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THE EFFECTS OF LANDSLIDE SILTATION ON THE SALMON AND TROUT RESOURCES OF STEQUALEHO CREEK AND THE MAIN CLEARWATER RIVER, JEFFERSON COUNTY, WASHINGTON, 1972-1975

by

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FINAL REPORT - PART II

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CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Field investigations on the effects of landslides, either naturally occurring or resulting from construction and operation of logging roads, on the composition of salmonid spawning gravel, stability of the streambed, abundance of benthic fauna, and populations of juvenile salmonids and nonsalmonids in Stequaleho Creek and the Clearwater River were carried out during 1972-1975. The Yahoo Lake and Debris Torrent landslides, which resulted from logging roads, influenced the entire anadromous zone of Stequaleho Creek and a 40 km portion of the mainstem of the Clearwater River below the entrance of the Stequaleho. The influence was principally on the mainstem spawning chinook salmon and steelhead trout with minor influences on tributary spawning coho salmon, steelhead, and cutthroat trout.

In the second (1972) and third (1973) summers following the landslides the percentages of fines (< 0.850 mm diameter) in spawning gravels of Stequaleho Creek and Clearwater River were significantly greater (5% level) in landslide affected areas than in the control areas. This difference was not present in the fourth summer (1974). Flushing of streambed sediments in the winter of 1972-1973 caused a recovery of spawning gravels to near natural conditions.

In the second (1972), third (1973), and fourth (1974) summers after the Yahoo Lake and Debris Torrent landslides the abundance of benthic fauna in downstream areas of Stequaleho Creek was significantly (5% level) lower than in the upstream control areas. Additional studies in Stequaleho Creek and other Clearwater River tributaries of the relationship between sediment levels and abundance of benthic fauna have shown no significant relationship. Therefore, we conclude that the low levels of benthos in lower Stequaleho Creek are due to streambed instability caused by both road-caused landslides and several natural landslides in lower Stequaleho Creek.

There was no significant (5% level) difference in abundance of benthos in the Clearwater River above and below the mouth of Stequaleho Creek for the summers of 1972, 1973, and 1974.

During the second (1972), third (1973), and fourth (1974) summers after the Yahoo Lake and Debris Torrent landslides, the mean relative biomass of coho salmon in the affected area of Stequaleho Creek was significantly (5% level) lower than the mean of the 1973 and 1974 populations in several other Clearwater tributaries. There was no significant difference in the trout or total teleost biomass for any of these years. Other studies of Clearwater River tributaries indicate the possibility of a general underseeded condition for coho salmon. This underseeded condition has probably been caused by a combination of factors including poor road construction practices in the past, overharvest in the commercial and sport fisheries, and natural causes.

It appears that the impact of the Stequaleho Creek landslides have had a minor short-term effect on the salmonid populations and their habitats; however, landslides of similar magnitude to the Yahoo Lake and Debris Torrent slides are occurring in other tributaries of the Clearwater basin at a rate that may be cumulatively significant.

The study of the Yahoo Lake and Debris Torrent landslides and other siltation sources of sediment (natural and man-caused) and their effects on fisheries resources of the Clearwater River system will continue for several years.

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INTRODUCTION

Sedimentation by logging-related practices of rivers and streams draining the western coast of the Olympic Peninsula has caused concern for the fisheries resources of the area. During the winter and early spring of 1971, two landslides caused by failure of logging roads occurred in an upper tributary (Stequaleho Creek) of the Clearwater River, Jefferson County, Washington (Fig. 1). These landslides occurred on state land administered by the Washington State Department of Natural Resources (DNR). Later, surveys by the Washington State Department of Fisheries (WDF) on July 7, 20, and 27, 1971, reported that siltation from these slides was affecting the abundance of fish food organisms and covering salmonid spawning beds in Stequaleho Creek and the lower Clearwater River (Deschamps 1971).

In December 1971, DNR contracted the Fisheries Research Institute (FRI) and the College of Forest Resources (CFR) of the University of Washington to investigate the extent of damage to the fisheries resources (Cederholm and Lestelle 1974; Cederholm, Lestelle, Edie, Martin, and Tagart 1975; Edie 1975; Wooldridge, Larson and Wald 1975; Wald 1975; Martin 1976; Tagart 1976; Larson and Jacoby 1976; Cederholm, Scarlett, and Salo 1977; and Lestelle [in preparation]). Over the past 3 1/2 years, we have gathered information on the Stequaleho landslide as well as on other sources of sediment (natural and man-caused) throughout the Clearwater River basin. The studies have been directed toward monitoring the Stequaleho landslides, while investigating the general effects of inorganic and organic substrate siltation on the salmonid resources of the Clearwater River and its tributaries. This report summarizes the studies of 3 1/2 years which are related to the Stequaleho Creek landslides. Abstracts of three Master of Science degree theses completed on this project are appended.[1]

LITERATURE REVIEW

Recognition of the Problems Associated with Sedimentation

Suspended sediment produced from heavily logged watersheds has been found to exceed that from natural sources by severalfold in many West Coast watersheds. The logging road and associated drainage devices have been singled out by many studies as the major contributors of sediment (Wallis and Anderson 1965; Fredrickson 1970; Brown and Krygier 1971; and Megahan and Kidd 1972). Recognition of this and the need for extensive rehabilitation and design improvements to protect water quality are emphasized in: Federal Water Pollution Control Administration 1970; Burroughs et al. 1973; U.S. Environmental Protection Agency 1975; and the Washington Forest Practice Board 1976.

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[1]The completed theses are on file at the University of Washington Fisheries-Oceanography Library, Seattle, Washington, 98195.

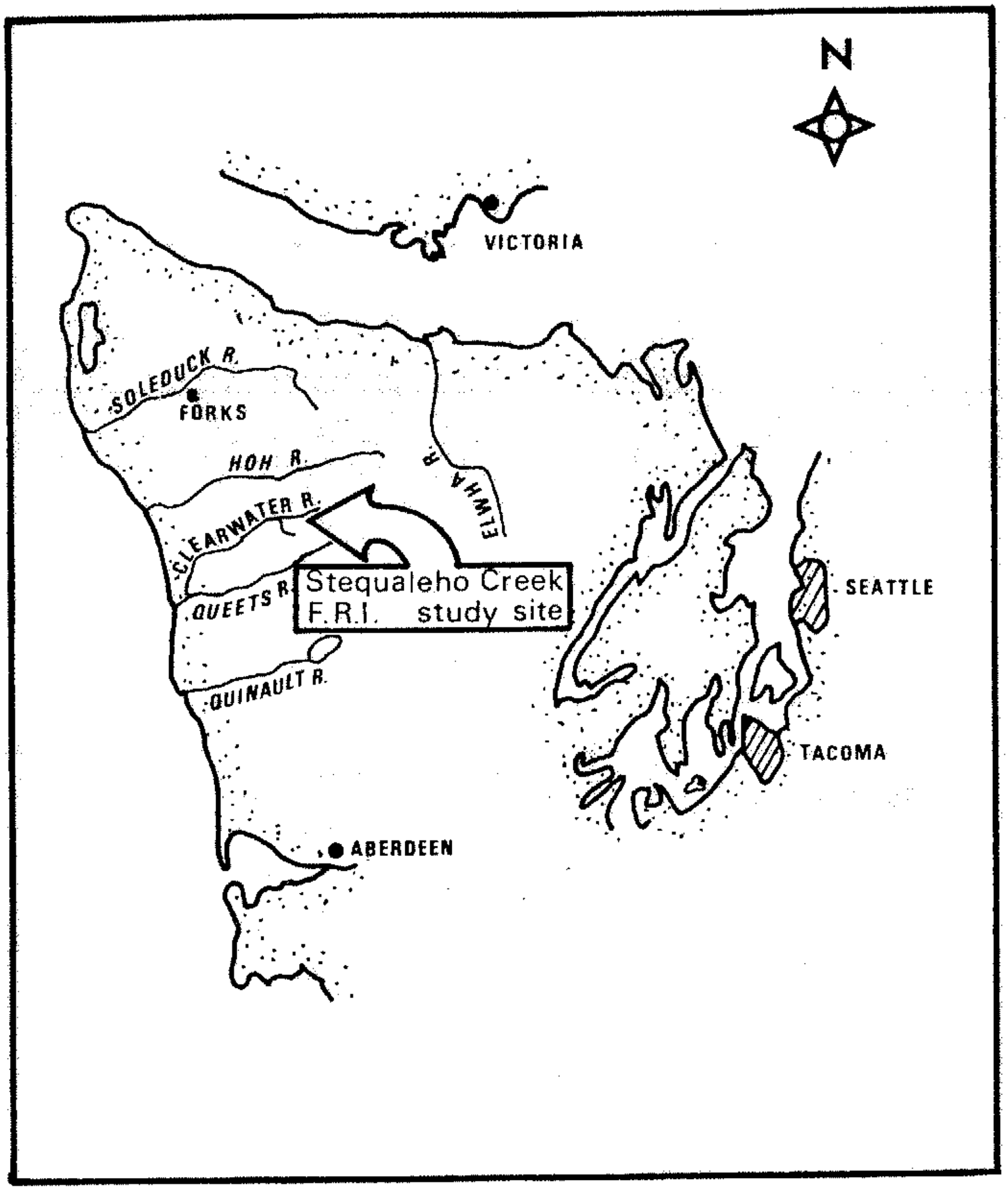

Fig. 1. Location of Clearwater River.

In this paper, the term sediment will be used in a general sense as defined by the American Geophysical Union Subcommittee on Terminology (1947), i.e., sediment is a general term for materials ranging in size from very fine clay to very large boulders. Sand or silt (fines) will be defined as that size of inorganic sediment considered to be detrimental to fish and insect life and more specifically, we will be referring to particles smaller than 0.85 mm diameter.

Effects of Fine Sediments on Fish Production

There has been extensive research, in both laboratory and field situations, on the effects of fine sediments produced from logging practices on fish and fish habitat. Findings of the physical effects of fines upon fishery resources are divided into the effects upon the fish's preemergent stages, and postemergent stages (Cordone and Kelley 1961; Hollis et al. 1964; McNeil 1966; Koski 1972; Gibbons and Salo 1973; and Meehan 1974). The following review includes only some of the more pertinent studies.

Fish Preemergent Life

There has been extensive research on the effects of spawning-bed sedimentation on the preemergent life of salmonids. During this intragravel life, high percentages of fines smaller than 0.85 mm can limit survival by: (1) inhibiting intragravel permeability, and (2) physically blocking fry emergence.

Wickett (1958) used a standpipe to measure permeability of spawning beds in streams in British Columbia, Canada, where freshwater survival of salmonids had been measured over a number of years. Wickett found a direct relationship between the average permeability of the beds and survival of salmon.

McNeil and Ahnell (1964) found that in six southeast Alaska streams the coefficient of permeability decreases as the percentage of fines (< 0.833 mm) increases in spawning gravels.

Vaux (1962) studied the interchange of stream and intragravel water in a salmon spawning riffle. He found that dissolved oxygen is supplied to intragravel water through (1) interchange of water from the stream above and (2) groundwater flow. Within the gravel, the primary variables that control interchange are gradients in the stream profile, permeability of the gravel bed, and dimensions of the bed. Sheridan (1962) found that the main source of oxygenated intragravel water is supplied through an exchange with the water surface above. Alderdice, Wickett, and Brett (1958) found that the rate of oxygen consumption for chum salmon was highest but variable during the first one-third of the intragravel development period and fairly constant thereafter. It seemed that the most critical oxygen needs were at time of hatching.

Hays et al. (1951) found that the oxygen level limiting survival in Atlantic salmon was greater for eggs (7.5 mg/l at 10°C) than for the posthatch alevins (4.5 mg/l). Initiation of active respiration across gill membranes was given as the mechanism accounting for the different requirements.

Wickett (1954) pointed out that the delivery rate of oxygen to an egg or larva is a function of velocity and the oxygen content of the water. Others (Coble 1961; Shumway 1960) have given experimental evidence that variations in velocity affected embryonic growth, development, and survival in much the same manner as variations in oxygen content.

Considerable research has been carried out on the effects of varying amounts of fines less than 3.3 mm or 0.8 mm diameter in spawning gravels. Cooper (1965) made an extensive laboratory study on the dynamics of sediment transport and its effect on spawning gravel. He explained the relationships between the permeability of the gravel and particle size, porosity and particle shape. Flow of silt-laden water over a gravel bed results in deposition of silt within the gravel, even though velocities exceed those allowing deposition on the surface. His results indicated that the least damaging effects of suspended sediment on salmon embryos and alevins would occur with a very coarse gravel and the most severe with fine gravel. He stressed the necessity for maintaining very low suspended sediment concentrations in water flowing over salmon spawning beds.

McNeil and Ahnell (1964) sampled the spawning gravels of six southeast Alaska pink salmon streams and determined the amount of fines passing a 0.833-mm sieve. Generally, they found an inverse relationship between the levels of fines and escapements of salmon.

Studies of the effects of sediments on intragravel survival, under natural conditions, were carried out on coho salmon in the Alsea watershed of Oregon. During the calibration phase of the study, it was found that in the redds of coho salmon, the gravel composition was the variable most clearly related to emergence survival. The mean survival from 21 redds was about 27% and ranged from 0% to 78%. The fines (< 0.833 mm) ranged from about 22% to 28% smaller. The Oregon Game Commission summarized the Alsea watershed data for the years 1964-1967 and high levels of fines were found to correlate strongly with low intragravel survival. The percentage of fines in the gravel smaller than 0.833 mm diameter had a slightly stronger correlation ($r = -0.83$) than did the percentage of sediment less than 3.327 mm diameter ($r = -0.73$). Koski (1972) pointed out that the amount of 0.833 mm and smaller fines in the Alsea redds had a range of only 8 percent, but the mean survival ranged from 0.2% to 54%. He stated that ". . . a 1% increase in sediment less than 0.833 mm resulted in a 4.5% decrease in survival to emergence."

Hall and Lantz (1969) carried out extensive laboratory studies on the emergent survival of coho salmon and steelhead trout. They mixed gravel to match that which was found in the Alsea field studies and then added 1 to 3 mm fines in 10% increments. The survival curves showed a very distinct reduction in survival with increasing amounts of fines, and also a difference in the ability (determined by numbers of emergent fry) of the two species to emerge through the silt-filled gravels. The steelhead fry were found to have better survival at each gravel size category; their smaller size was given as the explanation.

Bjornn (1968) used laboratory conditions to determine the survival of chinook salmon and steelhead trout. He mixed gravel with increasing percentages of granitic sand smaller than 6.35 mm (72% of which was smaller than 2.54 mm) and, as the percentage of these fine sediments increased, the salmonid survival decreased. The survival of steelhead was found to be greater than salmon for a given percentage of sand and it was thought that this was a result of the smaller fry.

A high proportion of the mortality in the redds of coho salmon in Oregon was believed to have been caused by the inability of fry to penetrate through the interstices of the gravel (Koski 1966). In conjunction with reductions in dissolved oxygen and intragravel water velocity, fines may form a barrier to fry migrating up through the gravel and actually entomb them within the redd. White (1942) found that where Atlantic salmon (Salmo salar) had spawned in gravel with an extensive amount of sand, 80% of the embryos were dead and 20% had produced fry which were unable to emerge through the compact layer.

Phillips (1965) observed that coho salmon embryos in aquaria suffered only low mortality rates prior to hatching in fine gravel, but after hatching, the coho alevins appeared distressed and died a short time later. The restriction of movement was dramatically illustrated by the trail of dead alevins as they struggled toward the surface. The more vigorous died about 2 inches short of emerging.

Detailed experiments by Koski (1975) at Big Beef Creek on the effects of gravel composition on the survival to emergence, and eventual fry fitness of chum salmon, led him to state:

"An array of ecological adaptations was disclosed which allowed for the continuity of the genetic differences between the early and late stocks of chum salmon in Big Beef Creek. The adaptations in the adult chums included the time of spawning, size and age of the spawners, fecundity, and egg size; adaptations in the emergent fry included timing of emergence, stage of development, and size and robustness. Criteria for describing fry fitness were based on the preceding adaptations of the emergent fry. Equations were developed which described the effects of low concentrations of dissolved oxygen and increased levels of fine sediment on survival to emergence and fitness of chum salmon fry. A quantitative estimate of the effects of increased sediment indicated that survival to emergence decreased 1.26% for each 1.0% increment in sand. A decrease in fry fitness was directly related to low dissolved oxygen and high percentages of sand in the spawning gravel. A selective mortality against fry of a larger size was also suggested in gravel containing high amounts of sand. A reduction in fry fitness may have pronounced effects on survival following emergence. Much of the observed variability in marine survival may be accounted for by a knowledge of the rate of survival to emergence and fry fitness."

Fish Postemergent Life

During the freshwater postemergent life (rearing phase) of salmonids, information concerning the direct or indirect effects of substrate siltation is not as complete as it is for the intragravel period. However, there is an extensive literature on the natural life history of salmon and trout which closely links high fish production to a clean and stable gravel substrate.

The rearing phase of salmonids can be divided into two critical periods: (1) the summer low-flow period, and (2) the overwinter period. A clean substrate is essential for fish food organisms, and for juvenile salmonids to use as shelter from predators and undesirable streamflows.

According to Frost and Brown (1967) and Thomas (1964), a productive salmonid habitat must have good clean, cool, hard water (pH 7 or greater), a stony and largely stable substratum, a plentiful source of detritus from riparian and aquatic vegetation, and most importantly, a low susceptibility to flooding.

On the determinants of stream production, Chapman and Bjornn (1969) stated "Where there is catastrophic instability, the positive influences of high ionic content, copious leaf-fall, and suitable temperatures cannot be lastingly effective. On the significance of floods, there is general agreement. Initially, and briefly, they (floods) benefit salmonids by making food more accessible; their main consequence is a reduction of the invertebrates (Allen 1959; Thomas 1964), and of allochthonous material."

Effects of Fine Sediments Upon Benthic Organisms

An increase in fines can cause a reduction in the abundance of benthic insects. This is of significance since benthic insects are a vital component in the food web of freshwater fishes (Hynes 1970).

Tebo (1955) observed a reduction in standing crop of benthic organisms in a small North Carolina stream following siltation due to logging. A total of 109 one-sq-ft bottom samples was collected above and below the sediment source and the reduction was statistically significant in the affected section. Bachman (1958) observed a statistically significant reduction in volume of benthic organisms in an Idaho stream following sedimentation from logging road construction. A similar reduction occurred in the Truckee River, California, following a gravel washing operation (Cordone and Pennoyer 1960); samples taken below the sediment source contained significantly fewer insects than samples upstream of the source. This difference was observed as far as 10.5 miles downstream from the sediment source. Erosion depositing approximately 10,000 m^3 of sand in a British stream over a period of 2 years reduced the downstream populations of aquatic food organisms when compared to samples above the sediment source. In fact, Chironomidae, which often increase in abundance in organic sedimentation, were either absent or occurred sporadically below this sediment source (Nuttall 1972).

Several mechanisms have been proposed to account for a reduction in insect abundance following increased sedimentation. Clogging of interstices with fines may affect insect abundance by a reduction in flow of oxygen-enriched water (Ziebell 1960). Usinger (1971) suggests there may be an abrasion effect or interference with the respiratory structures of insects caused by silt. Streams which rely on primary production as their principal energy source may be affected by a decrease in the photosynthesis process during increased suspended sediment loads, affecting the insect community by decreasing insect food abundance (Hynes 1960).

Dependence of Salmonids on a Clean Substrate for Cover

Phillips (1970) pointed out the need to maintain clean crevices and interstices in gravel substrates to provide escape cover to salmonid fry.

Chapman and Bjornn (1969) report that in the Salmon and Clearwater rivers of Idaho, young steelhead trout and chinook salmon tend to be under large stones in the winter months when water temperatures drop below 4 C. They also carried out extensive laboratory experiments on the substrate preferences of juvenile steelhead and chinook salmon. They said, "Steelhead are almost invariably associated with rubble particles and are in somewhat shallower water than chinooks. We have noted in laboratory work that chinook fry are easily frightened, darting away on very slight provocation. Steelhead, by comparison, are almost placid. It could be that steelhead have a 'security blanket' resulting from adaptive association with cover provided by rubble, while chinooks must rely on darting flight to escape from predators such as birds."

Observations by Ruggles (1966) and Hartman (1965) on coho salmon indicate that this species is less dependent on the substrate than young steelhead trout. Ruggles was able to decrease the holding capacity in an artificial stream for coho after adding substrate cover in the form of patio blocks while Hartman found that coho did not go beneath stones during the winter in stream aquaria.

Extensive field observations of the overwintering ecology of juvenile coho and steelhead were made by Bustard (1973) while snorkeling in Carnation Creek, a small stream on the west coast of Vancouver Island. His studies indicated a movement of coho and older steelhead into deep pools, while age-0-steelhead remained in the shallows and marginal areas of the stream as the temperature went from 9 C to 2 C. Steelhead fry were most often found under rubble, while coho and older steelhead were most often found within upturned roots and under logs. Bustard also carried out some interesting experiments with the substrate preference of coho salmon and cutthroat trout. He found a definite preference for clean rubble substrate as opposed to silted rubble substrate. At the end of his study, Bustard recommended that sediment loads in streams should be kept to a minimum to protect overwintering habitat, especially in streams that do not flush frequently.

Behavioral observations by Allee (1974) on the seasonal distribution of coho and steelhead fry in Big Beef Creek rated a movement of young-of-the-year coho fry into the shallow stream margins in March prior to steelhead emergence. By May, both coho and steelhead fry occupied the shallow stream margins, exhibiting intense territorial behavior. After the termination of the spring smolt migration, the coho fry began to take up residence in the pool habitat, while the majority of age-0 steelhead were present in the shallow areas of the stream, in the riffles, and along the sloping sides and bottoms of pools. In almost all the habitat situations, the latter species showed a close association with the substrate. Allee says "These fish (age-0 steelhead) exhibited territorial behavior, presumably based upon site orientation related to the substrate." He goes on to say that the steelhead yearlings were found mainly in the deep pools where cover was available and in areas of fast velocity where the average depth of a riffle deepened to form a pool.

By late fall, increased discharge and lower temperatures brought on a change in the salmonid distributions. At this time, the age 0 and older steelhead were both found in the pools with the coho. During the winter residence, it became very difficult to sample, but Allee did find some evidence of coho and both age groups of trout in pools in association with roots of stumps.

Retention Time for Fine Sediments in Spawning Gravels

The extent of damage to aquatic resources due to sedimentation is greatly influenced by the magnitude and timing of the sedimentation and the ability of the stream to flush these sediments during storm periods.

Studies in Alaska by McNeil and Ahnell (1964) determined that the deposition of fine sediments in the spawning substrates was temporary, depending on the amount of pink salmon spawning activity and the occurrence of floods. McNeil and Ahnell (1964) found "that an abundance of spawners in September of 1959 and 1960 caused removal of the fine particles from the intertidal area. A scarcity of spawners without adequate population pressure to move the spawners upstream resulted in a failure to remove the fines from the beds in the upper areas. The increase in volume of fine particles in the one upstream area between August and October of 1959 was attributed to sedimentation from logging, and the subsequent decrease in February was attributed to flooding."

Shapley and Bishop (1965) studied gravel movement in relation to logjams in a small pink salmon stream on Prince of Wales Island, Alaska. They discussed the relative settling rates of organic and inorganic suspended sediments. Apparently, the inorganic sediments would settle out first, due to differences in specific gravity during low-flow periods, but they were flushed and swept downstream by the first high-flows of the fall season. High streamflows can largely determine the size composition of streambed material, and that streams with low high-flow:low-flow ratios require less sediment load to make lasting changes in gravel composition.

Helmers (1966) studied changes in salmon spawning gravel composition in relation to log-debris jams before and after floods in an Alaskan stream. He found that the amount of fine material (less than 0.833 mm diameter) in the top 6 inches of streambed was less after flooding than before in four of the five areas and unchanged in the others.

Burns (1972) studied spawning bed sedimentation in relation to logging in several small California streams. He states that, "Sustained logging and associated road construction over a period of many years do not afford either the stream or the fish population a chance to recover."

Moring and Lantz (1974) reported that in 12 Oregon coastal streams under varying degrees of logging influence, spawning gravel composition was more variable and less evenly distributed in streams after logging operations. They also found that intragravel dissolved oxygen minimums declined on seven streams after logging, increased on three, and remained unchanged on two.

Results of 14 years of study on the Alsea watershed of coastal Oregon were reported by Moring 1975a, b; Moring and Lantz 1975. There was a 205.3% increase in suspended sediments in Needle Branch (clearcut) following road construction, and a 53.5% increase in Deer Creek (patchcut). Sediment discharge increased by only 0.1% in Flynn Creek (unaffected by logging or road construction) during this same period. Levels of fine material (< 0.833 mm and < 3.327 mm in diameter) in spawning gravels increased in Needle Branch and Deer Creek following logging, but the lack of sufficient prelogging data makes the statistical comparison weak. Permeability of the spawning gravel decreased in Needle Branch after logging, while the permeabilities in the other two streams remained essentially the same.

Summary

Several conclusions can be drawn from the literature regarding the effects of stream substrate composition on salmonid habitat and survival:

Preemergent life is the period in a salmonid's life from egg deposition to emergence from the gravel as fry.

1. A high intragravel survival is dependent on a permeable streambed that allows a good interchange of well-oxygenated water from the stream above.

2. High levels of fines (materials smaller than 0.85 mm in diameter) in or on spawning gravels can reduce the permeability of the intragravel water.

3. Higher than natural levels of fine sediments (0.833 mm diameter) in spawning gravels have been shown to have a strong inverse correlation with survival-to-emergence for almost all species of salmonids.

4. The degree of reduction in preemergent survival for a given gravel composition varies greatly and may depend on the species of salmonid as well as the hydrologic conditions of the watershed involved.

5. A significant amount of the preemergent mortality is caused by the inability of the button-up fry to swim up and out of the gravel due to the clogging of interstices by fine sediments.

6. The gravel composition of a spawning-bed may have selective effects on fry populations which may affect survival in the freshwater and saltwater environments.

<u>Postemergent life</u> is the period in a salmonid's life from fry emergence through smoltification.

1. A productive salmonid stream is characterized by clean, cold water, with a stony substrate, extensive streamside vegetation, a pH above 7, and moderate streamflows during winter.

2. An important part of a salmonid's diet comes from within the stream substrate as benthic fauna.

3. Extensive siltation on, or within, the substratum can substantially reduce the benthic fauna numbers.

4. Highly fluctuating winter streamflows act to clean streams of unwanted fine sediments, but they also can reduce the number of benthic organisms living on the stream bottom.

5. Considering the mobility of benthic fauna, reductions in the populations due to siltation can be short-term, depending on the stream's ability to flush the silt.

6. It is important to keep the gravel interstices from clogging with fines because the substrate is a very important source of predator escape cover for salmonid fry in summer, and hiding cover from streamflows in winter.

7. This dependence on the substrate for hiding cover seems to be most important in young-of-the-year trout.

8. On the retention time of fine sediments in substrates, there is probably a great degree of variation from region to region, depending on the soil type, magnitude and timing of the initial disturbance, the gradient of the streambed, and the general rainfall and runoff patterns of the particular streams.

9. It appears that given enough time, recovery can occur in most streams.

CLEARWATER RIVER RESEARCH OBJECTIVES

Specific Objectives

The purpose of this project has been to determine the influence of substrate siltation on the fisheries resources, at the levels encountered in the landslide-affected areas of Stequaleho Creek and the Clearwater River. The study is in two segments:

Phase I (January 1972 to June 1973). In this period we:

A) monitored the spawning gravel composition (fine sediment levels) in landslide-affected and unaffected areas of Stequaleho Creek and the Clearwater River;

B) monitored the streambed stability in lower Stequaleho Creek;

C) measured the suspended sediment concentrations in Stequaleho Creek and compared them to other tributaries of the Clearwater River;

D) monitored the abundance of benthic fauna found in landslide-affected and unaffected substrates of Stequaleho Creek and the Clearwater River;

E) measured the abundance of salmonids and nonsalmonids in landslide-affected areas of Stequaleho Creek, and compared them with other tributaries of the Clearwater River.

Phase II (July 1973 to June 1975). In this period we:

A) continued the program of Phase I;

B) carried out a census of the juvenile salmonids in the Clearwater River Basin, in relation to logging (Edie 1975);

C) investigated the influence of organic and inorganic siltation on the abundance and production of benthic fauna (Martin 1976);

D) investigated the relationship between gravel composition and the survival of coho salmon from egg deposition to the emergence of fry under natural (Tagart 1976) and artificial stream conditions (Cederholm and Tagart, unpublished).

THE CLEARWATER RIVER BASIN

The Clearwater River is the largest of four major tributaries of the Queets River, with a watershed area of approximately 350 km^2 (145 sq miles). The Clearwater enters the Queets River about 10 km above its mouth (Fig. 2). The Clearwater mainstream is approximately 64 km long and is fed by 10 major tributaries and many minor ones. There are about 100 km of tributary and 60 km of mainstream available to anadromous salmonids throughout the Clearwater River system.

The Clearwater River, in contrast to the Queets River, is unglaciated and flows southwest from the foothills of the Olympic Mountains. Rainfall often exceeds 381 cm (150 inches) per year and the proximity to the Pacific Ocean provides for rapid changes in weather throughout the year.

During water year October 1974 to September 1975 the mean annual stream discharge at the mouth was approximately 1,000 cfs, and the minimum was 35.0 cfs in August 1975 (Larson and Jacoby 1976).

The Clearwater River and its tributaries support a wide variety of fish species. Among these are coho salmon (Oncorhynchus kisutch), chinook salmon (O. tshawytscha), steelhead trout (Salmo gairdneri), and searun and resident varieties of coastal cutthroat trout (S. clarki). There are also minor runs of sockeye salmon (O. nerka) and chum salmon (O. keta). Some of the other species of fish found in this drainage are the torrent sculpin (Cottus rhotheus), prickly sculpin (C. asper), coast range sculpin (C. aleuticus), western speckled dace (Rhinichthys osculus), longnose dace (R. cataractae), Rocky Mountain whitefish (Prosopium williamsoni), two species of lamprey and an introduced variety of Mount Whitney rainbow trout.

LOGGING OF THE CLEARWATER RIVER BASIN

The Clearwater River Basin is under intensive old-growth timber management by state, federal, and private land owners. Approximately 80% of the drainage is managed by the DNR and in 1974, approximately 20% of the DNR statewide annual cut came from this area.

The principal timber harvesting practice throughout the Clearwater block is a sustained yield concept of clearcutting in a patchcut pattern. Clearcut areas are usually burned and replanted with conifers within 2 years after cutting. The size of each clearcut unit averages around 32 ha and seldom exceeds 81 ha. The retention of buffer strips and streamside management zones has been the general practice to date for most major tributaries and the main Clearwater River, but many small tributaries (Type 4 and 5 waters) are clearcut. The commercially harvested timber species are Western hemlock (Tsuga heterophylla), white fir (Abies amabilis), Sitka spruce (Picea sitchensis), Western red cedar (Thuja plicata), and Douglas fir (Pseudotsuga menziesii).

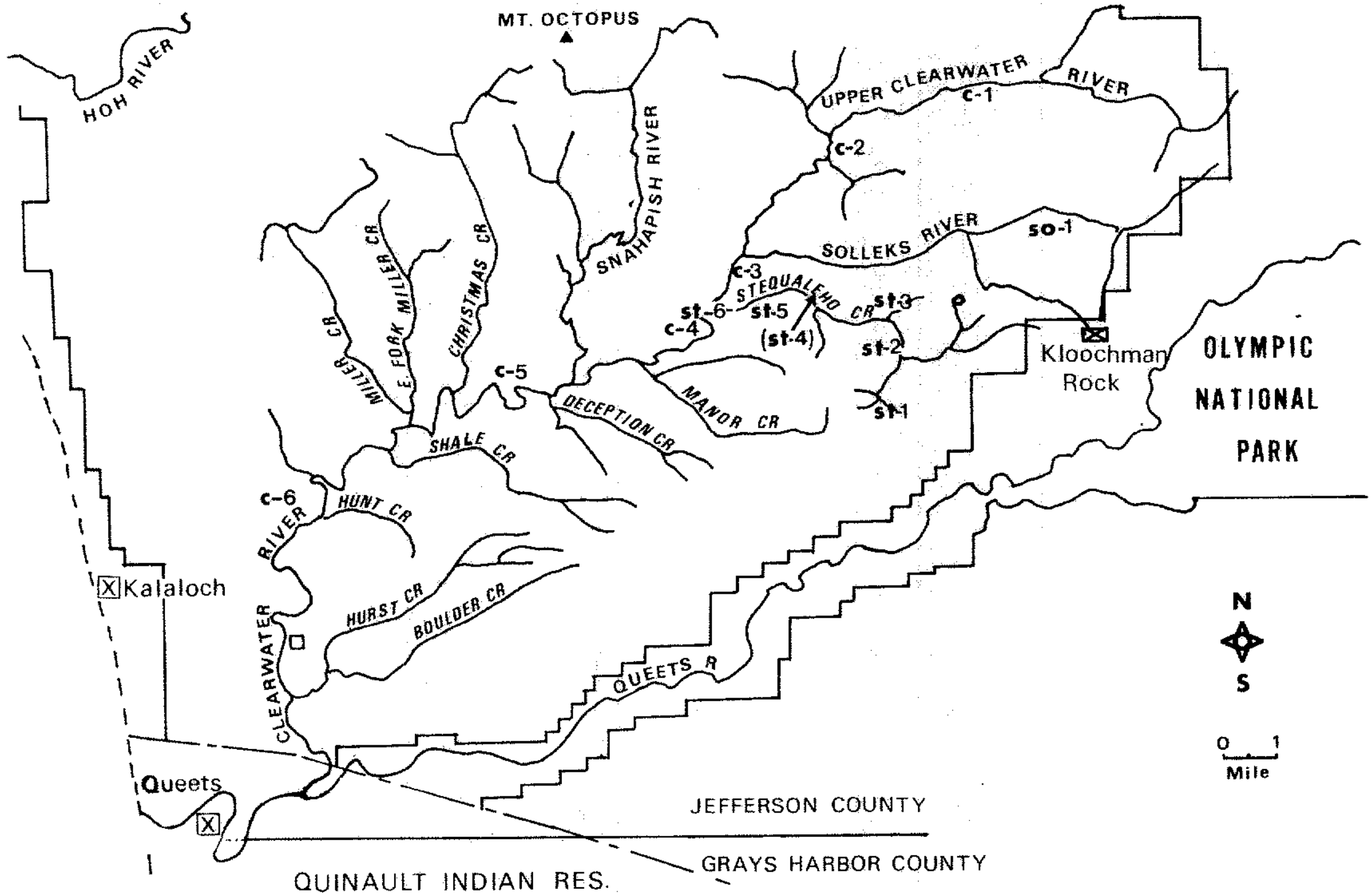

Fig. 2. General locations of experimental sampling sites in the Clearwater River, the Solleks River, and Stequaleho Creek.

Before 1960, the principal logging was by private companies who own about 15% of the drainage. After 1960, the DNR began extending its road system into the steep upper river areas, and by mid-1975 there were approximately 450 km (300 mi) of logging roads in the Clearwater River watershed.

The logging roads in the middle and upper Clearwater Basin are in steep terrain where sideslopes often exceed 100%. Natural landslides are quite numerous in this area, and man-caused landslides along logging roads and in clearcut units are occurring at an alarming rate (Fiksdal 1974a, 1974b). These natural and man-caused landslides contribute a considerable amount of siltation to the Clearwater River and its tributaries.

LANDSLIDE-AFFECTED AREA

In May 1971, two massive landslides were caused by logging road failure in the steep upper Stequaleho Creek basin. The slides are referred to as the Debris Torrent and Yahoo Lake landslides (Fig. 3). Combined, these landslides put approximately 16,000 m^3 (20,000 yd^3) of sediment and debris into Stequaleho Creek during the initial event. Since this study started, the Yahoo Lake slide has reactivated (1973) once, and there have been two additional significant road slides in upper Stequaleho Creek. There are four large natural slides in Stequaleho Creek which also add a considerable amount of sediment to the stream. One, located just downstream of the Debris Torrent slide, occurred at the same time as the Debris Torrent slide.

The influence of the Yahoo Lake and Debris Torrent includes 3 km of anadromous zone in lower Stequaleho Creek, and 40 km of the lower mainstem Clearwater River. The influence probably extended into the Queets River and its estuary, but these areas are beyond the scope of the study.

RESEARCH PROCEDURE

The landslides occurred in the spring of 1971, and the study began in January 1972, so no data are available for the first summer and fall. However, if the effects were of long-term significance they should have been detectable when compared to unaffected areas in Stequaleho Creek and other tributaries. It was assumed that the environment in the unaffected areas represent the conditions existing in the landslide-affected areas prior to the event, so the sampling locations were chosen upstream (controls) and downstream (experimentals) of the slides. Surveys and experiments have been conducted in other tributaries of the Clearwater River.

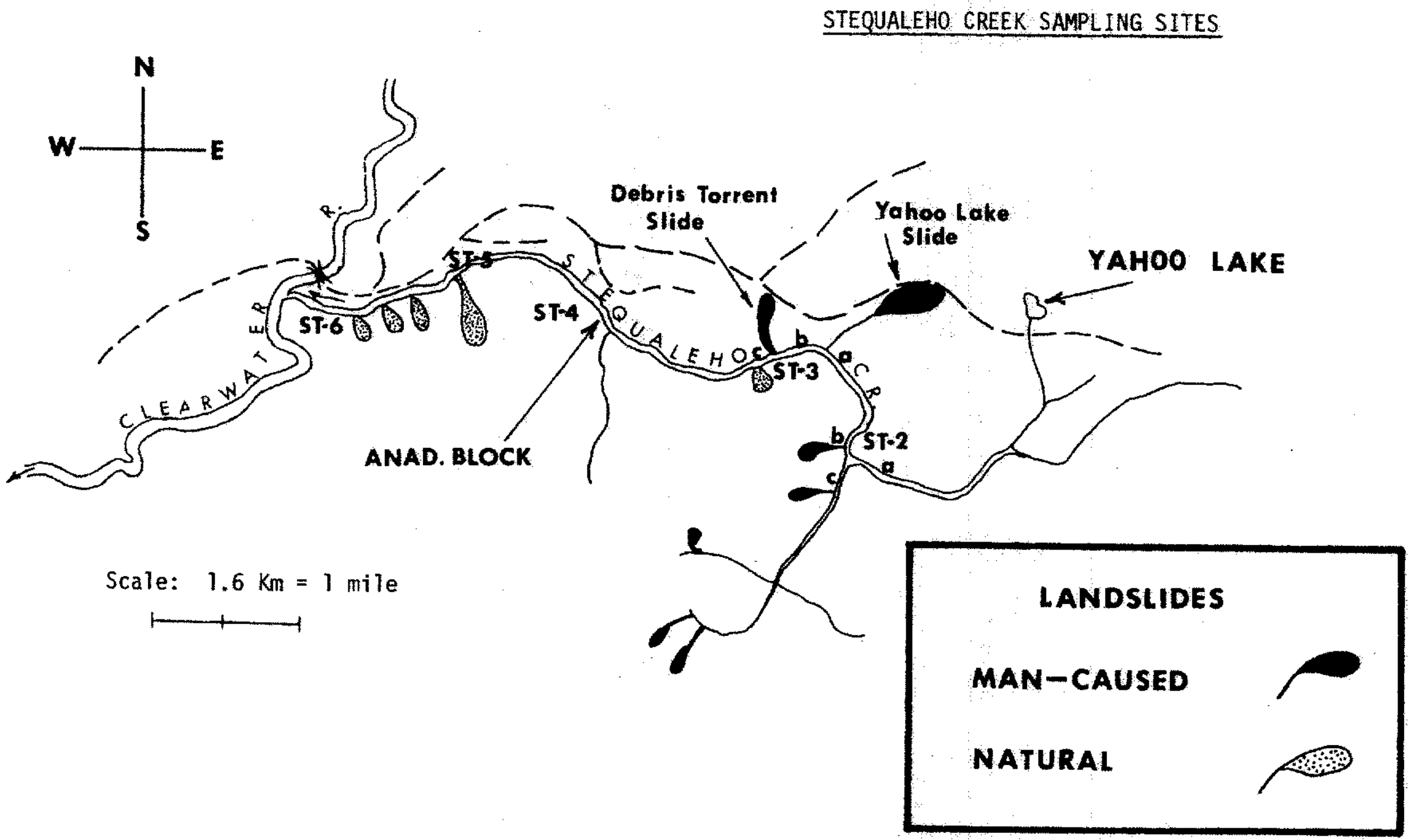

Fig. 3. Sampling sites, logging roads, natural and man-caused landslides in the Stequaleho Creek drainage basin. Depicted landslides are not drawn to scale.

METHODS

Spawning Gravel Composition

Over a 3.5-year period, we have analyzed over 600 spawning gravel samples from Stequaleho Creek, the mainstem Clearwater River and its tributaries (Figs. 2 and 3). Within Stequaleho Creek proper, four sites were established above the landslide source (ST-2-A, ST-2-B, ST-2-C, ST-3-A) and four sites below (ST-3-B, ST-4, ST-5, ST-6). Station ST-3-B was located between the two landslides and above the anadromous fish blockage. Stations were also established in the main Clearwater River above (Cl-1, Cl-2, Cl-3, SO-1) and below (Cl-4, Cl-5, Cl-6) the mouth of Stequaleho Creek. Due to ongoing logging and road building projects by the DNR after 1973, some of the landslide-unaffected control stations were eventually influenced by additional man-caused siltation (i.e., ST-2-B, ST-2-C, ST-3-A, Cl-1).

Spawning gravel samples were taken from riffles where salmon, or trout, or both, were known to spawn, using a technique developed in Alaska by McNeil and Ahnell (1964). The sampler, which was modified with a plunger to capture the smaller than 0.106 mm diameter sediments (Fig. 4), removes a circular core 15.24 cm (6 inches) in diameter and 20.32 cm (8 inches) deep. The samples were washed through a series of from five to seven Tyler sieves, which had the following square-mesh openings: 77 mm (3.0 inch), 26.9 mm (1.06 inch), 3.36 mm (0.132 inch), 0.850 mm (0.033 inch), 0.425 mm (0.017 inch), 0.212 mm (0.008 inch), and 0.106 mm (0.004 inch). The material passing through the smallest sieve size (0.106 mm [0.004 inch]) was allowed to settle for 1 hr in a graduated cylinder before the volume was read. The volume of material retained by each sieve was then measured in a volume displacement flask. The percentage of the total sample passing through each Tyler sieve size could then be determined.

Statistical tests were performed on the control and experimental sample means for Stequaleho Creek and the Clearwater River using a t-test with a Behrens-Fisher distribution. Since sample sizes were unequal, Cochran's approximation of the significance of t was used (Snedecor and Cochran 1967).

Streambed Cross Section Changes

Cross-sectional surveys (Cederholm 1972) provided information on the relative change of the streambed. Sixty stations were established in three locations (20 cross sections each) in the anadromous zone of Stequaleho. Measurements were taken in June 1972 and repeated in August 1973 (see Cederholm and Lestelle 1974).

During the winter of 1974-1975, we took cross-sectional measurements in Hurst, Shale, and Christmas Creeks, in addition to Stequaleho. The measurements were taken at 150-ft intervals in the lower mile of each of the four tributaries in September 1974, January 1975, and June 1975.

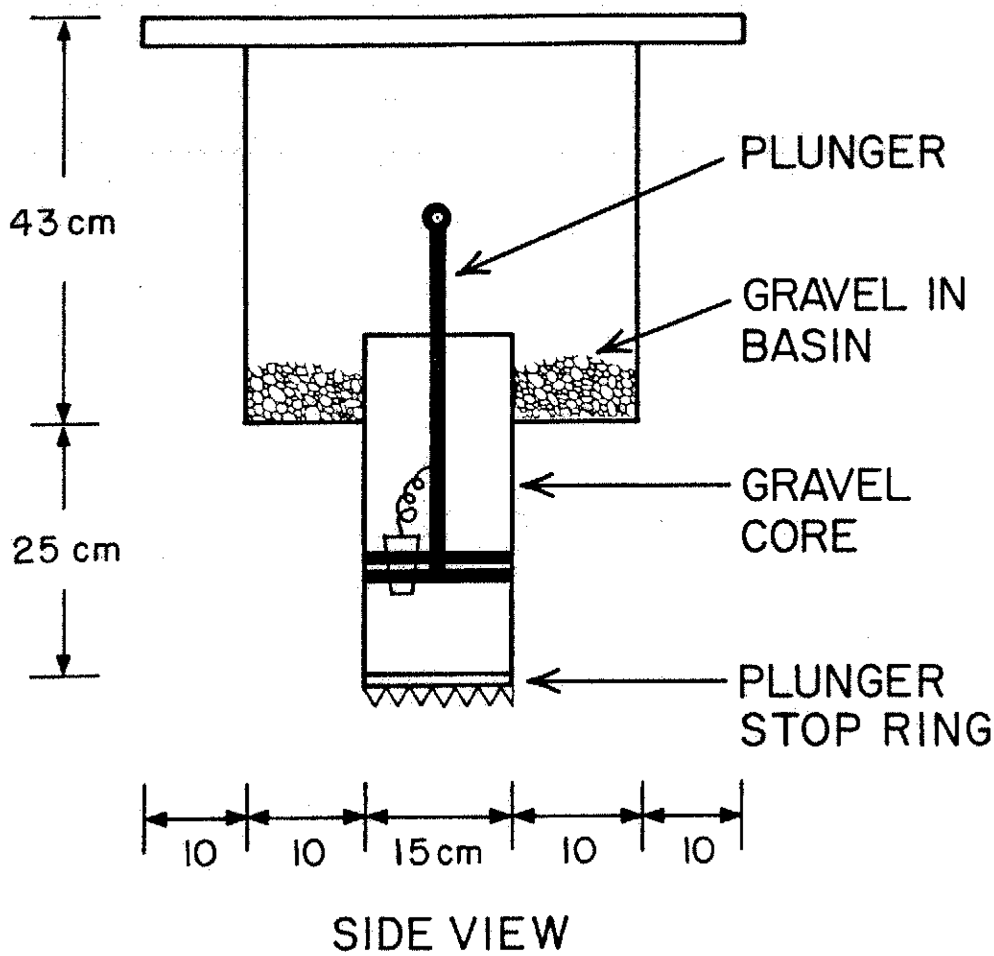

Fig. 4. The McNeil gravel sampler used to investigate gravel quality in the Clearwater River and its tributaries, 1973-75.

A station profile was made by hand level, rod and tape. The distances were measured from bench marks located on the banks of the stream and when the profiles for different periods were superimposed, the changes could be calculated. The areas of the change were divided into three categories: 1) erosion of embankments; 2) streambed scour; and 3) streambed fill. Streambed fill was given a positive value and streambed scour and streambank erosion were given negative values and the algebraic sum of the values was used to arrive at the net change. During the 1972-1973 surveys, the results were expressed in volumes, while in 1974-1975 the results are expressed in cross-sectional area changes. This technique measures only gross bedload changes and does not allow for changes in the very small (suspended) particle sizes.

Benthic Insect Abundance

During the summers of 1972, 1973, and 1974, a total of 325 samples of benthic organisms was collected from Stequaleho Creek, the Clearwater River, and its tributaries. Bottom samples were collected with a Neill cylinder (Neill 1938), which samples an area of 1,000 cm^2 (1.1 ft^2) of streambed to a depth of 10 cm (4 inches) (Fig. 5). Organisms trapped by the cylinder are washed into a trailing net by water passing through two openings. The net has 25 meshes per inch, or apertures of slightly less than 1 mm (the manufacturer's standard pore size for the Surber sampler is 1.02 mm). To determine the efficiency of the trailing net, we took 12 samples with a smaller net (pore size = 0.247 mm) tied behind it (see Cederholm and Lestelle 1974).

All samples collected with the nets were either preserved in 70% alcohol for laboratory analysis (1972 and 1973) or picked in the field (1974).

Classification was carried out to family during 1972 and 1973, and only total numbers of individuals were counted in 1974. Keys of insect larvae to species are lacking for this region of the country.

All stations were located on riffles with predominately velocities of 0.3 to 0.45 m/sec (1.0 to 1.5 ft/sec); occasionally they reached 0.6 m/sec (2.0 ft/sec). Sites were chosen randomly--substrate permitting.

During the summer of 1972, samples were taken in Stequaleho Creek and the main Clearwater River before and after a major storm in early July.

During July 1973, samples were collected in Stequaleho Creek and the main Clearwater River; in addition baseline data were gathered in the remaining Clearwater River tributaries.

Between July 31 and August 5, 1974, another set of samples was taken in Stequaleho Creek and no additional samples were needed from the other areas.

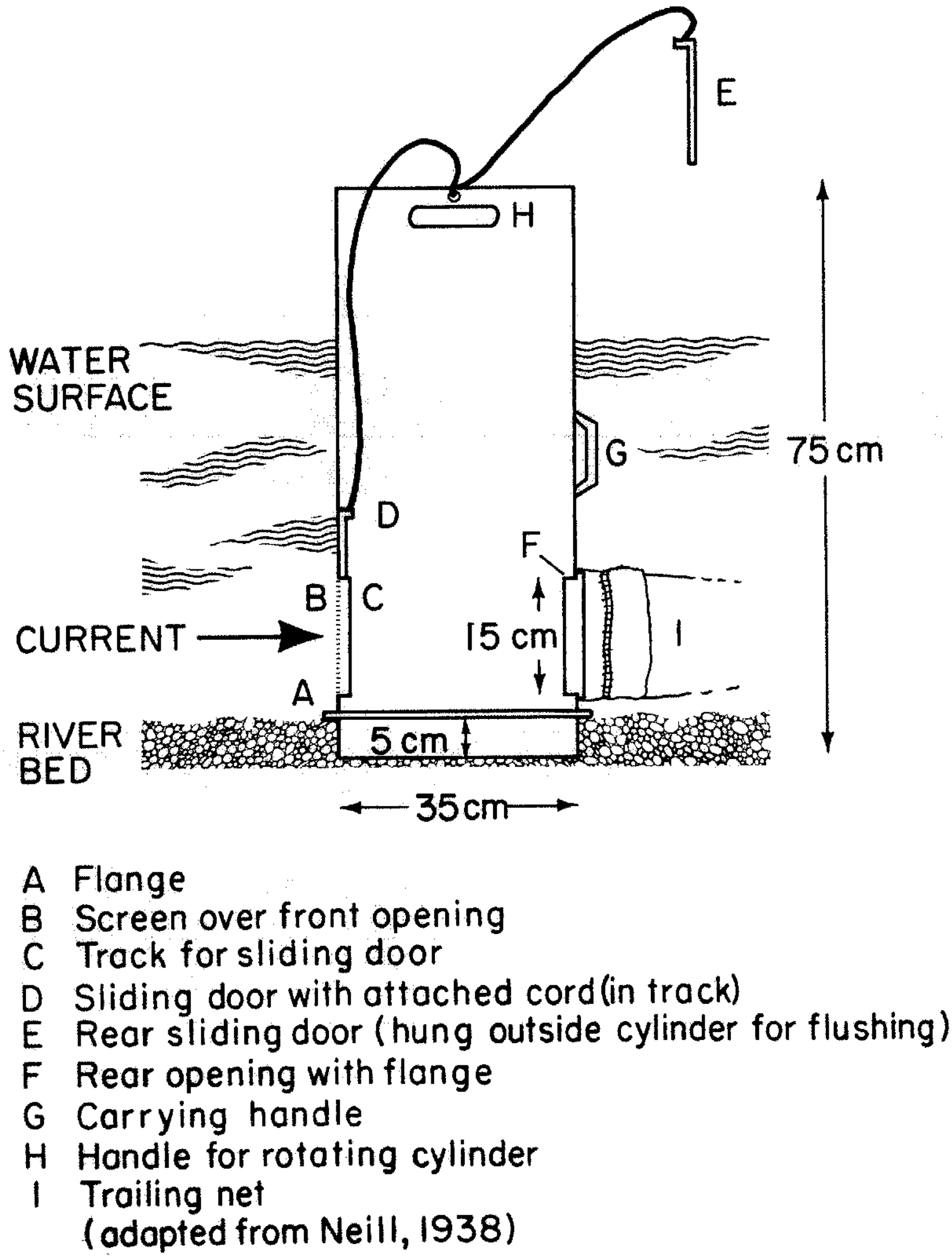

Fig. 5. Neill cylinder.

The data were analyzed by the use of a one-way analysis of variance with a Scheffe's comparison (McCaughran, personal communication), but normality is a basic assumption of this analysis and since it is known that the benthic fauna are not distributed in a normal fashion (Allen 1959), a square root transformation of the data was made. For the analysis, the control (ST-2-A, ST-2-C, ST-3-A) was considered one treatment, and the experimentals (ST-3-B, ST-4, ST-6) were considered a treatment. For the Clearwater River, the control (C-2, C-3) was considered as one treatment, and the experimental (C-4, C-5) as another.

Fish Abundance

Juveniles

During the summer low-flow periods of 1972, 1973, and 1974, the standing stock of juvenile salmonids and nonsalmonids was determined for the 31 locations in the anadromous zone of Stequaleho Creek and other tributaries of the Clearwater River. Due to the limitations of the backpack electrofisher, the mainstream of the Clearwater River was not sampled. The objective was to compare the fish populations of landslide-affected Stequaleho Creek with the unaffected Clearwater River tributaries. The biomass divided by the water surface area in a study section was chosen as the parameter for comparison.

A typical sampling location was from 70 to 140 m long and located in an area that could be sampled with a Smith-Root Mark V backpack electrofisher (i.e., where the stream depth did not exceed 1 m). During sampling, the upstream and downstream limits of each section were blocked with small mesh stop nets. A Petersen mark-recapture census was made (Chapman modification, 1951) for each major size group of the principal species.

The fish were anesthetized with MS-222 and were marked with a small clip of the dorsal lobe of the caudal fin. Lengths, weights, and scales were taken on most of the fish.

When the fish were sampled, each study section was subdivided into pool, riffle, and run habitat, and physical measurements were determined for the water surface area of each. The relative biomass of each species and age group of fish was calculated based on the standing biomass (of each species) divided by the total water surface area of each study location. For further information on the species and age composition of the salmon and trout populations, *see* Edie (1975).

Adults

The spawning distribution of steelhead trout and chinook and coho salmon was estimated for the Clearwater River and its tributaries between 1973 and 1975. The mainstem was observed by helicopter and the tributaries by foot surveys. Timing was governed by streamflow levels and general weather conditions. The peak of spawning was determined by the greatest number of redds observed on any one date.

Surveys of the mainstem were usually separated by 1 to 2 weeks, and the number of redds observed on each survey was treated as a distinct count. The entire mainstem could be surveyed on each flight. The number of redds formed by an escapement of spawners was therefore the summation of all redds observed during the season. From four to seven surveys were made for each species during a spawning season.

Surveys were carried out in index sections of 12 tributaries. The total length of the index sections accounted for approximately one-third of the areas open to anadromous migration. Each stream index section was surveyed at least once, and in some cases as many as seven times, per season. The number of redds per mile was determined for each index area and extrapolated to the remainder of the stream. Due to the difficulty in seeing all the redds constructed by steelhead, coho, and chinook in tributaries, all counted redds were multiplied by a factor of 2.

A redd was called one female's complement of deposited eggs, and a redd could be made up of more than one nest. In the case of coho and chinook salmon, a female's eggs were seldom spawned in more than one nest, but the steelhead were found to spawn anywhere from one to three separate nests per redd. Therefore, when a redd surveyor was counting salmon redds, he merely counted the total number of full-sized nests; but when counting steelhead redds, he had to make a judgment as to how many nests made a single redd, usually based on the relative proximity of the nests. Small test digs and lamprey redds were noted, but not included in the total number of steelhead redds.

When making redd surveys, it was often very difficult to know when one was recounting redds or counting newly spawned ones. Obviously, the redd survey information is very subjective and open to considerable error, but we feel that the data are usable in relative terms within the Clearwater River system.

RESULTS

Clearwater River System Anadromous Area Influenced by the Stequaleho Creek Landslides

The Yahoo Lake and Debris Torrent landslides are located upstream of the anadromous block in Stequaleho Creek. Therefore, these landslides had the potential to influence the anadromous zone of Stequaleho, and the Clearwater River mainstem below Stequaleho. It was determined between 1973 and 1975 that on the average approximately 32% (range = 21%-48%) of the Clearwater River winter-run steelhead and 41% (range 34%-65%) of the fall-run chinook salmon and 3% (range 2%-4%) of the coho spawn within this area (Table 1). The winter steelhead and chinook are

Table 1. Estimated distribution of winter-run steelhead and fall salmon redds in the landslide-affected and -unaffected areas of the Clearwater River[1]

	Number of redds in the landslide-affected area in Stequaleho Creek and the Clearwater River				Number of redds in the landslide-unaffected area in Clearwater River and the remaining tributaries			
Year	Winter steelhead	Fall chinook	Fall coho	Total	Winter steelhead	Fall chinook	Fall coho	Total
1973	209	97	26	332	773	189	584	1,546
1974	52	119	12	183	56	64	348	468
1975	268	115	4	387	315	221	210	746
Total	529	331	42	902	1,144	474	1,142	2,760
$\overline{X}$	176	110	14	301	381	158	381	920

[1]These estimates cannot be used to represent total escapements of the three species of salmonids; but are probably correct in terms of relative distribution of numbers of redds in landslide-affected and -unaffected areas.

principally lower-river mainstem spawners, while coho are primarily tributary spawners, which accounts for the minor influence on coho stock.

Spawning Gravel Composition Changes--Control vs. Stequaleho Creek (1972, 1973, and 1974)

The mean percentages of fine material (< 0.85 mm) in spawning gravels of Stequaleho Creek were found to be significantly (5% level) higher in the landslide-affected zone than in the control in 1972 and 1973; but not in 1974 (Table 2). This would represent the second, third, and fourth summers since the landslides occurred. In 1972, the mean percentage of fines in the landslide-affected zone was 10.91% compared to 7.78% in the control, an increase of 3.13%. In 1973, the mean percentage of fines in the landslide-affected zone was 9.91% compared to 7.49% in the control, an increase of 2.42%. In 1974, the mean percentage of fines in the landslide-affected zone was 9.00% compared to 9.50%, a decrease of 0.50%. It is important to note, however, that new road-caused landslides occurring in the control areas may have influenced the gravels before they were sampled in 1973 and 1974 (Table 2) (Fig. 6).

Station St-3-B, located between the two landslides, had mean percentages of fines of 6.72% in 1972; 21.20% in 1973; and 17.62% in 1974. The reactivation of the Yahoo Lake landslide in 1973 (before sampling) is believed to be the reason for the high levels at this station in 1973 and 1974. These heavy siltation levels in 1973 and 1974 were found deposited behind the large logjam caused by material coming out of the Debris Torrent landslide.

Spawning Gravel Composition Changes--Control vs. Clearwater River (1972, 1973, and 1974)

The mean percentages of fine material (< 0.85 mm) in spawning gravels of the mainstem Clearwater River were found to be significantly (5% level) higher in the landslide-affected areas (below Stequaleho mouth) in 1972 and in 1973, but not in 1974 (Table 2). In 1972, the percentage of fines in the landslide-affected area was 9.21% compared to 7.78% in the control, an increase of 1.43%. In 1973, the percentage of fines in the landslide-affected area was 9.24% compared to 7.49% in the control, an increase of 1.75%. In 1974, the percentage of fines in the landslide-affected area was 8.68% compared to 9.50% in the control, a decreased difference of 0.82% (Table 2) (Fig. 6). Again, these 3 years of measurement represent the second, third and fourth summers since the original landslides occurred. Also, the controls may have been influenced by new road-caused landslides in 1973 and 1974.

Streambed Cross-sectional Changes

During 1972 and 1973, changes in the streambed cross sections were measured using three 150-m sections of Stequaleho Creek (ST-4, ST-5,

Table 2. Mean and 95% confidence interval for percentage of fine material in landslide-unaffected (control) and landslide-affected Stequaleho Creek and the landslide-affected Clearwater River spawning gravels, 1972, 1973, and 1974

		Percentage fine material passing a 0.850-mm Tyler sieve				
		1972		1973		1974
Location	N	$\bar{X}$ (95% con)	N	$\bar{X}$ (95% con)	N	$\bar{X}$ (95% con)
Control						
ST-2-A	8	7.223 (±1.828)	9	6.073 (± 1.822)	8	7.388 (± 2.049)
ST-2-B	8	7.111 (±1.823)	8	10.220 (± 2.253)	7	10.399 (± 3.339)
ST-2-C	7	8.795 (±2.953)	5	6.523 (± 3.066)	8	11.163 (± 6.661)
ST-3-A	6	7.309 (±1.224)	8	8.250 (± 2.317)	-	- *
SO-1-A	15	8.238 (±0.920)	6	6.568 (± 3.224)	2	6.400 (±33.017)
Cl-1-A	8	7.612 (±2.205)	2	8.165 (±25.315)	6	10.085 (± 2.357)
$\bar{X}$ =		7.780 (±0.605)		7.494 (± 0.997)		9.500 (± 1.757)
Experimental (Stequaleho)						
ST-3-B	8	6.715 (±3.021)	9	21.197 (±14.980)	8	17.621 (± 9.246)
ST-4	9	10.972 (±2.712)	5	10.297 (± 3.683)	8	7.992 (± 4.228)
ST-5	11	11.357 (±2.471)	11	8.210 (± 2.122)	8	10.081 (± 1.897)
ST-6	12	10.462 (±1.469)	11	11.433 (± 2.095)	5	8.886 (± 4.377)
$\bar{X}$ =		10.913 (±1.112)		9.910 (± 1.324)		9.001 (± 1.716)
Experimental (Clearwater)						
Cl-4	10	9.537 (±0.782)	11	7.244 (± 1.602)	10	10.359 (± 1.759)
Cl-5	17	8.431 (±1.675)	17	7.333 (± 1.451)	12	9.004 (± 1.080)
Cl-6	8	10.455 (±2.460)	16	12.649 (± 3.863)	11	6.322 (± 2.847)
$\bar{X}$ =		9.210 (±0.958)		9.244 (± 1.652)		8.687 (± 1.140)

*These samples were destroyed by vandals.

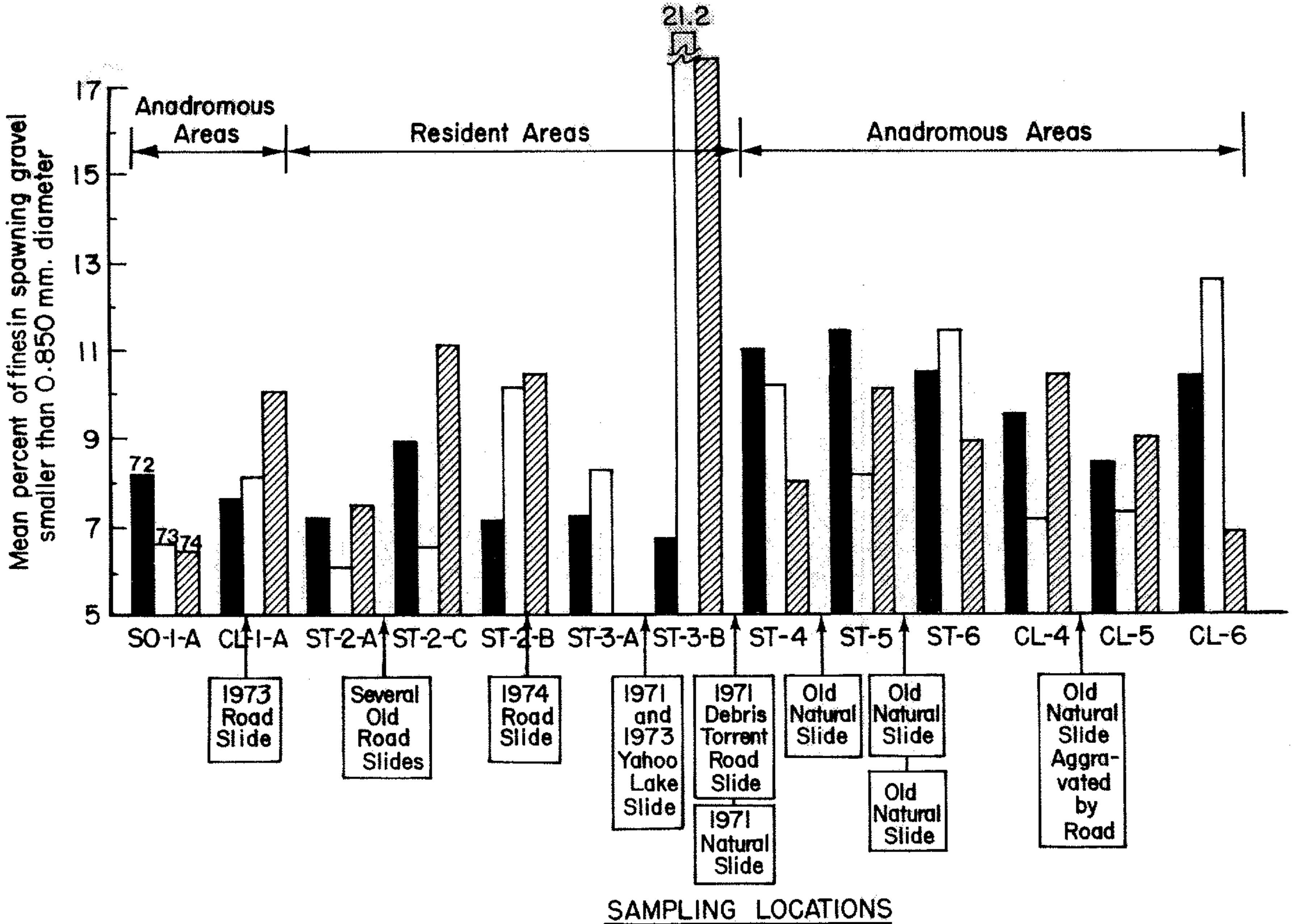

Fig. 6. Mean percent of fines (<0.850mm dia.) in landslide affected and unaffected spawning gravels of Stequaleho Creek and the Clearwater River. Also shown are significant sized natural and logging road caused land slides. (1972, 73, 74)

ST-6). Station ST-4 had a net change in the streambed of -18 m^3 and station ST-5 had a net change in the streambed of -330 m^3. This latter degree of change is quite high in the scour category, while station ST-6 had a net change in the streambed of +365 m^3. There is a considerable fill with some deposition as deep as 2 m.

During the winter of 1974-1975, comparisons in streambed cross sections were made among the lower 1.7 km of Stequaleho Creek and Hurst, Shale, and Christmas Creeks (Table 3). The surveys were made in the fall, winter, and spring. The cross-sectional survey stations were established 167 m apart, and the results were expressed as cross-sectional area changes.

The most drastic changes in the streambed and embankments occurred during the first half of winter (September 1974 to February 1975) when Stequaleho Creek had an average streambed scour rate of -1.53 m^2/section; Hurst Creek, -2.07; Shale Creek, -1.32; and Christmas Creek, -0.85. Stequaleho Creek had an average streambank erosion rate of -0.25 m^2/section; Hurst Creek, -0.08; Shale Creek, -0.05; and Christmas Creek, -0.24. Stequaleho Creek had an average streambed fill rate of +0.33 m^2/section; Hurst Creek, +0.52; Shale Creek, +0.48; and Christmas Creek, +0.29.

During the second half of winter (February to June 1975), Stequaleho Creek had an average streambed scour rate of -0.63 m^2/section; Hurst Creek, -0.23; Shale Creek, -0.31; and Christmas Creek, -0.53. Stequaleho Creek had an average streambank erosion rate of -0.03 m^2/section; Hurst Creek, -0.05; Shale Creek, -0.06; and Christmas Creek, -0.11. Stequaleho Creek had an average streambed fill rate of +1.56 m^2/section; Hurst Creek, +1.04; Shale Creek, +0.66; and Christmas Creek, +0.46.

For the entire winter, Hurst Creek showed the greatest average rate of streambed scour, -2.31 m^2/section, with Stequaleho Creek a close second, -2.16. Christmas Creek showed the greatest average rate of streambank erosion, -0.35 m^2/section, with Stequaleho Creek a close second, -0.28. Stequaleho Creek showed the greatest rate of streambed fill, +1.89 m^2/section, with Hurst Creek a close second, +1.56.

Suspended Sediment Concentrations

These data are reported in Wooldridge, D. D., A. G. Larson, and A. R. Wald. 1975. Hydrologic Data Summary Clearwater River Basin Water Year 1973-1974. O.W.R.T. Project Number A-059-WASH.

Benthic Fauna Abundance

Stequaleho Creek (1972, 1973, and 1974)

In all 3 years, including four samplings (two in 1972), the mean number of benthic fauna per 1000 cm^2 (ft^2) of substrate in the landslide-affected zone was found to be significantly (5% level) lower than the

Table 3. Mean changes in the streambed cross-sectional area in the lower reaches of Stequaleho, Hurst, Shale, and Christmas Creeks, 1974-1975

Tributary	Date	Streambed scour (-) (m^2/section)	Streambank erosion (-) (m^2/section)	Streambed fill (+) (m^2/section)
Stequaleho Creek	9/74-2/75	1.53	0.25	0.33
	2/75-6/75	0.63	0.03	1.56
	9/74-6/75	2.16	0.28	1.89
Hurst Creek	9/74-2/75	2.07	0.08	0.52
	2/75-6/75	0.24	0.05	1.04
	9/74-6/75	2.31	0.13	1.56
Shale Creek	9/74-2/75	1.32	0.05	0.48
	2/75-6/75	0.31	0.06	0.66
	9/74-6/75	1.63	0.11	1.14
Christmas Creek	9/74-2/75	0.85	0.24	0.29
	2/75-6/75	0.53	0.11	0.46
	9/74-6/75	1.38	0.35	0.75

landslide-unaffected control (Tables 4a and b). During the first sampling period of 1972 (June), the mean number of individuals was 159 in the control compared to 54 in the landslide-affected zone, a 68% reduction. During the second sampling period of 1972 (July and August), the mean number of individuals was 125 in the control compared to 52 in the landslide-affected zone, a 58% reduction. In 1973 (July), the mean number of individuals was 104 in the control compared to 53 in the landslide-affected zone, a 49% reduction. In 1974 (July and August), the mean number of individuals was 168 in the control compared to 100 in the landslide-affected zone, a 41% reduction (Fig. 7). Some evidence of recovery of benthic fauna is evident in the 1974 data, four summers following the initial landslides. Reductions in benthic fauna abundance for 1972 and 1973 were found to be evenly distributed through all major taxonomic groups.

Clearwater River (1972, 1973, and 1974)

In all 3 years, including four sampling periods (two in 1972), there was no significant (5% level) difference between the abundance of benthic fauna in landslide-affected and -unaffected areas of the Clearwater River (Table 5). During the first sampling period of 1972 (June), the mean number of individuals was 94 in the control compared to 76 in the landslide-affected zone, a 19% reduction. During the second sampling period of 1972 (July and August), the mean number of individuals was 75 in the control compared to 84 in the landslide-affected zone, an increase of 12%. During the 1973 sampling period (July), the mean number of individuals was 100 in the control compared to 127 in the landslide-affected zone, an increase of 27%. During the 1974 sampling period (August), the mean number of individuals was 179 in the control (only one location sampled) compared to 105 in the landslide-affected zone.

Juvenile Fish Populations

Coho Salmon (1972, 1973, and 1974)

During the summer low-flow period in 1972, the mean standing stock (biomass) of coho salmon in the anadromous area of Stequaleho Creek was 0.302 g/m^2 (range = 0.146 to 0.481) (Table 6).

During the summer low-flow period of 1973, the mean standing stock of coho salmon was 0.054 g/m^2 (range = 0.044 to 0.064) in Stequaleho Creek (Table 6) and 0.716 g/m^2 (range = 0.000 to 1.280) in seven other Clearwater River tributaries (Table 7).

During the summer low-flow period of 1974, the mean standing stock of coho salmon was 0.062 g/m^2 (range = 0.046 to 0.078) in Stequaleho Creek (Table 6) and 0.899 g/m^2 (range = 0.169 to 2.748) in the other seven tributaries (Table 7).

Table 4a. Stequaleho Creek--abundance of benthic fauna in the landslide-unaffected (control) areas, 1972-1974

	ST-2-A				ST-2-B				ST-2-C				ST-3-A			
	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974
No. of samples	6	6	6	4	--	--	6	--	6	5	6	4	6	6	6	4
Coleoptera	135	233	96		--	--	67	--	52	111	73		228	394	118	
Diptera	130	63	49		--	--	38	--	215	168	27		54	30	23	
Ephemeroptera	466	274	424		--	--	310	--	446	212	333		509	402	489	
Oligochaeta	6	2	3		--	--	2	--	0	0	0		1	3	1	
Plecoptera	139	64	77		--	--	86	--	92	18	67		135	21	63	
Tricoptera	64	16	6		--	--	6	--	40	7	7		55	23	22	
Others + unidentified	17	61	24		--	--	34	--	49	28	34		16	9	12	
	957	713	679	611	--	--	543	--	900	544	541	716	998	882	728	693
$\bar{x}$ No./ft^2	160	119	113	153			91		150	109	90	179	166	147	121	173

Table 4b. Stequaleho Creek--abundance of benthic fauna in the landslide-affected (experimental) areas, 1972-1974

	ST-3-B				ST-4				ST-5				ST-6			
	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974	June 1972	July-August 1972	July 1973	July-August 1974
No. of samples	6	6	6	4	6	6	7	6	--	--	6	--	6	6	6	6
Coleoptera	80	172	46		23	43	37		--	--	50	--	28	18	33	
Diptera	52	56	25		37	4	25		--	--	7	--	17	13	20	
Ephemeroptera	256	271	366		175	113	188		--	--	106	--	92	138	224	
Oligochaeta	1	0	3		2	0	0		--	--	0	--	2	0	0	
Plecoptera	60	30	23		17	10	21		--	--	6	--	17	5	16	
Tricoptera	32	19	19		16	12	21		--	--	6	--	49	19	4	
Others + unidentified	7	5	19		14	2	9		--	--	3	--	4	0	21	
Total	488	553	501	639	282	184	301	441	--	--	178	--	209	194	318	397
$\bar{x}$ No./ft^2	81	92	84	160	47	31	43	74			30		35	32	53	66

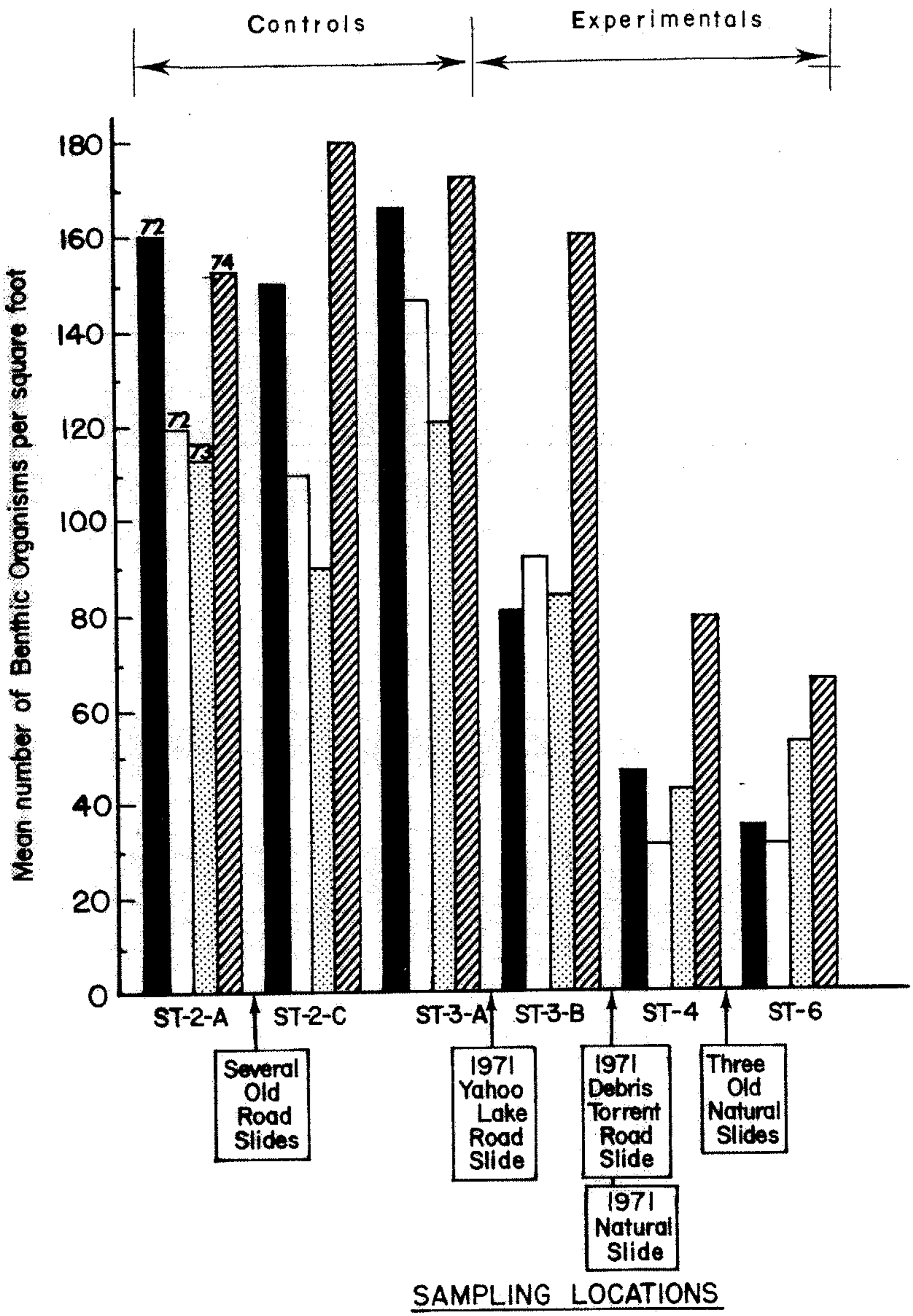

Fig. 7. Mean number of Benthic Organisms per square foot in landslide affected and unaffected areas of Stequaleho Creek, 1972-1974.

Table 5. Clearwater River--abundance of benthic fauna above and below the mouth of Stequaleho Creek, 1972-1974

	Landslide-unaffected											
	Cl-1				Cl-2				Cl-3			
	July 1972	July-August 1972	July 1973	August 1974	June 1972	July-August 1972	July 1973	August 1974	July 1972	July-August 1972	July 1973	August 1974
No. of samples			4		9	8	6		9	8		4
Coleoptera			116		276	138	54		156	151		
Diptera			55		114	36	48		54	17		
Ephemeroptera			342		506	480	198		128	234		
Oligochaeta			2		13	1	2		0	15		
Plecoptera			32		53	45	16		61	30		
Tricoptera			14		89	27	29		185	11		
Others + unidentified			9		27	5	3		15	5		
Total			570		1080	732	350		600	462		717
$\bar{x}$ No./ft^2			143		120	91	58		67	58		179

	Landslide-affected											
	Cl-4				Cl-5				Cl-6			
	July 1972	July-August 1972	July 1973	August 1974	June 1972	July-August 1972	July 1973	August 1974	July 1972	July-August 1972	July 1973	August 1974
No. of samples	8	9	9	6	9	9	10	8			10	
Coleoptera	141	217	97		33	75	139				57	
Diptera	35	25	448		129	329	592				209	
Ephemeroptera	195	352	498		250	384	575				319	
Oligochaeta	16	6	10		0	0	12				0	
Plecoptera	38	37	65		19	41	173				114	
Tricoptera	208	30	81		176	855	116				32	
Others + Unidentified	18	2	58		9	8	55				17	
Total	652	669	1257	709	617	855	1662	742			748	
$\bar{x}$ No./ft^2	82	74	140	118	69	95	166	93			75	

Table 6. Stequaleho Creek--summer low-flow estimates of standing stocks (means) of coho salmon, trout, and total teleosts, 1972-1974 (95% confidence intervals for 1973 and 1974 are available in Edie 1975)

		Habitat parameters			Relative biomass g/m^2*			
Location	Year	Section length (m)	Total area (m^2)	Pool area (m^2)	Coho	Age 0 trout	Age 1 trout	Total** Teleosts
Upper Stequaleho Creek	1972	142.1	1129.6	391.3	0.481			6.47
Middle Stequaleho Creek	1972	137.8	865.4	395.5	0.269	0.578	0.855	10.58
	1973	61.0	362.6	71.0	0.044	1.646	1.206	12.78
	1974	64.0	456.7	149.3	0.046	0.982	1.287	8.79
Lower Stequaleho Creek	1972	144.5	1403.8	517.6	0.146	0.402	0.598	7.13
	1973	70.1	611.3	267.1	0.064	0.420	0.266	5.22
	1974	69.8	682.7	278.5	0.078	0.490	1.101	6.54

*Relative biomass is expressed as the absolute biomass of a species per total water surface area in the study section.
**Including dace and sculpins
( ) = Age 0 and Age 1 trout are combined.

Table 7. Mean standing stock estimates of coho salmon, trout, and total teleosts in seven Clearwater River tributaries 1973 and 1974 (95% confidence intervals on all estimates are available in Edie 1975)

		Study section parameters					Relative biomass g/m²*			
Location	Year	Flow 7/30-31/74 (m^3/sec)	Streambed gradient (%)	Length (m)	Total area (m^2)	Pool area (m^2)	Coho	Age 0 trout	Age 1+ trout	Total teleosts**
Lower Hurst Creek	1973	-	1.7	67.4	233.6	128.9	0.902	0.000	0.542	9.40
	1974	0.161		64.6	359.0	89.6	0.518	0.010	0.394	9.12
Upper Hurst Creek	1973	-	1.9	86.0	271.1	98.0	1.009	0.007	0.000	7.32
	1974	0.065		85.0	320.8	56.5	0.553	0.019	0.040	4.83
Lower Christmas Creek	1973	-	2.0	76.2	475.2	239.4	0.864	0.352	1.277	11.47
	1974	0.379		78.0	644.4	280.0	0.169	0.271	0.916	3.75
Middle Christmas Creek	1973	-	1.8	81.7	390.2	146.7	0.864	0.728	1.153	11.08
	1974	0.379		83.8	475.0	149.1	0.707	0.369	1.045	5.54
Upper Christmas Creek	1973	-	2.1	77.7	543.6	158.5	0.705	0.805	1.181	9.79
	1974	0.308		84.7	686.1	184.0	0.625	0.815	1.699	7.24
Lower Shale Creek	1973	-	1.4	61.0	329.1	127.2	0.435	0.225	1.137	11.25
	1974	0.221		61.3	350.6	177.3	0.968	0.061	0.780	9.16
Middle Shale Creek	1973	-	1.6	86.9	349.5	98.6	0.976	0.252	0.799	8.12
	1974	0.122		87.5	324.7	140.1	0.589	0.074	1.074	9.88
Upper Shale Creek	1973	-	1.5	91.4	347.2	149.3	0.533	0.473	1.049	7.77
	1974	0.102		-	-	-	-	-	-	-
Bull Creek	1973	-	1.6	79.2	194.2	89.4	1.228	0.063	1.108	9.44
	1974	0.108		75.6	231.4	135.9	0.891	0.000	1.458	9.80
Lower E. F. Miller Cr.	1973	-	1.8	63.4	332.2	75.1	0.000	0.000	0.000	4.10
	1974	0.277		63.4	463.8	154.1	0.047	0.091	0.000	4.33
W. F. Snahapish Creek	1973	-	2.4	65.5	153.5	90.0	1.280	0.483	3.704	9.66
	1974	0.142		64.3	197.5	127.2	2.748	0.429	1.605	15.84
Middle Solleks River	1973	-	2.5	61.0	457.9	145.8	0.510	1.500	1.293	7.96
	1974	0.773		57.6	509.1	91.8	1.413	0.992	0.911	9.04
Upper Solleks River	1973	-	2.3	56.4	287.6	87.7	0.000	2.713	1.042	8.98
	1974	0.442		58.2	385.0	182.0	0.709	1.784	0.980	8.16
Mean	1973						0.716	0.585	1.099	8.95
	1974						0.899	0.438	0.991	8.40

*Relative biomass is expressed as the absolute biomass of a species per total water surface area in the study section.

Age 0 Trout (1972, 1973, and 1974)

During the summer low-flow period of 1972, the mean standing stock of age 0 trout in the anadromous area of Stequaleho Creek was 0.490 g/m^2 (range = 0.402 to 0.578) (Table 6).

During the summer low-flow period of 1973, the mean standing stock of age 0 trout in the anadromous area of Stequaleho Creek was 1.033 g/m^2 (range = 0.420 to 1.646) (Table 6), and 0.585 g/m^2 (range = 0.000 to 2.713) in seven other Clearwater River tributaries (Table 7).

During the summer low-flow period of 1974, the mean standing stock of age 0 trout in the anadromous area of Stequaleho Creek was 0.736 g/m^2 (range = 0.490 to 0.982) (Table 6); and 0.438 g/m^2 (range = 0.000 to 1.784) in seven other Clearwater River tributaries (Table 7).

Age 1+ Trout (1972, 1973, and 1974)

During the summer low-flow period in 1972, the mean standing stock of age 1+ trout in the anadromous area of Stequaleho Creek was 0.726 g/m^2 (range = 0.598 to 0.855) (Table 6).

During the summer low-flow period in 1973, the mean standing stock of age 1+ trout in the anadromous area of Stequaleho Creek was 0.736 g/m^2 (range = 0.266 to 1.206) (Table 6), and 1.099 g/m^2 (range = 0.040 to 3.704) in seven other Clearwater tributaries (Table 7).

During the following year at summer low-flow, the mean standing stock in Stequaleho Creek was 1.194 g/m^2 (range = 1.101 to 1.287) (Table 6), and 0.991 g/m^2 (range = 0.040 to 1.699) in the other seven Clearwater tributaries (Table 7).

Total Teleosts (1972, 1973, and 1974)

This category includes all fish (coho, age 0 and age 1+ trout, sculpins, and dace) residing in the study sections, expressed in relative standing stock terms (biomass) at summer low-flow.

During summer low-flow in 1972, the mean biomass of all teleosts in the Stequaleho Creek anadromous area was 8.06 g/m^2 (range = 6.47 to 10.58) (Table 6).

During the same period in 1973, the mean biomass of teleosts for Stequaleho Creek was 9.00 g/m^2 (range = 5.22 to 12.78) (Table 6) compared to 8.95 g/m^2 (range = 4.10 to 11.47) in seven other Clearwater River tributaries (Table 7).

During low-flow in 1974, the mean standing stock (biomass) for Stequaleho Creek was 7.66 g/m^2 (range = 6.54 to 8.79) (Table 6), compared to 8.40 g/m^2 (range = 3.75 to 15.84) for the remaining seven tributaries (Table 7).

SUMMARY AND DISCUSSION OF RESULTS

Landslides

Since the original landslides of early spring 1971 occurred, the Yahoo Lake slide has reactivated once, and there have been two additional logging road-caused slides in upper Steqhaleho Creek. There have also been three large natural landslides reactivated in lower Stequaleho Creek, in addition to one natural slide that occurred in upper Stequaleho at the same time as the original Yahoo Lake and Debris Torrent slides.

Influence of the Yahoo Lake and Debris Torrent Landslides

The Yahoo Lake and Debris Torrent landslides probably had an influence on the coho, chinook, and steelhead populations of Stequaleho Creek, as well as the resident and searun cutthroat population below the landslide influence. These landslides also may have influenced the major mainstream chinook and steelhead populations spawning below Stequaleho Creek mouth. The influence of these landslides on Clearwater River total coho salmon habitat was probably minor due to their use of tributaries for spawning and rearing. These judgments are based on known effects under laboratory and test stream experiments extrapolated by measurements made in the field. No quantitative estimates were made as to losses.

Changes in Gravel Composition

For the second (1972) and third (1973) summers since the Yahoo Lake and Debris Torrent landslides, the mean percentages of fine material in the affected spawning gravels of Stequaleho Creek have been significantly higher in the percentage material < 0.850 mm diameter than the unaffected control areas. However, there was no significant difference in 1974.

The mean levels of fines in the spawning gravels in the Clearwater River below the mouth of the Stequaleho were also found to be significantly greater than the controls during the second (1972) and third summers (1973) after the slides but not during the fourth.

Spawning gravel compositions in Stequaleho Creek and the Clearwater River have shown significant signs of recovery since this study began in January 1972. Photographs by Deschamps (1971) show that heavy siltation must have existed the first summer following the landslides but heavy runoff and gravelbed movement during the winter of 1972-1973 (Cederholm and Lestelle 1974) brought about a major flushing. Additional recovery occurred in the second winter. Other tributaries of the Clearwater River have shown higher siltation levels in the spawning gravels than were measured in Stequaleho Creek (Fig. 8). The West Fork of Miller Creek, East Fork of Miller Creek, and Christmas Creek have high levels of siltation probably due to extensive logging and poor road construction.

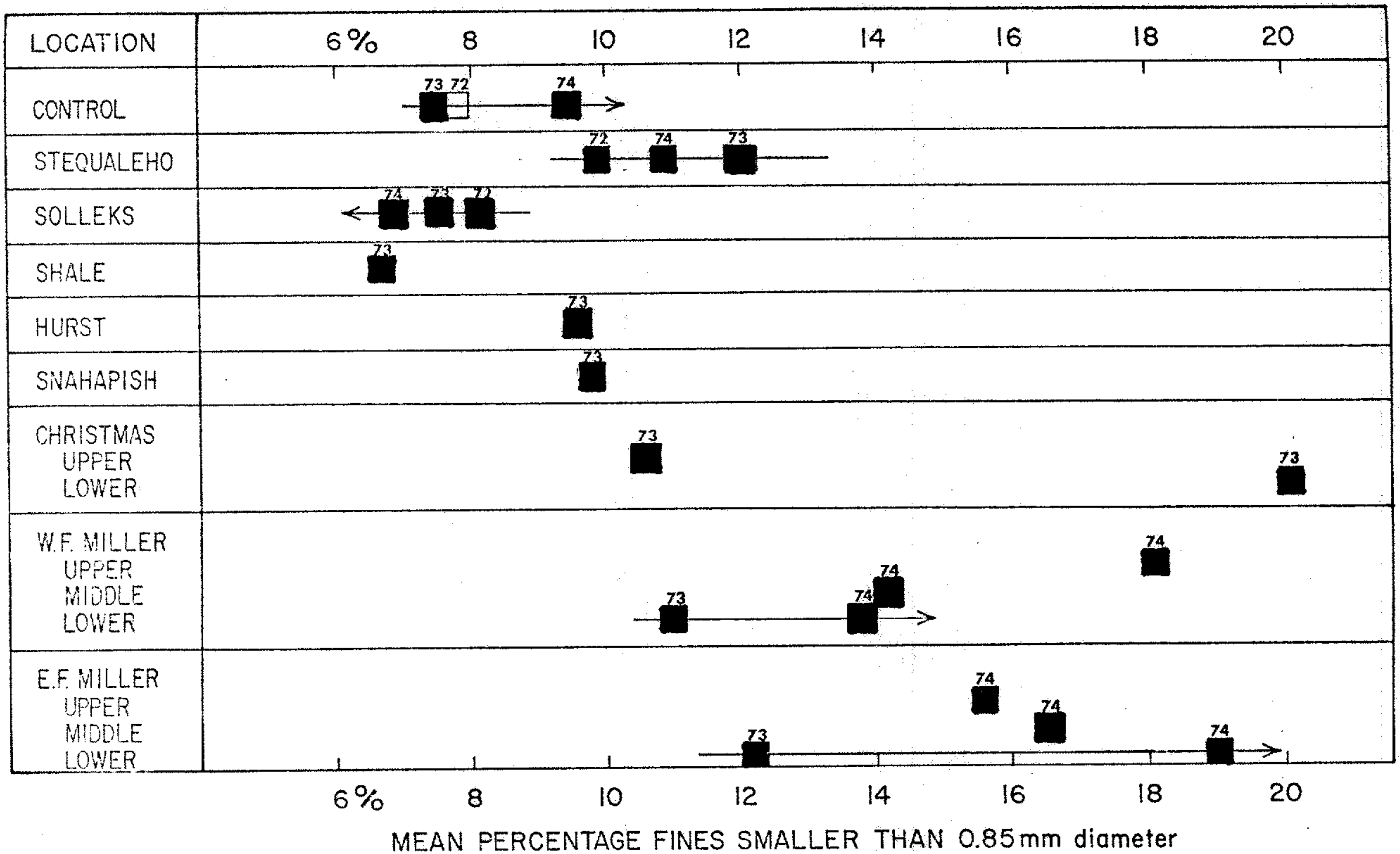

Fig. 8. Spawning gravel composition throughout the major tributaries of the Clearwater River, 1972-74.

Changes in the Cross Sections of Streambeds

During the winter of 1972-1973, there was noticeable instability in the streambed of lower Stequaleho Creek. Much of the sediment deposited (2 m deep) in lower Stequaleho Creek may have been washed down from the Yahoo Lake and Debris Torrent landslides.

During the winter of 1974-1975, Hurst Creek had the greatest streambed scour rate (2.31 m^2/section); Stequaleho Creek had the second greatest (2.16 m^2/section); Shale Creek had 1.63 m^2/section; and Christmas Creek had 1.38 m^2/section. Christmas Creek had the greatest streambank erosion rate (0.35 m^2/section); Stequaleho Creek had the second greatest streambank erosion rate (0.28 m^2/section); Hurst Creek had 0.13 m^2/section; and Shale Creek had 0.11 m^2/section. Stequaleho Creek had the greatest streambed fill rate (1.89 m^2/section); Hurst Creek had the second greatest streambed fill rate (1.56 m^2/section); Shale Creek had 1.14 m^2/section, and Christmas Creek had 0.75 m^2/section. All four of these streams have been influenced by logging to some degree.

Changes in Benthic Fauna

For the second (1972), third (1973), and fourth (1974) summers since the Yahoo Lake and Debris Torrent landslides the abundance of benthic fauna in the affected areas of Stequaleho Creek have been significantly lower than the unaffected control areas. Also, the effect seems to be uniform on all major taxonomic groups.

Benthos abundance in Stequaleho Creek is showing some signs of recovery in the fourth summer following the landslides. There was no significant difference in benthos abundance in the Clearwater River above and below the mouth of Stequaleho Creek for the summers of 1972, 1973, and 1974.

The results of benthic fauna and spawning gravel investigations in Stequaleho Creek suggest that substrate fines have affected benthic fauna abundance. In the landslide-affected zone, the mean percentage of substrate fines (< 0.850 mm diameter) was significantly greater and the mean number of benthic fauna was significantly lower than in the landslide-unaffected zone. This apparent inverse relationship between substrate fines and benthic fauna is based on the assumption that spawning gravel conditions in the experimental stream sections were similar to those in the control section previous to the 1971 landslides.

Closer examination of the results indicates that benthic fauna abundance may not have been affected by the levels of substrate fines measured in Stequaleho Creek. The numbers of benthic fauna at Station ST-3b were not significantly lower than those at the control stations (ST-2a, 2c, 3a) in 1972, 1973 (Cederholm and Lestelle 1974, Cederholm et al. 1975), and 1974 (Fig. 7). Yet, the level of substrate fines at Station ST-3b was the highest among all stations measured in 1973 and 1974 (Fig. 6).

This analysis contradicts the tendency that substrate fines have reduced benthic fauna populations at Station ST-3b and suggests the same may be true for Stations ST-4 and ST-5.

Correlation analysis between benthic fauna abundance and substrate fines were performed on the 1972 and 1973 results (Cederholm and Lestelle 1974 and Cederholm et al. 1975). The correlation was significant for the 1972 data but no significant correlation was statistically demonstrated between benthic fauna and substrate fines in 1973. The inconsistent results from this analysis leads us to believe that no significant correlation exists between benthic fauna and substrate fines in Stequaleho Creek, or recovery is underway.

Benthic Fauna Abundance and Geomorphology in Stequaleho Creek

The significantly low benthic fauna population at Station ST-4 and ST-6 may be a result of the unstable streambed in Stequaleho Creek. Station ST-6 was more unstable than Stations ST-4 and ST-5 (Cederholm and Lestelle 1974). However, Stequaleho Creek showed the greatest rate of streambed fill and the second greatest rate of streambed scour (Table 3) when compared to other tributaries in the Clearwater system. The dynamic nature of the streambed in Lower Stequaleho Creek definitely must affect the abundance of benthic fauna. This, in our opinion, is the primary reason for low benthic fauna populations at Stations ST-4 and ST-6.

The final question we must address is: "Did the 1971 landslides alter the streambed in Lower Stequaleho Creek, thus causing a significant reduction in benthic fauna population." The landslides from natural causes (Fig. 3) in Lower Stequaleho Creek suggest that this area is historically unstable. Thus, the road-caused landslides may have contributed changes to an already disturbed environment poorly suited for benthic fauna. Therefore, we cannot give a precise answer to the question.

Juvenile Fish Population Changes

During the second (1972), third (1973), and fourth (1974) summers after the Yahoo Lake and Debris Torrent landslides, the mean relative biomass of coho salmon in the affected area of Stequaleho Creek has been significantly (5% level) lower than the mean of the 1973 and 1974 populations in several other Clearwater tributaries. There has, however, been no difference in the trout (cutthroat and steelhead) or total teleost mean biomasses for any of these years.

A variety of fish species utilize the anadromous areas of Stequaleho Creek. In this discussion they are sorted into three groups. The coho salmon and steelhead trout populations are each discussed individually; the third group combines all of the teleost species (salmon, trout, sculpins and dace) found in the stream.

Unfortunately, little or no information is available about the fish resources in Stequaleho Creek, until after the landslides had occurred. This discussion is therefore limited to comparing the Stequaleho stocks with those in other streams. Stream-to-stream comparisons are a reasonable alternative to before and after studies; however, care must be taken to insure that the streams offer similar environments to the fish.

Stequaleho Creek supports only a small population of coho salmon and there are several possible explanations for the scarcity of coho salmon. One possibility is that the stream has never been very productive for coho. In its anadromous zone Stequaleho Creek is a much larger stream than coho prefer, and good rearing habitat is not abundant. The species has a patchy distribution within the anadromous zone, because the salmon are collected into the areas with suitable habitat.

The Clearwater basin seems to have too low an escapement of adult spawners to fully utilize the coho rearing potential of the tributaries (Edie 1975). The small number of rearing coho juveniles in Stequaleho Creek may be a result of this basin-wide problem.

Finally, the landslide could also have caused problems for the coho salmon, although this seems to be a less likely possibility. The other fish species in the stream are present in reasonably good numbers, and it is doubtful that the impact of the slides would fall only on the coho.

Just one species of trout (steelhead trout) was found in the anadromous zone of Stequaleho Creek, although cutthroat trout are present in its headwaters. This makes it difficult to compare the Stequaleho trout populations to those in most other Clearwater tributaries. The only other stations in the basin that had pure steelhead trout populations were those in the Solleks River.

The data from the Stequaleho and Solleks stations are compared in Table 8. The average density and relative biomass estimates are consistently higher for the Solleks River than they are for Stequaleho Creek. The differences between the two streams are greater with the young-of-the-year trout, than they are with the yearling and older trout.

Although Stequaleho Creek seems to support fewer steelhead trout than the Solleks River, the differences probably are due to causes other than the landslides. Our data does show, however, that steelhead trout are reasonably abundant in Stequaleho, which is a striking contrast to the small populations of coho salmon in the creek.

The teleost species in Stequaleho Creek are dominated by the sculpin species. The Torrent sculpin (*Cottus rhotheus*) and the prickly sculpin (*Cottus asper*) are very abundant, and small numbers of the Coastrange sculpin (*C. aleuticus*) are also found in the stream.

Table 8. Estimates of the mean density and relative biomass of steelhead trout in Solleks River and Stequaleho Creek for 1973 and 1974

Stream*	Young-of-the-year		Yearling and older	
	Fish/m^2	g/m^2	Fish/m^2	g/m^2
Solleks River	0.946	1.747	0.046	1.056
Stequaleho Creek	0.215	0.884	0.036	0.965

*Two stations were sampled on each stream.

Sculpins are characteristically a hardy group of fish and are tolerant of adverse conditions. Both because the sculpins are durable and because they represent a large fraction of the teleost biomass it is less likely that the teleost group would show any adverse effects of the landslides. It is not surprising then that the average relative biomass for the teleosts in Stequaleho Creek (8.33 g/m^2) differs only slightly from the basin-wide average (8.67 g/m^2).

ABSTRACTS OF MASTER OF SCIENCE THESES COMPLETED ON THE CLEARWATER RIVER EFFECTS OF LOGGING STUDY

A Census of the Juvenile Salmonids of the Clearwater River Basin, Jefferson County, Washington, in Relation to Logging

By Brian Gale Edie

During the summers of 1973 and 1974, the populations of juvenile salmonids and other teleosts were estimated at 20 sites in the Clearwater River basin. Additionally, various physical features of the study stations were measured, including: the relative discharge rate; the stream's gradient; the composition of the substrate; the basin area above the station; the percentage of the watershed logged; and the suspended sediment load carried past the station.

Most of the major tributaries of the Clearwater River were surveyed on foot during the course of the study to define the limits of penetration by the anadromous fishes. The fish-inhabited waters in the river basin were divided into three zones based on the utilization of particular areas by the various species. The Chinook zone is located in the main river, the Coho zone is found in the middle reaches of the tributaries, and the Cutthroat zone includes the headwaters of the river.

The age structure of each species was studied, but with the exception of the cutthroat trout, the fish were little different from salmonid and cottid populations studied elsewhere. The anadromous zone cutthroat were unusual because they lacked the 2, 3, and 4-year-old fish that have been reported by other authors.

Comparisons between the two years that samples were taken showed some significant differences in the growth of the fish. The cottids were much shorter in 1974, and the salmonids were more robust that year. The differences were attributed to the strikingly different weather that occurred between the two years.

The habitat preferences (pool, riffle, run) of five fish species were studied (*Oncorhynchus kisutch*, *Salmo gairdneri*, *S. clarki*, *Cottus asper*, and *C. rhotheus*). Each species was typed as either a pool or a riffle dweller, although all five overlapped the other habitat types. Coho salmon were found to be the most selective in their habitat utilization.

Relative biomass (g/m^2) seemed to give the best measure of the standing stock abundance. The natural range of relative biomass observed for each species was: coho salmon 0.000-2.748 g/m^2; young-of-the-year trout 0.000-2.713 g/m^2; yearling and older trout 0.000-3.704 g/m^2; and total teleosts 3.75-15.84 g/m^2.

Fry plants made in the Miller Creek Basin were able to substantially increase the standing stocks of coho salmon at two stations. Although the fry planting data is minimal, it is likely that the Clearwater tributaries are underseeded for coho salmon.

The relationship between fish abundance and various environmental influences was studied through correlation analysis. Factors easily influenced by logging were of particular interest. No correlations were found with coho salmon and Cottus asper, probably because of experimental design problems. The trout and C. rhotheus showed significant relationships with habitat area, stream gradient, and relative discharge. The species composition of the trout population was also correlated with the abundance of age-0 trout.

The most important correlation for land managers was the negative relationship between the fine sediment load in the substrate and the abundance of both young-of-the-year trout and C. rhotheus.

No conclusions could be made about the impact logging may have had on the ability of Clearwater River tributaries to support salmonids from fry emergence to late summer.

The Effects of Sediment and Organic Detritus on the Production of Benthic Macroinvertebrates in Four Tributary Streams of the Clearwater River, Washington

By Douglas John Martin

The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington, were investigated. Three streams receiving different logging intensities were compared to a stream unaffected by logging. Benthic fauna and substrate were collected monthly from September 1973 through September 1974 with a Neill cylinder. The fauna were identified and the substrate materials were partitioned into organic and inorganic particle categories. There were no significant ($P<0.05$) differences between benthic fauna standing crop in logging-affected and unaffected streams. Significant correlations between sediments, organic detritus and bottom fauna standing crop were present, but these correlations were not consistent for each study stream.

The quantities of detritus measured in the study streams ranged from 8.8 g/m^2 to 44.2 g/m^2. Bottom samples collected from deeper in the substrate indicated that the Neill cylinder sampled less than 50% of the total quantity of detritus. The quantity of detritus was inversely related to particle size and there was a significant ($P<0.05$) positive correlation between quantity of organic detritus and sediment, for particle sizes <0.250 mm.

The annual aquatic insect production in the four study streams, estimated by the Hynes and Coleman method, ranged from 11.6225 g/m^2 to 20.5764 g/m^2. The scraper trophic category contributed 29.8% to 51.4% of the total production; the predators contributed 18% to 29.2% of the production, and the remaining production was contributed by shredders, collectors and chironomids. The production estimates were underestimated by four to eight times based on back calculations from fish production.

The Survival From Egg Deposition To Emergence of Coho Salmon in the Clearwater River, Jefferson County, Washington

By Jack V. Tagart

Survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence was measured over two spawning seasons 1973-74 and 1974-75. Nineteen redds were trapped in eight tributaries of the Clearwater River, Washington.

Female coho were observed attending a redd and egg deposition was estimated from the length of those fish. A length-fecundity relationship was developed from a stock of coho returning to the Washington State Department of Fisheries Soleduck River Salmon Hatchery. Redds were trapped with a cap of nylon net and survival was calculated from the ratio of the estimated egg deposition to total emergents.

The intragravel incubation environment was characterized by measuring gravel composition, permeability, and dissolved oxygen. Emergent fry were weighed and measured, and length of the emergence period was recorded. These variables were analyzed using correlation analysis to detect the possible inputs of logging.

The composition of spawning gravels was heterogeneous in space and stable over time. Percentage of gravel <0.850 mm was defined as "poor gravel", while the percentage of gravel <26.9 mm and >3.35 mm was defined as "good gravel." Mean intragravel permeability ranged from 319 cm/hr to 4,440 cm/hr. Mean intragravel dissolved oxygen ranged from 8.6 ppm to 11.8 ppm.

The length of the emergence period ranged from 21 to 70 days. Peak emergence occurred from 1 to 46 days after first emergence. Mean fry length ranged from 37.5 mm to 40.1 mm. Mean dry fry weight ranged from 0.064 g to 0.081 g.

Survival-to-emergence ranged from 0.9% to 77.3%. Mean survival was 30.7% in 1973-74, 15.3% in 1974-75, and 22.1% over both years. Survival was inversely correlated with poor gravel and permeability and positively correlated with good gravel. Correlations of survival with gravel were significant in 1973-74 but not in 1974-75. Permeability was measured only in 1974-75.

"Good gravel" was found to be due to its positive correlation with permeability. Poor gravel was inversely correlated with dissolved oxygen and fry size. Fry size was positively correlated with dissolved oxygen.

LITERATURE CITED

Alderdice, D. F., W. P. Wickett, and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15:229-250.

Allee, B. J. 1974. Spatial requirements and behavioral interactions of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Ph.D. dissertation, Univ. Washington, Seattle. 160 pp.

Allen, K. R. 1959. The Horokiwi Streams: a study of a trout population. Fish. Bull. New Zealand, 10:1-238.

American Geophysical Union. 1947. Report of the subcommittee on sediment terminology. Transactions 28(6):936-938.

Bachman, R. W. 1959. The ecology of four North Idaho trout streams with reference to the influence of forest road construction. M.S. thesis, Univ. Idaho. 97 pp.

Bjornn, T. C. 1968. Survival and emergence of trout and salmon in various gravel-sand mixtures. Pages 80-88 *in* Proceedings of a Forum on the Relation Between Logging and Salmon. Amer. Inst. Fish. Res. Board and Alaska Dep. Fish Game, Juneau.

Brown, G. W., and J. T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resour. Res. 7(5): 1189-1198.

Burns, J. W. 1972. Some effects of logging and associated road construction on north California streams. Trans. Amer. Fish. Soc. 101(1):1-17.

Burroughs, E. R., Jr., G. R. Chalfant, and M. A. Townsend. 1973. Guide to reduce road failures in western Oregon. Bur. Land Mgmt. Rep. 111 pp.

Bustard, D. R. 1973. Some aspects of the winter ecology of juvenile salmonids with reference to possible habitat alteration by logging in Carnation Creek, Vancouver Island. M.S. thesis. Univ. British Columbia. 85 pp. (mimeo).

Cederholm, C. J. 1972. The short-term physical and biological effects of stream channelization at Big Beef Creek, Kitsap County, Washington. M.S. thesis, Univ. Washington, Seattle. 80 pp.

Cederholm, C. J., and L. C. Lestelle. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington, 1972-73. Univ. Washington, Fish. Res. Inst. Final Rep. FRI-UW-7404. 89 pp.

Cederholm, C. J., L. C. Lestelle, B. G. Edie, D. J. Martin, and J. V. Tagart. 1975. Observations on the effects of logging on salmon and trout resources of the Clearwater River, Jefferson County, Washington, 1973-74. Univ. Washington, Fis. Res. Inst. Annu. Rep. 55 pp.

Cederholm, C. J., W. J. Scarlett, and E. O. Salo. 1977. Salmonid spawning gravel composition data summary from the Clearwater River and its tributaries, Jefferson County, Washington, 1972-76. Univ. Washington, Fish. Res. Inst. Circ. 77-1. 135 pp.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. Pages 153-176 *in* T. G. Northcote, ed. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. Vancouver, B.C.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90(4):469-474.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. Int. Pac. Sal. Fish. Comm. Bull. 18. 71 pp.

Cordone, A. J., and D. W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish Game 47(2):189-228.

Cordone, A. J., and S. Pennoyer. 1960. Notes on silt pollution in the Truckee River drainage, Nevada and Placer Counties. Calif. Dep. Fish Game, Inland Fish. Admin. Rep. 60-14. 25 pp. (mimeo).

Deschamps, G. 1971. A report of siltation in Stequaleho Creek. Wash. Dep. Fish., Mgmt. Res. Div. 7 pp. (mimeo).

Edie, B. G. 1975. A census of juvenile salmonids of the Clearwater River Basin, Jefferson County, Washington, in relation to logging. M.S. thesis, Univ. Washington, Seattle. 86 pp.

Federal Water Pollution Control Administration. 1970. Industrial Waste Guide Logging Practices. 50 pp.

Fiksdal, A. J. 1974a. A landslide survey of the Stequaleho Creek watershed. Suppl. Rep. *in* Cederholm and Lestelle observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington. Univ. Washington, Fish. Res. Inst. Final Rep. FRI-UW-7404. 89 pp.

Fiksdal, A. J. 1974b. A landslide survey of the upper Clearwater and Solleks River areas, Jefferson County. Mimeo Rep. 6 pp.

Fredrickson, R. L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. USFS Res. Paper PNW For. & Range Exp. Sta. No. PNW 104.

Frost, W. E., and M. E. Brown. 1967. The Trout. Collins: The New Naturalist.

Gibbons, D. R., and E. O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S.D.A. For. Serv. Gen. Tech. Rep. PNW-10. 145 pp.

Hall, J. D., and R. L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. Pages 355-376 *in* T. G. Northcote, ed. Symposium on salmon and trout in streams, Univ. British Columia, Vancouver.

Hays, F. R., I. R. Wilmot, and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. J. Exp. Zool. 116(3):377-395.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*S. gairdneri*). J. Fish. Res. Board Can. 22:1035-1081.

Helmers, A. E. 1966. Some effects of log jams and flooding in a salmon spawning stream. U.S.D.A. For. Serv. Res. Note NOR-14, 4 pp. Northern For. Exp. Sta., Juneau, Alaska.

Hollis, E. H., J. G. Boone, C. R. Delose, and G. J. Murphy. 1964. A literature review of the effects of turbidity and siltation on aquatic life. Staff Rep., Dep. Chesapeake Bay Affairs, Annapolis, Md. 26 pp. (mimeo).

Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool Univ. Press. 202 pp.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press. Pp. 197-300.

Koski, K V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. M.S. thesis, Oregon State Univ., Corvallis. 84 pp.

Koski, K V. 1972. Effects of sediment on fish resources. Paper presented at the Wash. State Dep. Nat. Resour. Mgmt. Seminar, Lake Limerick, Washington. 36 pp.

Koski, K V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. dissertation, Univ. Washington, Seattle. 212 pp.

Larson, A. G., and H. J. Jacoby. 1976. Hydrologic Data Summary Clearwater River Basin Water Year 1974-75. 22 pp.

Martin, J. M. 1976. The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington. M.S. thesis, Univ. Washington, Seattle. 79 pp.

Meehan, W. R. 1974. The forest ecosystem of southeast Alaska. #3 Fish habitats. U.S.D.A. For. Serv. Gen. Tech. Rep. PNW-15. 41 pp.

Megahan, W. F., and W. J. Kidd. 1972. Effects of logging roads on sediment production rates in the Idaho batholith. U.S.D.A. For. Serv. Res. Paper. Int-123.

McNeil, W. J. 1966. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish Wildl. Serv., Fish. Bull. 65(2):495-523.

McNeil, W. J., and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish Wildl. Serv. Spec. Sci. Rep.--Fish. 469. 15 pp.

Moring, J. R. 1975a. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II - Changes in environmental conditions. Oregon Dep. Fish Wildl., Fish. Res. Rep. 9. 39 pp.

Moring, J. R. 1975b. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part III - Discussion and recommendations. Oregon Dep. Fish Wildl., Fish. Res. Rep. 9. 24 pp.

Moring, J. R., and R. L. Lantz. 1974. Immediate effects of logging on the freshwater environment of salmonids. Oregon Wildl. Comm., Res. Div. Proj. AFS-58, Final Rep. 101 pp.

Moring, J. R., and R. L. Lantz. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I - Biological studies. Oregon Dep. Fish Wildl., Fish Res. Rep. 9. 66 pp.

Neill, R. M. 1938. The food and feeding of the brown trout in relation to the organic environment. Trans. Roy. Soc. Edin. 59:481-520.

Nuttall, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biol. 2:181-186.

Phillips, R. W. 1965. Effect of fine materials on salmon and trout redds. Meeting on Erosion and Sedimentation. Water Supply and Water Pollution Control Subcommittee, Columbia River Inter-Agency Committee. Pp. 59-61.

Phillips, R. W. 1970. Effects of sediment on the gravel environment and fish production. Pages 64-74 *in* Proceedings of a Symposium on Forest Land Uses and Stream Environment, Oregon State Univ., Corvallis.

Ruggles, C. P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Canad. Fish. Cult. 38:35-53.

Shapley, P. S., and D. M. Bishop. 1965. Sedimentation in a salmon stream. J. Fish. Res. Board Can. 22(4):919-928.

Sheridan, W. L. 1962. Waterflow through a salmon spawning riffle in Southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep.--Fish. 407. 20 pp.

Shumway, D. L. 1960. The influence of water velocity on the development of salmonid embryos at low oxygen levels. M.S. thesis, Oregon State Univ., Corvallis. 50 pp.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State Univ. Press, Ames, Iowa. 115 pp.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. thesis, Univ. Washington, Seattle. 101 pp.

Tebo, L. B., Jr. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. The Progr. Fish-Cult. 17(2):66-70.

Thomas, J. D. 1964. Studies on the growth of trout, *Salmo trutta* L. from four contrasting habitats. Proc. Zool. Soc. Lond. 142:459-509.

U.S. Environmental Protection Agency. 1975. Logging roads and protection of water quality. Rep. Region X Water Div. 313 pp.

Usinger, R. L. 1971. Aquatic insects of California. Univ. California Press. 508 pp.

Vaux, W. A. 1962. Interchange of stream and intragravel water in a salmon spawning riffle. U.S. Fish Wildl. Serv., Spec. Sci. Rep.--Fish. 405. 11 pp.

Wald, A. R. 1975. The impact of truck traffic and road maintenance on suspended-sediment yield from a 14' standard forest road. M.S. thesis, Univ. Washington, Seattle. 38 pp.

Wallis, J. R., and H. W. Anderson. 1965. An application of multivariate analysis to sediment network design. Int. Assoc. Sci. Hydrol. Publ. 67:357-378.

Washington Forest Practice Board. 1976. Washington forest practice rules and regulations. Handbook.

White, H. O. 1942. Atlantic salmon redds and artificial spawning beds. J. Fish. Res. Board Can. 6(1):37-44.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11(6):933-953.

Wickett, W. P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15(5):1103-1126.

Wooldridge, D. D., A. G. Larson, and A. R. Wald. 1975. Hydrologic data summary Clearwater River Basin water year 1973-74. O.W.R.T. Project Number A-059-WASH, O.W.R.T. Agreement Number 14-31-0001-4048. July 1, 1972 to June 30, 1974. 58 pp.

Ziebell, C. D. 1960. Problems associated with spawning and growth of salmonids in northwest watersheds. Proc. Seventh Symp. on Water Pollution Res., U.S. Dep. Health, Education and Welfare, Portland, Oregon.