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Effects of Logging on the Habitat of Coho Salmon and Cutthroat Trout in Coastal Streams[1]

ABSTRACT

The effects of two patterns of Douglas-fir logging on water quality and fish populations have been studied in three coastal headwater streams. Clearcut logging of an entire watershed of 71 hectares (175 acres) is being compared to clearcutting in patches on a larger watershed of 304 hectares (750 acres), where about 30 percent of the area has been harvested and a strip of timber left along the stream. The third watershed of 203 hectares (500 acres) will remain unlogged as a control. Pre-logging studies began in 1958, access roads were constructed in 1965, and logging took place in 1966.

Substantial changes in temperature and dissolved oxygen content of stream water followed logging in the entirely clearcut watershed. A maximum temperature of 30°C and a maximum diurnal fluctuation of 16° were recorded. Comparable pre-logging maximums were 16° and 1.5°, respectively. Dissolved oxygen levels of surface and intragravel water dropped below 2 mg/l during logging operations. Survival of coho salmon and cutthroat trout in the clearcut watershed has been affected by logging, but the significance of the effect cannot yet be fully evaluated.

No significant changes in the fish population or its habitat have been noted in the patch-cut watershed. Studies will continue for several years to evaluate long-term effects of logging on the stream and to determine the period of recovery.

INTRODUCTION

On the Pacific Coast of North America, salmon and trout spend most of their freshwater life in streams that flow through watersheds containing valuable timber. The close association of salmon and trout streams with timbered watersheds creates potential problems for fishery management because the harvest of timber can affect the streams.

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These problems may be particularly acute when clearcut logging is carried out near small streams.

There has been much speculation about the effects of logging practices on the welfare of the trout and salmon resource. Even though timber and fish are both important to the economy of the Pacific Northwest, their interrelations have been poorly understood. Chapman (1962a) has reviewed some of the potential interactions between logging and fish resources. Earlier studies encompassing entire watersheds were more concerned with effects of logging on water yield than on water quality. Few studies of this kind have been concerned with the effects of timber harvest on stream ecology and fishery resources.

The first intensive long-term study of the problem at the watershed level was begun in 1956 in Alaska by the University of Washington's Fisheries Research Institute, under a contract from the U.S. Bureau of Commercial Fisheries (Sheridan and McNeil, 1968). Much useful information resulted from this study, but unfortunately it was terminated prematurely and replaced by a small-scale monitoring operation (Sheridan, Olson, and Hoffman, 1967).

The Alsea Watershed Study was begun in Oregon in 1957 at the recommendation of the Governor's Committee on Natural Resources. The specific objective of this work is to compare the effects of two patterns of Douglas-fir logging on water quality and fish resources in small coastal streams. Among the parameters of water quality studied are temperature, streamflow, suspended sediment, dissolved oxygen, and dissolved chemical nutrients. Biological studies have included analyses of production of algae, abundance of aquatic insects, and the status and productivity of the fish populations, primarily coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*). Studies on the fish populations have emphasized the survival of eggs and alevins in the spawning beds and the production of juveniles in the stream. In this paper we present a general description of the study and a summary of some of the initial changes in the stream habitat following logging.

DESCRIPTION OF THE STUDY AREA

Three small tributaries of Drift Creek (Deer Creek, Flynn Creek, and Needle Branch) on the central Oregon Coast were chosen for this study. The study streams drain watersheds ranging from 71 to 304 hectares, which lie about 16 km from the Pacific Ocean at elevations between 140 and 490 m. The watersheds are precipitous, having mean slopes between 34 and 40 percent. The streams flow about 40 km before emptying into Alsea Bay near Waldport, Oregon (Fig. 1).

The climate is maritime. Mean annual precipitation recorded from 1959 to 1965 was 244 cm, ranging from 208 to 292 cm. Most of the precipitation occurs from October through March. Air temperatures are relatively mild, generally ranging from -7^{o} to 32^{o}C. Snow usually falls in two or three storms per year, but rarely remains on the ground for more than a few days.

The geology of the area is typical of the extensive Tyee sandstone formation of the northern Oregon Coast Range. At the beginning of the study the watersheds were forested with commercial stands of Douglas-fir intermixed with varying percentages of red alder. The predominant age of the fir was 100-110 years. The understory consisted primarily of vine maple, salmonberry, sword fern and salal. A summary of the soil and vegetation characteristics of the area is available in Corliss and Dyrness (1965).

There is a large seasonal variation in streamflow. Freshets occur when the salmon are spawning, from November through February, and streamflow drops to a low level during the dry summers (Table 1). The annual temperature regimes of the three streams were similar before logging, and diurnal fluctuations were minimal (Table II).

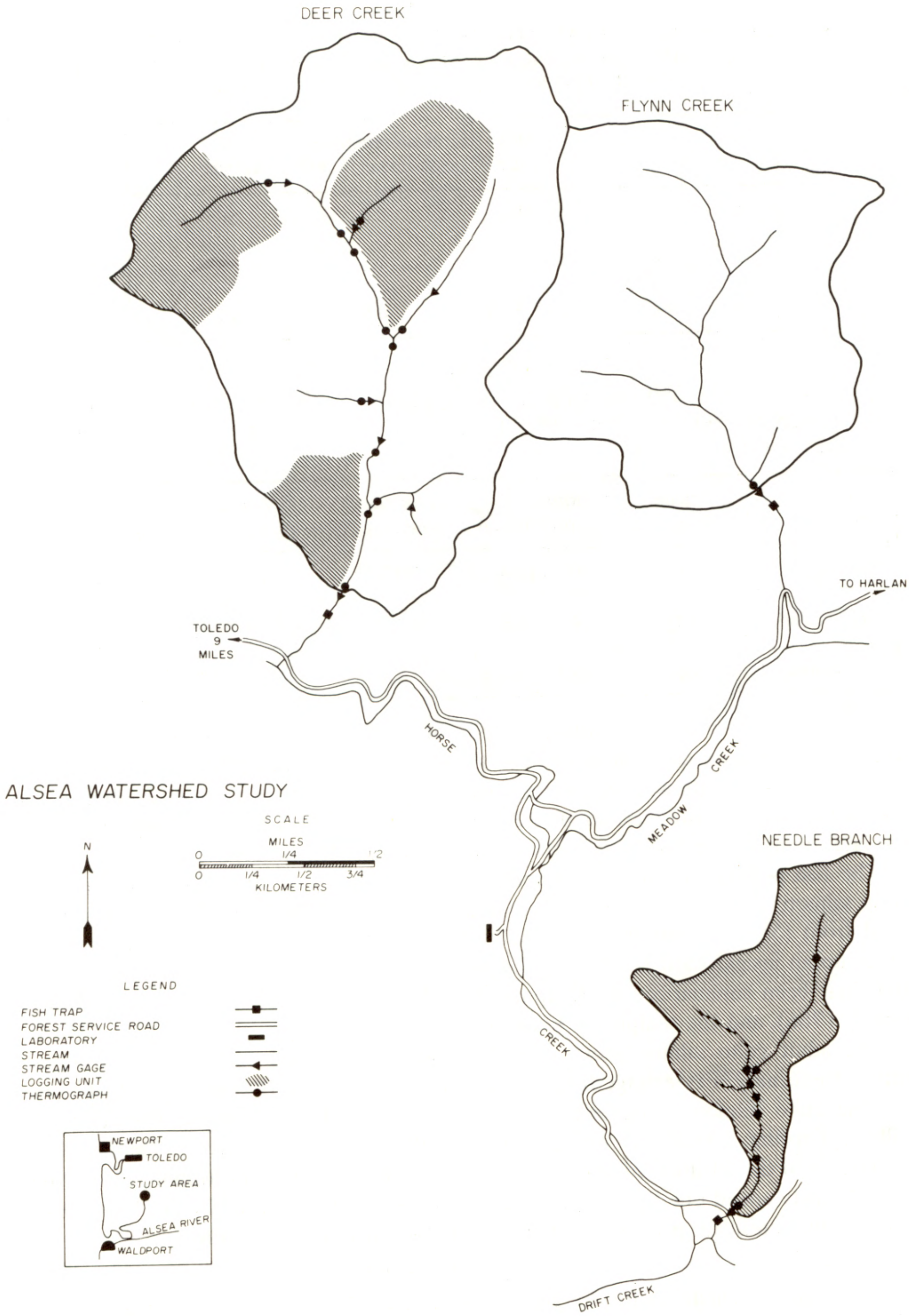

FIGURE 1

MAP OF THE STUDY WATERSHEDS. APPROXIMATE LENGTH OF STREAM ACCESSIBLE TO ANADROMOUS FISH: DEER CREEK - 2300 m, FLYNN CREEK - 1300 m, NEEDLE BRANCH - 900 m.

TABLE I

SUMMARY OF THE STREAMFLOW REGIMES IN THE THREE STUDY STREAMS BEFORE LOGGING, 1959 THROUGH 1965. DATA FROM U.S. GEOLOGICAL SURVEY EXPRESSED IN LITERS PER SECOND (1 c.f.s. = 28.3 liters/sec).

Stream	*Daily Mean*	*Mean minimum summer flow*	*Peak winter flow*
Deer Creek	183	8.5	5688
Flynn Creek	126	4.5	3877
Needle Branch	41.6	0.6	1415

TABLE II

SUMMARY OF THE TEMPERATURE REGIMES (^{o}C) IN THE THREE STUDY STREAMS BEFORE LOGGING, 1959 THROUGH 1965. DATA FROM U.S. GEOLOGICAL SURVEY.

Stream	*Annual Mean*	*Range of monthly means*	*Minimum temperature*	*Maximum temperature*	*Diurnal temperature range*
Deer Creek	9.6	6.7 - 12.8	1.1	16.1	0.5 - 2.2
Flynn Creek	9.7	7.2 - 12.8	2.2	16.6	0.5 - 2.2
Needle Branch	9.7	6.1 - 12.8	1.6	16.1	0.5 - 1.5

Headwater streams such as these, in spite of their small size, are important spawning and rearing areas for coho salmon and cutthroat trout. Individual pools in Needle Branch, the smallest study stream, are nearly isolated by stretches of exposed streambed at the lowest flows in late summer, about 0.3 liter second (.01 cfs). This low streamflow during the late summer belies the importance of such streams to the fishery.

The fish populations in the three streams include about an equal biomass of juvenile coho salmon, coastal cutthroat trout, and the reticulate sculpin (*Cottus perplexus*). Steelhead trout (*Salmo gairdneri*) occasionally spawn in Deer Creek, the largest stream, but make up an insignificant fraction of the population. The biology of the salmon populations has been summarized by Chapman (1962b, 1965), the cutthroat trout by Lowry (1965, 1966), and the sculpin by Krohn (1968).

The adult coho salmon move into the study streams and spawn from November through February. Fry emerge from the gravel from February through May. Most of the juvenile coho salmon spend one year in the stream before moving to the ocean the following spring; a small percentage remain in the stream for two years. Timing of the migrations of the anadromous cutthroat trout is similar to that of the salmon, except that juveniles may spend one to three years in the stream before leaving the headwater area. There is also a resident population of cutthroat trout in all three streams.

DESIGN OF THE STUDY

The study is scheduled for 15 years. Seven years (1958 to 1965) were devoted to pre-logging inventory in the three watersheds. Construction of logging roads occurred in 1965; the logging operation was carried out in 1966. One watershed of 71 hectares (Needle Branch) was completely clearcut (Fig. 2). A second watershed of 304 hectares (Deer Creek) was partially clearcut in three isolated units, so that about 30 percent of the watershed was harvested and a narrow strip of timber (mainly alder) left along the stream

FIGURE 2

THE NEEDLE BRANCH WATERSHED AFTER STREAM CLEARANCE AND SLASH BURNING, SHOWING MODERATELY HIGH STREAMFLOWS DURING NOVEMBER 1966. ANADROMOUS FISH HAVE ACCESS UPSTREAM TO A FALLS AT THE LOWER RIGHT-HAND CORNER OF PHOTOGRAPH. (PHOTOGRAPH COURTESY OF BUREAU OF LAND MANAGEMENT).

(Fig. 3). A third watershed of 203 hectares (Flynn Creek) will remain unlogged as a control for the duration of the study. Changes in the streams and on the logged watersheds will be followed for seven years after logging to document immediate and long-term changes and the rate of recovery.

METHODS

Water temperature has been measured continuously on each watershed. A network of 20 Partlow thermographs was placed along the three study streams by the Oregon State University School of Forestry (Fig. 1). In addition, thermographs are attached to the water-stage recorders housed in the standard U.S. Geological Survey gauging stations located at the downstream end of each watershed.

Streamflow is recorded continuously at the outlet of each stream at a concrete V-notch weir. In addition, six gauging stations have been maintained on Deer Creek by the School of Forestry (Fig. 1). The suspended sediment load is measured at the stage-control weirs daily during most of the year and more intensively during storms. Pint samples are collect with the standard Geological Survey DH-48 hand sampler.

Permanent upstream-downstream traps near the mouth of each stream provide a nearly-complete inventory of spawning salmon and trout moving into the streams and downstream migrants moving to the sea. Upstream-migrant coho salmon females are anaesthetized, weighed, measured, distinctively tagged, and released. Periodic stream

FIGURE 3

AERIAL VIEW OF ONE OF THE THREE DEER CREEK CLEARCUT AREAS DURING LOGGING OPERATIONS (1966) SHOWING THE STRIP OF VEGETATION BORDERING THE STREAM (LOCATION SHOWN BY DASHES).

surveys are conducted to locate the spawning site of each tagged female. The boundaries of these redds are marked for later study.

A cap of nylon netting is placed over marked redds to trap coho salmon fry as they emerge from the stream bed (Phillips, 1966). The captured fry are enumerated and released into the stream. The potential egg deposition is estimated for each redd from the weight of the spawning female, based on a regression equation developed for coho salmon from a nearby stream. Egg retention is determined by examination of carcasses. The survival from individual redds can be computed from the actual emergence and the estimated number of eggs deposited. Differences in the intragravel environment can then be related to this measure of survival.

Dissolved oxygen levels of surface and intragravel waters are monitored by the standard Winkler method. Periodically during the time that eggs and alevins are in the gravel, intragravel water samples are obtained at a depth of 25 cm from a series of Mark VI standpipes (Terhune, 1958) permanently installed in the three study streams. Permeability of the stream bed, a measure of its porosity, is also periodically determined through the Mark VI standpipes (Terhune, 1958).

The size composition of gravel materials from individual redds is expressed as a percentage of wet volume, and is determined by the technique described by McNeil and Ahnell (1964). Three gravel cores (10 cm in diameter, 25 cm deep) are removed from each trapped redd and washed through a series of seven Tyler soil sieves with mesh sizes ranging from 50.4 to 0.833 mm. Materials passing the smallest sieve are collected in a graduated cylinder, and their volume is determined after the particles have been allowed to settle for 45 minutes.

EFFECTS OF LOGGING

In Needle Branch, the watershed that was entirely clearcut, felling of timber along the stream, cable yarding of the logs across the stream channel to uphill landings, and the burning of slash caused substantial changes in the stream. Felling began in mid-March 1966. Considerable debris remained in the stream channel during the summer (Figs. 4 and 5), forming small dams that slowed the flow of water. In September the larger debris (tops and branches) was cleared from the stream channel, permitting the stream to flow freely (Fig. 6). In October the watershed was completely burned to remove the slash hazard and prepare for reseeding, which occurred during the winter.

In Deer Creek, the patch-cut watershed where strips of vegetation were left along the larger stream courses, there have been no significant changes in the quality of the stream or the size of the fish populations. There have been two landslides in this watershed associated with road construction that pose a threat of future sedimentation, however.

Several more years of study are planned to evaluate the long-term consequences of these changes and to determine the period of recovery. This interim report is primarily concerned with the initial changes following the logging operation on Needle Branch, the clearcut watershed.

FIGURE 4

FINE DEBRIS FROM A PONDED AREA IN NEEDLE BRANCH DURING THE CLEARCUTTING OPERATION. THIS MATERIAL WAS COMPOSED LARGELY OF DOUGLAS-FIR NEEDLES, TWIGS, BARK CHIPS, ORGANIC DUFF, AND SOIL BROUGHT INTO THE STREAM DURING YARDING OPERATIONS.

FIGURE 5

A TYPICAL VIEW OF LOGS AND SLASH THAT FILLED THE STREAM CHANNEL DURING CLEARCUTTING ON NEEDLE BRANCH.

FIGURE 6

NEEDLE BRANCH AFTER STREAM CLEARANCE AND SLASH BURNING, NOVEMBER 1966.

STREAM TEMPERATURE

Removal of streamside vegetation can produce significant increases in the temperature of small headwater streams (Brown and Krygier, 1967). In Needle Branch there has been a substantial change in the temperature regime following logging, an increase in both the summer maximum and diurnal fluctuation (Fig. 7). The highest temperature recorded during the summer of 1966 was 24°C, 8° higher than the previous maximum. The maximum diurnal temperature fluctuation was also 8°, compared with previous values of 0.5 to 1.5°. During the summer of 1967 the entire length of the stream was subjected to nearly the full intensity of solar radiation. The maximum temperature recorded during 1967 was 30°C, and there was a maximum diurnal fluctuation of 16°. These increases occurred over much of the year and were substantial as early as May (Fig. 8), while the alevins were still in the gravel.

Temperature increased progressively as the stream moved through the clearcut. However, maximum temperatures were not attained at the outlet, but about 200 m upstream. Temperatures decreased about 3° as the water passed through a somewhat shaded area in the lower 200 m of the stream channel, where the streamside vegetation had been less affected by logging and slash burning. This indicates that increases in temperature are at least partially reversible if water that has been warmed subsequently passes through a shaded area.

The burning of slash on Needle Branch in October also had an effect on stream temperature. In the upper canyon of the stream, at a station about 915 m above the weir, the temperature rose rapidly during the fire from 13°C to at least 28°. Many juvenile coho salmon, cutthroat trout, and sculpins were found dead in this upper area. The temperature increase and fish mortality were confined to the canyon area above a point about 550 m above the weir. This was above the major rearing area for coho salmon. In the lower part of the watershed, where the slopes are not as steep, the fire was less intense near the stream. In the Deer Creek watershed, where the fire was separated from the stream by a buffer strip, there was no significant increase in temperature associated with slash burning.

DISSOLVED OXYGEN

Significant decreases in dissolved oxygen content in both surface and intragravel water were observed at an early stage during logging on Needle Branch. The reduction in dissolved oxygen was first noted in intragravel water, after felling began along the stream. A layer of debris on the gravel and ponding of the surface water caused a substantial decrease in the rate of interchange between surface and intragravel water. This decrease, coupled with an oxygen demand from the decomposing debris, caused a rapid decline in dissolved oxygen in the intragravel water (Table III). By June 30 these values averaged 1.3

TABLE III

INTRAGRAVEL DISSOLVED OXYGEN LEVELS (mg/1) FROM EIGHT STANDPIPES IN THE CLEARCUT WATERSHED (NEEDLE BRANCH) AND FROM SIX STANDPIPES IN THE CONTROL WATERSHED (FLYNN CREEK) ON THREE DATES DURING THE LOGGING OPERATION IN 1966.

	Needle Branch		*Flynn Creek*	
Date	*Mean*	*Range*	*Mean*	*Range*
April 19	10.7	7.0 - 12.0	10.2	7.7 - 11.8
May 30	4.2	2.4 - 7.3	9.0	6.8 - 10.8
June 30	1.3	0.5 - 2.2	7.2	4.0 - 9.1

mg/l, a level low enough to cause complete mortality of fry in the gravel, had they not already emerged. During this same period dissolved oxygen levels in standpipes on the control stream dropped only slightly in response to normal decreases of flow and warming temperatures.

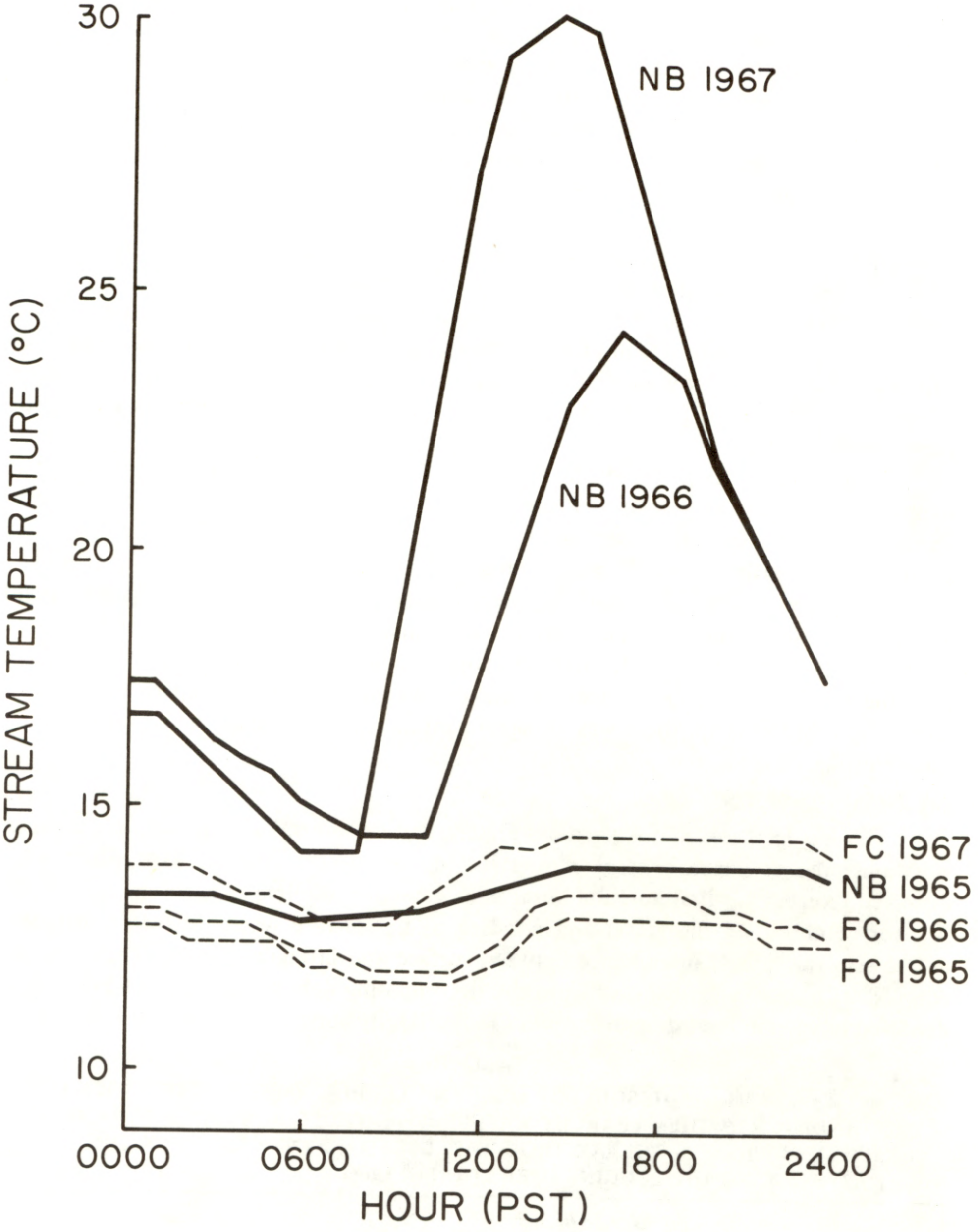

FIGURE 7

HOURLY STREAM TEMPERATURES ON THE DAY OF MAXIMUM TEMPERATURE IN THE CLEARCUT (NEEDLE BRANCH) AND CONTROL (FLYNN CREEK) WATERSHEDS. VALUES SHOWN ARE FOR ONE DAY IN AUGUST BEFORE LOGGING (1965), DURING LOGGING (1966), AND AFTER LOGGING (1967). DATA FROM SCHOOL OF FORESTRY, OREGON STATE UNIVERSITY.

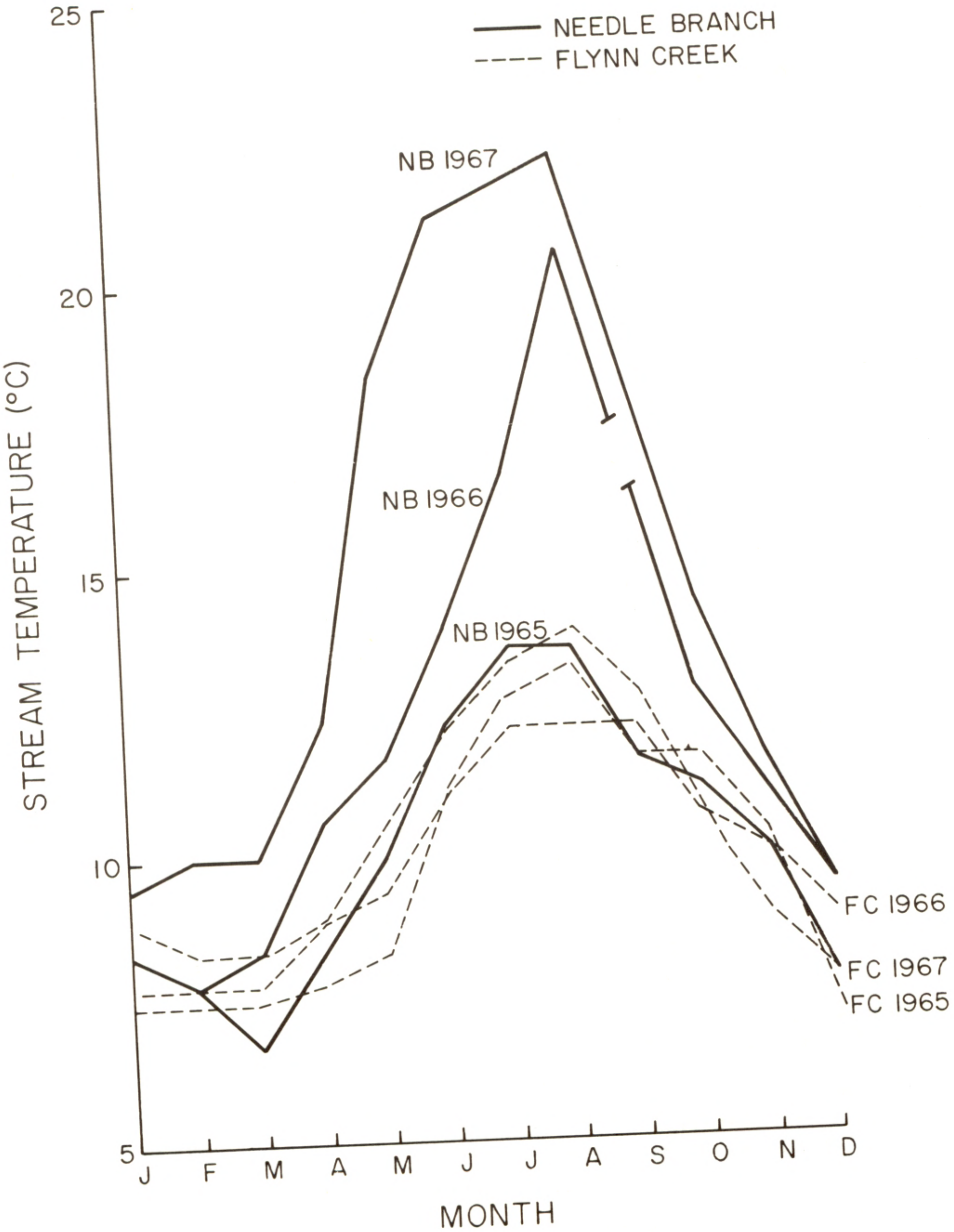

FIGURE 8

AVERAGE MONTHLY MAXIMUM STREAM TEMPERATURE AT THE POINT OF HIGHEST TEMPERATURE IN THE CLEARCUT (NEEDLE BRANCH) AND CONTROL (FLYNN CREEK) WATERSHEDS BEFORE LOGGING (1965), DURING LOGGING (1966), AND AFTER LOGGING (1967). DATA FROM SCHOOL OF FORESTRY, OREGON STATE UNIVERSITY.

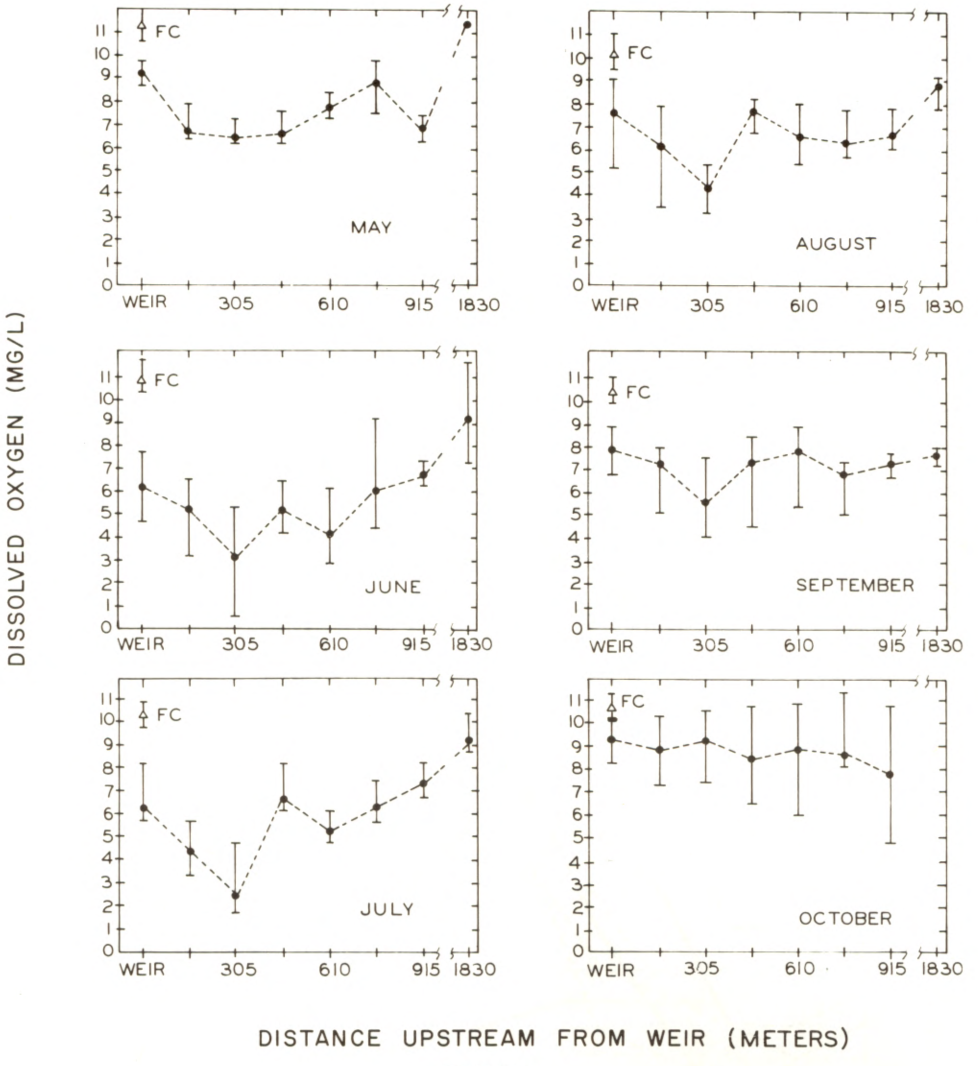

FIGURE 9

SURFACE DISSOLVED OXYGEN LEVELS (MEAN AND RANGE) TAKEN TWICE WEEKLY IN THE CLEARCUT WATERSHED (NEEDLE BRANCH) AND CONTROL WATERSHED (FLYNN CREEK) DURING 1966. SAMPLING ON NEEDLE BRANCH OCCURRED AT 152 m INTERVALS IN THE AREA ACCESSIBLE TO SALMON, AND AT 1830 m (UPPER EDGE OF THE CLEARCUT). SAMPLES FROM FLYNN CREEK WERE TAKEN ONLY AT THE WEIR.

A substantial reduction in dissolved oxygen also occurred in the surface water from May through October (Fig. 9). Samples were taken twice weekly at intervals of 152 m along the stream. In general the decline was progressive from May through July, when the levels began to increase. The lowest oxygen concentration observed, 0.6 mg/l, occurred at a station 305 m above the weir on June 27. More intensive sampling in the stream at distances between 152 and 456 m above the weir (one-third of the area available to salmonids) indicated that dissolved oxygen levels in most of this area were too low to support salmon and trout in late June and through most of July. Juvenile coho salmon placed in live-boxes there survived less than 40 minutes.

Mortality of the test fish placed in live-boxes during the summer of 1966 was apparently caused by low levels of dissolved oxygen, not by toxic substances in the water. There were no unusual mortalities of juvenile salmon in live-boxes in the lower portion of the stream where oxygen levels were adequate for survival. However, during part of this period there were substantial amounts of organic material in the water. The possibility of some interaction between low dissolved oxygen levels and the presence of these organic substances cannot be ruled out.

There was a substantial improvement in surface oxygen levels after debris was cleared from the stream in mid-September. There was a further improvement after fall freshets moved much of the fine debris downstream and uncovered spawning gravels in the study area. The oxygen content of surface waters returned to approximately pre-logging levels by autumn.

Intragravel water remained lower in oxygen than it had been before logging. From November through May (the period of egg incubation and larval development) the average level of dissolved oxygen was about 3 mg/l lower in 1966-67 than it was in the year before logging (Fig. 10). Dissolved oxygen remained at about the same level below pre-logging values during the second winter following logging, 1967-68. Dissolved oxygen levels in the gravel of the control stream remained high during these three seasons.

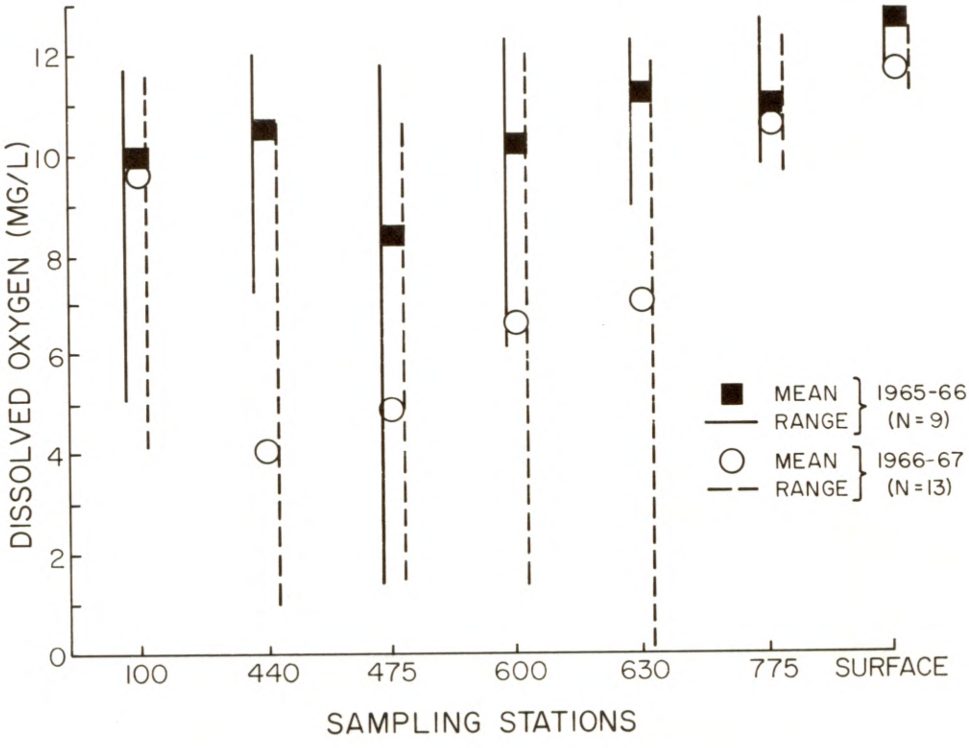

FIGURE 10

INTRAGRAVEL DISSOLVED OXYGEN LEVELS IN THE CLEARCUT WATERSHED (NEEDLE BRANCH) FROM DECEMBER 1965 TO MAY 1966 (BEFORE LOGGING) AND FROM NOVEMBER 1966 TO MAY 1967 (AFTER LOGGING). (ALL STANDPIPES IN NEEDLE BRANCH WERE REMOVED DURING LOGGING; THE SIX FOR WHICH DATA ARE SHOWN WERE REPLACED IN THEIR PREVIOUS LOCATIONS.) SURFACE DISSOLVED OXYGEN LEVELS ARE SHOWN FOR COMPARISON.

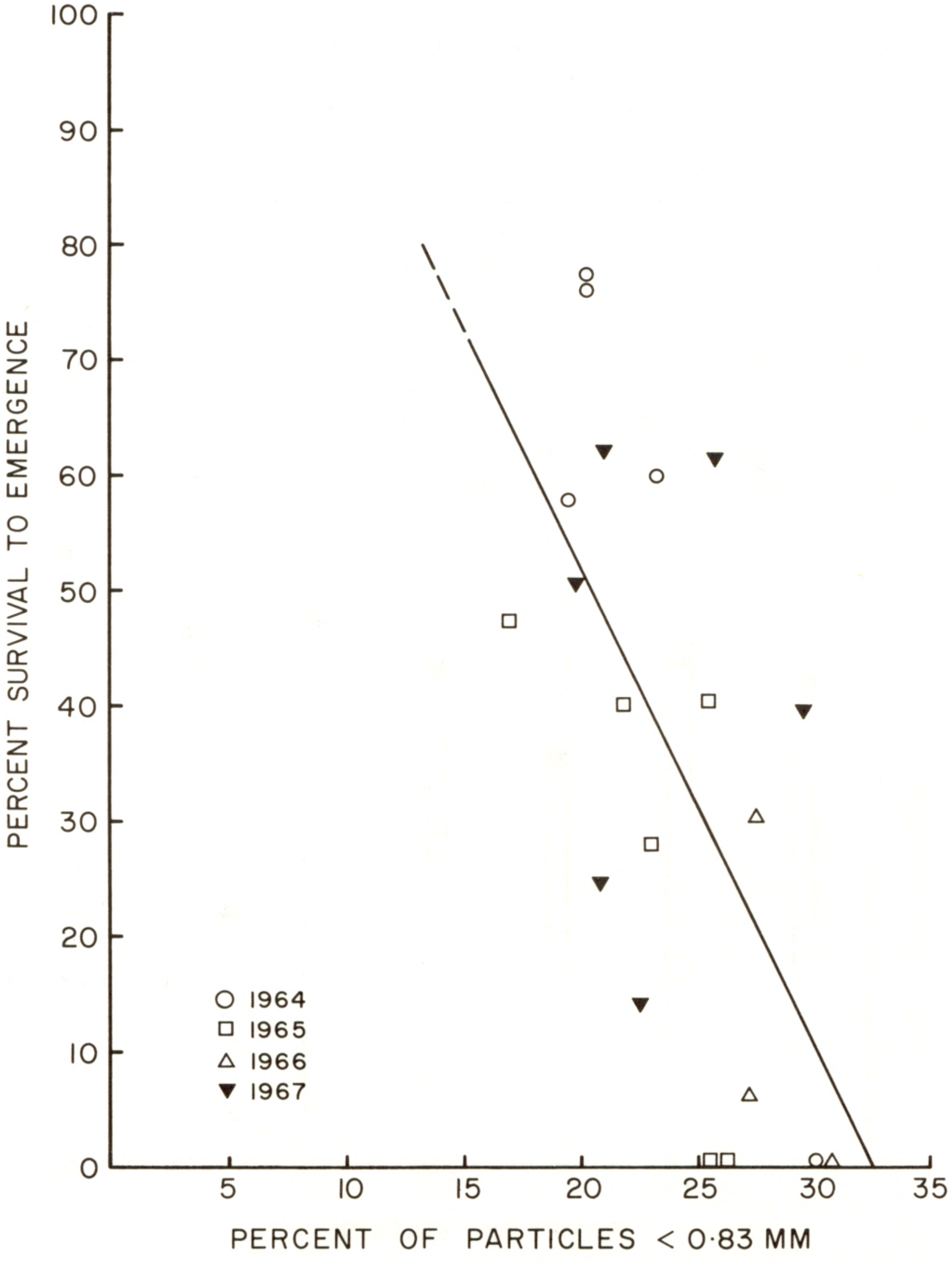

FIGURE 11

THE RELATION BETWEEN PERCENTAGE SURVIVAL OF COHO SALMON FROM EGG DEPOSITION TO EMERGENCE IN INDIVIDUAL REDDS AND THE PERCENTAGE OF FINE PARTICLES LESS THAN 0.83 mm IN REDDS IN DEER CREEK. THE LINEAR REGRESSION (r = -0.62) IS SIGNIFICANT AT THE 1 PERCENT LEVEL. DATA FOR 1964 ARE FROM KOSKI (1966).

SEDIMENTATION

Logging operations often cause increased sediment loads in streams (Packer, 1967). The addition of fine sediments to spawning beds can decrease the permeability of spawning gravel (McNeil and Ahnell, 1964; Cooper, 1965). Such a reduction can affect the survival of salmonid embryos by reducing their supply of oxygen and inhibiting removal of waste products.

Sediment can also affect survival by impeding emergence of fry. Some of the first evidence of the effect of fine particles on emergence under natural stream conditions was provided on the Alsea Watershed Study by Koski (1966). He estimated the survival to emergence of coho salmon fry from 21 individual redds and showed an inverse relationship between success of fry emergence and the percentage of fine sediments in the redd. A continuation of this work has confirmed the relationship (Fig. 11). In some redds that he excavated, Koski found fry that had successfully hatched but had been unable to emerge. Subsequent laboratory tests on the effects of fine sediments (1-3 mm in diameter) on emerging coho salmon and steelhead trout fry have quantified and confirmed the entrapping action.

In these experiments, materials smaller than 1 mm in diameter were excluded so that intragravel dissolved oxygen and water velocity could be maintained at adequate levels. The materials not tested included many sands and all silt and clay-sized particles that may also affect fish and their environment. Six replications of eight well-mixed gravel matrices containing from 0 to 70 percent fine materials in 10 percent increments were tested. Fifty pre-emergent fry were placed 25 cm below the surface of the gravel in each of the 48 separate cells. The control mixture was based on the gravel composition of a redd where natural survival was high. There was a significant inverse relationship between the amount of fine sediments and the ability of coho salmon and steelhead trout fry to emerge from the gravel (Fig. 12).

The variability of data on suspended sediment loads from the Alsea study makes analysis difficult at this point. In general, levels have increased significantly in the clearcut watershed (Needle Branch) during the two winters following logging. The average concentration of suspended sediment during storm periods has increased approximately three to four times over pre-logging values. Increases in sediment production from the patch-cut watershed (Deer Creek), while noticeable, have been much below those for Needle Branch.

FISH POPULATIONS

The ultimate measure of the effects of logging on the fishery lies in the response of the fish populations to changes in their habitat. We have demonstrated that significant physical changes can occur in a stream draining a clearcut watershed. Changes in fish populations following logging must be evaluated in terms of the populations that were present before logging. Because of the wide range of natural variation before logging, it will be some time before the effects on fish populations can be fully evaluated.

Following clearance of the stream channel, adult coho salmon have spawned in Needle Branch in numbers approximating those before logging. The number of juvenile coho migrating to the ocean in the two years following logging has been within the range of variation recorded before logging (Table IV). These fish had been subjected to severe habitat modifications during their year of stream residence, which included the logging operation in 1966 and the high temperatures in the summer of 1967. The coho salmon seems to be a resilient fish, able to compensate to some degree for adverse conditions. Whether it is sufficiently resilient to survive the high summer stream temperatures and return to spawn in good numbers remains to be seen.

To date, the resident cutthroat trout population appears to be more susceptible to changes than is the coho. Following logging, the numbers of resident fish have dropped to approximately one-fourth of their previous abundance (Table V).

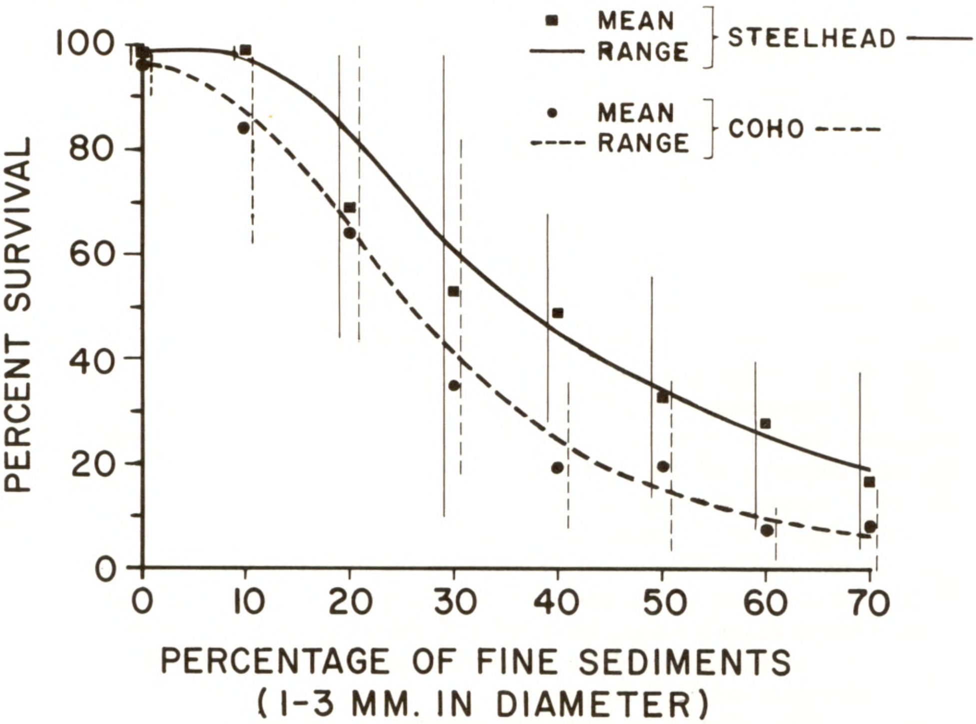

FIGURE 12

THE RELATION BETWEEN PERCENTAGE OF FINE PARTICLES IN AN ARTIFICIAL GRAVEL BED AND THE ABILITY OF COHO SALMON AND STEELHEAD TROUT FRY TO EMERGE THROUGH THE GRAVEL.

TABLE IV

YIELD IN NUMBERS OF DOWNSTREAM-MIGRANT YEARLING[a] COHO SALMON IN THE THREE STUDY STREAMS BEFORE AND AFTER LOGGING. THE MEAN FOR THE PRE-LOGGING PERIOD INCLUDES SEVEN YEAR-CLASSES, 1959-1965. THE AREA SHOWN IS ESTIMATED LOW-WATER STREAM AREA ACCESSIBLE TO SALMON (SQUARE METERS).

		Pre-logging		*Post-logging*	
Stream	*Area*	*Mean*	*Range*	*1966*	*1967*
Deer Creek	4720	2339	1809-3175	2252	2460
Flynn Creek	2660	882	566-1413	969	622
Needle Branch[b]	1060	334	166-630	327	276

a Counts are of migrants by year-class, tabulated from November 1 to July 1, but include a small fraction of two-year-old fish. Counts are minimal due to incomplete trapping during some periods of high water.

b Counts for Needle Branch could not be made for the months of November, December, and January for the 1960-1965 year-classes because of inadequate trapping facilities. Counts for these years have been adjusted upward by 10 percent, based on percentage of migration for that period from Deer Creek and Flynn Creek.

TABLE V

POPULATION ESTIMATES OF RESIDENT CUTTHROAT TROUT (ALL AGE = GROUPS) IN THE THREE STUDY STREAMS BEFORE AND AFTER LOGGING. ESTIMATES MADE ONCE EACH YEAR IN LATE SUMMER BY MARK AND RECAPTURE. THE PRE-LOGGING MEAN INCLUDES FOUR ESTIMATES, 1962-1965.

	Pre-logging		*Post-logging*	
Stream	*Mean*	*Range*	*1966*	*1967*
Deer Creek	796	731-898	834	853
Flynn Creek	557	493-640	612	720
Neddle Branch	264	199-361	65	78

DISCUSSION

A watershed is a dynamic entity. The changes that occurred as a result of clearcutting the entire watershed of Needle Branch will not be permanent. It seems clear that most watersheds subject to logging can reestablish favorable conditions for fish production, if adequate attention is given to stream protection and channel clearance. One of the important objectives of our long-term study is to determine the rate of recovery and to suggest modifications of present logging practices that could hasten this recovery. In the interim it may be appropriate to focus attention on some of the immediate results of our studies.

For many years there have been indications that removing vegetative cover can lead to higher stream temperatures. Titcomb (1926) suggested that streamside logging was responsible for increased water temperatures that made many streams unsuitable for trout. Increases in water temperatures ranging up to 7°C have been reported following logging in eastern hardwood forests (Greene, 1950; Eschner and Larmoyeux, 1963).

Increased temperature can affect fish populations in many ways. Among the consequences of substantial increases in temperature are direct heat-induced death, increased metabolic rate and maintenance requirement, increased activity of pathogenic organisms, and a decreased solubility of oxygen in water.

The significance of temperature increases in Needle Branch, the clearcut watershed, is currently being investigated. There was no apparent immediate mortality of fish associated with the extreme temperatures, which were above the 25° maximum reported to be lethal for coho salmon (Brett, 1952). This may have been due to the relatively short exposure to extreme temperatures each day. Little information is available on the response of fish to widely fluctuating temperatures such as those experienced following clearcutting.

Brown (1967), in his work on the Alsea study, employed net solar radiation and other meteorological variables in the development of an equation to predict stream temperature. He showed that heating of the water in small streams is primarily caused by direct solar radiation on the stream surface. He also pointed out that stream volume is an important determinant of the temperature change to be expected; for the same length of stream exposed, temperature increases will be greater in small streams than in larger ones. His work has provided a basis for predicting the temperature increase to be expected when vegetation is removed from a given length of stream. Thus, temperature increases can be modified, where necessary, by planning to maintain some shade along the stream channel. It should be emphasized that merchantable timber is not necessarily required for shade. On small streams a dense canopy of understory vegetation can be effective in modifying temperature increases.

Successful incubation of salmonid embryos requires relatively high levels of dissolved oxygen in intragravel water (McNeil, 1966). Any appreciable decrease in concentration of dissolved oxygen below saturation can cause a reduction of fry size and a delay in hatching (Shumway, Warren, and Doudoroff, 1964). The ecological significance of such an effect was suggested by Mason (1966), who showed that fry incubated under conditions of low oxygen were less successful in competition in the stream with those incubated at higher levels of oxygen. Lowered intragravel oxygen levels could also produce weaker fry with a reduced ability to emerge from spawning gravels.

The amount of oxygen reaching embryos in the stream bed depends on both oxygen concentration and water velocity (Wickett, 1954). The primary mechanism for renewal of intragravel oxygen is through interchange with surface water (Vaux, 1962, 1968; Sheridan, 1962). By increasing the percentage of fine particles in gravel beds, logging could affect this interchange and thus reduce intragravel oxygen levels.

The instances of oxygen depletion observed in Needle Branch point up two modifications of present practices that should be given consideration. The rapid decrease in intragravel dissolved oxygen levels during logging operations suggests the need to avoid the felling of timber along salmon streams during the period when eggs and fry are in the gravel. The possible occurrence of unfavorable conditions for fish survival during the summer suggests, further, that the removal of debris from the stream channel should be an integral part of the logging operation, concurrent with timber removal.

From the point of view of the fishery manager, the most desirable practice would be to keep all debris out of the stream channel. The strip of timber remaining along the stream in Deer Creek kept logging debris from reaching the channel. There were no decreases in dissolved oxygen in the stream and only moderate increases in temperature (1 to 2°C). The unburned stream margin undoubtedly helped to keep sediment increases to a low level. Thus a buffer strip, where it is feasible, may serve in several ways to protect streams from changes following logging.

Few long-term studies of the effects of sedimentation on fish habitats and populations have been undertaken. There is considerable information, however, on the biological effects of sedimentation. Cordone and Kelley (1961) have compiled a comprehensive review of the influences of inorganic sediment on the aquatic life of streams. Among the effects of sediment that they consider are those on fish production, spawning adults, development of eggs and alevins, and production of aquatic plants and fish food organisms. High levels of suspended sediment in a stream can also adversely affect the rate of catch in a sport fishery.

At the present time, there is little quantitative data on the accrual of fine sediments to spawning gravels following logging. However, one study in Alaska indicated that where reasonable care is exercised, increases in sediment loads in the gravel may be only temporary. The percentage of fine particles in the spawning beds increased following logging, but the amount present five years later was not significantly different from the pre-logging value (Sheridan and McNeil, 1968).

The sustained reduction in intragravel dissolved oxygen during the two winters following logging on Needle Branch is indicative of some change in the composition of the gravel environment. There could have been a reduction in interchange between surface and intragravel water as a result of sedimentation, an increase in oxygen demand from organic matter in the gravel, or both. The specific causes of the decrease are now being investigated.

Changes in temperature, dissolved oxygen, and sediment are not the only effects of logging that can be expected to influence the fish populations. Among other potential effects are changes in the streamflow pattern, chemical water quality, and fish food resources (Chapman, 1962a).

Considerable evidence has accrued on the effects of timber harvest on water yield. Logging has often resulted in higher peak flows, more rapid attainment of peaks, and some increase in minimum flow (Hibbert, 1967). The most extensive data are from eastern deciduous forests. The only comparable data on controlled watersheds in the Pacific Northwest are from the H.J. Andrews Experimental Forest in the Oregon Cascades. These data suggest that changes in streamflow following logging may be minimal in this region; the primary effect reported was a moderate increase in the volume of minimum flow (Rothacher, 1965). An analysis of streamflow records for several much larger watershed in the same region, both logged and unlogged, suggested that logging had significantly increased flood peaks (Anderson and Hobba, 1959).

Higher peak flows can be detrimental to fish production because of increased gravel bed movement. Movement of gravel can reduce fish survival by scouring eggs and alevins from the redds, or by simply jarring them during early development. Food production can be reduced by scouring or filling of pools with sediment. In contrast, an increased summer flow might improve conditions for fish production by increasing living space for territorial salmonids or by increasing the area of productive stream bottom (Chapman, 1962a).

The dissolved chemical load of a stream may be a significant fraction of its total dissolved and suspended load. In the Andrews watersheds and some others, solute erosion may greatly exceed physical erosion (Rothacher, Dyrness, and Fredriksen, 1967). Clearcutting of all vegetation in an eastern deciduous watershed caused a significant increase in the rate of nutrient loss, particularly nitrate (Bormann *et al.*, 1968). In the latter case, the felled timber was not removed from the watershed and regrowth was inhibited by an herbicide, so the conclusions may not be applicable to a normal harvest operation. Nevertheless, some increases in chemical nutrient concentration of stream water may be expected following normal logging operations, particularly when slash burning follows the harvest (Chapman, 1962a).

Fish populations in some small headwater streams have been shown to be more dependent on terrestrial than aquatic sources of energy for their ultimate food resource. Chapman (1966) estimated that more than half of the annual diet of juvenile coho salmon in one of the Alsea streams was based on terrestrial energy sources. These sources of energy include terrestrial insects and organic debris that reaches the stream and serves as food for aquatic organisms. Production of algae in these heavily shaded streams is generally low. Clearcutting might be expected to significantly modify the energy resources available to the fish populations.

Research results obtained in Oregon may not be widely applicable in other areas. The wide variation, between Oregon and Alaska for example, in geology, soils, climate, vegetation, and life histories of the fish species involved, necessitate regional studies to determine the significance of changes caused by logging. Even in one region, detailed studies on a few watersheds may not be adequately representative of conditions in that geographic area as a whole. This realization has caused us to expand our work in Oregon to include a less intensive study of about 12 additional watersheds over the next three years. This additional information should make our data more representative of conditions, and our conclusions more broadly applicable in the coastal Douglas-fir region.

All states are now faced with the problem of setting meaningful water quality standards to comply with the Federal Water Quality Act of 1965. The conditions that developed following clearcut logging in the Needle Branch watershed did not meet the currently prescribed Oregon standards for temperature and dissolved oxygen. These standards, recently adopted for all waters in the state, do not seem appropriate for small streams affected by logging. An intensified research effort seems necessary to develop meaningful standards that would apply to these many small streams. One function of studies such as ours is to provide the information necessary to establish reasonable standards that would allow orderly timber harvest and at the same time afford protection for other resources. Such work should also be helpful in suggesting means by which these standards could most effectively be met.

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