Fish and Wildlife Relationships in Old-Growth Forests

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OLD-GROWTH FORESTS—FISHERIES ECOLOGY

James R. Sedell, Session Leader

ECOLOGICAL CHARACTERISTICS OF STREAMS IN OLD-GROWTH FORESTS OF THE PACIFIC NORTHWEST

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ABSTRACT

Forest vegetation strongly affects aquatic habitat in streams and rivers of all sizes. Streams associated with old-growth forests are dominated by large tree-sized woody debris. Large woody debris traps sediment and creates a great diversity of habitat for both fish and aquatic invertebrates. Woody debris slows the routing of finer organic matter, and allows organisms time to more fully process these materials before they are moved downstream. The structural influences of woody debris differ little between streams flowing through old-growth and through natural, young, post-wildfire stands. Large logs may reside in a channel for a century, or more, and provide a variety of benefits to the aquatic ecosystem until the post-wildfire stand matures to the point of contributing large debris to the channel. The United States has few remaining examples of the full, natural interaction of rivers with adjacent forests except in Alaska and national parks. Undisturbed streams in old-growth forests are restricted to small, high-gradient examples in relatively inaccessible and mountainous areas. A rich archival record documents man-imposed changes in forest influences on rivers in a variety of regions and geological and topographic settings. These old records—from fur trappers, the U. S. Army Corps of Engineers, and others—describe natural river systems greatly influenced by numerous downed trees, and large jams of floated debris.

INTRODUCTION

Forests control the structure and food base of small streams (Cummins 1974; Franklin *et al.* 1981; Triska *et al.* 1982). Characteristics of a stream, such as channel shape, productivity, and salmonid populations, reflect stand conditions. These forest/stream interactions are particularly well displayed in old-growth forests. Old-growth forests are still common in the mountains of the Pacific Northwest and shores of southeast Alaska, but their extent is steadily diminishing. Most of the remaining old-growth forests are on public lands, particularly lands managed by the U.S. Department of Agriculture, Forest Service, and the U. S. Department of Interior, Bureau of Land Management. Substantial acreages of old-growth forest have been preserved in national parks, wilderness areas, research natural areas, and other reserves. Disposition of the remaining old-growth stands on public lands is highly controversial. How fisheries resources are affected by cutting the old-growth is an aspect of the controversy.

This paper introduces the ecological characteristics of streams in old-growth forests in the Pacific Northwest and Alaska. We contrast streams flowing through unmanaged and managed forests, in different stages of development, based on the information available. Comprehensive ecological knowledge is limited for all successional stages including old-growth. Examination of streams in old-growth forests and historical records that document conditions along unmanaged stream systems provide points of reference for comparison between present managed stream habitats and pristine environments. Our present efforts at habitat protection and enhancement often lack the conceptual rationale needed to assure success in maintaining and rehabilitating wild stocks of salmonids.

We have identified four stream conditions, as determined by the history of the adjacent stand, and discuss the structural and functional characteristics of each. Large woody debris, the quality of food resources, and the base of the food web are key criteria for distinguishing the stream condition. Much of the information presented here has been generated by USDA Forest Service and university scientists working in Douglas fir/western hemlock forests at the H.J. Andrews Experimental Forest in the Willamette National Forest, Oregon. The principles outlined, however, are broadly applicable to forest streams anywhere.

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STREAM CHARACTERISTICS IN OLD-GROWTH FORESTS

Streams in old-growth forests contain vast quantities of large organic debris (Swanson *et al.* 1976; Anderson *et al.* 1978; Triska and Cromack 1980; Triska *et al.* 1982; Naiman and Sedell 1979; Sedell *et al.* 1982; Franklin *et al.* 1981). This large organic debris shapes the stream channel by serving as dams, which pond sediments and water, and as large roughness elements causing formation of pools. Big wood in streams provides a diversity of spawning and rearing habitat for salmonids. In the smallest streams, over 50 percent of the habitat is related to large wood (Swanson and Lienkaemper 1978; Anderson and Sedell 1979; Triska *et al.* 1982). In larger third-order streams, about 25 percent is created and maintained by wood. In the Panhandle National Forest in northern Idaho, 80 percent of the pools in small- to intermediate-sized streams with gradients of 6 percent are formed by wood (Bob Rainville, Panhandle National Forest, personal communication). The food base or energy supply of a stream in an old-growth forest is mostly litter from the adjacent forest combined with algae growing in stream reaches exposed to light. Pristine streams tend to retain the forest litter; over 70 percent is retained long enough to be biologically processed by organisms in the stream (Triska *et al.* 1982; Sedell *et al.* (1975). Naiman (1982) found similar results in pristine streams in the boreal forest of Canada.

The influence of the forest as a source of energy and shaper of stream channels diminishes as a stream gets larger. The edges of a natural stream, however, are dominated by forest vegetation lining the banks and large downed trees creating and maintaining side channels and small backwater areas—prime sites for deposition of organic materials and rearing of coho salmon (Sedell *et al.* 1982).

The salient features of a stream under an old-growth forest are an abundance of large wood, a mix of deciduous and coniferous leaf and wood litter, and large gaps of light which allow algae to grow (Fig. 1). These elements provide a stable, highly interactive, terrestrial-aquatic ecosystem. This diversity of food and habitat provides a rich mix of vertebrates and invertebrates and age-classes within a species.

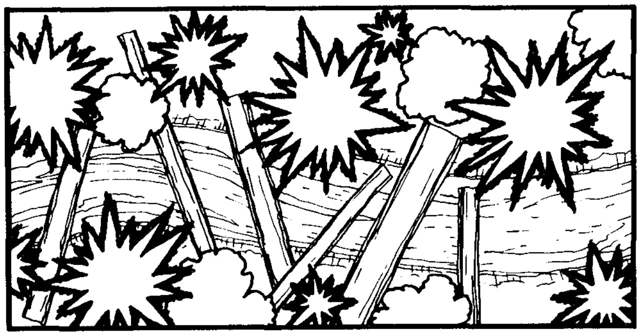

Figure 1. Schematic representations of a stream reach in an old-growth forest composed of conifer (serrated crown margins) and deciduous (rounded crown margins) trees. Streams in old-growth forests are characterized by large organic debris, mixed litter inputs as a food resource to the stream, and lighted openings that allow algae to grow.

Old-growth forests have never blanketed the entire natural landscape of the Pacific Northwest. Big floods exposed areas where deciduous trees and shrubs became established and wildfire periodically burned across the landscape. Fire is a relatively frequent perturbation of forests in the Pacific Northwest. Indians in California, Oregon, and Washington historically burned the broad valley floors that typically left savannah-like conditions; the boggy nature of the streamsides, however, usually left a wide, dense riparian zone (Fremont 1846). Recent studies in mountain environments by Hemstrom (1982),

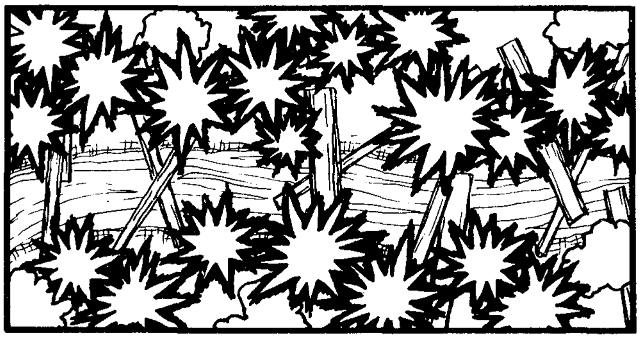

Figure 2. Schematic representations of a stream reach in second-growth forest following wildfire composed of conifer (serrated crown margins) and deciduous (rounded crown margins) trees. Emphasis is on abundant large wood, heavy shade, and mix of litter inputs as a food resource for the stream.

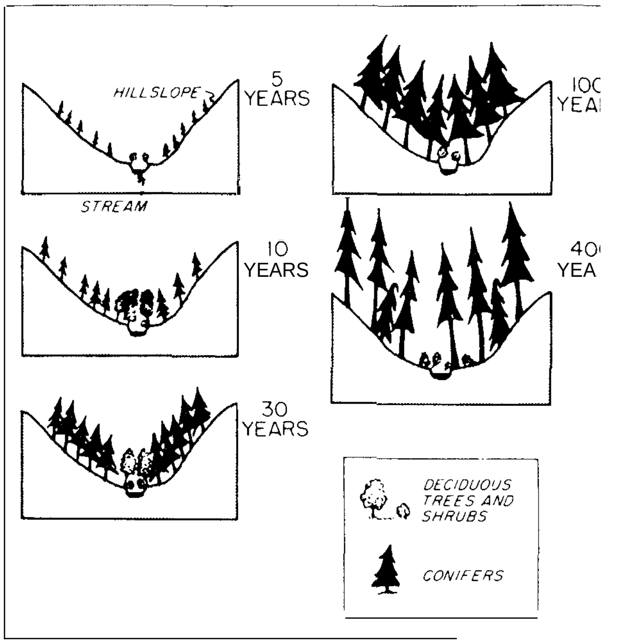

Figure 3. Hypothetical changes in the riparian zone through succession in Douglas fir-western hemlock forests (Meehan *et al.* 1977 and Swanson *et al.* 1982) from Analysis of Coniferous Forests Ecosystems in the Western United States, US/IBP Synthesis Series U.14 edited by R. L. Edmonds, copyright 1982 by Hutchinson and Ross, Inc., Stroudsberg, Pa. Reprinted by permission of the publisher.

Hemstrom and Franklin (1982) in Mt. Rainier National Park, James Agee, USDI National Park Service, Seattle, Washington (personal communication), and McKee *et al.* (1982) in Olympic National Park revealed that the oldest stand ages commonly occur along streams and rivers. In Olympic National Park, in particular, fire rarely extends onto the valley floor.

Even where fires burn across valley floors and riparian zones, the structural influence of the forest is retained because most of these fires consume little of the large wood pieces. Old burns usually contain numerous snags. Swanson and Lienkaemper (1978) examined organic debris loading in streams flowing through stands that are in different stages of recovery following major wildfire. They observed that large organic debris in small- and intermediate-sized streams may persist for long periods, even through the period of stand reestablishment following wildfire (Fig. 2). The large wood component continues to influence and shape stream channels until the post-fire stand begins to produce large woody debris.

The environment of forestdominated streams varies with stand age in response to structural changes in streamside vegetation through time (Fig. 3; Meehan *et al.* 1977). In small streams in the western Cascade Range of Oregon, dense riparian stands of deciduous shrubs and small trees develop in 1-2decades. Beyond that point, up-slope conifers begin to overtop and suppress deciduous streamside vegetation. Older stands have a multi-layered structure, and more light penetrates to streams.

Temporal variations in structure of a stand are reflected by shifts in both energy base and habitat in streams up to fifth-order (intermediate size, 10-15 m in width). Although little is known about actual productivity of streams through vegetation succession, algae are known to be a dominant source of energy before canopy closure (Gregory 1980; Triska *et al.* 1982). Algae continue to be an important contributor in small- to intermediate-sized streams as long as there is a canopy cover of hardwood. Algal production is important in the spring before the leaves come out and in the fall after leaf abscission. When the stream is completely enclosed by a conifer canopy, the ecosystem shifts to a food base of confier litter that is lower in nutrient quality than algae or deciduous leaf litter. The more open canopy of old-growth conifers provides greater diversity of nutrient inputs, including algae and litter of herbs, shrubs, hardwoods, and conifers.

STREAMS IN MANAGED FORESTS

Effects of forest management on streams, and fish habitat in particular, have been reviewed by Gibbons and Salo (1973) and Everest and Harr (1982). Research results from the Pacific Nothwest have focused on the effect of watershed disturbance on aquatic resources (Hall and Lantz 1969; Burns 1972; Moring and Lantz 1975). Results of these investigations yielded mixed results because of difficulty in distinguishing effects of alteration of habitat, food sources, and other factors on abundance of aquatic biota (Hall *et al.* 1978). We examine how two critical stream characteristics—large organic debris and diversity of food sources—are affected by forest management practices.

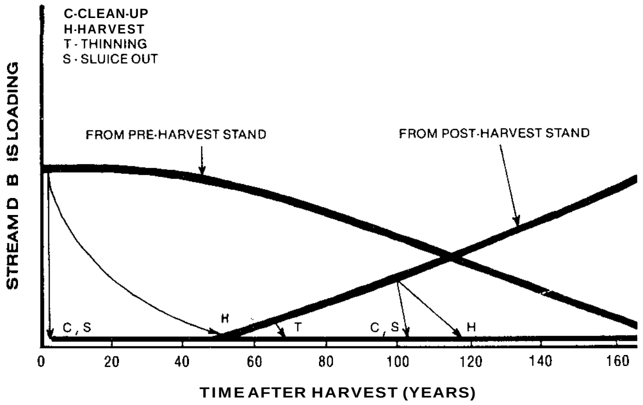

Figure 4. Changes in loading of large organic debris into streams through time, contrasting unmangaged debris loading with timber harvest and second-growth stand management (adapted from Swanson and Lienkaemper 1978). Vertical arrows denote abrupt decreases in debris loading caused by direct clean-up and increased incidence of torrents. Diagonal arrows show delayed reduction in loading caused by removing stems in the stand adjacent to the stream.

Organic Debris

Forest management reduces debris loading in several ways (Fig. 4). Thorough clean-up of streams and increased number of channel-scouring debris torrents cause abrupt and direct loss of debris. Thinning and harvest operations remove the future source of large debris for streams, thereby eliminating resupply of stream debris. Intensive management of streamside stands exclusively for timber production will ultimately result in total elimination of large debris as residual woody debris is lost to decomposition, abrasion, and transport out of the stream.

Streams throughout North America have been systematically cleaned of snags and organic debris for more than 150 years (Sedell *et al.* 1982; Sedell and Luchessa 1982). From the middle 1800s to about 1920, large- and intermediate-sized rivers in the Pacific Northwest were cleared of drift jams and snags so steamboats and barge rafts could navigate the rivers to transport supplies and agricultural products. From the 1880s to 1915, small rivers and streams were used to transport logs from the woods to the mills. Before the logs could be driven, the streams had to be cleaned of debris. Many streams required several expensive splash dams to augment the flow enough to drive logs (Sedell and Luchessa 1982). Logging debris was a big problem in streams in Oregon and Washington during the 1940sand 1950s when stream beds were used as logging roads and the fallen trees pulled into them. The 1960s and 1970s were marked by an increase of debris avalanches from midslope roads and clearcuts in very steep slopes, resulting in increased scouring of small stream channels. Much of the remaining old growth covers steep, deeply-incised terrain. The demand for wood fiber has also resulted in less woody debris left on slopes and in streams (Triska and Cromack 1980). Finally, overzealous stream clean-up continues to remove debris and to disassociate a stream from its forest.

The net result of this clean-up has been a reduction of pools and an increase in riffles, providing less productive rearing areas but more spawning areas (Everest and Meehan 1981). Bisson and Sedell (this volume) and Toews and Moore (1982) showed that debris was less stable, debris volumes were lower, number of debris pieces greater, and average piece size was smaller following logging and stream clean-up. These changes were attributed to the removal and breaking up of stable instream debris and the addition of unstable debris during logging.

Bryant (1980) described the evolution of large organic debris after timber harvest in Maybeso Creek in southeast Alaska. He found fewer accumulations of large debris 15-20 years after logging than existed before logging. This resulted in a decrease in pool areas and an increase in riffles. Although amount of debris decreased in general, remaining debris along the banks and projecting into the channel still influenced channel morphometry and streambank stability. This residual debris was still helping to maintain pools that were important rearing areas for juvenile salmonids.

Debris inputs have been studied in streams flowing through 75- to 135-year-old fire stands by Swanson and Lienkaemper (1978). By evaluating size of debris, time of residence in channel, and other factors, they determined whether the debris was derived from the pre-fire or post-fire stand. They found that the change in dominance of debris of pre-fire and post-fire origin is gradual; it occurs over more than a century where the pre-fire stand was old growth (Fig. 4). The size distribution and species composition of the pre-fire stand determined the residence times of debris in streams. Cedar and Douglas fir of large diameter last the longest. If the pre-fire stand was young and the stream contained only small-diameter material, the debris carried over to post-fire conditions decomposed faster than large, old-growth material. Under these circumstances total stream debris may decline appreciably during stand reestablishment.

Food Quality

Recent research has emphasized the role that the surrounding riparian canopy plays in determining abundances of stream biota (Lyford and Gregory 1975; Hall *et al.* 1978; Gregory 1980; Murphy and Hall 1981; Triska *et al.* 1982; Hawkins *et al.* 1982; Bisson and Sedell this volume). These studies and others (Albrecht 1968; Hunt 1979; Newbold *et al.* 1980) provide convincing evidence that streams with open canopies are more productive than heavily shaded streams.

Streams with open canopies have algae as their chief energy source. Algae is a very high quality food compared to leaf and needle litter. Hawkins *et al.* (1982) and Newbold *et al.* (1980) found that streams without shade had higher abundances of invertebrates than shaded streams. Murphy *et al.* (1981), Hawkins *et al.* (1983) and Bisson and Sedell (this volume) report greater salmonid biomass in open versus shaded study streams extending from northern California to southwest Washington and in both coastal and Cascade streams. Further, most guilds of invertebrates were more influenced by qualitative differences in available food rather than quantity of food or substrate composition. Invertebrate prey of both salmonids (Antonelli ***et*** *al.* 1972; Elliott 1973; Fahey 1980; Allan 1981) and sculpins (Andreasson 1971; Antonelli *et al.* 1972; Walker 1975) tend to be dominated by Chironomidae and Baetidae, taxa that are characteristically small individuals with high turnover (P/B) ratios (Waters 1969; Benke *et al.* 1979). These organisms feed primarily on algal-derived material, and canopy removal tends to increase the abundance of both of these groups (Newbold *et al.* 1980; Hawkins *et al.* 1982).

The observed relationship between light and salmonid biomass for canopy densities typical of second growth, old growth, and recent clearcuttings, (Fig. 5), leads to the scenario illustrated in Fig. 6. Canopy opening results in a

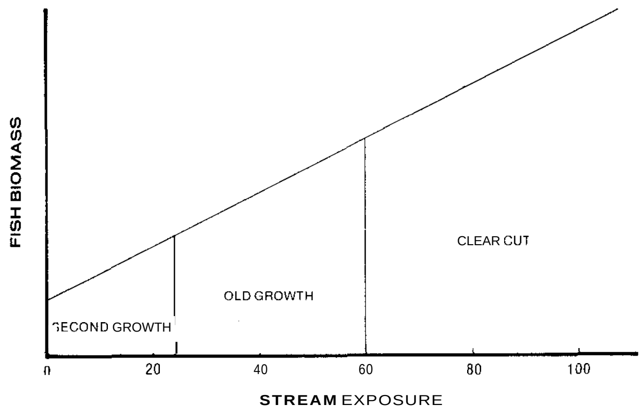

Figure 5. Salmonid population response to light reaching streams. Percent exposure to light for streams flowing through different forest types: young second-growth forests 10-60 years of age; old-gorwth forests 350 years of age; and recent clearcutting 0-10 years of age.

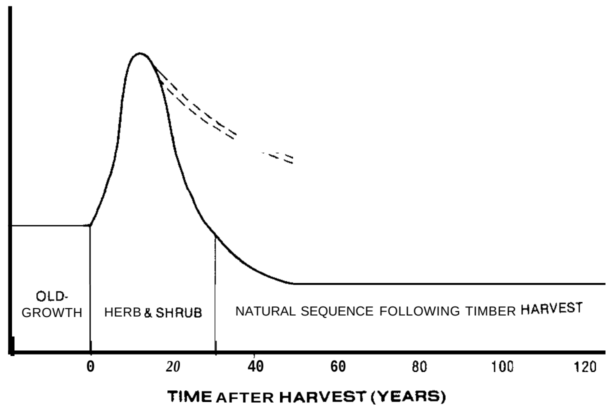

Figure 6. Temporal (120-year) response of salmonid population to harvesting old-growth forests. Active streamside vegetation management can increase fish biomass within a length of stream by managing for larger light flecks along the stream and maintaining input of large woody debris that creates and maintains habitat.

significant increase in primary production and an attendant shift in invertebrate guilds and increased salmonid biomass. The duration of open canopy conditions is variable but generally short-lived (less than 20-year maximum) (Summers 1982), because riparian vegetation responds rapidly to canopy removal in the hypothetical successional sequence sketched by Swanson *et al.* (1982). A thicket of alder and willow typically would occupy the riparian zone within 10-15 years and reshade the stream. This results in a decline in the algal food base and increasing importance of deciduous litter as a food base. The quality of allochthonous inputs, primarily litter of alder and willow, is much higher than coniferous litter of old-growth forests and is processed more rapidly by the biotic community. As the coniferous canopy recovers, shrub species in the riparian zone are shaded out and the alder/willow component becomes scattered and suppressed. Mortality in the riparian zone reintroduces wood debris to the stream. Since the wood of deciduous trees decomposes more rapidly, debris dams are not as persistent as organic debris of conifer wood. As inputs of alder and willow litter decline in amount, the increasing proportion of coniferous litter brings about a general decline in food quality for aquatic biota and overall production declines. As a stand matures toward old-growth condition, mortality produces more complex stand structure, species diversity increases, and flecks of light along the stream are more numerous.

Thus, streams that flow through intensively managed second-growth conifer forests may contain low quality food resources and habitat of reduced stability and abundance of pools (Fig. 7). Many streamside vegetation zones in Oregon and Washington are managed by default with no time or money spent to shape them (Fig. 8). They tend to have high-quality food, but fewer pools and fish habitat that benefit older cutthroat trout or coho salmon. This habitat tends to favor salmonids like young-of-the-year cutthroat and steelhead trout (Bisson and Sedell this volume).

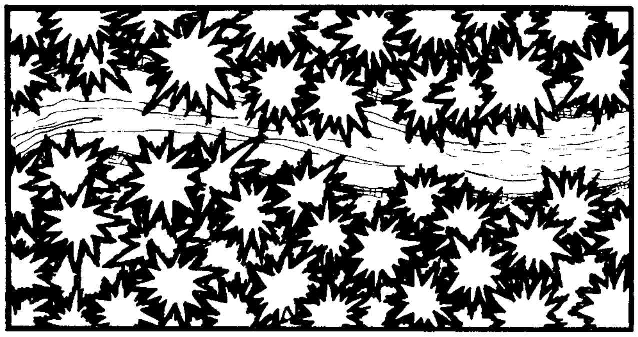

Figure 7. Stream reach in a second-growth forest where the streamside is actively managed for coniferous timber (serrated crown margins). Emphasis is on heavy coniferous shading of the stream, low-quality food resource into the stream, and no wood in the stream. This combination results in the least desirable aquatic resource situation.

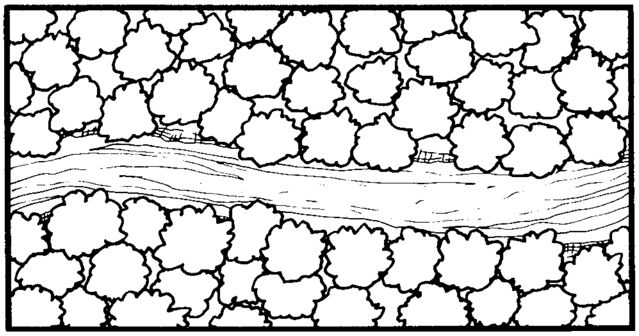

Figure 8. A stream reach in a managed second-growth forest where streamside vegetation is not actively managed. Deciduous forest (rounded crown margins) develops as the dominant overstory canopy, which provides seasonal light openings that allow algae to grow, a single litter type as a food resource, and no inputs of large wood.

MANAGEMENT LESSONS FROM OLD-GROWTH FORESTS

The preceding discussion has strong implications for managing streamsides for aquatic resources, particularly fish. Much of the habitat in streams in old-growth forests is created or maintained by woody debris. Stable spawning gravels and juvenile salmonid rearing areas are dependent on a supply of large woody materials from the adjacent streamside forest. As young stands mature, selective thinning could increase the production of salmonids within a reach by providing a mix of food resources. A hypothetical scenario for fish production within a reach of stream is illustrated in Fig. 6. A strategy for managing streamside areas for long-term fisheries values would be to keep the large woody materials in the stream during harvest, leave large coniferous trees to serve as a future source of instream debris, and selectively thin dense second-growth stands along the stream to provide a mix of food resources, including algae (Fig. 9).

Most of the studies that show increased fish biomass with canopy opening (Hall *et al.* 1978; Murphy and Hall 1981) use an experimental design with the forested stream reach as the control upstream from the clearcut reach.

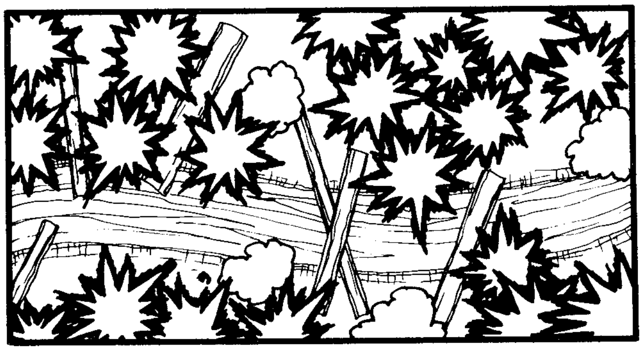

Figure 9. A stream reach managed for aquatic resources, where streamside vegetation is actively managed. Dominant overstory canopy is a mix of large coniferous (serrated crown margins) and deciduous (rounded crown margins) trees that provide a mix of food resources and large wood to the stream. Large wood would be left in the stream and large trees left streamside at time of harvest for future wood inputs. Light openings would be created by selective thinning as canopy closes over the stream.

The open reach conceivably receives the benefits of both forested and exposed streams; a low sediment supply, drift of forest litter, and cool water from the shaded stable forest systems flows into the clearcut where increased supply of salmonid food is provided by algae-eating invertebrates that are prone to drift. These combined factors can enhance fish production.

It is important to examine each reach, however, in terms of its position within the drainage basin. The comparison of streams in completely clearcut and completely forested watersheds might be quite different, because large clearcuts will have greater effect on water temperature, sediment load, and litter quality and quantity. However, the studies that show an increase in salmonid biomass also tend to show a shift to fewer and smaller fish. This indicates that habitat for raising smolt-sized salmonids is limited in some way. Very little is known about how to link information from reaches of streams within a drainage network. How different species of salmonids are distributed within a basin and what their critical basin habitat needs are throughout the year are also poorly known. Models (Brown 1969) can accurately predict the relatively simple phenomenon of thermal loading of stream water for a basin. Once water heats up, it holds the heat unless diluted. An increase in water temperature in the upper basin can have serious impacts on salmonid rearing in downstream areas.

In pristine conditions, "warm" rivers of the Pacific Northwest have numerous pockets of cool water in pools throughout the basin. Large woody debris contributes to formation of cool-water pockets that are important thermal refuges for fish (Keller and Hofstra 1982). Keller and Hofstra (1982) observe that cold pools develop where cool intergravel waters at tributary mouths flow into pools of warmer mainstream water where pool morphology retards mixing. In Redwood Creek, California, for example, large organic debris is important in slowing mixing of the cold and warm waters.

Hartman *et al.* (1982) found that following clearcut logging in British Columbia, small increases in temperature during the winter and spring caused coho salmon juveniles to smolt three weeks earlier than in streams in the old-growth forest. How this early smolting is synchronized with food resources in the ocean is not understood. Important ocean upwelling along British Columbia, however, occurs later in the summer. Thus, the timing of freshwater events in a juvenile salmon's life history (such as temperature-controlled growth or smolting) has been tightly coupled with ocean food and habitat throughout evolutionary time.

Critical temperature requirements for rearing juvenile salmonids and the presence of pools to hold adult chinook salmon and steehead trout throughout the summer are important basin-wide concerns. Maintaining habitat structure that can provide refuges during periods of high temperature are also important to basin-wide rearing of juvenile salmonids.

Sedimentation problems can be a basin-wide phenomenon. Unless a stream has been completely inundated with sediments, however, like Redwood Creek, California (Janda 1978), and South Fork Salmon River, Idaho (Platts and Megahan 1975), sedimentation of spawning gravel is not as critical as destruction of good rearing habitat both within a stream and its sidechannels along the banks. Many river systems naturally have very high sediment loads, including an abundance of fine sediments (less that 1 mm diameter), and yet, historically there has been significant spawning and rearing success. In such areas, fish habitat was maintained by scouring around boulders and wood. The routing of sediment through a basin and the accumulation of sediment in the channel due to accelerated inputs from timber harvest and roads are poorly understood at the basin or even stream-reach level. Platts and Megahan's (1975) work in the South Fork Salmon River showed that spawning and rearing habitat damaged by inundation with sand-sized sediment recovered within five years after forest management activities were halted.

An old-growth forest has less sediments moving through it. Stream areas that have recently experienced wildfire have a much higher sediment input, storage, and transport than old-growth forest, but habitat may recover faster than in logged and cleared streams because structural features in the stream are intact. Increases in sediments and temperatures are not just local problems in the stream reach, but basin problems that can have adverse impacts throughout the whole basin. The salmonid populations and biomass may increase in managed areas of stream, but the cumulative effects of increased temperature and large increases in sediments can reduce the number of salmonids in the basin or set up catastrophic population declines during droughts or from disease. The basin fisheries can still be enhanced by manipulation of the streamside forest for light (both shade and openings) and addition of large wood.

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