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Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

SILVICULTURAL TREATMENTS

FRED H. EVEREST AND R. DENNIS HARR

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

Distribution of anadromous salmonids and coniferous forest coincides along much of the Pacific slope; consequently, the habitat of anadromous'fish is subject to a wide variety of silvicultural treatments required to establish and nurture young forests. Silvicultural treatments discussed in this report include cutting prescriptions, broadcast burning, mechanical site preparation, planting, and competition reduction. Timber harvest, and use of pesticides and fertilizers are discussed in other papers in this series. Broadcast burning and machine scarification and piling can increase sedimentation and thermal heating of streams and have the potential to damage habitat of anadromous fish. Habitat damage usually does not occur, however, because of the limited extent of treatments. The highest risk of habitat damage from silvicultural activities occurs in small streams in areas with erosive soils and high rainfall, or with high summer solar radiation and low streamflow. Silvicultural activities discussed in this paper affect fish habitat far less than timber harvest or road construction activities.

KEYWORDS: Silvicultural treatments, fish habitat, anadromous fish, salmonids.

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INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

6. Silvicultural Treatments

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PREFACE

This is one of a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in Western North America. This paper addresses the effects of silvicultural treatments on anadromous fish habitat. Our intent is to provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we summarize published and unpublished reports and data as well as observations of resource scientists and managers. These compilations should be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references serve as a bibliography on forest and rangeland resources and their uses.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.
2. "Impacts of natural events," by Douglas N. Swanston.
4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.
7. "Effects of livestock grazing," by William S. Platts.
8. "Effects of mining," by Susan B. Martin and William S. Platts.
11. "Processing mills and camps," by Donald C. Schmiege.

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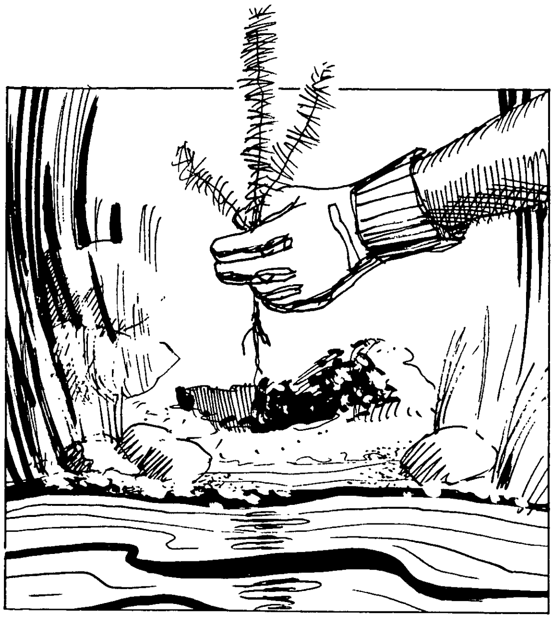
COMMON AND SCIENTIFIC NAMES OF TROUT, SALMON, AND CHARRS—
FAMILY SALMONIDAE[1]

Common name	Scientific name
Pink salmon	*Oncorhynchus gorhuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Cutthroat trout	*Salmo clarki* Richardson
Rainbow (steelhead trout)	*Salmo gairdneri* Richardson
Atlantic 'salmon	*Salmo salar* Linnaeus
Brown trout	*Salmo trutta* Linnaeus
Arctic charr	*Salvelinus alpinus* (Linnaeus)
Brook charr	*Salvelinus fontinalis* (Mitchill)
Dolly Varden	*Salvelinus malma* (Walbaum)
Lake charr	*Salvelinus namaycush* (Walbaum)
Bull charr	*Salvelinus confluentus* (Suckley)

[1] Adapted from "A list of common and scientific names of fishes from the United States and Canada," American Fisheries Society Special Publication No. 6. 3rd ed., 1970. 150 p.



INTRODUCTION

Waters in forested lands of the Pacific slope of North America are major producers of anadromous salmon and trout. Eight species of anadromous salmonids inhabit fresh and marine waters of much of the Pacific Northwest, western Canada, and Alaska. There are five Pacific salmon--chinook, coho, sockeye, chum, and pink; two trout--steelhead rainbow and coastal cutthroat; and one charr--Dolly Varden.

The size of the resource is large, but it is diminishing as a result of human activities and currently represents only a fraction of its original size. Collectively, many millions of adult anadromous salmonids still reproduce in these western waters annually, and the harvestable surplus from National Forests alone provided about 5 million angler-days of recreation in 1977 (Everest and Summers, in press), and a commercial harvest of more than 76 million pounds.

In addition to anadromous fish, forested watersheds of the West produce an array of natural resources, including a variety of wood products. Production areas of both timber and fish coincide along much of the Pacific slope (fig. 1), and the increasing public demand for both of these resources creates frequent management conflicts. Simultaneous production of timber and anadromous fish are not totally compatible in a watershed but neither are they mutually exclusive (e.g., Lantz 1971). Under most circumstances, both timber and fish can be successfully managed in the same watershed if measures to protect water quality and fish habitat are carefully coordinated with timber management plans.

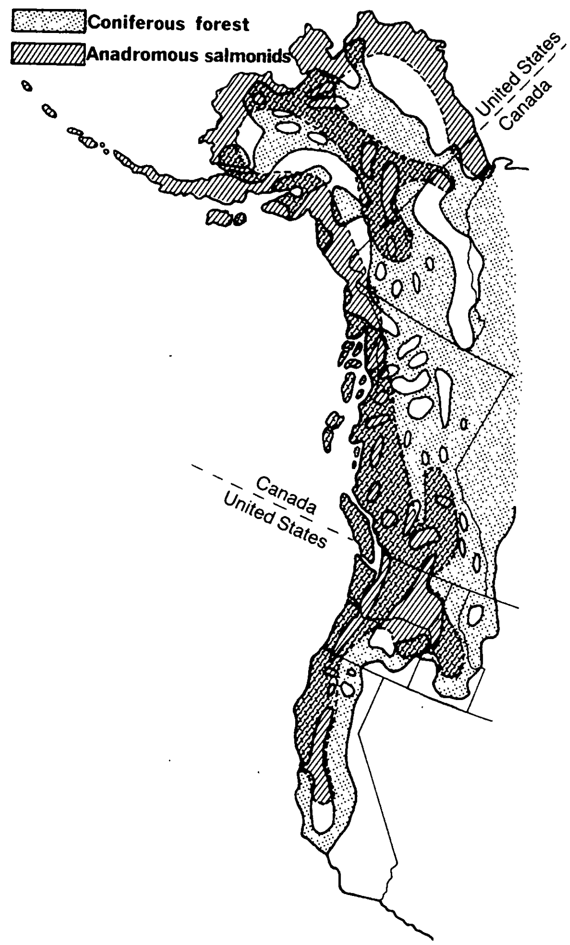


Figure 1.--Distribution of coniferous forest and anadromous salmonids in western North America.

Silviculturists make many decisions with potential consequences for habitat of anadromous salmonids. They prescribe where, when, and how timber will be harvested, the transportation, yarding, and felling systems that will be used, and what trees will be left to produce seed or protect streams. Silvicultural decisions establish the framework within which timber will be managed on a continuing basis, and therefore are of utmost importance to fishery managers. Silvicultural and associated activities have been divided into several broad subject areas for this compendium; reports on timber harvest, forest roads, and forest chemicals are discussed in other papers.

Silvicultural activities which are used to establish and nurture a forest stand are discussed in this report (paper 6). These include (1) special cutting prescriptions such as small clearcuttings and shelterwood cuttings to improve natural regeneration; (2) site preparation by broadcast burning, ripping, or scarification; (3) fire hazard reduction by controlled broadcast burning or machine piling and burning; (4) artificial regeneration by planting or seeding; and (5) competition reduction by brush removal and precommercial thinning.

The general kinds of effects on anadromous fish habitat resulting from silvicultural activities discussed in this report are the same as those resulting from timber harvest activities as described in paper 3.[2/] The severity of the effects of silvicultural activities, however, is generally much less than timber harvest activities because the temporal and spatial intensity of silvicultural activities in a watershed is less.

[2/] Chamberlin, T. W. Influence of forest and rangeland management on anadromous fish habitat in Western North America: 3. Timber harvest, Gen. Tech. Rep. PNW-136, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. Manuscript in preparation,

GENERAL HABITAT REQUIREMENTS OF ANADROMOUS SALMONIDS

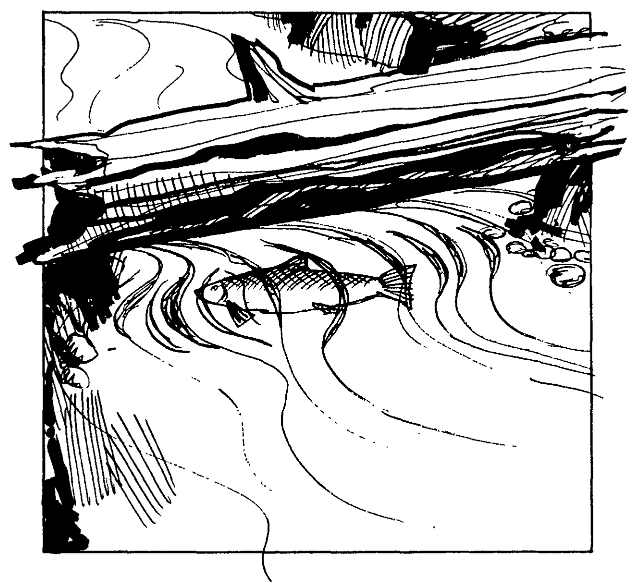
Anadromous salmonids utilize both freshwater and marine environments and have rather exacting habitat requirements. All species reproduce in fresh water and most juveniles rear there for some time before migrating to sea where they mature. Freshwater habitat requirements vary slightly, but all species share some common requirements. For optimum production, all species require cool flowing waters (5.6-14.6°C preferred); free migratory access to and from the sea: clean gravel substrate (<10 percent sediment smaller than 1-mm diameter) for reproduction; water of low turbidity (<50 NTU (nephelometric turbidity units) during the growing season (for sight feeding); high levels of dissolved oxygen (>6 mg/liter) in streams, lakes, and intragravel environment; and invertebrate organisms for food. Species preferences for these parameters vary slightly and are presented in detail by Reiser and Bjornn (1979). Substantial deviations from optimum conditions can markedly reduce production.

HABITAT UTILIZATION IN TIME AND SPACE

Temporal and spatial utilization of other features of the aquatic environment vary significantly and are related to subtle differences in morphology, physiology, and behavior of species. Preferences for different water depths and velocities, food organisms, cover, and substrate, as well as duration of residence in fresh water, and timing of migration and reproduction, tend to keep species ecologicallly isolated from one another in time or space during freshwater residency. Since most streams contain several species of anadromous salmonids with slightly different life histories and habitat preferences, and since no two species can occupy the same ecological niche at the same time, subtle differences in preferred habitat tend to minimize competitive interactions between species, and maximize production in a given habitat.

The variety of physical habitat available in freshwater streams is limited, but nevertheless it offers an opportunity for ecological specialization of salmonid species. For example, adult pink and chum salmon usually make short spawning migrations into fresh water, and after emergence, fry immediately migrate to sea, thus avoiding fresh water as a rearing area. Sockeye salmon migrate to inlet or outlet streams of lakes where they spawn; after emergence, fry move into the lakes where they rear for up to 3 years. Adult coho salmon make upstream migrations of intermediate length and spawn primarily in small tributary streams where juveniles rear in pools for about 1 year. Chinook salmon spawn in both large and small streams from tidewater to as far as 1 500 km up major rivers; rearing occurs in pools of small, intermediate, and large streams. Fall chinook fry rear in fresh water for a few months, whereas spring and summer races rear in streams for about 1 pear. Steelhead are widely distributed in large and small streams, make long or short migrations, spawn in intermediate to small streams, and rear for up to 3 years--primarily in riffles. Cutthroat trout generally make short spawning migrations to small, steep tributaries where rearing occurs for up to 2 years. Dolly Varden make short or long migrations into small streams and rivers where fry rear primarily in pools for 1 to 3 years. Each species uses slightly different resources at different times and locations; consequently, a combination of species uses freshwater habitat more completely and produces more biomass than does any single species.

When several species of anadromous salmonids are present in a watershed and access is unrestricted, habitat is usually filled to capacity, and both fish population structure and biomass are in equilibrium with available food and suitable living space. Any substantial changes in habitat, either natural or as a result of human activities, shifts the equilibrium and causes changes in the structure of fish populations. Eventually a new equilibrium is established where total production of salmonids is either increased or decreased, or production of one species is favored over another.



IMPORTANCE OF SMALL STREAMS

Anadromous salmonids of the Pacific slope utilize a wide variety of streams ranging in size from headwater tributaries to the mainstem Columbia River. Spawning, migration, and short-term rearing occur even in some first-order streams (definition of Strahler 1957) that become intermittent or dry in summer. The majority of spawning and rearing activity in forested watersheds, however, takes place in second- and third-order streams in Oregon, Washington, and Alaska (table 1), and second- to fourth-order streams in Idaho and California. Streams of this magnitude are usually small, yet combined they account for the majority of stream mileage available to anadromous salmonids in most watersheds. Reproduction of anadromous fish in small streams is often adequate to seed larger waters many miles downstream with fry. First-order streams are often inaccessible to anadromous salmonids because of barriers or steep gradient; hence they contribute little onsite production, and yet are vitally important to the quality of habitat for anadromous fish downstream. The channels of these streams act as viaducts that carry water, sediment, nutrients, and woody debris from upper portions of the watershed to larger tributaries downstream. The quality of the habitat downstream for anadromous salmonids is determined partly by how fast and at what time these organic and inorganic materials are transported downstream.

VULNERABILITY OF SMALL STREAMS

While small streams (first- and second-order) are responsible for a high proportion of anadromous salmonid production in a basin and for maintaining the quality of habitat in larger tributaries downstream, they are also the streams most easily altered by human activities. Small streams are "extrinsic" in character; that is, they are intimately associated with their riparian zones and are highly responsive to alterations in riparian vegetation and the adjacent watershed. Vegetative crown cover is often complete in first- through third-order streams, and since the streams are dependent largely on litterfall for organic energy input (heterotrophic system), any manipulation of the canopy or streambank vegetation, or any upslope activity such as road development and timber harvest, creates immediate changes in stream equilibrium. Removal of the canopy, or in some cases merely a portion of it, results in direct solar heating of surface waters, a shift from a detrital energy base to a solar base

Table 1--Anadromous fish use of streams by stream order, in a typical coastal watershed, east fork of the Winchuck River, Oregon

Stream order	Linear miles	Percent total miles	Percent anadromous fish use
I	290	48.4	8.6
II	165	27.5	48.8
III	110	18.4	32.5
IV	34	5.7	10.1
Total	599	100.0	100.0

(autotrophic system), and often increases the quantity of woody debris added to the channels. Road development, clearcutting, site preparation, and other activities in the watershed above a stream may rapidly increase sediment transport to the channel. Changes in habitat often have a negative impact on production of anadromous salmonids.

Large streams, unlike small streams, are "intrinsic" in character because they are not easily influenced by changes in their immediate environment. Wide streams with large volumes of flow are usually open to direct sunlight but are more resistant to solar heating and more capable of transporting sediment and woody debris. Human activities along large streams can affect the quality of fish habitat, but to a lesser degree than similar activities along small streams.

Small streams suffer a greater risk of habitat degradation than large streams; and soils, climate, and geomorphology within a watershed generally determine the degree of risk. The risk of fish habitat degradation resulting from silvicultural treatments is linked to two primary factors: the potential for (1) increased or decreased water temperatures, and (2) increased sedimentation.

Physical and climatic features within the range of anadromous salmonids cause a greatly elevated risk of damage in some geographic areas. Maximum risk from solar heating occurs in western and northeast Oregon, western and central Washington, northwest California, and central Idaho (fig. 2). These geographic areas produce both commercial timber and anadromous fish and have mean monthly maximum temperatures in July which exceed 27°C. Damage from decreased water temperatures can occur during cold winter weather where insulating streamside vegetation has been removed. High-risk areas are located in northern and central Idaho, northeastern Oregon, southeastern Washington, northern British Columbia, and Alaska.

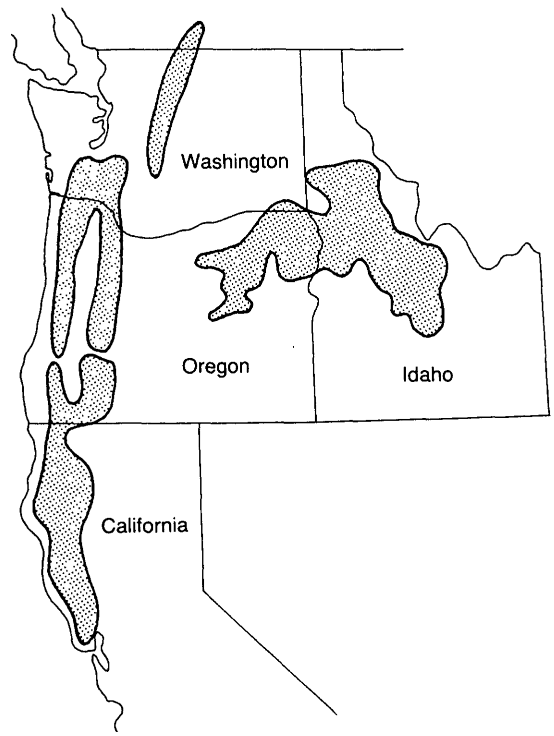


Figure 2.--Zones in western North America where silvicultural treatments have the highest risk of damaging habitat of anadromous salmonids as a result of solar heating.

The maximum risk of damage from sedimentation also covers an extensive area (fig. 3). Areas of central Idaho; northwest California; western Oregon, Washington, and British Columbia; and southeast Alaska are vulnerable to surface erosion and mass wasting. Streams in mountainous areas with sedimentary or granitic soils that receive more than 120 cm annual precipitation, or intense rainstorms (or rain on snow), and that produce both commercial timber and anadromous fish are most vulnerable to damage from sediment released by silvicultural activities. Fish habitat could be degraded by silvicultural treatments in other geographic areas, but the risk of damage is substantially lower.

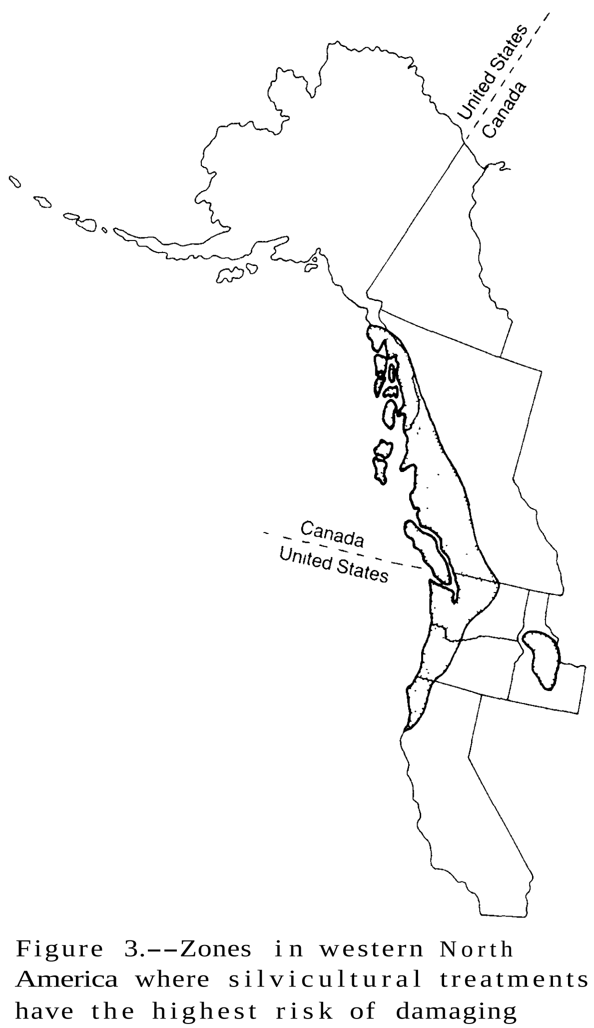


Figure 3.--Zones in western North America where silvicultural treatments have the highest risk of damaging habitat of anadromous salmonids as a result of sedimentation.

RELATION BETWEEN FISH HABITAT AND FISH PRODUCTION

The relation between land management activities and fish production is difficult to predict quantitatively. The link between watershed manipulation and fish production is complex and depends on many variables. Various combinations of physical, climatic, and biological variables can be either antagonistic or synergistic; therefore, effects are difficult to predict.

Some general predictive relationships have been defined, however, that link changes in fish habitat to fish production. Some of the relationships were developed through laboratory studies and others resulted from field investigations. For example, lab and field studies have demonstrated an inverse relationship between the proportion of fine sediments (<6.4 mm-diameter) in gravels and survival to emergence of salmonid fry (fig. 4). If watershed manipulation increases the proportion of fine sediments in spawning areas (as determined by sampling), a rough prediction of the effects on salmonid reproduction can be made. Predicting the effect on smolt production, however, requires additional information because the rearing habitat, rather than spawning success, might be limiting production.

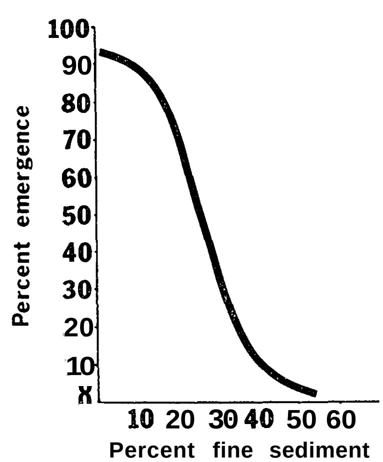


Figure 4. --Percentage emergence of fry from newly fertilized eggs in mixtures of gravel and sand. Fine sediment was granitic sand with particles less than 6.4 mm (adapted from Reiser and Bjornn 1979).

Sediment can also affect the rearing potential of streams by altering substrate composition and riffle-pool ratios. Juvenile coho, for example, prefer pool habitat (fig. 5) whereas juvenile steelhead in the same streams prefer the swifter water of riffles (fig. 6). Channel aggradation resulting from sedimentation can reduce channel stability and reduce pool area in a stream. The result could be reduced rearing potential for coho and increased habitat availability for steelhead. Winter survival of anadromous salmonids in cold streams (<5°C) is also reduced by fine sediments. Juvenile salmonids survive harsh icing conditions in the winter by entering crevices in the substrate (Bjornn 1971, Everest 1969, Miller 1970). Carrying capacity in the winter is reduced if sediment fills the crevices.

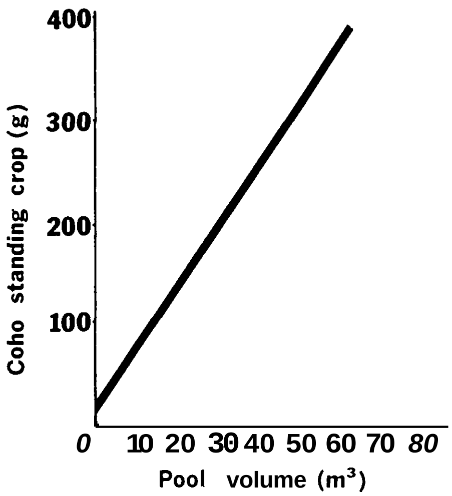


Figure 5.--Relationship between pool volume and juvenile coho standing crop (from Nickelson, T. E.; Hafele, R. E. Streamflow requirements of salmonids. Portland, OR: Oregon Department of Fish and Wildlife; 1978; Prog. Rep. AFS-62, Contract 14-16-0001-77-538. 25 p.

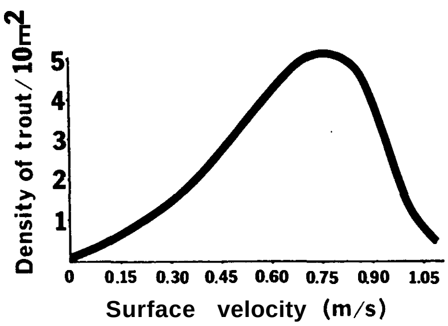


Figure 6.--Relationship between surface velocity and the density of yearling and older steelhead trout parr (adapted from Everest and Chapman 1972).

Relationships between suspended sediment and (1) growth of salmonids[3] (fig. 7), and (2) angler behavior[4] (fig. 8) have also been documented.

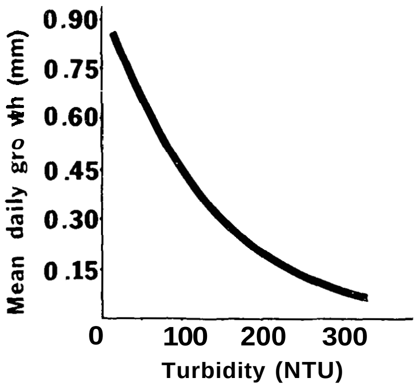


Figure 7.--Relationship between turbidity and growth of steelhead trout fry (adapted from Sigler, J. W.; Bjornn, T. C. Effects of chronic turbidity on feeding, growth, and social behavior of steelhead trout and coho salmon. Moscow, ID: University of Idaho, Idaho Cooperative Fish Research Unit; 1980; Completion Rep. 157 p.).

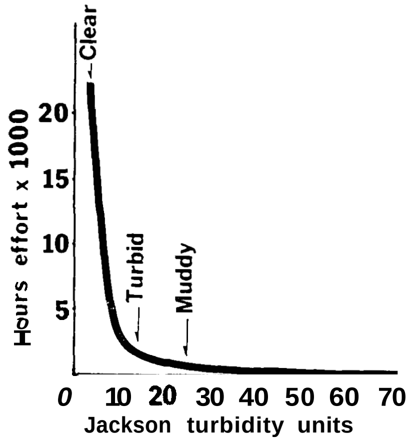


Figure 8.--Relationship between turbidity and angling effort, (adapted from Puckett, L. Sport fisheries of the Eel River, 1972-1973. Eureka, CA: California Department of Fish and Game; 1975; Memorandum Rep. 35 p.)

Because juvenile salmonids are sight feeders, suspended sediment in excess of 50 NTU at water temperatures above 5°C generally reduces feeding success, growth, and competitive ability. Chronically turbid waters, particularly during the spring, can substantially reduce growth of salmonid fry. Also, angling generally ceases when suspended sediment concentrations exceed 20 JTU (Jackson turbidity units). Even if fish production is unaffected, angling opportunities can be substantially reduced.

The effects of changes in stream temperature are also roughly predictable. The effects are most critical during the summer when juveniles are rearing, and during the winter when embryos are incubating. In general, production of anadromous salmonids begins to decline when summer water temperatures exceed 20°C; total mortality of salmonids usually occurs

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[3] Sigler, J. W.; Bjornn, T. C. Effects of chronic turbidity on feeding, growth, and social behavior of steelhead trout and coho salmon. Moscow, ID: University of Idaho, Idaho Cooperative Fish Research Unit; 1980; Completion Rep. 157 p.

[4] Puckett, L. Sport fisheries of the Eel River, 1972-1973. Eureka, CA: California Department of Fish and Game; 1975; Memorandum Rep. 35 p.

if temperatures exceed 25°C for a few days (fig. 9). Lethal or near-lethal high temperature& or low temperatures (Chapman 1962) can result from removal of riparian vegetation bordering streams. If water temperatures in the winter fall low enough to allow formation of anchor ice in areas where salmonid eggs are incubating, complete mortality of embryos can result (see fig. 9).

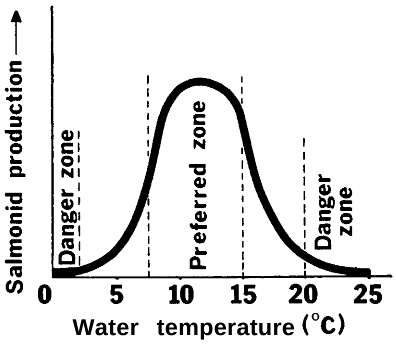


Figure 9.--Temperature preference zone and danger zones for incubating and rearing anadromous salmonids (adapted in part from Brett 1952).

The relation between large woody debris and rearing salmonids is not well quantified, but some trends have been noted (Baker 1979, Meehan and others 1977, Sedell and Triska 1977). In general, the more habitat diversity created by large woody debris, the greater the rearing potential for anadromous fish. The abundance of juvenile cutthroat (and steelhead) in second- and third-order streams is closely correlated with cover (fig. 10), and most cover in small forest streams is provided by large woody debris. Woody debris is important for enhancing rearing habitat during summer and for providing survival cover in off-channel areas during winter floods. Large woody debris also provides a nutrient reservoir for the aquatic ecosystem. At some undefined point, debris loading in small streams can become so great that the upstream migration of adult salmonids is stopped by barriers, and production ceases.

The effects of silvicultural treatments on relations between fish and fish habitat mentioned above are usually minimal. The silvicultural activities discussed in this paper seldom result in major changes to stream habitat of anadromous salmonids, and potential conflicts can usually be mitigated through coordinated planning.

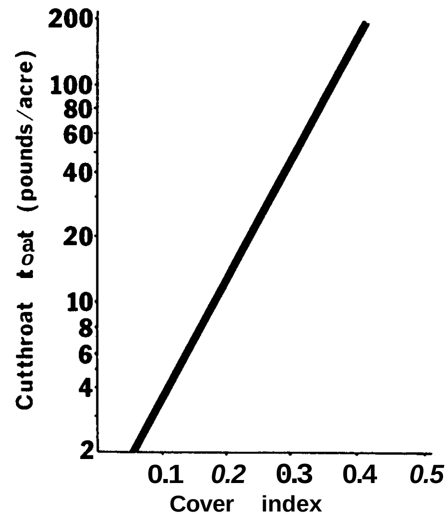


Figure 10.--Relationship between cover index and cutthroat trout standing crop in three coastal Oregon streams (adapted from Nickelson, T. E.; Reisenbichler, R. R. Streamflow requirements of salmonids. Portland, OR: Oregon Department of Fish and Wildlife; 1977; Prog. Rep. AFS-62, Contract 14-16-0001-4247. 24 p.).

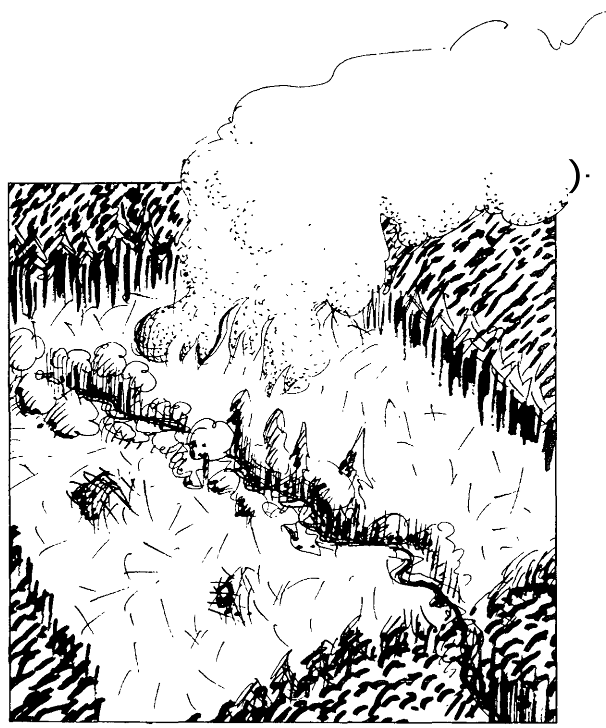
5/ Moring, J. R.; Lantz, R. L. Immediate effects of logging on the freshwater environment of salmonids. Portland, OR: Oregon Wildlife Commission, Research Division; 1974; Project AFS-58 Final Report. 101 p.

SILVICULTURAL TREATMENTS

CUTTING PRESCRIPTIONS

On a number of sites throughout the geographical range of anadromous fish, special cutting prescriptions are used to ensure proper regeneration. Such prescriptions, which include shelter-wood cuts and small patch clearcuttings to provide a favorable environment for seedling survival and growth on dry sites, may occasionally dictate transportation systems or yarding systems that could lead to more erosion and stream sedimentation than would otherwise be the case.

For example, a prescribed shelter-wood cut might require yarding by tractor or skidder to protect leave trees rather than use of a cable system more typically used in clearcuts. More haul roads, skid roads, soil compaction, and ground disturbance would likely result from tractor or skidder yarding (Bockheim and others 1975, Dyrness 1965, Wooldridge 1960), and erosion potential at the site would be increased. Damage to fish habitat resulting from such a choice of cutting prescriptions might or might not occur depending on factors such as erosion hazard, proximity to streams, post-yarding treatment, etc. The highest risk of damage from sedimentation would occur in areas outlined in fig. 3.



BROADCAST BURNING

Broadcast burning is a common silvicultural practice used to prepare a site for planting or to reduce fire hazard. In some instances, such burning may affect anadromous fish habitat by causing erosion and sedimentation, releasing nutrients, increasing water temperature by removing streamside shade and by direct heating during burning, and by slightly increasing summer base flows. The most important effects of burning on fish habitat result from erosion and sedimentation; other effects are minor in most cases. The nature of the effect of burning depends on characteristics of the burn itself as well as physiographic characteristics of the site, soil properties, and climate because they all relate to vegetative recovery of the site after burning.

Soil Heating

The degree of damage to soil properties that may, in turn, result in damage to anadromous fish habitat is directly related to the degree of soil heating. During broadcast burning, 92 percent of the heat generated is released upward into the atmosphere; the remaining 8 percent absorbed at the soil surface (Wells and others 1979) can alter all physical, chemical, and biological properties of soil that are dependent on organic matter.

The degree of heating, which is highly variable at both soil surface and soil depth, depends on (1) type and amount of fuel present, (2) the intensity of burning, (3) the nature of the litter layer including thickness, packing, and moisture content, and (4) soil properties. If soil temperatures reach the point where litter and organic matter in the surface layers are consumed, the stability of soil aggregates is altered and the erosion hazard is usually increased. Subsequent storms might cause extensive transport of sediment and nutrients to spawning and rearing areas of anadromous salmonids. Soil moisture content is the single most important soil property controlling the degree of heating. When water is present in the soil, the temperature at any soil depth does not exceed 100°C until the water at that depth has evaporated or moved to a lower depth (De Bano and others 1976).

Fire Intensity

The potential effect of fire on erosion, nutrient loss, and ultimately on fish habitat can be estimated by assessing fire intensity. As intensity of fire increases, the potential for soil erosion, substantial loss of nutrients, and damage to fish habitat increases. It is important for resource managers, therefore, to determine the intensity of the fire so mitigating treatments such as grass seeding can be initiated immediately on severely burned spots or entire watersheds. Also, if conditions that can lead to severe burns are recognized, such severe burns may be eliminated by postponing burning.

Intensity of a fire can be classified according to the appearance of litter and soil after the fire (Wells and others 1979). Any particular spot of a fire is classified lightly burned if both litter and duff are scorched but not altered over the entire depth. During moderate burns, litter and duff are charred, but underlying soil is not visibly altered. In severely burned spots, all the organic layer is consumed, and both the structure of mineral soil and its color are visibly altered. These criteria for spots may be extended to classify larger or entire areas burned. An area is classified severely burned if more than 10 percent of it has spots severely burned, more than 80 percent at least moderately burned, and the rest lightly burned. A moderately burned area has less than 10 percent severely burned but over 15 percent moderately burned. In a lightly burned area, less than 2 percent is severely burned, less than 15 percent moderately burned, and the rest lightly burned or not burned.

Wells and others (1979) state that the appearance of the remaining brush should also be used to estimate fire intensity. After a light burn, litter is singed and less than 40 percent of the brush canopy remains. Some leaves and small twigs remain on plants either unharmed or slightly singed. A moderately intense burn occurs when most of the litter is charred but not ashed, 40-80 percent of the plant canopy is burned, and the remaining charred twigs are 6-12 mm in diameter. After a severe fire, the area is completely burned, and only ashes remain on the soil surface. Plant stems that remain are greater than 12 mm in diameter.

Surface Erosion

Though fire may affect anadromous fish habitat through both surface and mass erosion, surface erosion is by far the most prevalent because it may occur on any burn surface; mass erosion is usually restricted to steeplands. Surface erosion is a two-step process consisting of detachment of soil particles and their transport downslope. The size and density of soil particles, the degree of cementing of particles into aggregates, and the degree of protection afforded by plant and litter cover control the detachment process.

The two types of surface erosion are categorized according to mode of transport--raindrop splash or flowing water. Particles can be detached and moved downslope by raindrop splash--a type of erosion called sheet erosion. Sheet erosion, which may go virtually unnoticed, can be identified by pedestals of soil under impervious materials such as stones, wood chips, or exposed roots. Water flowing over the soil surface creates rills and gullies which are easily recognized from scars left on the ground. Rill and gully erosion following fire generally transport far more sediment to streams than sheet erosion and are therefore far more detrimental to fish habitat.

Structural and hydrologic properties of soil are indicators of erosion potential. Surface erosion is rare on most undisturbed forest soils because of (1) the litter layer and (2) the fact that individual particles are cemented together by organic matter and clay to form aggregates--larger structural units whose movement requires more energy. After broadcast burning of logging residue and the protecting layer of litter and organic material, raindrops may freely impact soil and detach soil particles. If the burning is of high enough intensity, even the organic matter cementing particles into aggregates may be consumed, thus rendering soil aggregates susceptible to raindrop impact and flowing water.

The strength of aggregates is often indicated by the type of bedrock from which soils are formed. Lowest strengths of aggregation and highest erodibilities are associated with soils derived from granite, quartz diorite, granodiorite, and certain high quartz sandstones. In general, the higher the quartz content of the parent material, the greater the potential erosion of the resultant soil.

The greater erosion hazards of soils high in quartz are largely the result of poor aggregation. Granitic soils tend to be coarse textured in surface layers and deficient in silts and clays. Because of little clay, coarse-textured soils tend also to have few stable aggregates that can resist the force of raindrop impact or the wearing action of flowing water (Clayton and others 1979). On the other hand, basalts, andesites, and gabbro contain minerals that decompose to form clay, a primary cementing agent in aggregate formation. Because soils derived from these latter parent materials tend to have higher productivities, they also have higher organic matter contents which also contribute to the stability of soil aggregates. Thus, soils of the Idaho Batholith and other areas of granitic intrusives tend to be highly erodible, whereas most soils of the western Cascades of Oregon, having developed from volcaniclastic rocks, are resistant to surface erosion (Fredriksen and Harr 1979).

Water repellency, an important effect of fire in the Southwest, is generally of minor importance throughout the geographic range of anadromous fish habitat in western North America. It has been detected, however, in areas burned by wildfire in Oregon (Dyrness 1976).

Broadcast burning may also indirectly affect erosion through changes in nutrient contents of soils. Volatile elements such as nitrogen, sulfur, and phosphorous are lost from soil when burning temperatures exceed the temperature of volatilization (Wells and others 1979). Other nutrients may be removed by leaching and by surface erosion. Nutrient losses from the site are important only if they cannot be resupplied to the ecosystem to meet requirements for optimum plant growth. In some cases, productivity may be so reduced that revegetation is slowed, and the site remains susceptible to surface erosion for a much longer period (Heavilin 1977).

Mass Erosion

Another indirect effect of broadcast burning on erosion involves mass erosion. Where roots of residual brush provide strength to soil masses, killing brush species by broadcast burning of logging residue could cause mass failures. This potential effect would be greatest on steep slopes when burning is of sufficient intensity to kill brush species.

Fire-caused erosion could affect salmonid reproduction, rearing, and angler use or success in streams draining forested watersheds by increasing the amount of fine sediment in the streambed and the annual number of days with turbid streamflow. Substantial increases in bedload and suspended sediments caused by fire can be avoided, however, by yarding heavy concentrations of unmerchantable slash from cutting units and then burning the residue when soil moisture content is high enough to prevent damage to soil structure and fertility. In areas where soils are extremely fragile, burning might be avoided altogether.

Stream Temperature

Broadcast burning may increase stream water temperature directly during the burning and indirectly during the summer by killing streamside vegetation that provides shade. For example, after a 96-ha watershed in the western Cascades of Oregon was clearcut, slash and understory vegetation provided enough shade to prevent the average weekly maximum water temperature from increasing more than 2°C in July and August; but after broadcast burning, which killed streamside vegetation and also consumed most of the slash, average weekly maximum water temperatures were 7-8°C higher than before logging and burning (Levno and Rothacher 1969).

The magnitude of temperature increases arising from shade removal may be easily predicted by an equation developed by Brown (1969). Stream temperature depends on the amount of sunlight absorbed by the stream and the accretion of cool ground water. Temperature increase is inversely proportional to streamflow rate. Thus in some cases, increased summer flows after clearcut logging may somewhat offset increased heat load to streams. The potential increase in summer water temperature depends on latitude, cloudiness, and the influence of ground water.

Streamflow Increases

Clearcutting frequently increases base flow during periods of low flow in the summer by reducing interception and transpiration losses and by making more water available for streamflow. Generally such increases are temporary, and may disappear in less than 5 years (Harr 1979). Any additional reduction in transpiration and interception caused by killing brush species by broadcast burning will be very small and short lived.

Release of Nutrients

Plant communities accumulate and cycle nutrients in their role as the biological continuum linking soil, water, and atmosphere. Nutrients are cycled in an orderly and relatively predictable manner until some disturbance alters the form or distribution of nutrients. Tiedemann and others (1979) summarized the response of various ecosystems to fire and other treatments. In all studies of effects of broadcast burning on nutrient content of streams, burning followed clearcut logging. Effects of burning alone, therefore, have been determined for only wildfire (Hoffman and Ferreira 1976, Johnson and Needham 1966, Tiedemann and others 1978).

In general, levels of nutrients in streams have been low after burning of slash (Tiedemann and others 1979). Lotspeich and others (1970) concluded that changes in the chemical makeup of water after a wildfire in Alaska were below the levels required to exert an impact on stream macroinvertebrates. Similar conclusions were reached by Wood (1977) for macroinvertebrates and by Hoffman and Ferreira (1976) for periphytic algae production. Toxic concentrations of nutrients and heavy metals have Seen found only where logging residue was burned in stream channels (Fredriksen 1971).

MECHANICAL SITE PREPARATION

A number of techniques other than broadcast burning are commonly used to reduce logging residue and to prepare a site for reforestation. Mechanical site preparation methods include machine piling of slash with a tractor equipped with a brush rake or some other type of blade, removing brush by machine, and ripping areas such as landings and primary skid roads that have been compacted during logging. Although such activities improve seedbed conditions, they may also lead to soil erosion and stream sedimentation in some instances.

The potential for erosion is directly related to the extent soil is exposed or disturbed, slope gradient, intensity of rainfall, and stability of exposed soil aggregate. The potential for adverse effects on anadromous fish habitat also depends on the proximity of the site to water courses. In the case of ripping previously compacted areas, the loose exposed soil is preferable to compacted exposed soil because the latter, owing to revegetation problems, may remain a chronic source of turbid water and sediment for a much longer time.

PLANTING

Reestablishing a forest stand by planting does not immediately affect anadromous fish habitat, but latent effects might occur. For example, streams receiving energy inputs (leaves or twigs) from deciduous canopies are apparently more productive for invertebrates than streams receiving energy inputs from coniferous canopies.[6] Manipulating streamside vegetation by planting conifers in lieu of hardwoods might reduce food production for salmonids in the adjacent reach of stream. Also, because open or semiopen stream reaches are often more productive than reaches with closed canopies (Murphy and Hall 1981, Newbold and others 1980), it might be best for fish production to maintain the semiopen condition as long as solar heating is not a problem. In open areas where water temperatures are too high for optimum production of salmonids, planting conifers or fast-growing deciduous species (cottonwood or alder) might improve fish production.

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[6] C. Hawkins. Corvallis, OR: Oregon State University; 1981. Personal communication.

REDUCTION OF COMPETITION

Depending on the age of a reestablished forest, one of several methods may be used to reduce competition. When trees are between seedling and sapling size, brush competition may be reduced by herbicide application or manual removal of brush. Application of herbicides, discussed in detail in paper 9 of this compendium, will not be discussed further here. The other method of brush removal, the manual method, does not adversely affect anadromous fish habitat because damage to the site is so limited both in severity and areal extent.

As trees in a forest stand reach the point when the struggle for existence threatens to become injurious, precommercial thinnings may be used to remove least desirable trees. The effects of precommercial thinning on anadromous fish habitat are slight. Any surplus of nutrients or water resulting from thinning is immediately used by remaining trees. No changes occur in erosion or sedimentation because the roads used during timber harvest provide adequate access for thinning.

SUMMARY

The silvicultural activities discussed in this paper are those necessary to rapidly establish and nurture young forest stands. These activities include (1) cutting prescriptions to improve natural regeneration, (2) preparing sites for planting, (3) removing slash to reduce fire hazard, (4) seeding and planting, and (5) reducing competition to enhance growth of young trees. Timber harvest, road construction, and use of pesticides and fertilizers are discussed in other papers in this compendium.

The distribution of coniferous forests and anadromous salmonids coincides along much of the Pacific slope, and simultaneous management of the two resources creates some conflicts. Several timber management activities, including some silvicultural treatments, have the potential to damage the habitat of anadromous fish through accelerated sedimentation and solar heating. The ability to predict the consequences of specific silvicultural activities on fish production, however, is not well developed.

Anadromous salmonids have exacting habitat requirements and most production in forested watersheds occurs in small (first- to third-order) streams. Some silvicultural treatments such as broadcast burning and machine scarification and piling can degrade water quality and fish habitat in small streams, but seldom do so because of the low spatial and temporal intensity of the activities. The highest risk of habitat damage from silvicultural activities occurs in areas with erosive soils and high annual precipitation, or high summer solar radiation and low streamflow.

The effects of the silvicultural activities discussed in this paper are generally much lower than the effects of timber harvest and road construction activities.

METRIC EQUIVALENTS

1 millimeter (mm) = 0.03937 inch
1 centimeter (cm) = 0.3937 inch
1 kilometer (km) = 0.6214 mile
1 hectare (ha) = 2.471 acres
1 milligram (mg) = 0.03527 ounce (avoirdupois)
1 liter = 1.0567 quarts
°C = 5/9 (°F - 32)

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