediment: Fragments of rock, soil, and organic material transported and deposited in beds by wind, water, or other natural phenomena.

Seral stage: One in a series of ecological communities that succeed one another in the biotic development of an area (also see *succession*). Forests pass through four recognized stages: 1) early seral stage, the period from disturbance to crown closure; 2) mid-seral stage, from crown closure to first merchantability (usually age 15–40 years); 3) late-seral stage, from first merchantability to culmination of mean annual increment (100 years); and 4) mature seral stage, from culmination of mean annual increment to old-growth stage (200 years).

Shelterwood cutting: Selective cutting of regenerating plants so as to establish a new tree crop under the protective remnants of a former stand.

Skid trail: A constructed trail or established path used by tractors or other vehicles for skidding logs in going to and from landings.

Site-potential tree: A tree that has attained the average maximum height possible given site conditions where it occurs.

Site class: A measure of an area's relative capacity for producing timber or other vegetation.

Site index: A measure of forest productivity expressed as the height of the tallest trees in a stand at an index age.

Skidding: Yarding logs by sliding or dragging with tractors or other ground-based equipment.

Skid trails: Trails on which logs are moved to landings by sliding or dragging.

Skyline yarding: Method of powered cable logging in which a heavy cable (the skyline) is stretched between two spars and used as an overhead track for a load-carrying trolley.

Slash: Woody residue left after trees are felled, limbed, and yarded.

Smolt: The seaward-migrant stage of an anadromous salmonid that has undergone physiological changes to cope with the marine environment.

Splash dam: Dam built to create a head of water for driving logs.

Stock: Group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction.

Stream order: A number ranked from headwaters to river mouth that designates the relative position of a stream in a drainage basin. First-order streams have no discrete tributaries; the junction of two first-order streams forms a second-order stream; the junction of two second-order streams forms a third-order stream; etc.

Succession: A series of dynamic changes by which one group of organisms succeeds another through stages leading to potential natural community or climax. An example is the development of series of plant communities (called seral stages) following a major disturbance.

Tributary: Stream flowing into a lake or larger stream.

Upwelling: The movement of groundwater through stream substrate into the stream water column.

Waterbar: Shallow channel (cross drain) or raised barrier of packed earth laid diagonally across the surface of a road to guide water off the road. Also called "waterbreaks."

Watershed: Total land area draining to any point in a stream.

Watershed analysis: A systematic process to describe current watershed conditions and develop prescriptions to prevent cumulative impacts.

Watershed restoration: A broad-based program to control erosion from roads and bare soils, upgrade or remove culverts to restore fish access, restore natural streamflow regimes, and manage all uses of the stream and watershed.

Yarding: hauling of timber from the point of felling to a yard or landing.

Acronyms

ADFG	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AWGCFFR	Alaska Working Group on Cooperative Forestry Fisheries Research
BLM	Bureau of Land Management
BMPs	Best Management Practices
CDF	California Department of Forestry and Fire Protection
CDFG	California Department of Fish and Game
cfs	Cubic feet per second (a measure of stream discharge)
dbh	Diameter at breast height of trees
DO	Dissolved oxygen
ECA	Equivalent Clearcut Area
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FEMAT	Forest Ecosystem Management Assessment Team
FS	U.S. Forest Service
HCP	Habitat Conservation Plan

IDL	Idaho Department of Lands
LWD	Large woody debris
NEPA	National Environmental Policy Act
NFP	Northwest Forest Plan
NMFS	National Marine Fisheries Service
ODF	Oregon Department of Forestry
ODFW	Oregon Department of Fish and Wildlife
PACFISH	Pacific Anadromous Fish Habitat Management Strategy
RHCA	Riparian Habitat Conservation Area
RMAs	Riparian Management Areas: buffer zones in Oregon
RMZs	Riparian Management Zones: buffer zones in Washington
SPZs	Stream Protection Zones; buffer zones in Idaho
TFW	Washington State's Timber Fish Wildlife Agreement
TLMP	Tongass Land Management Plan
TTRA	Tongass Timber Reform Act of 1990
USDI	U.S. Department of Interior
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
WDNR	Washington Department of Natural Resources
WLPZs	Watercourse and Lake Protection Zones: buffer zones in California

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