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Forest Management and Anadromous Fish Habitat Productivity

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Introduction

In 1976, the USDA Forest Service established a research program to study the biological, physical, and economic aspects of anadromous salmonid habitat. The Anadromous Fish Habitat Research Program is a cooperative effort involving scientists at three USDA Forest Service forest and range research stations: the Pacific Northwest at Portland, Oregon; the Intermountain at Ogden, Utah; and the Pacific Southwest at Berkeley, California.

Scientists at these facilities are studying the relationship between forest management practices and the habitat of anadromous salmonids to develop better ways to achieve concurrent production of timber, fish, minerals, livestock, and other resources. The program is oriented around three types of studies: (1) habitat requirements, (2) effects of various land uses on habitat, and (3) development of ways to improve fish habitat.

The anadromous fishery resources of western North America are produced largely within forested watersheds. Eight species of anadromous salmonids including five salmon—chinook *(Oncorhynchus tshawytscha)*, coho *(O. kisutch)*, sockeye *(O. nerka)*, chum *(O. keta)*, and pink *(O. gorbuscha)*; two trout—steelhead rainbow *(Salmo gairdneri)* and coastal cutthroat *(S. clarki)*; and one char—Dolly Varden *(Salvelinus malma)*, inhabit waters of the Pacific Northwest and Alaska. Habitat requirements of the fish are specific, and alterations of habitat by humans affects production in many ways.

Forest and rangeland management activities that can influence the quality of anadromous fish habitat include timber harvest, road construction, livestock grazing, mining, water developments of various kinds, and recreational pursuits. This paper discusses some of the specific interrelationships between fish habitat and timber harvest, road construction, and livestock grazing. These three activities were selected for discussion because the USDA Forest Service is actively engaged in studies pertaining to these areas of concern.

More specifically the following subjects will be discussed: (1) effects of organic debris and its removal on fish habitat; (2) effects of mass soil movements on fish habitat; and (3) preliminary results of studies concerned with the relationship between different livestock grazing systems and fish habitat.

Organic Debris

Organic debris from forested watersheds of the Pacific Northwest and Alaska enters streams through direct litterfall, various lateral movements including landslides, debris torrents, timber felling, and streambank erosion, plus blowdown of trees, treetops, and branches. Natural accumulation of debris in streams is slow and fairly constant in mature forests, and eventually moves toward an equilibrium between the rate of increase and rate of biological and physical processing in old-growth forests (Sedell and Triska 1977). Logging, or change in forest succession due to natural events can shift the equilibrium causing significant changes in streams and fish populations.

Organic debris can be divided into two categories based on size of individual pieces. Large debris consists of tree boles, rootwads, and large limbs, while small debris is composed of needles, leaves, twigs, and branches. The two categories of debris affect the physical characteristics of streams and production of anadromous fish in different ways.

The effects of organic debris on fish production can be either beneficial or detrimental. The effect is often determined by the size of the recipient stream, the size, quantity, and accumulation rate of woody debris entering the channel, and species of fish. Small streams in the Pacific Northwest are strongly influenced by adjacent terrestrial environments and are dependent largely upon external energy inputs, thus tend to be extrinsic and heterotrophic. The following discussion pertains primarily to small streams—first to third order (Strahler 1957)—which are important producers of anadromous salmonids, and yet because of their size are readily influenced by organic debris.

Several major positive effects of organic debris have been identified in previous studies. Large debris creates physical habitat diversity for rearing salmonids (Swanson and Lienkaemper 1978), provides hiding and resting cover in summer (Baker 1979), respites from floods and ice in winter (Bustard and Narver 1975), and stabilizes streambeds and banks (Swanson and Lienkaemper 1978). It also slows downstream movement of inorganic sediments and fine organic matter (Swanson and Lienkaemper 1975), thus providing an energy base for the aquatic food chain and retaining gravels essential for salmonid reproduction and production of fishfood organisms. On the other hand, massive accumulations of large debris can create barriers to migration of anadromous fish (Holman and Evans 1964), cause bank erosion and channel instability during flood events (Helmers 1966), and debris jams when dislodged by high flows can scour streambeds, thereby removing cover and gravel and altering stream morphology. Small debris provides the primary source of energy for the aquatic food chain in small forested streams (Cummins 1974), but excesses of small debris sometimes cause ponding and depletion of dissolved oxygen in stream waters (Hall and Lantz 1969). Small debris that infiltrates stream gravels can also cause the depletion of intragravel dissolved oxygen (Hall and Lantz 1969) and mortality of incubating salmonid embryos. Accumulations of fine organic material can also produce potentially toxic leachates, particularly in estuaries (Buchanan et al. 1976).

Bryant (1980) measured the evolution of large organic debris after timber harvest in the Maybeso Creek watershed in southeast Alaska. He found a decrease in accumulations of large debris 15 to 20 years after logging, resulting 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 in some instances contributed to streambank stability. This residual debris helped to maintain pools that were important rearing areas for juvenile salmonids.

Removal of debris has been a concern of resource managers for many years. When should debris be removed and when should it be retained? Often all logging-associated debris has been removed, including large material. In southeast Alaska, natural debris accumulates very slowly (Swanson et al. 1977), and total debris removal often results in a completely open channel (Bryant unpublished). Effects of total debris removal on aquatic invertebrates and Dolly Varden populations were assessed by Elliott (1976). He found a shift in the invertebrate community structure in Starrigaven Creek near Sitka, Alaska, to taxa associated with riffles within a year after debris removal. Dolly Varden populations also exhibited an 80-percent reduction.

Differences between natural and logging debris were also apparent in recent studies in southeast Alaska (Bryant unpublished). Natural debris was often partially decomposed and less concentrated than logging debris. Logging debris was smaller, contained more floatable material, and occurred in more dense and patchy concentrations. Streambed scour and channel instability resulted more from logging debris than from natural debris.

The effects of organic debris may depend on the species of anadromous salmonids present (Narver 1971). Debris that forms pools used by rearing coho salmon may promote sediment deposition in riffles used by pink salmon for spawning. Conversely, removal of debris accumulations may reduce pools and increase riffles, providing less productive rearing areas, but more spawning areas.

Mass Soil Movements

Mass erosion events are a common occurrence in forested steeplands of western North America. Landslides, slump earthflows, and debris torrents account for most mass erosion in the Pacific Northwest but debris torrents are the most universally distributed and frequent events. The rate at which debris torrents occur in steep unstable watersheds is closely linked to timber management and the presence of roads (Swanson and Dyrness 1975). Since anadromous fish and timber are concurrent crops in most western watersheds, it is important to understand how debris torrents affect fish production and harvest.

Debris avalanches, the precursors of debris torrents, are often initiated when intense precipitation saturates exposed soils in road cuts and fills, or clearcuts. The saturated soil slumps under its own weight and forms a slurry which moves rapidly downslope, entraining additional soil, rock, and woody debris. Before losing momentum, most torrents enter the channels of small streams. Once in streams, the soil, rock, and debris might move downstream, scour the channel to bedrock, or be deposited in a massive dam of organic and inorganic debris. In either case, the physical features of the stream channel are changed and fish habitat is altered.

In 1978 we initiated a study to assess the relationships between debris torrents and habitat of anadromous salmonids. The study was designed to: (1) quantify site-specific effects on salmonid habitat immediately below the egress of a debris torrent and assess longevity of those effects, and (2) determine the long-term relationships between debris torrents and fish habitat within an extended reach of stream. The first objective was accomplished with an extensive study of four debris torrents in different watersheds, and the second with an intensive study in a single watershed.

Site-Specific Effects—Extensive Evaluation

Torrents on four streams in the Oregon Coast Ranges about 50 miles (80 km) west of Eugene were studied from 1978 through 1980. Two of the streams (Hadsall Creek and Knowles Creek) were small at the study sites, flowing less than 0.5 cubic feet per second (cfs) (14 liters/sec.) in summer, and two were larger (Tenmile Creek and Cummins Creek), flowing more than 2.5 cfs (71 liters/sec.) in summer. The smaller streams received large inputs of debris (greater than 1,000 cubic yards (765 m^3)) while the larger streams received smaller amounts (less than 500 cubic yards (380 m^3)). The torrents on Hadsall and Knowles creeks occurred in February 1978, and those on Cummins and Tenmile creeks date from November 1975. The study was designed to assess both spatial and temporal habitat changes caused by debris torrents. Spatial effects were assessed by sampling similar stream habitats above and below a torrent egress (point where torrent exited first order stream and entered second or third order stream) at low summer streamflow and comparing results. Consistent major differences were assumed to be attributable to the effects of debris torrents. Samples collected at given locations over a period of years will also be compared to assess recovery rates.

The major parameters examined included:

1. structure and biomass of fish populations,
2. numbers, biomass, and size of aquatic invertebrates,
3. textural composition of spawning gravels,
4. surface and intragravel dissolved oxygen, and
5. instream cover.

Fish populations examined included cutthroat trout, juvenile steelhead trout, juvenile coho salmon, and freshwater sculpins *(Cottus perplexus* and *C. gulosus).* Numbers and biomass of all species of fish were reduced in all sampling areas impacted by debris torrents (Table 1). Biomass of salmonids was reduced an average of 90 percent in the small streams and 55 percent in the larger streams. Populations of sculpins suffered similar reductions. In three years of sampling, no definite trends toward recovery were noted.

The effects on aquatic invertebrates were variable. Biomass of benthic macroinvertebrates longer than 0.39 inches (1 mm) was lower in square-foot bottom samples collected in torrent-disturbed areas in three of the four streams sampled, but no definite trends in numbers or mean lengths of individual organisms were noted. The largest reduction of benthic invertebrates was observed on the smallest stream, Hadsall Creek.

Texture of spawning gravels and supply of intragravel dissolved oxygen are critical factors in survival of incubating salmonid embryos. Fine sediments less than 0.39-inch (<1-mm) diameter and low concentrations of intragravel dissolved oxygen tend to reduce reproductive success of salmonids. We noted an initial increase in fine sediments of more than 90 percent by weight in torrent-disturbed gravels of Hadsall Creek, and little improvement occurred during two years of sampling (Table 2). Knowles Creek had no upstream gravels near the torrent egress so comparative data for that stream are lacking. No major changes were observed in gravels of the larger streams. Intragravel dissolved oxygen followed a similar pattern, dropping substantially in the disturbed area of Hadsall Creek where sand and organic debris were entrained in gravels, but changing little on the larger streams (Table 2).

Table 1. Biomass of fish in stream habitat above and below a debris torrent egress.

Stream	Species	Biomass, pounds per acre (g per m2)					
		1978		1979		1980	
		Above	Below	Above	Below	Above	Below
Hadsall	Cutthroat	42.97(4.82)	7.93(0.89)	48.85(5.48)	dry	intermittent	dry
Creek	Sculpins	32.36(3.63)	0.36(0.04)	47.24(5.30)	dry	intermittent	dry
Knowles	Coho	4.10(0.46)	2.85(0.32)	4.01(0.45)	0.80(0.09)	dry	5.17(0.58)
Creek	Sculpins	11.86(1.33)	6.86(0.77)	10.70(1.20)	8.65(0.97)	dry	14.00(1.57)
Cummins	Steelhead	9.81(1.10)	3.39(0.38)	31.02(3.48)	6.51(0.73)	21.48(2.41)	4.10(0.46)
Creek	Sculpins	13.28(1.49)	8.74(0.98)	33.42(3.75)	16.58(1.86)	16.40(1.84)	16.31(1.81)
Tenmile	Steelhead	11.32(1.27)	5.61(0.63)	16.76(1.88)	2.94(0.33)	16.49(1.85)	12.75(1.43)
Creek	Sculpins	77.55(8.70)	29.24(3.28)	47.51(5.33)	19.52(2.19)	51.35(5.76)	30.49(3.42)

Table 2. Percent weight fine sediment less than .039-inch (<1 mm) diameter and intragravel dissolved oxygen (mg/1) in salmonid spawning areas above and below a debris torrent egress.

		1978		1979		1980	
Stream	Parameter	Above	Below	Above	Below	Above	Below
Hadsall	Sediment	12.06	23.33	17.16	23.56	—	—
Creek	Oxygen	9.3	6.7	6.5	4.4	6.5	dry
Cummins	Sediment	8.99	6.31	6.73	8.67	—	—
Creek	Oxygen	10.3	8.3	10.7	11.0	8.3	6.1
Tenmile	Sediment	7.26	7.14	8.93	8.54	—	—
Creek	Oxygen	10.0	7.3	10.3	11.7	8.0	6.3

Instream cover was also examined in disturbed and undisturbed areas in the stream channels of Hadsall and Tenmile creeks. The largest changes in cover were observed for the small stream. The torrent scoured most instream cover from the channel of Hadsall Creek below the egress and filled most pools with sediment. Both cover and pool area were reduced by about 70 percent. Pool area on Tenmile Creek was unchanged by the debris torrent, but cover in the form of woody debris increased about 30 percent in the disturbed area.

In summary, the site-specific effect of debris torrents on fish habitat and production was generally negative in the area immediately below the torrent egress. The cumulative effects were greatest on small streams that received large quantities of debris.

Extended Reach Effects—Intensive Evaluation

The effects of debris torrents on habitat and production of anadromous fish were also studied on a 1-mile (1.6-km) reach of Knowles Creek in 1979 and 1980. Observations were also made outside the 1-mile (1.6-km) reference reach. Bedrock in the Knowles Creek watershed is sandstone, and about 80 percent of the stream substrate along the main-stream is composed of sandstone bedrock. In this sediment-poor system, fish habitat diversity in terms of cover, pools, and variations in substrate in the study reach was directly related to organic and inorganic materials deposited in the channel by debris torrents. Habitat utilization by adult and juvenile coho salmon was also strongly associated with habitat changes resulting from debris torrents.

Debris torrents entering first- through third-order stream channels of Knowles Creek appear to have consistent and predictable effects on habitat of anadromous fish. Recent torrents on this stream occurred during intense storm events when all streams in the basin were at or near flood stage. Typically a large mass (>1,000 yd^3(765 m^3)) of large woody debris, rock, and soil entered the stream from a steep side channel. High flows tended to float the woody material out of the system, or deposit it at the stream margins or in a massive debris jam somewhere downstream. Large rock, rubble, and soil in the torrent created a dam in the channel, changed the channel gradient, and created a small lake upstream. Sediment transported by subsequent winter freshets was deposited at the head of the lake, forming new gravel bars. Over a period of years the lakes fill with gravel.

There is evidence of three large debris torrents in the 1-mile study reach of Knowles Creek. Two are recent—one occurred on November 14, 1980, and the other in February 1977. The third is an old torrent of unknown age. Gradient changes caused by the 1977 torrent and the undated torrent were similar. The stream channel rises at 0.8 percent grade in the area of both torrents. A stable dam of boulders and rubble increased the gradient at the egress of the 1977 torrent to 1.6 percent for a distance of 450 feet (137 m), and gradient at the undated torrent was increased to 1.9 percent for 600 feet (183 m). Gradient changes caused by the 1980 torrent have not yet been surveyed. None of the debris dams retarded upstream passage of anadromous salmonids. The 1977 and 1980 torrents created lakes with volumes of 1.7 and 1.8 acre feet (2,097 and 2,220 m^3), respectively. The capacity of the debris torrent ponds for rearing underyearling coho salmon exceeded other habitats available in the stream. The population of coho rearing during the summer in the pond created by the 1977 torrent was estimated at 875 fish in 1979 and 965 in 1980, or an average of about 1.77 fish per lineal foot (5.8 fish per lineal meter) of stream channel. Coho population estimates from four unponded segments of Knowles Creek indicated an average of 0.18 coho per lineal foot (0.6 per m) in summer. In 1979 and 1980, the debris torrent pond was rearing underyearling coho at a rate nearly 10 times greater than the unponded channel. The number of coho rearing in the 530-foot-long (160-m) pond was estimated to be approximately equal to the number rearing in 1 mile (1600 m) of unponded habitat.

The debris torrent ponds also provided habitat for adult coho. Ponds created by the torrents provided resting habitat for adult coho awaiting spawning. Ponds also provided natural settling basins for gravels transported downstream during freshets. Observations made during the winter of 1980 illustrate the importance of torrent ponds to adult coho. On December 13, 1980, 92 adult coho salmon were observed in the 1-mile (1.6-km) study reach of Knowles Creek. Eighty-five percent of the fish were either resting in the deep ponds created by the 1977 and 1980 torrents, or spawning on gravels impounded by the three torrents. Ten coho redds were counted in the reach and 7 were in gravels impounded by torrent-produced dams.

Coho make immediate use of habitat created by debris torrents. The 1980 torrent was less than three weeks old when 14 adults were seen resting in the new pond and 2 redds were observed on 25 yd^2 (21 m^2) of freshly impounded gravel at the head of the pond.

Our study of an extended reach of stream on Knowles Creek has helped clarify the effects of debris torrents on fish habitat in that watershed. Although torrents have a negative effect on habitat in areas inundated with organic and inorganic debris, the over-all effect on Knowles Creek appears positive. Within the extended reach, debris torrents enhanced spawning and rearing habitat for adult and juvenile coho salmon and did not interfere with adult migration routes.

The results obtained on Knowles Creek might be generally characteristic of other sediment-poor systems in the Coast Range sandstone formation. Similar changes in habitat probably do not occur in sediment-rich systems where sediment added by torrents would add little to habitat diversity and torrent-created ponds would fill rapidly with sediment. Additional research is needed to determine how broadly results from Knowles Creek can be inferred.

Future research is also needed to determine how the accelerated occurrence of debris torrents caused by timber management affects fish habitat. The rate of accumulation of debris in stream channels could be the determining factor in whether cumulative effects on habitat of anadromous salmonids are positive or negative.

Livestock Grazing Systems

Livestock use streamside areas heavily, for feeding and resting. The stream itself is often their only source of water; this also promotes use of streamside areas. Many studies have described the adverse impacts of overgrazing and concentration of livestock along streams, but these have usually dealt with physical impacts such as soil compaction, streambank trampling, and reduction of streamside vegetation (Meehan and Platts 1978). A few studies have compared biomass of salmonids in stream reaches protected from streamside grazing with reaches along which grazing occurred. Gunderson (1968) showed that brown trout (*Salmo trutta* Linnaeus) production was considerably greater in sections of Rock Creek, Montana, adjacent to ungrazed areas than in sections adjacent to grazed areas. These findings were later verified by Marcuson (1971). Platts and Rountree (1972) reported fish habitat was damaged, primarily from bank trampling, more along sections of Bear Valley Creek, Idaho, than along ungrazed sections.

Several different livestock grazing systems are in use today (Meehan and Platts 1978). These systems differ primarily in the intensity of use within various pastures of a grazing allotment. All pastures may be grazed continuously throughout the grazing season; a given pasture may be grazed during the early part of the season and left ungrazed during the latter part, or vice versa; various pastures may be rested periodically for a full grazing season; or any number of combinations or modifications of these strategies may be used.

The USDA Forest Service Anadromous Fish Habitat Program has two studies underway to evaluate the effects of various grazing systems on fish habitat. One of the studies is being conducted on several streams in central Idaho; the other is on Meadow Creek in northeastern Oregon's Blue Mountains. Neither study has been completed, so conclusive results cannot be reported at this time. We have been working on the Meadow Creek study, and will briefly discuss this study and some preliminary observations.

The stream was divided into four 1.25-mile (2.0-km) sections to study effects of various livestock grazing systems, with and without wildlife (deer and elk) influence, with a separate 1.25-mile upstream "control" section. The fisheries portion of the study concentrated on the upstream treatment section. This section was subdivided into five units. The first year, cattle grazed season-long in the unit farthest downstream, while upstream units remained ungrazed. The second year, the two downstream units were grazed, etc., so that at the end of the five-year study, the most downstream unit had been grazed for five years, the next upstream unit for four years, etc. with the farthest upstream unit being grazed for one year. Stream channel and bank profiles, benthic and invertebrate drift samples, and steelhead trout population estimates and stomach contents were obtained before cattle were put on, at mid-season, and after cattle were removed each year. Water temperature and various chemical parameters were measured as well.

Data analysis will continue for about two more years. Presently, nothing can be said about effects of grazing on invertebrate organisms. Preliminary observations show no obvious differences between fish standing crops in the control section and the treatment sections after three years of season-long grazing. Stream channel changes have not yet been fully analyzed, but preliminary examinations indicate changes are due more to flow conditions than to direct livestock effects.

The primary purpose of this discussion has been to outline the general scope of the grazing study and the kinds of data that will result.

Summary

The USDA Forest Service Anadromous Fish Habitat Research Program is investigating relationships between forest and rangeland management and fish habitat productivity. Scientists are studying habitat requirements of anadromous salmo-

nids, the effects of various land uses on habitat, and habitat enhancement techniques. Current research is clarifying the impact of large woody debris, mass soil movements, and livestock grazing systems on habitat productivity for anadromous salmonids.

Large woody debris can create habitat for rearing salmonids, but may cause sedimentation in spawning areas. Large, naturally occurring debris can promote streambank stability and reduce streambed scour. Large accumulations of fine organic debris can adversely affect salmonid habitat by reducing dissolved oxygen and producing toxic leachates. In some instances, large debris accumulations may impede fish movement. Total removal of debris can result in a completely open channel, promoting streambed scour, streambank instability, and loss of fish habitat productivity.

Debris torrents, a common mass erosion event in the Pacific Northwest, have a negative impact on habitat and production of anadromous salmonids in small streams immediately downstream from the torrent egress. In a restricted area, both spawning and rearing habitat are degraded and fish production is reduced. Studies within a 1-mile (1.6-km) reach of Knowles Creek, however, indicate that the total effect of debris torrents in that sediment-poor watershed tends to be positive. Torrents created habitat diversity by adding boulders, rubble, gravel, and woody debris to the channel and increased both quantity and quality of habitat for juvenile and adult coho salmon. Torrents are a natural physical process that provide woody debris and gravel necessary to maintain productive fish habitat. The rate at which debris torrents occur might be the most important factor in determining whether cumulative effects are positive or negative:

Very preliminary results of our livestock grazing study do not show profound effects on fish populations among various grazing systems or between one to three years of season-long grazing and ungrazed controls. Final analysis of results should be completed in 1982.

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