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THE EFFECTS OF LOGGING ROAD LANDSLIDE SILTATION ON THE SALMON AND TROUT SPAWNING GRAVELS OF STEQUALEHO CREEK AND THE CLEARWATER RIVER BASIN, JEFFERSON COUNTY, WASHINGTON, 1972-1978

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C. J. Cederholm
and
E. O. Salo

FINAL REPORT - PART III

This work was sponsored by the
Washington State Department of Natural Resources

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FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

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Approved
Robert L Burgner

CONTENTS

Page

INTRODUCTION 1

LITERATURE REVIEW 3

Recognition of the Problems Associated with Sedimentation 3
Effects of Fine Sediments on Fish Production 3
Fish Preemergent Life 3
Fish Postemergent Life 7

Effects of Fine Sediments Upon Benthic Organisms 9
Dependence of Salmonids on a Clean Substrate for Cover 10
Retention Time for Fine Sediments in Spawning Gravels 11

Summary 12

CLEARWATER RIVER RESEARCH OBJECTIVES 15

Specific Objectives 15

THE CLEARWATER RIVER BASIN 17

LOGGING OF THE CLEARWATER RIVER BASIN 19

Logging Roads 19

STEQUALEHO CREEK LANDSLIDE-AFFECTED AREA 22

STEQUALEHO CREEK LANDSLIDE STUDY RESEARCH PROCEDURE 24

METHODS 25

Spawning Gravel Composition 25
Coho Salmon Survival to Emergence Experiments 30
Adult Abundance 30
East Fork Miller Creek Coho Salmon Egg Survival Experiment 31

RESULTS 34

Spawning Gravel Composition Changes-- Control vs Stequaleho Creek (1972-1976) 34
Spawning Gravel Composition Changes-- Control vs Clearwater River (1972-1976) 34

Page

Sediment Accumulation in Spawning Gravels 37
Adult Spawner Utilization of Stequaleho Creek, Other Clearwater Tributaries, and the Mainstem Clearwater River, 1972-1978 42
Coho Salmon Fry Survival Experiments - 1975 42
1977 42
East Fork Miller Creek Experiment 46

SUMMARY 49

DISCUSSION AND CONCLUSIONS 52

LITERATURE CITED 54

APPENDICES 61

ABSTRACTS OF MASTER OF SCIENCE THESES COMPLETED ON THE CLEARWATER RIVER EFFECTS OF LOGGING STUDY 62

A Census of the Juvenile Salmonids of the Clearwater River Basin, Jefferson County, Washington, in Relation to Logging (by Brian Gale Edie) 63

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) 67

The Survival from Egg Deposition to Emergence of Coho Salmon in the Clearwater River, Jefferson County, Washington (by Jack V. Tagart) 70

Behavioral, Physiological and Lethal Effects of Suspended Sediment on Juvenile Salmonids (by Charles C. Noggle) 73

The Effects of Forest Debris Removal on a Population of Resident Cutthroat Trout in a Small Headwater Stream (by Lawrence Charles Lestelle) 75

APPENDIX TABLE I 77

LIST OF TABLES

Number		Page
1	Annual DNR numbers of sales, miles of logging roads, and acres of clearcut in the Clearwater River basin, 1960-1978	20
2	Descriptive data for twenty-one major study basins	28
3	Mean and 95% confidence intervals for percentage of fine material in landslide-unaffected (control) and landslide-affected Stequaleho Creek and the landslide-affected Clearwater River spawning gravels, 1972, 1973, 1974, 1975, and 1976	35
4	Salmonid spawning gravel composition at 44 sampling locations throughout the Clearwater and its tributaries and adjacent streams in the Olympic National Park, 1972-1978	39
5	Simple linear correlations between nine salmonid spawning gravel sieve categories and the degree of clearcut logging, miles of logging road per basin square mile, and percent of basin area in roads for 44 sampling locations throughout the Clearwater and its tributaries and adjacent streams in the Olympic National Park, 1972-1978	40
6	Annual peak redd counts (and miles surveyed) of steelhead, coho, and chinook in tributaries and the mainstem of the Clearwater River, 1972-1978	43
7	Coho salmon egg trough experiment on survival from green-egg deposition to emergence (1975)	44
8	Coho salmon egg trough experiment on survival from green-egg deposition to emergence (1977)	46
9-A	East Fork Miller Creek effects of logging road landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development (control sites)	47
9-B	East Fork Miller Creek effects of logging road landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development (affected sites)	47

LIST OF FIGURES

Number		Page
1	Location of Clearwater River	2
2	Composite of experimental inverse relationships between percentage fine sands in gravels and survival to emergence of salmonids	6
3	Relationship between the percentage of sand in the gravel and the rate of survival to emergence of chum salmon for the combined years of 1968 and 1969	8
4	General locations of experimental sampling sites in the Clearwater River, the Solleks River, and Stequaleho Creek	18
5	Sampling sites, logging roads, natural and man-caused landslides in the Stequaleho Creek drainage basin	23
6	Gravel sampling locations throughout the Clearwater River System	26
7	Location of control gravel sampling sites in tributaries of the Upper Hoh and Queets rivers in the Olympic National Park	27
8	The McNeil gravel sampler used to investigate gravel quality in the Clearwater River and its tributaries	29
9	East Fork Miller Creek showing the landslide and the control and landslide-affected incubation sites	32
10	Mean spawning gravel compositions for the Stequaleho Creek landslide study	36
11	Mean spawning gravel composition levels at three locations	38
12	Statistical relationship between percent of basin logged, miles of road per square mile of basin, percent of basin area in roads and the percent of fine material in the spawning gravels at the lower end of 44 basins . . .	41

Number Page

13 Coho salmon egg trough experiments on survival from green-egg deposition to emergence (1975) and (1977) 45

14 East Fork Miller Creek effects of landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development 48

THE EFFECTS OF LOGGING ROAD LANDSLIDE SILTATION ON THE SALMON AND TROUT SPAWNING GRAVELS OF STEQUALEHO CREEK AND THE CLEARWATER RIVER BASIN, JEFFERSON COUNTY, WASHINGTON
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ABSTRACT

The effects of logging road landslides on the sedimentation of salmonid spawning gravels in Clearwater River tributaries were studied for 6 years. Conclusions include: (1) certain steep gradient tributaries like Stequaleho Creek have the energy to flush sediments in relatively short periods of time; (2) other tributaries of lower stream power can retain sediments in spawning gravels for longer periods of time. The principal difference in the physical structure of these streams is related to gradient, discharge, and the amount of large organic debris deposited on the floodplain.

The levels of fine sediments (<0.850 mm) have increased from a mean of 8.36% (controls) to 10.69% (test) in Stequaleho Creek, and from 8.36% to 9.12% in the main Clearwater River below Stequaleho Creek. The salmonid intragravel survival to emergence decreased by about 11.60% in Stequaleho Creek and 3.80% in the main Clearwater River over the 6 year period of study.

Sediments less than 0.850 mm diameter were found to be accumulating basin-wide in spawning areas influenced by logging road sediments. This subtle buildup of intragravel sediments was positively correlated (1% level) with percent of sub-basin clearcut, miles of logging road per basin square mile, and percentage of basin area in roads.

Sediments less than 0.850 mm diameter were significantly (5% level) inversely correlated with the survival of coho salmon eggs in artificial streams. Also, coho salmon eggs in landslide affected gravels of East Fork Miller Creek survived only 40% as well to hatching and 9% as well to the button-up stage of development when compared to control groups.

Surveys over a 6-year period revealed a high degree of variation in abundance of salmon and steelhead redds among streams although the numbers in Stequaleho Creek were not significantly different than other Clearwater tributaries. This variation can partially be explained by annual differences in sport and commercial catches.

While logging road-caused landslides can have relatively short-term local impacts on spawning gravels in some tributaries as in Stequaleho Creek, the basin-wide accumulation of sediments is the primary concern.

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INTRODUCTION

Sedimentation, caused by logging roads, of rivers and streams draining the western coast of the Olympic Peninsula has raised concern for the fisheries resources of the area. During the early spring of 1971, two landslides precipitated 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 et al. 1975 and 1978; Edie 1975; Wooldridge et al. 1975; Wald 1975; Martin 1976; Tagart 1976; Larson and Jacoby 1976; Cederholm, Scarlett, and Salo 1977; Lestelle 1978; and Noggle 1978). Over the past 6 years, we have gathered information on the Stequaleho landslides 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 related to the effects of logging road sediments on spawning gravel sedimentation levels. Abstracts of five fisheries-related Master of Science degree theses completed on this project are appended.[1]

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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.

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; The Washington Forest Practice Board 1976; Iwamoto et al. 1978).

In this paper, the term sediment will be used in the sense 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 particles smaller than 0.85 mm in diameter for it is those sizes of inorganic sediments that have influences on fish and insect life.

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 the postemergent stages (Cordone and Kelley 1961; Hollis et al. 1964; McNeil 1966; Koski 1972; Gibbons and Salo 1973; Meehan 1974; and Myren 1976). 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 that 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 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%, but the mean survival ranged from 0.2% to 54%. He stated: ". . .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 (Fig. 2).

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 (Fig. 2).

Hausle (1973) studied the embryonic survival and emergence of brook trout (Salvelinus fontinalis) in the laboratory and in Lawrence Creek, Marquette County, Wisconsin. Sand in spawning gravel slowed emergence in a laboratory experiment in which brook trout alevins were buried in artificial redds and captured as they emerged. In another laboratory experiment in which eyed brook trout eggs were buried in artificial redds, dissolved oxygen concentrations of 0.5-7.1 ppm and sand in excess of about 20% in spawning gravel reduced the number of fry emerging (Fig. 2).

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

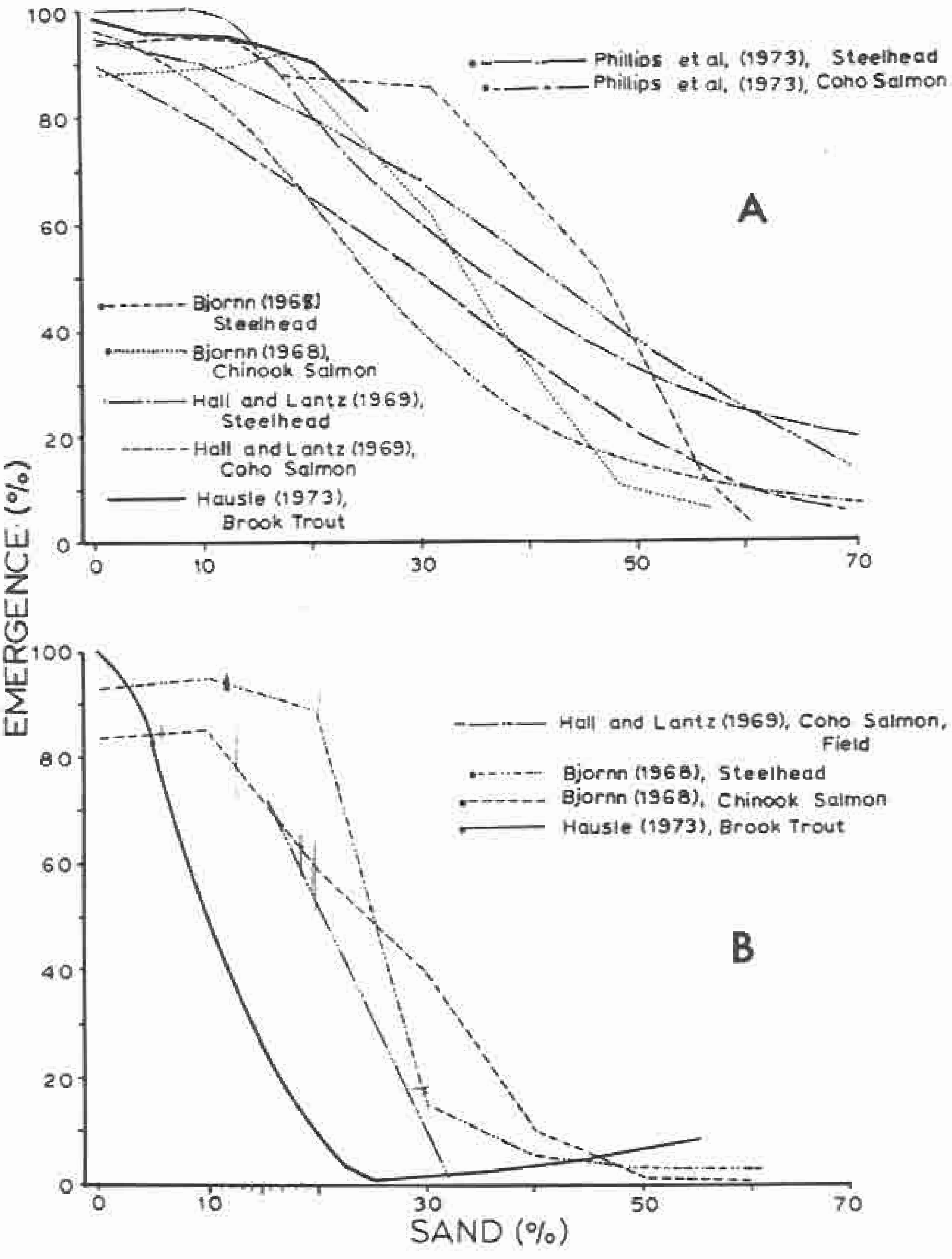

Fig. 2. Composite of experimental inverse relationships between percentage fine sands in gravels and survival to emergence of salmonids. A) Alevins put into artificial redds, B) eggs deposited in redds.

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, Washington 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 (Fig. 3). 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 postemergent life in freshwater, the "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 production to a clean and stable gravel substrate.

The rearing phase of salmonids includes two critical periods: 1) the summer low-flow period, and 2) the overwinter period. A clean substrate is an essential part of the habitat of fish-food organisms, and for juvenile salmonids which use it as shelter from predators and high streamflows.

According to Frost and Brown (1967) and Thomas (1964), a productive salmonid habitat must have 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.

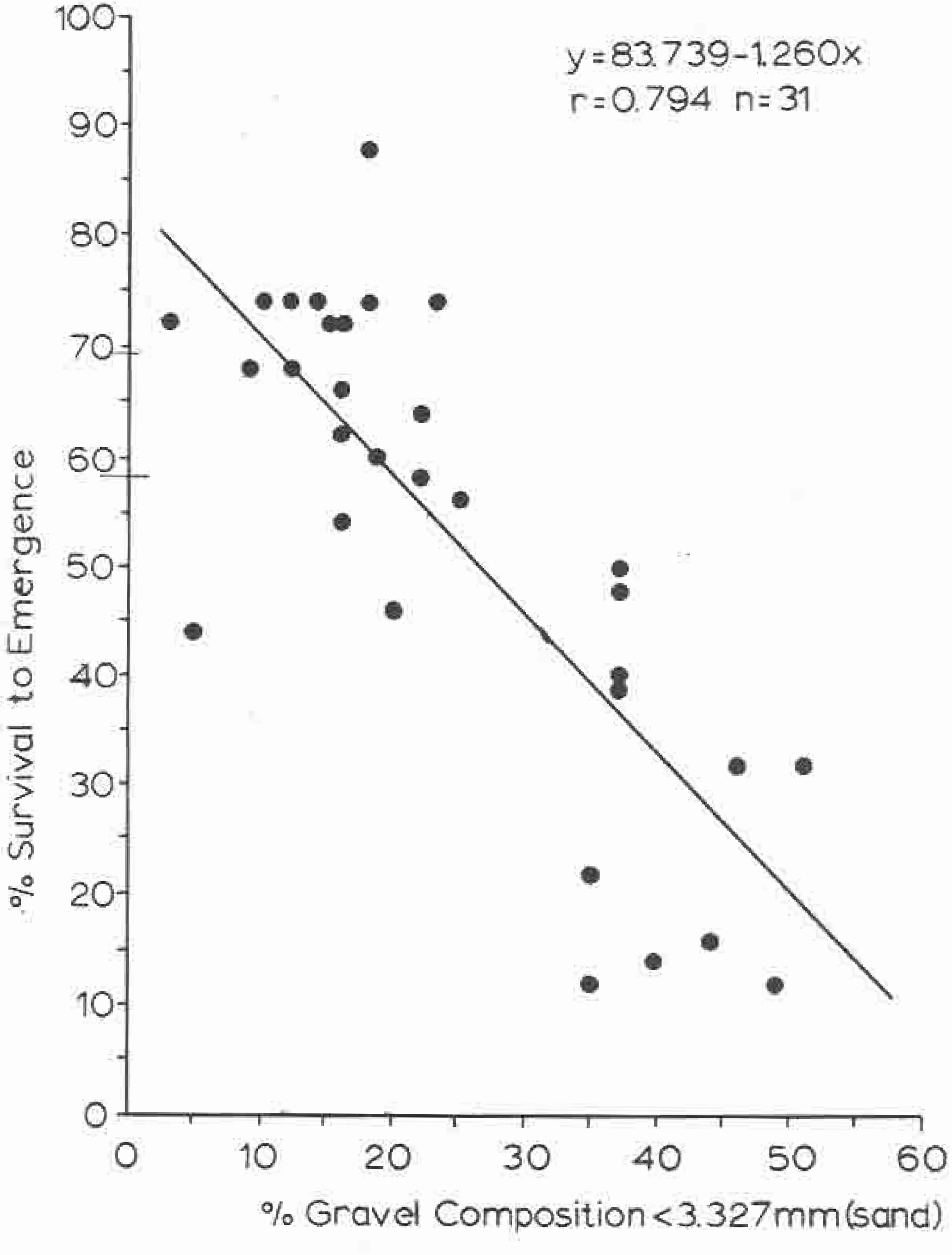

Fig. 3. Relationship between the percentage of sand (fines < 3.327 mm but ≤ 0.105 mm) in the gravel and the rate of survival to emergence of chum salmon for the combined years of 1968 and 1969 (adapted from Koski 1975).

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). Studies by Luedtke and Brusven (1976) in both natural and artificial streams have shown that some insects (heavy-cased caddisfly) recolonize stream areas by upstream, downstream, and cross-channel movements. Many other insect species in the mayfly and stonefly groups were observed to make similar migrations to colonize disturbed areas. Also, it was determined that upstream movements on sand were impeded by flows as low as 12 cm/s, except for the heavily-cased caddisfly *Discosmoecus* sp.

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 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.

Behaviorial observations by Allee (1974) on the seasonal distribution of coho and steelhead fry in Big Beef Creek noted 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 was 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 of 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 minimum 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. Peak streamflows increased significantly over pre-logging levels in Needle Branch; probably hastening recovery of that stream through the increased flushing action (Au 1972).

Platts and Megahan (1975) studied time trends in riverbed sediment composition in salmon and steelhead spawning areas of the South Fork Salmon River, Idaho. They found that riverbed surface conditions deleterious to fish spawning may result if soil disturbances from logging and road construction are allowed to progress without restriction on steep mountain lands in the Idaho Batholith. The percentage of fines in the four individual spawning areas studied ranged from 45 to over 80 percent in 1966. Presently, the size composition of bottom materials is at or near optimum levels in the individual spawning areas, where fines range from 12 to 26 percent (% < 6 mm diameter); these values should decrease even further in the future. These results show that streams similar to the S.F.S.R. can recover in time if sediment flows into the stream resulting from accelerated erosion on watershed lands are reduced to levels below the capacity of the stream to flush fines from the system.

Summary

Conclusions from the literature regarding the effects of stream substrate composition on salmonid habitat and survival are:

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 from heavy sedimentation can occur in most streams.

CLEARWATER RIVER RESEARCH OBJECTIVES

Specific Objectives

The objectives are to determine the influence of substrate siltation at the levels encountered in the landslide-affected areas of Stequaleho Creek and the Clearwater River on the fisheries resources of these two streams. The study was divided into three phases:

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 (Cederholm and Lestelle 1974; Cederholm et al. 1978);

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; Cederholm et al. 1978);

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).

Phase III (July 1975 to June 1977). In this period we:

A) continued the program of Phase I related to monitoring the spawning gravel composition of landslide-affected and unaffected areas of Stequaleho Creek and the Clearwater River, (reported here);

B) monitored the streambed stability in lower Stequaleho Creek and compared it to Hurst Creek, Christmas Creek, and Shale Creek, (will be reported under separate cover);

C) investigated the correlations between area clearcut, lineal miles of logging road, and area of logging road and composition of spawning gravels downstream, (reported here);

D) attempted to better judge the comparative impacts of ocean over-harvest and habitat changes due to logging on coho salmon stocks. We began studies into "The influence of the environment on the population dynamics of coho salmon." (Brian Edie, in preparation);

E) carried out studies into the "Behavioral, physiological, and lethal effects of suspended sediment on juvenile salmonids (Charles Noggle 1978);

F) carried out two laboratory experiments that tested the effects of gravel compositions of various siltation levels on survival of coho salmon to emergence, (reported here);

G) continued to monitor the escapement of winterrun steelhead, chinook salmon, and coho salmon in the Clearwater River and its tributaries, (reported here).

H) carried out a coho salmon egg incubation experiment in landslide-affected and unaffected areas of West Branch of East Fork of Miller Creek, (reported here).

THE CLEARWATER RIVER BASIN

The Clearwater River is the largest of four major tributaries of the Queets River, with a watershed area of approximately 145 mi^2. The Clearwater enters the Queets River about 10 km above its mouth (Fig. 4). The Clearwater mainstream is approximately 45 mi long and is fed by 10 major tributaries and many minor ones. There are about 70 mi of tributary and 38 mi of mainstream available to anadromous salmonids throughout the Clearwater River system.

The Clearwater River, in contrast to the Queets River, is presently unglaciated and flows southwest from the foothills of the Olympic Mountains. Rainfall often exceeds 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 of the Clearwater was approximately 1,000 cfs, and the minimum was 35.0 cfs in August 1975 (Larson and Jacoby 1976). Additional hydrologic information for the Clearwater River and its tributaries can be found in Cederholm and Lestelle 1974; Wooldridge et al. 1975; Larson and Jacoby 1976 and 1977; and Aberchrombie et al. 1978).

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.

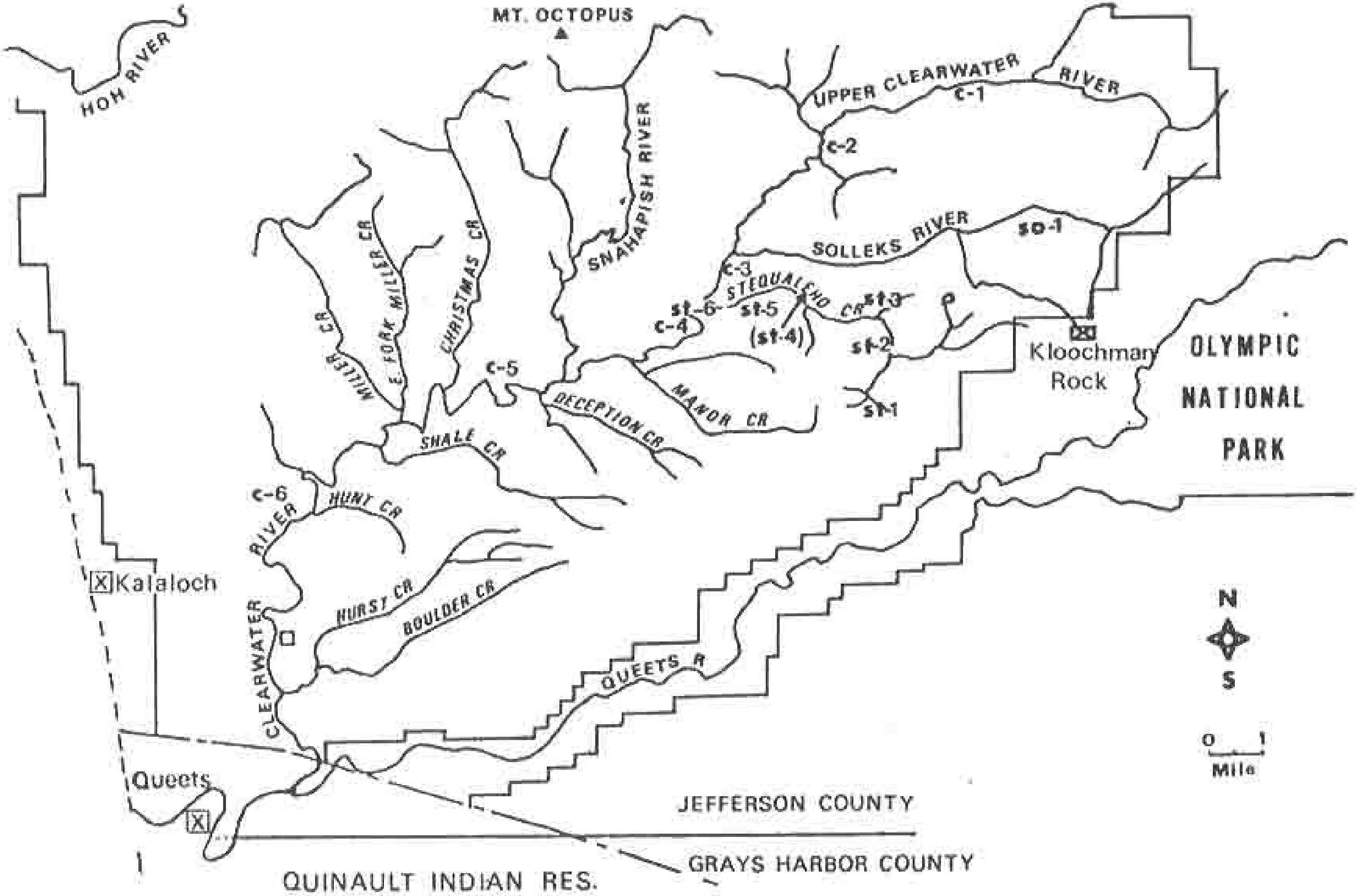

Fig. 4. General locations of experimental sampling sites in the Clearwater River, the Solleks River, and Stequaleho Creek.

LOGGING OF THE CLEARWATER RIVER BASIN

The Clearwater River basin is under "sustained yield" old-growth timber management by state (DNR), federal, and private land owners. Approximately 80% of the drainage is owned by DNR and in 1976 approximately 20% of the statewide annual cut on state timber lands came from this drainage. The timber sales, miles of logging roads built, and the extent of clearcut area on DNR lands in the Clearwater River system are in Table 1. The commercially harvestable 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).

The principal timber harvesting practice in the Clearwater is hi-lead clearcutting in a patchcut pattern. There has been some balloon logging in recent years, but this has not apparently proven to be economically sound for this area. Clearcut areas are usually slash burned and replanted with Douglas fir within 2 years after cutting. The size of each clearcut unit averages 80 acres. The retention of "buffer strips" and "streamside management zones" has been the general practice to date for most large tributaries and the main Clearwater River; but many small headwater streams are clearcut. The Clearwater basin is approximately 35% cut.

Logging Roads

To date the logging road system, which is approximately two-thirds complete in the Clearwater River drainage, extends from the mouth to the headwaters with almost no tributary area not influenced. After 1963 the DNR began extending its road system into the steep headwater areas, and by mid-1976 there were approximately 350 mi of logging road in the basin. The road system is about 66% complete.

The logging roads in the middle and upper Clearwater River are in steep terrain, where sideslopes average 30% and often exceed 100%. The density of roads in a particular tributary basin may vary depending on the road design, logging technique, and type of terrain. Many of the older roads constructed prior to 1970 have a relatively high road density and were built with sidecast practices. The principal logging road uses are for timber removal, reforestation, fire control, and recreation. There are three main logging road designs:

1) logger choice - in most cases built to minimum standards to be used just once. Approximately 10% of the road mileage on state land is of this type;

2) management standard - built to strict state specifications to be used intensively over several sales. Approximately 30% of the road mileage on state land is of this type;

3) main haul roads - built to the highest standards, both single and double lane, for extensive longterm use. Approximately 60% of the road

Table 1. Annual DNR numbers of sales, miles of logging roads, and acres of clearcut in the Clearwater River basin, 1960-1978.

Fiscal year sale was made	Number of sales	Miles of roads[1]	Clearcut area[2] (acres)
1960-1961-1962	3	16	850
1963	3	18	1,150
1964	3	15	1,020
1965	4	11	860
1966	4	7	750
1967	8	30	2,000
1968	13	36	2,200
1969	4	14	900
1970	13	41	2,900
1971	10	34	2,000
1972	12	27	2,400
1973	12	26	2,301
1974	10	12	1,820
1975	13	19	2,197
1976	21	28	3,188
1977	19	17	2,368
1978	8	6	979
	160	357	29,883

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[1] Management standard and logger choice roads included (these are estimates made at the time of sale).

[2] Does not include small district sales and these are estimates made at the time of sale.

mileage on state land is of this type. There are over 60 lane miles of asphalt-paved mainline and secondary road.

Gravel used for surfacing is either mined from the 10 borrow-pits located within the Clearwater watershed or from Winfield Creek Pit on the Hoh River or Tacoma Creek Pit on the Queets River. The two latter pits have a considerably better quality (harder) rock than the Clearwater pits. Unfortunately, this preferred rock requires much longer hauling distances at much greater expense.

Since about 1972 the improved logging and road building practices in the Clearwater River watershed have resulted in significant reductions in logging-associated impacts on fisheries habitats. Some of these improvements are: 1) skyline logging systems such as multispan and balloon to decrease road mileage and soil disturbance in steep country; 2) leaving old growth buffer strips and "streamside management zones" to reduce exposure of streams to temperature extremes and to reduce physical damage to streambanks; 3) tree jacking and pulling of trees away from streams when operating near the riparian zone; 4) improved road locationing; 5) end hauling of waste material rather than sidecast; 6) use of good quality crushed rock on roads and asphalt paving of primary and secondary road systems; 7) use of bridges and culverts in a manner that assures the migration of juveniles and adult salmon; 8) protecting road fills with gabions and flumed downspouts to reduce the erosion at the inlets and outlets of road drains; 9) grass seeding of old exposed cut and fill slopes with hydromulching techniques; 10) intensively training new personnel in interpretation of the relatively new Washington State Forest Practices Rules and Regulations to increase awareness of stream protection.

STEQUALEHO CREEK 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. 5). Combined, these landslides deposited approximately 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.

STEQUALEHO CREEK SAMPLING SITES

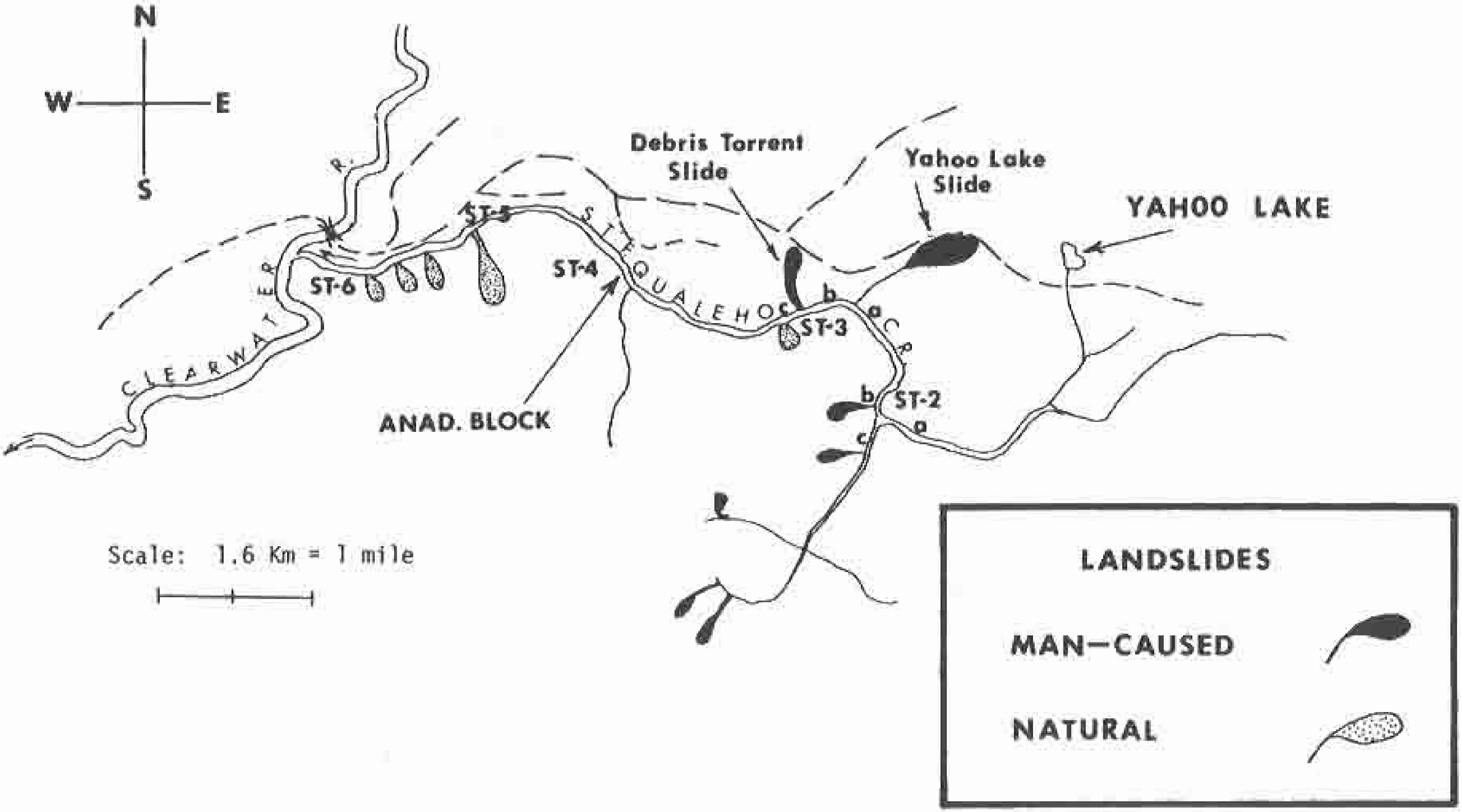

Fig. 5. Sampling sites, logging roads, natural and man-caused landslides in the Stequaleho Creek drainage basin. Depicted landslides are not drawn to scale.

STEQUALEHO CREEK LANDSLIDE STUDY RESEARCH PROCEDURE

The landslides occurred in the spring of 1971, and the study began in January 1972, so no data were available for the first summer and fall after the slide. 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 represented 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 were also conducted in other tributaries of the Clearwater River and in the Olympic National Park.

METHODS

Spawning Gravel Composition

Over a 6-year period (January 1972-June 1977) we have collected and analyzed approximately 1,000 gravel samples, from the spawning areas of Stequaleho Creek, the main Clearwater River and its tributaries, and some tributaries in the upper Hoh and Queets Rivers in the Olympic National Park. These samples were collected: 1) to monitor the effects of the Stequaleho Creek landslides on downstream areas; and 2) to determine if a significant relationship existed between clearcut area, logging road mileage, road area, and the gravel compositions of downstream areas.

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 (Fig. 5). 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 (Fig. 4). Due to on-going logging and road building projects by the DNR after 1973, most of the landslide-unaffected control stations were eventually influenced by additional logging road-caused siltation (i.e., ST-2-B, ST-2-C, ST-3-A, Cl-1, SO-1).

To determine if a general relationship existed between logging (clearcut area, road mileage, and road area) and downstream spawning gravel composition, we chose 29 additional gravel sampling locations throughout the Clearwater Basin (Fig. 6), and in some adjacent tributaries in the Olympic National Park (Fig. 7). An attempt was made to gather samples from areas of varying logging activity, and some control areas of no logging. The number of samples collected from each site varied from year to year and from stream to stream. The largest number of samples was available from Stequaleho Creek and the main Clearwater River where other studies (effects of landslides) were already underway. Other criteria that determined the number of samples collected were accessibility to sampling sites, availability of gravel, time available to sample, and statistical variability within specific gravel compositions. In 1976 we determined the general relationship that existed between logging activity and downstream spawning gravel composition. We lacked control samples from unlogged areas so chose five streams in the upper Hoh (South Fork, and an unnamed tributary) and Queets Rivers (Tshletchy Creek, Harlow Creek, and Bob Creek). Watershed descriptive data on 21 of the major study basins is given in Table 2.

Spawning gravel samples were gathered during the summer low-flow period from riffles where salmonids were known to spawn. A modified version of the McNeil and Ahnell (1964) cylinder with a plunger (Koski 1966) was used (Cederholm et al. 1978) (Fig. 8). This sampler removes a circular core of gravel 6 inches in diameter and 8-10 inches deep. The samples were then washed through a series of five 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), and 0.106 mm

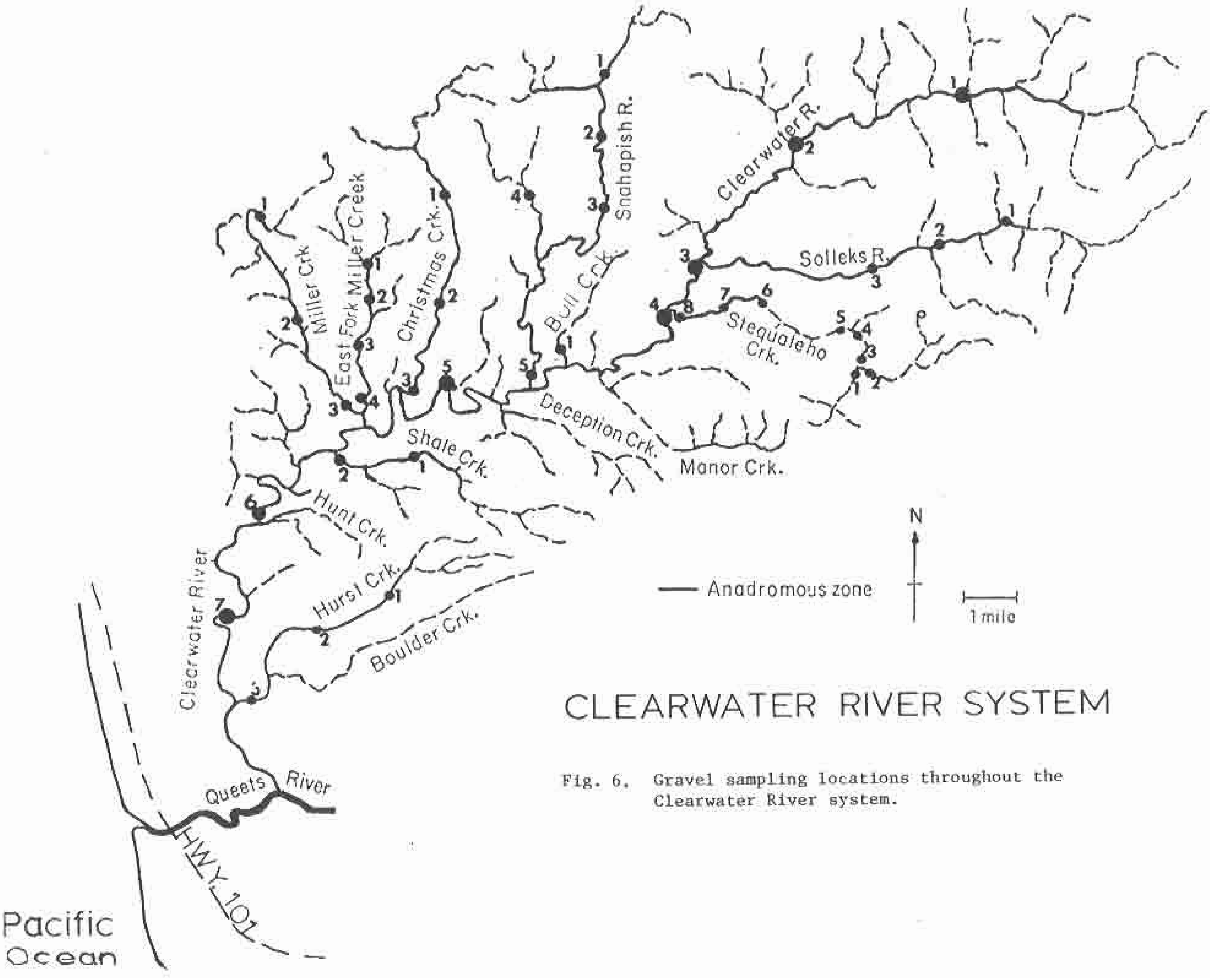

Fig. 6. Gravel sampling locations throughout the Clearwater River system.

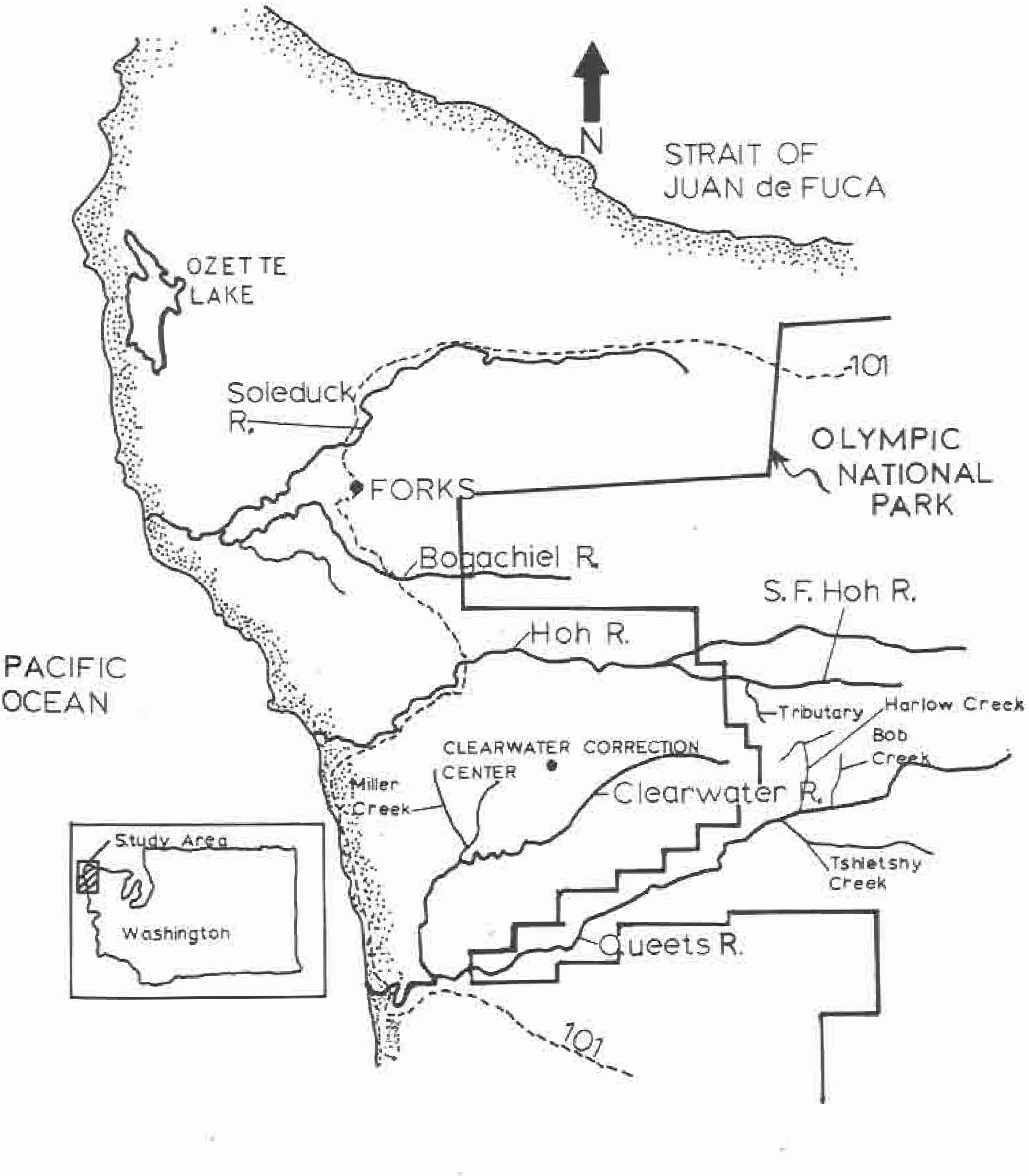

Fig. 7. Location of control gravel sampling sites in tributaries of the Upper Hoh and Queets rivers in the Olympic National Park.

Table 2. Descriptive data for twenty-one major study basins.

Basin	Basin area (mi^2)	Minimum-maximum basin elevation (ft)	Stream flow aspect	Stream channel gradient (%)	Stream order[1]
Solleks River	9.00	400 - 3,000	S 85° W	2.3	3
Stequaleho Creek	9.76	350 - 2,200	N 82° W	2.0	4
Shale Creek	6.66	140 - 1,200	N 74° W	1.5	3
Hurst Creek	8.82	50 - 1,000	S 67° W	1.8	4
W. F. Miller Creek	7.31	140 - 1,000	S 30° E	1.7	3
E. F. Miller Creek	5.68	150 - 1,200	S 9° E	2.1	3
Christmas Creek	9.07	180 - 1,200	S 11° W	2.0	3
Snahopish River	18.95	250 - 1,600	S 12° W	0.8	4
Bull Creek	2.26	270 - 1,000	S 29° W	1.6	2
Clearwater River #1	14.55	860 - 2,800	N 75° W	1.1	3
Clearwater River #2	25.92	550 - 2,850	S 87° W	1.0	3
Clearwater River #3	49.26	380 - 3,050	S 63° W	0.7	4
Clearwater River #4	59.54	325 - 3,050	S 63° W	0.4	5
Clearwater River #5	97.70	225 - 3,050	S 60° W	0.3	5
Clearwater River #6	134.39	100 - 3,050	S 74° W	0.2	5
Clearwater River #7	141.10	70 - 3,050	S 55° W	0.2	5
S. F. Hoh River Trib.	4.50	760 - 2,800	N 5° W	3.0	2
S. F. Hoh River	36.00	750 - 6,000	N 82° W	0.8	3
Tshletchy Creek	35.00	550 - 2,600	N 83° W	2.0	3
Bob Creek	2.30	550 - 3,000	S 32° W	2.5	2
Harlow Creek		550 - 3,000	S 33° W	1.0	3

[1] Stream order is a measure of the position of a stream in the hierarchy of tributaries (Leopold et al. 1964). The Strahler (1957) stream order system is used in this study.

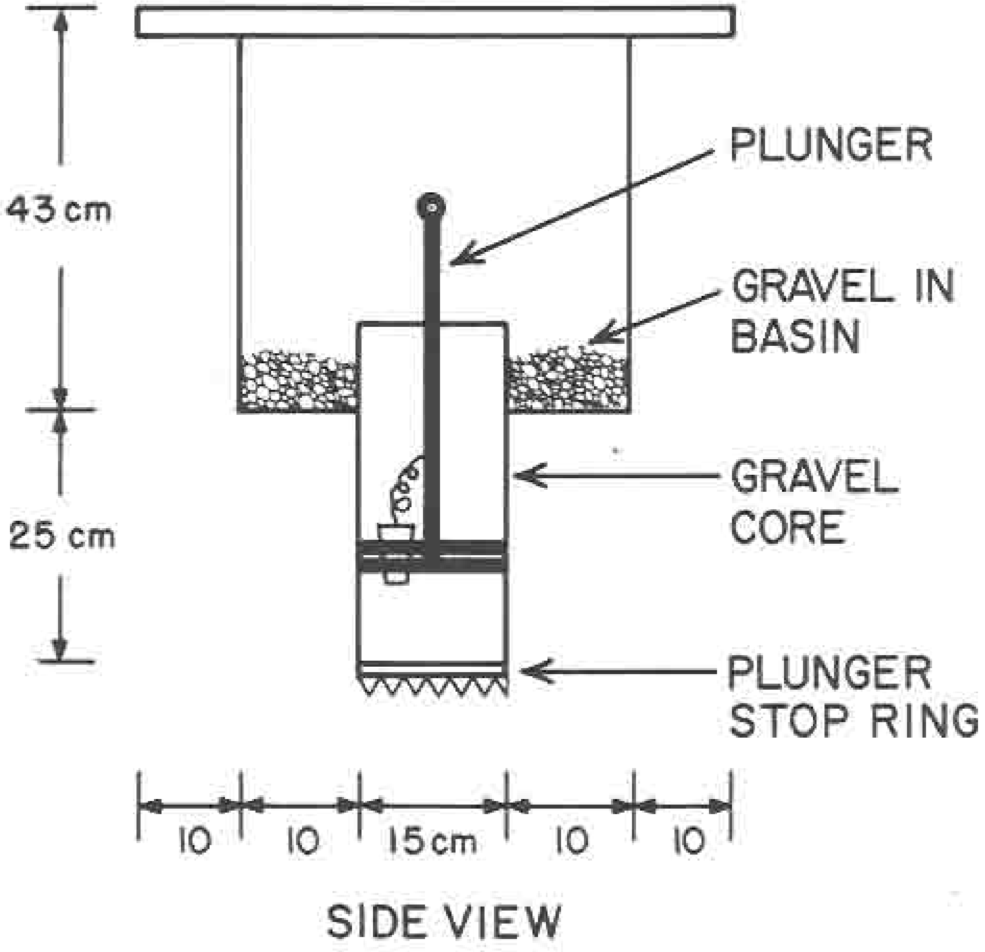

Fig. 8. The McNeil gravel sampler used to investigate gravel quality in the Clearwater River and its tributaries.

(0.004 inch). The material passing the smallest sieve size was allowed to settle for 1 hour in a graduated cylinder before the volume of sediment was recorded. The volume of material retained by each of the sieves was then measured in a volume displacement flask. The percentage of the total sample passed or retained by each sieve was then determined. Computation of the data was made with a modified version of the computer program FR5063, FRI, University of Washington.

Watershed area, clearcut area, road mileage, and road area were determined from aerial photographs with a scale of 1 to 1,000. The area in roads is expressed as the product of lineal road mileage and a mean road width (top of cut-bank to toe of side-cast slope) divided by total basin area. A planimeter, mileage wheel, and millimeter scale were used to determine areas of clearcut, lineal miles of road, and road widths, respectively. The state of logging activity existing in June 1976 was used for these correlations.

Simple linear regression analysis was used to determine correlations between logging intensity and gravel composition. Nine separate gravel categories (dependent variables) were regressed with total basin area, percentage clearcut area, lineal miles of logging roads, and area of logging roads (independent variables). The intensity of the association of these variables is expressed with the correlation coefficient (r) and coefficient of determination (r^2).

Coho Salmon Survival to Emergence Experiments

During the wingers of 1975, and 1977, two experiments were conducted in artificial streams at the Sole Duc River Salmon Hatchery at Sappho, Washington, to test the influence of gravel composition on survival from the green-egg stage to emergence for Sole Duc River fall-run coho salmon. Due to the low abundance of Clearwater River coho salmon we chose to use Sole Duc River stock, and assumed a similar response for Clearwater River coho. A series of 18 individual troughs (measuring 180 cm long x 38 cm wide x 25 cm deep) were used in 1975, and 13 in 1977. In 1975, each trough was stocked with an average of 1,200 eggs (range 911-1470); and in 1977 each trough was stocked with an average of 1,800 eggs (range 784-2794). The eggs were buried in either three (1975) or two (1977) separate egg pits per trough. Each spring-water-fed trough was supplied with a different mixture of gravel over a wide range of sediment levels. The emergent fry from each trough were captured separately in a small net trap located at its downstream end. The survival of fry to emergence was correlated at its downstream end. The survival of fry to emergence was correlated with the gravel composition of each individual trough. Control eggs were held in deep trough incubators at the hatchery.

Adult Abundance

The spawning distribution of Clearwater River steelhead trout and chinook and coho salmon was monitored from 1972 to 1978. The mainstem was observed by helicopter and the tributaries by foot surveys. Timing of surveys 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. However, many streams were surveyed only once and in those cases that survey was reported.

Tributary surveys were carried out in index sections. 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 five times, per season.

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

East Fork Miller Creek Coho Salmon Egg Survival Experiment

During the early winter of 1975, there was a massive logging-road caused landslide that occurred in a small tributary of upper East Fork of Miller Creek. The storm that triggered the slide took place during the third week of October 1975, when 11.66 inches of rain were recorded at the Clearwater Correction Center over a 6-day period. The peak of the storm occurred on October 16 when 5.09 inches fell in 24 hr. The stream discharge of Main Miller Creek increased from an average of approximately 100 cfs during the second week of October to 1,300 on October 17th.

The landslide was caused by logging road sidecast material which sluiced out 900 ft of a type-5 stream and was deposited in a type-4 and -3 waters downstream (Fig. 9). The type-4 water supported a population of resident cutthroat trout; and the type-3 water, populations of resident and searun cutthroat and steelhead trout; and coho and chinook salmon. During the previous years East Fork Miller Creek has supported significant numbers of salmonids and is a key spawning area (Cederholm, unpublished data).

Several hundred cubic yards of material were deposited at the toe of the slide, and the streambed for about 1/2 mile downstream was filled with fine sediments to the tops of the existing embankment. We chose eight sites for determining the survival of coho salmon eggs. Five locations were within the influence of the landslide beginning at a point

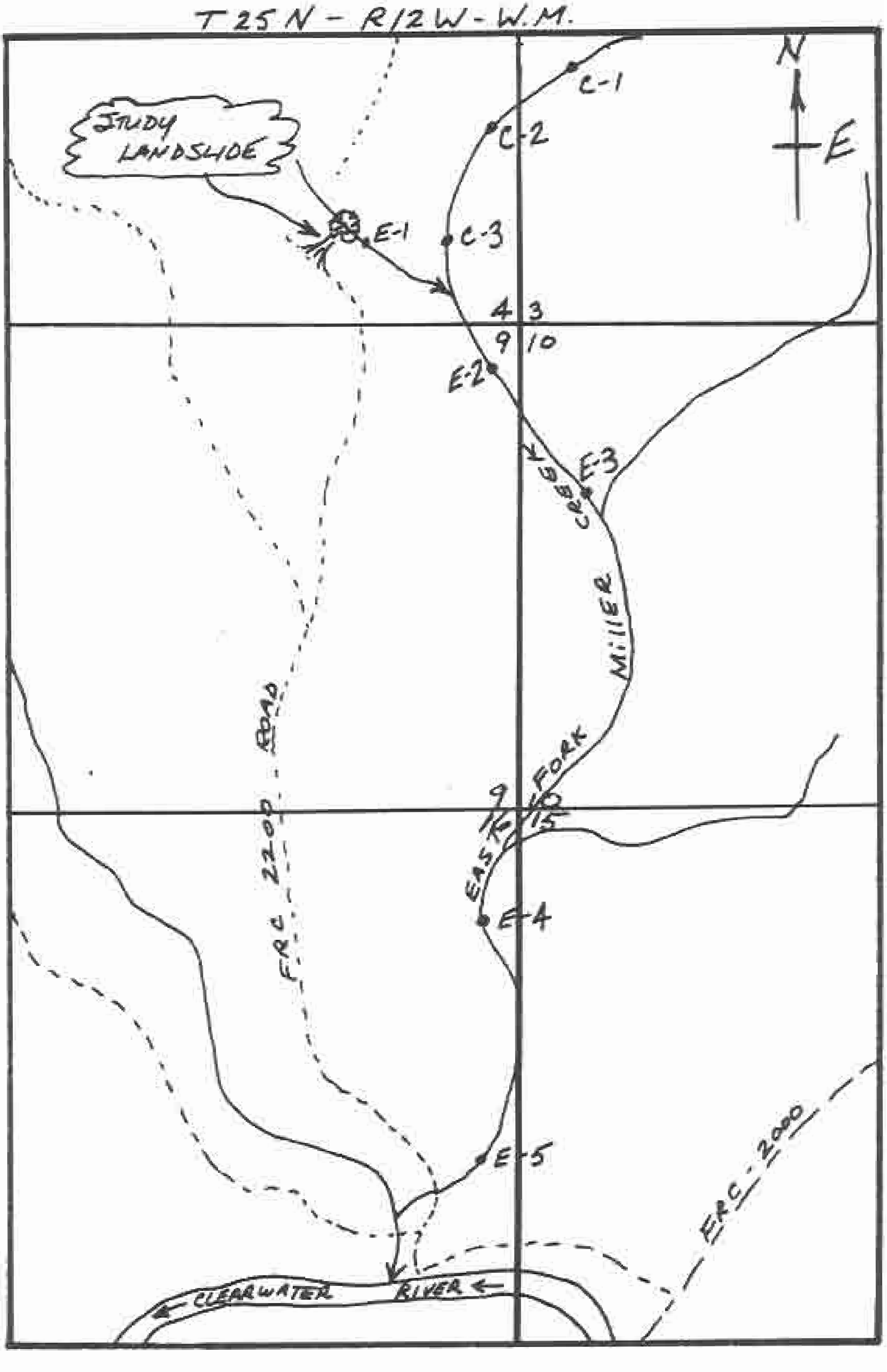

Fig. 9. East Fork Miller Creek showing the landslide and the control (C-1, C-2, C-3) and landslide-affected incubation sites (E-1, E-2, E-3, E-4, and E-5).

immediately below the slide (in the small type-4 tributary) and ending at a point 4 miles downstream (near the mouth of East Fork Miller Creek). These control sites were established in the main creek upstream of the mouth of the small tributary within which the slide is located (Fig. 9). Unfortunately, these control sites cannot be considered completely natural as some logging roads existed upstream.

At each of the 8 experimental sites (5 influenced and 3 control) we buried 200 coho salmon "eyed" eggs in each of three separate pits. Each of the groups of 200 eggs was enclosed in small 1/16-inch mesh nylon net bags. These envelopes would allow for intragravel water circulation, but would prevent escape of fry upon hatching. Therefore, there were 15 separate mesh bags, of 200 eggs each, buried in the landslide-influenced zone at five locations over a 4-mile stretch of stream; and nine separate mesh bags, of 200 eggs each, buried at three locations above the landslide influence.

The coho salmon eggs were incubated at the WDF Sole Duc River Salmon Hatchery until they reached the "eyed" stage. The eggs were placed into the nylon mesh bags and transported in a 5-gal bucket packed in wet forest moss. Approximately 2 hrs later, the eggs were inspected for mortality, dead eggs were removed, the bags were sewn shut and buried in 10-inch deep pits. For identification each site was marked with a plastic-coated wire, with a streamer floating in the stream.

The eggs were buried on January 4, 1977, and were recovered on March 16 and 17, 1977. At recovery, the live and dead fry were counted. Survival to hatching was considered to be the total (live plus dead) fry, and the survival to recovery (button up) was the number of live fry.

RESULTS

Spawning Gravel Composition Changes--
Control vs Stequaleho Creek (1972-1976)

The mean percentages of fine material (<0.850 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, 1973, 1975 and 1976, but not in 1974 (Table 3). 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%. In 1975, the mean percentage of fines in the landslide-affected zone was 12.01% compared to 7.63% in the control, an increase of 4.38%. In 1976, the mean percentage of fines in the landslide-affected zone was 11.60% compared to 9.41% in the control, an increase of 2.19%. It is important to note, however, that new road caused landslides occurring in the control areas may have influenced the spawning gravels before they were sampled in 1973 (Table 3, Fig. 10).

Sampling Station ST-3-B, located in Stequaleho Creek between the Debris Torrent and Yahoo Lake landslides (Fig. 5), had mean percentages of fines of 6.72% in 1972; 21.20% in 1973; 17.62% in 1974; no gravel to sample in 1975; and 8.74% in 1976. The reactivation of the Yahoo Lake landslide in 1973 (before sampling) is believed to be the reason for the high sediment levels at this station in 1973 and 1974. These materials were deposited behind a large logjam originally caused by the Debris Torrent landslide in 1971. In 1975 the logjam had disappeared and the gravel bar that had been deposited had been washed downstream. In 1976, a new gravel bar had formed in the area of ST-3-B which we found to be relatively clean (8.74%) (Table 3, Fig. 10). Some of the gravel that washed out of this was deposited in the anadromous zone, causing the increases in sediment noted in 1975 and 1976. Some sediment was deposited in accumulations of debris and inside channels upstream of the anadromous area (i.e., just behind the anadromous block logjam). These data represent the gravel compositions in the Stequaleho Creek anadromous area for the second, third, fourth, fifth, and sixth years since the landslides. Additional data and statistics relating to spawning gravel compositions at these stations are reported in Cederholm et al. (1977).

Spawning Gravel Composition Changes--
Control vs Clearwater River (1973-1976)

The mean percentages of fine material (<0.850 mm) in spawning gravels of the mainstem Clearwater River were found to be significantly (5% level) higher than in the controls used in the landslide-affected areas (below Stequaleho Creek mouth) in 1972, 1973, and 1976, but not in 1974 and 1975 (Table 3, Fig. 10). In 1972, the percentage of fines in the landslide-

Table 3. Mean and 95% confidence intervals for percentage of fine material in landslide-unaffected (control) and landslide-affected Stequaleho Creek and the landslide-affected Clearwater River spawning gravels, 1972, 1973, 1974, 1975, and 1976.

		Percentage fine material passing a 0.850-mm Tyler sieve								
		1972		1973		1974		1975		1976
Location	N	$\bar{X}$ (95% con)	N	$\bar{X}$ (95% con)	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)	10	5.634 (±1.530)	8	8.799 (2.107)
ST-2-B	8	7.111 (±1.823)	8	10.220 (± 2.253)	7	10.399 (± 3.339)	7	9.980 (±2.915)	8	7.144 (1.807)
ST-2-C	7	8.795 (±2.953)	5	6.523 (± 3.066)	8	11.163 (± 6.661)	6	8.376 (±4.690)	8	11.047 (1.686)
ST-3-A	6	7.309 (±1.224)	8	8.250 (± 2.317)	-	- *	-	– –	5	10.551 (3.957)
SO-1-A	15	8.238 (±0.920)	6	6.568 (± 3.224)	2	6.400 (±33.017)	8	7.937 (±2.214)	6	11.061 (4.134)
Cl-1-A	8	7.612 (±2.205)	2	8.165 (±25.315)	6	10.085 (± 2.357)	5	6.957 (±2.264)	6	8.471 (2.363)
$\bar{X}$ =		7.780 (±0.605)		7.494 (± 0.997		9.500 (± 1.757)		7.632 (±1.067)		9.411 (0.924)
Experimental (Stequaleho)										
ST-3-B	8	6.715 (±3.021)	9	21.197 (±14.980)	8	17.621 (± 9.246)		**(No gravel)	4	8.736 (3.760)
ST-4	9	10.972 (±2.712)	5	10.297 (± 3.683)	8	7.992 (± 4.228)	6	8.987 (±2.095)	7	10.159 (2.725)
ST-5	11	11.357 (±2.471)	11	8.210 (± 2.122)	8	10.081 (± 1.897)	9	10.846 (±3.907)	8	11.851 (2.217)
ST-6	12	10.462 (±1.469)	11	11.433 (± 2.095)	5	8.886 (± 4.377)	12	14.400 (±2.768)	6	12.963 (2.461)
$\bar{X}$ =		10.913 (±1.112)		9.910 (± 1.324)		9.001 (± 1.716)		12.013 (±1.857)		11.604 (1.270)
Experimental (Clearwater)										
Cl-4	10	9.537 (±0.782)	11	7.244 (± 1.602)	10	10.359 (± 1.759)		**(No gravel)	8	11.751 (4.018)
Cl-5	17	8.431 (±1.675)	17	7.333 (± 1.451)	12	9.004 (± 1.080)	19	4.781 (±0.926)	8	11.484 (2.004)
Cl-6	8	10.455 (±2.460)	16	12.649 (± 3.863)	11	6.322 (± 2.847)	18	7.173 (±1.033)	8	13.246 (3.766)
$\bar{X}$ =		9.210 (±0.958)		9.244 (± 1.652)		8.687 (± 1.140)		6.319 (±1.068)		12.160 (1.671)

*These samples were destroyed by vandals.

**There was no gravel available to sample. The stream had apparently scoured the gravel away.

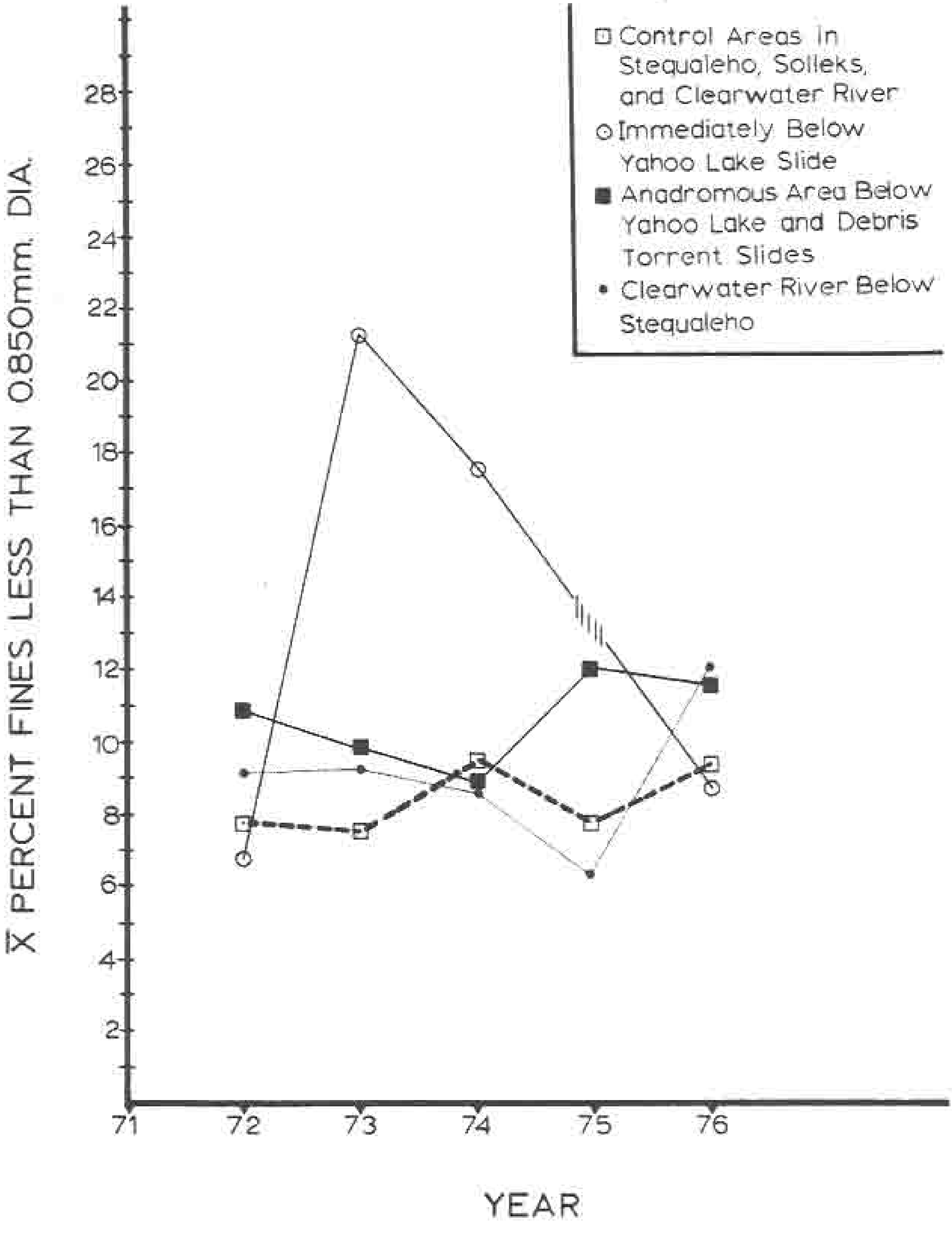

Fig. 10. Mean spawning gravel compositions for the Stequaleho Creek landslide study.

affected area was 9.21% compared to 7.78% in the controls (a difference of +1.43%). In 1973, the percentage of fines in the test area was 9.24% compared to 7.49% in the control (a difference 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 difference of -0.82% and in 1975, the percentage of fines in the landslide-affected area was 1.31% less than in the controls (6.32% compared to 7.63%). In 1976, the percentage of fines in the landslide-affected area increased again by 2.75% over the controls (12.16% compared to 9.41%) (Table 3, Fig. 10). The controls may have been influenced by landslides caused by construction of roads after 1973; and the test areas may have been influenced by sediments from other tributaries.

Sediment Accumulation in Spawning Gravels

One of the problems we faced was been the lack of data on gravel composition before the landslides and road construction began in Stequaleho Creek. To separate out natural influences from slide-caused events, we set up three of our original control sampling locations (stations ST-2-A, SO-1, and C1-1) in areas where there would not be logging or road construction for 1-2 years. We tested the sediment levels to monitor any increases as the logging road activities progressed after the base line data were acquired. The results are included in Table 3 and in Fig. 11. It appears as if there is an accumulation of fine sediments since road construction began; however, the rate is variable from stream to stream (See Cederholm et al. 1977, for detailed statistical information).

In the second part of the study we attempted to detect the accumulation of sediments by simple linear regression analysis (Table 4) and the correlation coefficients are presented in Table 5, with the detailed statistics in Appendix I. There was a significant (1% level) relationship between percentage fines (% material <0.850 mm diameter) in spawning gravels, and the amount of logging and road miles in the various basins (Fig. 12). The 44 basins ranged in size from 1.21 to 141.1 mi^2 and their watersheds were as much as 36.17% clearcut logged. Some basins had road densities as high as 3.64 lineal mi/basin mi^2. The amount of basin in logging road area was as high as 6.14% (Appendix Table I).

The sediment sizes in spawning gravels that correlated strongest with percent basin logged, miles of road per basin mi^2, and percent of basin area in roads, were total materials less than 0.850 mm diameter (r^2 values of 0.44685, 0.42688, and 0.47200, respectively). These coefficients of determination were all significant at the 1% level of significance) (Table 5). When the various sieve size categories were separated, it became apparent that the sand-sized particles 0.850 mm and smaller were accumulating in strong relation to these logging associated activities (Appendix Table I).

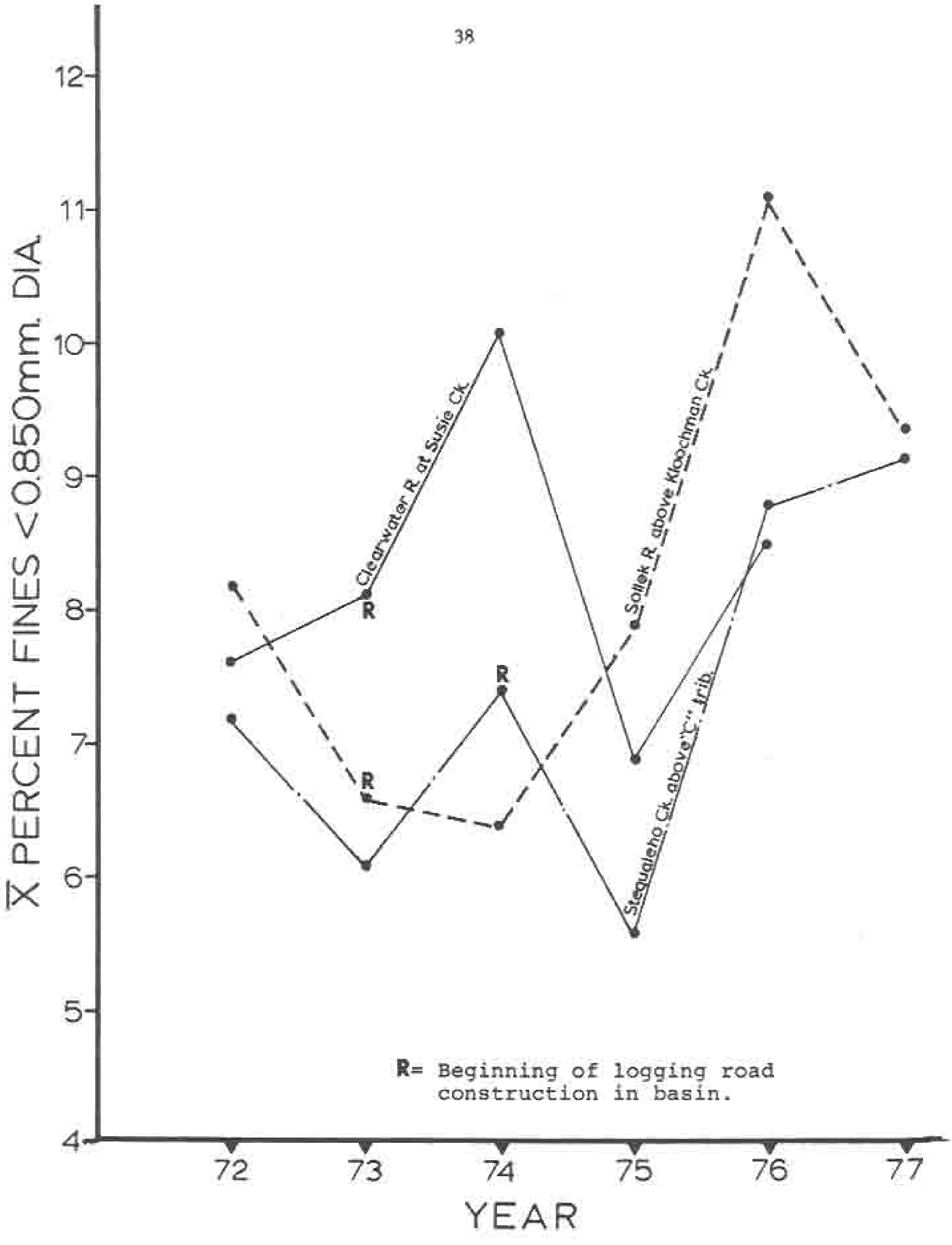

Fig. 11. Mean spawning gravel composition levels at three locations: (Upper Stequaleho, Upper Clearwater, and Solleks Rivers).

Table 4. Salmonid spawning gravel composition at 44 sampling locations throughout the Clearwater and its tributaries and adjacent streams in the Olympic National Park, 1972-1978.

Basin		N	Logging area		Road mileage		Road area		$\bar{x}$ Percent gravel composition								
			Total basin area (mi²)	% logged	Length roads (mi)	Mi road/ basin mi²	Road area (mi²)	% of basin area	<77 mm	<26.9 mm	<3.36 mm	<0.850 mm	<0.105 mm	<77 mm >26.9 mm	<26.9 mm >3.36 mm	<3.36 mm >0.85 mm	<0.85 mm >0.105 mm
Hurst Cr.	#1	10	5.12	13.04	11.79	2.30	.030	1.37	98.16	64.95	22.95	8.30	1.21	33.21	42.00	14.65	5.09
Hurst Cr.	#2	10	6.19	20.39	18.25	2.94	.109	1.76	94.93	54.76	18.37	6.57	2.34	40.17	36.39	11.80	4.23
Hurst Cr.	#3	16	8.82	29.34	23.91	2.71	.142	1.61	97.34	57.22	21.60	10.83	1.21	40.12	35.63	10.77	7.62
Shale Cr.	#1	17	4.60	15.20	12.92	2.80	.131	2.64	89.75	50.90	17.89	7.81	2.22	38.85	33.01	10.08	5.59
Shale Cr.	#2	15	6.66	23.44	19.39	2.91	.182	2.73	86.89	52.68	23.82	10.03	3.18	34.21	28.86	13.79	6.85
W.F. Miller Cr.	#1	18	1.55	33.09	5.07	3.27	.092	5.95	97.46	73.31	33.76	16.24	7.42	24.15	39.55	17.52	8.82
W.F. Miller Cr.	#2	16	4.78	30.11	13.93	2.91	.253	5.30	87.16	56.74	26.51	12.96	4.46	30.42	30.23	13.57	8.48
W.F. Miller Cr.	#3	21	7.31	32.95	24.66	3.37	.449	6.14	98.21	68.45	29.10	11.67	3.14	29.76	39.35	17.43	8.53
E.F. Miller Cr.	#1	14	1.21	24.32	3.11	2.56	.043	3.54	97.08	58.26	28.00	16.31	5.47	39.82	30.26	11.69	10.84
E.F. Miller Cr.	#2	6	3.14	22.98	8.83	2.81	.122	3.87	100.00	66.07	30.32	17.31	4.28	33.98	35.50	13.21	13.03
E.F. Miller Cr.	#3	4	4.27	32.29	13.26	3.10	.183	4.28	100.00	72.31	36.06	15.75	4.49	27.69	36.25	18.31	11.26
E.F. Miller Cr.	#4	21	5.68	36.08	18.34	3.22	.253	4.45	95.63	61.44	25.36	13.22	3.58	34.22	36.07	12.14	9.64
Christmas Cr.	#1	4	6.31	20.57	12.94	3.01	.131	3.04	91.80	54.51	22.59	10.62	2.39	37.29	31.92	11.97	8.23
Christmas Cr.	#2	8	7.99	29.86	26.67	3.33	.270	3.38	92.12	65.98	28.82	16.85	7.82	26.14	37.16	11.97	9.03
Christmas Cr.	#3	14	9.07	34.43	33.03	3.64	.335	3.69	96.98	70.07	31.93	19.09	4.11	26.90	38.14	12.84	14.98
Snahapish R.	#1	6	4.42	32.52	11.85	2.81	.126	2.84	95.58	66.86	21.62	8.57	1.87	28.72	45.24	13.05	6.70
Snahapish R.	#2	10	11.25	26.05	29.92	2.66	.317	2.82	98.87	56.39	24.56	12.47	2.97	42.48	31.83	12.07	9.50
Snahapish R.	#3	6	12.11	29.68	33.14	2.73	.351	2.90	91.81	56.43	25.17	14.22	3.98	35.36	31.28	10.95	10.24
Snahapish R.	#4	8	2.65	22.22	6.34	2.39	.067	2.53	100.00	59.66	23.48	11.71	2.74	40.34	36.18	11.77	8.97
Snahapish R.	#5	14	18.95	30.13	55.82	2.94	.591	3.12	95.65	49.20	16.13	9.76	3.94	46.45	33.07	6.37	5.82
Bull Cr.	#1	20	2.26	36.17	7.00	3.10	.061	2.69	93.68	57.90	21.85	10.95	5.28	35.78	36.05	10.90	5.67
Stequaleho Cr.	#1	34	1.87	28.89	4.30	2.31	.068	3.63	96.23	58.09	20.31	9.47	3.06	38.14	37.76	10.86	6.41
Stequaleho Cr.	#2	43	2.98	1.25	2.72	0.91	.043	1.44	94.67	55.83	19.68	6.94	1.96	38.84	36.15	12.76	4.98
Stequaleho Cr.	#3	38	4.85	15.72	7.02	1.44	.111	2.29	97.22	56.32	19.27	8.91	2.38	40.90	37.05	10.36	6.53
Stequaleho Cr.	#4	19	5.50	13.85	8.32	1.51	.132	2.39	97.56	63.91	21.81	8.54	1.86	33.65	42.10	13.25	6.70
Stequaleho Cr.	#5	29	6.22	13.24	9.73	1.56	.154	2.47	95.73	65.40	27.48	14.50	3.44	30.35	37.92	12.98	11.06
Stequaleho Cr.	#6	35	8.01	16.11	15.15	1.71	.239	2.72	97.41	67.60	23.37	9.69	2.21	24.81	44.23	13.68	7.48
Stequaleho Cr.	#7	47	9.49	18.38	17.64	1.85	.279	2.94	95.96	65.68	24.97	10.39	2.32	30.28	40.71	14.58	7.87
Stequaleho Cr.	#8	46	9.76	19.52	18.32	1.87	.289	2.97	95.96	65.33	29.61	11.88	3.62	30.63	35.72	17.73	8.26
Solleks R.	#1	29	4.33	5.45	1.36	0.13	.021	0.49	90.50	58.71	20.67	8.14	3.15	31.79	38.04	12.53	4.99
Solleks R.	#2	28	7.39	7.33	5.40	0.74	.086	1.17	94.92	69.76	21.31	9.26	2.55	25.16	48.43	12.07	6.71
Solleks R.	#3	34	12.03	8.56	10.28	0.85	.162	1.35	94.61	63.47	19.00	6.52	2.02	31.14	44.47	12.48	4.50
Clearwater R.	#1	27	14.56	8.51	13.84	0.95	.218	1.58	95.38	71.66	24.61	8.27	2.15	23.72	47.05	16.34	6.12
Clearwater R.	#2	22	25.92	15.38	36.46	1.41	.576	1.58	96.27	67.23	24.83	8.34	1.34	29.04	42.40	16.49	7.00
Clearwater R.	#3	25	49.26	15.39	66.39	1.35	1.052	1.58	94.41	59.57	25.72	8.73	2.40	34.84	33.85	16.99	6.33
Clearwater R.	#4	39	59.54	16.31	81.18	1.36	1.386	1.71	90.94	57.50	24.87	9.56	2.23	33.44	32.63	15.31	7.33
Clearwater R.	#5	73	97.20	22.98	192.50	1.97	2.433	2.49	96.17	54.43	21.39	7.65	1.82	41.74	33.04	13.74	5.83
Clearwater R.	#6	61	136.40	24.40	286.46	2.13	3.441	2.56	99.27	70.01	17.78	9.77	2.35	29.26	52.23	8.01	7.22
Clearwater R.	#7	17	141.10	25.90	311.76	2.21	3.739	2.65	99.52	54.55	23.47	16.46	4.93	44.96	31.08	7.01	11.53
S.F. Hoh R. Trib		6	4.50	0.00	0.00	0.00	0.00	0.00	90.00	48.54	14.14	3.08	0.36	41.46	34.40	11.06	1.95
S.F. Hoh R.		19	16.00	0.00	0.00	0.00	0.00	0.00	95.00	44.35	26.45	8.30	1.12	50.65	37.90	18.15	7.18
Tshletchy Cr.		6	35.00	0.00	0.00	0.00	0.00	0.00	100.00	56.27	23.07	6.02	1.22	43.73	33.20	17.05	4.80
Bob Cr.		6	2.30	0.00	0.00	0.00	0.00	0.00	100.00	56.79	14.22	4.89	1.38	43.21	42.07	9.33	3.51
Harlow Cr.		5		0.00	0.00	0.00	0.00	0.00	100.00	86.63	20.38	9.56	2.02	13.37	66.25	10.82	7.54
		948															

Table 5. Simple linear correlations between nine salmonid spawning gravel sieve categories and the degree of clearcut logging, miles of logging road per basin square mile, and percent of basin area in roads for 44 sampling locations throughout the Clearwater and its tributaries and adjacent streams in the Olympic National Park, 1972-1978.

Sieve category	Percent logged		Mile road per basin mi^2		Percent of basin area in roads	
	r	r^2	r	r^2	r	r^2
% < 77 mm	+.01097	.00012	-.05163	.00267	-.01140	.00013
% < 26.9 mm	-.01339	.00018	-.06139	.00377	+.11540	.01332
% < 3.36 mm	+.45161	.20395	+.045837	.21011	+.57304	.32837
% < 0.850 mm	+.66847	.44685	+.65336	.42688	+.68702	.47200
% < 0.105 mm	+.66288	.43941	+.64993	.42240	+.65662	.43115
< 77 mm % > 26.9 mm	-.00793	.00006	+.01136	.00013	-.15463	.02391
< 26.9 mm % > 3.36 mm	-.32521	.10576	-.37411	.13996	-.28501	.08123
< 3.36 mm % > 0.850 mm	-.10346	.01070	-.09533	.00909	+.11644	.01356
< 0.850 mm % > 0.105 mm	+.55866	.31210	+.54558	.29766	+.58776	.34546

Critical values of r (43 df)

α = .10 = (0.248) 90% conf
α = .05 = (0.294) 95% conf
α = .02 = (0.346) 98% conf
α = .01 = (0.380) 99% conf

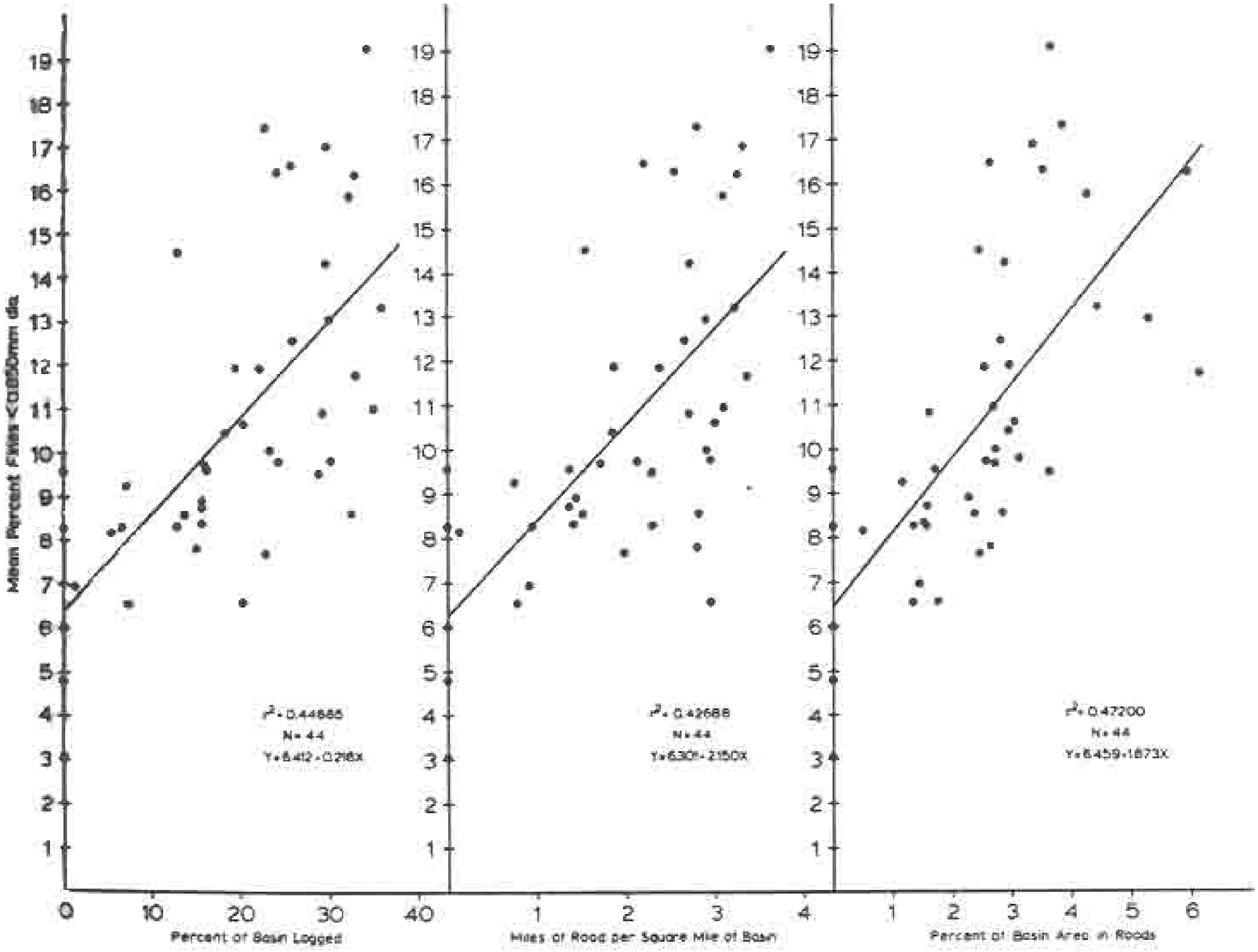

Fig. 12. Statistical relationship between percent of basin logged, miles of road per square mile of basin, percent of basin area in roads and the percent of fine material in the spawning gravels at the lower end of 44 basins.

Adult Spawner Utilization of Stequaleho Creek, Other Clearwater Tributaries, and the Mainstem Clearwater River, 1972-1978

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 entire anadromous zone of Stequaleho, and the Clearwater River mainstem below Stequaleho Creek. It was determined from 1973 to 1978 that on the average approximately 30% of the Clearwater River winter-run steelhead, and 40% of the fall-run chinook salmon, and 3% of the fall-run coho salmon spawn within this reach. The steelhead and chinook are primarily lower-river mainstem spawners, while coho are primarily up-river and tributary spawners, which accounts for the relatively minor influence on coho stocks.

The distribution of redd counts in the tributaries and mainstem areas below the confluence of Stequaleho Creek showed no noticeable differences in abundance in the Clearwater tributaries for the three salmonid species covered (Table 6). There is, however, a considerable basin-wide variation in redd abundance within years and from year to year. These fluctuations are probably partly caused by annual differences in tribal and nontribal commercial and sport fisheries harvest rates.

Coho Salmon Fry Survival Experiments - 1975

A study of coho salmon survival from egg deposition to emergence was carried out in artificial streams in 1975 (Table 7 and Fig. 13). The mean streambed sedimentation levels over the eighteen incubation cells was 66.97% material less than 26.9 mm diameter, 21.87% material less than 3.36 mm, 11.81% material less than 0.850 mm, and 5.6% material less than 0.105 mm (Table 8). Simple linear regression analysis of these data produced significant inverse relationship between percent fines and survival of eggs to emergence ($N = 18$, $r^2 = -0.696$).

Approximately 12% of the emergent fry were still in the yolk sac stage and these were counted as survivors.

1977

Another study of coho salmon survival from egg deposition to emergence was carried out in artificial streams in 1977 (Table 8, Fig. 13). The mean streambed sedimentation levels over the 13 incubation cells was 66.58% material less than 26.9 mm diameter, 20.54% material less than 3.36 mm, 10.65% material less than 0.850 mm, and 4.86% material less than 0.105 mm (Table 8). Simple linear regression analysis of these data produced a significant inverse relationship between percent fines and survival to emergence ($N=13$, $r^2=-0.692$).

Approximately 32% of the surviving emergent fry were still in the yolk sac stage.

Table 6. Annual peak redd counts (and miles surveyed) of steelhead, coho, and chinook in tributaries and the mainstem of the Clearwater River, 1972-1978.

Steelhead tributaries	1973	1974	1975	1976	1977	1978
Stequaleho Creek	16(2.0)	2(2.0)	9(2.0)	6(2.0)	10(2.0)	15(2.0)
Hurst Creek	10(3.1)	1(3.6)	9(1.6)	4(3.5)	-	-
Miller Creek	12(1.3)	2(5.8)	16(4.0)	8(5.0)	9(5.6)	5(4.0)
Shale Creek	5(0.3)	4(1.0)	9(3.0)	2(3.5)	4(2.0)	12(3.5)
Solleks River	-	5(1.8)	17(1.5)	3(3.0)	29(5.4)	12(3.0)
Snahapish River	-	2(1.7)	18(3.0)	9(5.0)	21(3.0)	28(4.0)
Mainstem[1]						
Clearwater River	63(25.0)	22(25.0)	103(25.0)	39(25.0)	128(25.0)	152(25.0)

Coho tributaries	1972	1973	1974	1975	1976	1978[2]
Stequaleho Creek	13(2.0)	10(2.0)	3(1.8)	1(2.0)	10(2.0)	4(1.5)
Hurst Creek	10(1.4)	16(3.4)	3(2.8)	2(4.1)	7(3.5)	13(3.0)
Miller Creek	5(2.0)	3(2.0)	23(5.9)	6(7.5)	28(9.8)	30(6.0)
Shale Creek	12(0.8)	22(1.1)	6(2.0)	2(3.0)	6(3.0)	13(2.5)
Solleks River	8(1.6)	-	2(1.1)	1(1.5)	7(2.1)	7(1.5)
Snahapish River	-	16(2.4)	17(2.3)	19(4.5)	10(4.6)	90(10.0)

Chinook tributaries	1972	1973	1974	1975	1976
Stequaleho Creek	6(1.0)	0(0.3)	1(1.8)	2(1.0)	1(1.0)
Hurst Creek	15(1.4)	10(1.5)	2(1.0)	2(1.1)	5(1.0)
Miller Creek	23(2.6)	9(1.7)	8(2.4)	16(1.4)	12(2.4)
Shale Creek	7(0.8)	7(1.1)	2(1.0)	12(1.0)	3(1.0)
Christmas Creek	-	0(1.2)	3(0.5)	1(1.0)	3(1.0)
Snahapish River	-	-	-	4(2.0)	25(2.3)
Mainstem					
Clearwater River	-	35(25.0)	62(25.0)	-	42(25.0)

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[1] Twenty-five mile index located from mouth to confluence of Stequaleho Creek.

[2] Information supplied by the Quinault Department of Natural Resources and the Washington State Department of Fisheries.

Table 7. Coho salmon egg trough experiment on survival from green-egg deposition to emergence (1975).

Trough No.	Percent survival	Mean percentages of gravel classes smaller than each sieve size category			
		<26.9 mm	<3.36 mm	<0.850 mm	<0.105 mm
1	69.17	71.9	9.4	6.4	4.9
2	11.98	77.9	36.1	16.3	5.7
3	2.91	72.5	35.2	18.9	8.9
4	62.58	61.8	9.8	5.4	3.6
5	15.01	71.4	23.7	10.6	3.4
6	11.03	73.6	33.2	18.6	7.8
7	63.84	68.2	10.8	7.4	5.9
8	24.79	71.7	25.7	12.7	5.0
9	11.77	71.8	36.6	21.0	7.2
10	69.67	57.6	8.6	6.3	4.8
11	23.74	62.0	21.3	9.9	3.5
12	7.42	68.8	30.0	15.7	6.5
13	71.78	59.6	10.2	7.5	6.3
14	4.37	62.2	23.8	10.7	3.6
15	12.17	62.5	25.0	14.9	8.0
16	65.65	53.2	5.0	3.5	2.6
17	19.11	72.8	27.7	14.3	6.5
18	46.68	66.0	21.5	12.4	6.6
x	32.98	66.97	21.87	11.81	5.6

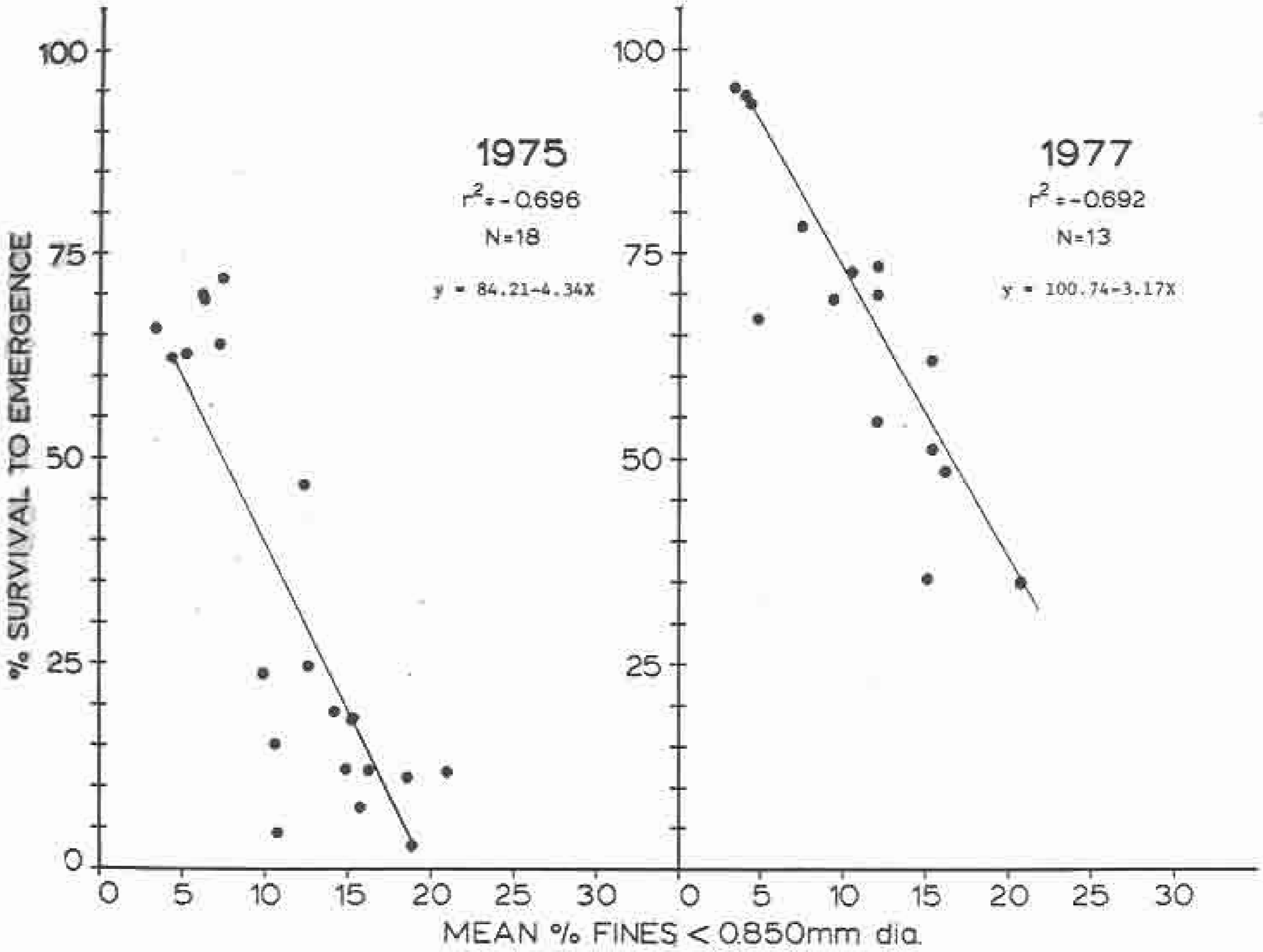

Fig. 13. Coho salmon egg trough experiments on survival from green-egg deposition to emergence (1975) and (1977).

Table 8. Coho salmon egg trough experiment on survival from green-egg deposition to emergence (1977).

		Mean percentages of gravel classes smaller than each sieve size category			
Trough No.	Percent survival	<26.9 mm	<3.36 mm	<0.850 mm	<0.105 mm
1	95.35	64.7	4.8	3.4	1.8
2	73.47	65.9	26.0	12.1	4.2
3	48.68	72.0	25.4	16.2	10.5
4	78.29	65.9	9.6	7.5	5.6
5	51.24	71.6	30.6	15.4	5.6
6	54.53	71.7	19.4	12.1	7.3
7	94.20	60.3	6.6	4.1	1.3
8	72.71	59.9	26.4	10.5	3.3
9	69.25	60.8	18.6	9.4	4.1
10	66.99	67.5	8.2	4.8	2.6
11	35.38	64.7	31.6	15.1	6.4
12	69.89	70.5	25.4	12.0	4.8
13	62.03	69.6	33.8	15.3	5.2
x	67.08	66.5	20.5	10.6	4.8

East Fork Miller Creek Experiment

This experiment involved the incubation of 3,000 coho salmon eggs buried in the landslide affected area, and 1,800 buried in the unaffected control areas. The eggs were checked for survival to hatch and to the button-up stage of developement at exhumation. The mean survival of the eggs to hatch was significantly (5% level) lower in the landslide affected area, 23.1% (range 0.0-67.0) than in the unaffected control locations 57.2% (range 34.0-83.0)(Table 9-A&B)(Fig. 14).

The mean survival of the eggs to button-up was also significantly (5% level) lower 2.4% (range 0.0-13.0) in the landslide affected area than in the unaffected control locations 25.6% (range 0.0-74.0)(Table 9A&B) (Fig. 14).

Table 9-A. East Fork Miller Creek effects of logging road landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development (control sites).

Site		Number of eggs planted	Number of fry survived	Number fry dead	Mean % survival to hatch	Mean % survival to exhumation
C-1	a.	200	62	84	73.0	31.0
	b.	200	18	97	57.0	9.0
	c.	200	0	97	48.0	0.0
			80	278	59.3	13.3
C-2	a.	200	148	19	83.0	74.0
	b.	200	96	37	66.0	48.0
	c.	200	0	84	42.0	0.0
			244	140	63.6	40.7
C-3	a.	200	24	70	47.0	12.0
	b.	200	113	17	65.0	56.0
	c.	199	0	68	34.0	0.0
			137	155	48.7	22.7

Table 9-B. East Fork Miller Creek effects of logging road landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development (affected sites).

Site		Number of eggs planted	Number of fry survived	Number fry dead	Mean % survival to hatch	Mean % survival to exhumation
E-1	a.	200	0	0	0.0	0.0
	b.	199	0	63	32.0	0.0
	c.	199	0	137	67.0	0.0
			0	197	33.0	0.0
E-2	a.	200	0	0	0.0	0.0
	b.	200	0	0	0.0	0.0
	c.[1]	200	-	-	-	-
			0	0	0.0	0.0
E-3	a.	200	0	94	47.0	0.0
	b.	200	2	4	3.0	1.0
	c.	199	27	79	53.0	13.0
			29	177	34.3	4.7
E-4	a.	200	0	79	39.0	0.0
	b.	200	4	39	21.0	2.0
	c.	199	1	3	2.0	5.0
			5	121	20.6	2.3
E-5	a.	199	17	47	32.0	8.0
	b.	200	0	0	0.0	0.0
	c.	199	14	85	50.0	7.0
			31	132	27.4	5.0

[1] Could not find at recovery time.

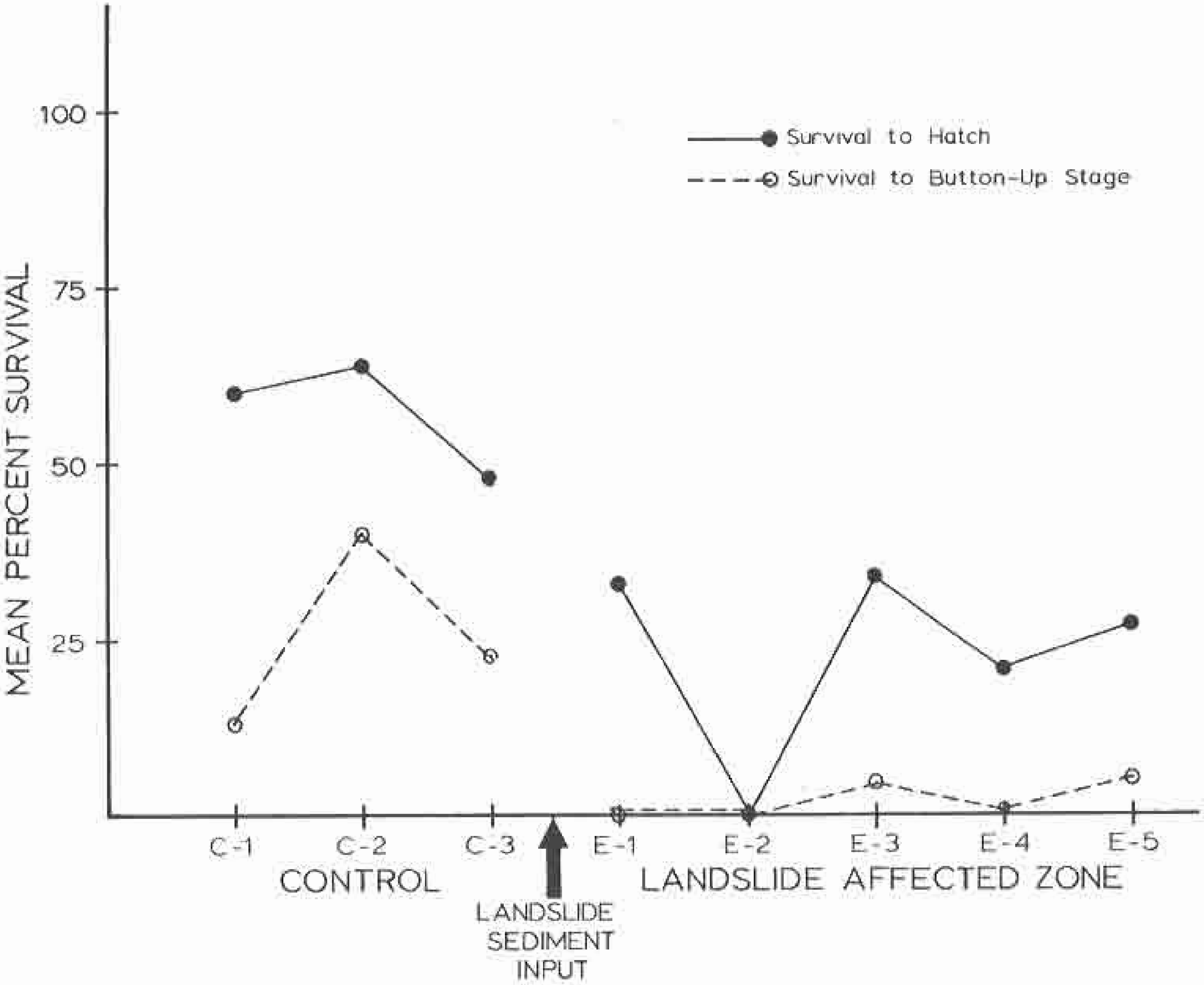

Fig. 14. East Fork Miller Creek effects of landslide sedimentation on survival of coho salmon eggs to the hatch and button-up stages of development (control and affected sites).

SUMMARY

1. During the early spring of 1971, two landslides caused by failure of logging roads occurred in Stequaleho Creek, a tributary of the Clearwater River, Jefferson County, Washington.

2. In December 1971, the DNR contracted the FRI of the University of Washington to investigate the extent of damage to the fisheries resources.

3. Other watershed studies throughout the Northwest United States have shown that logging roads and associated practices can be major contributors of sediments to streams.

4. Unusually high levels of fine sediments (material less than 0.850 mm dia) can be harmful to fisheries habitat by affecting a salmonid's preemergent and postemergent life.

5. The physical and biological characteristics of a watershed in combination will determine the rate of recovery of a stream system from a heavy sediment input. The power available to a stream to flush sediments is related to gradient, water volume, and channel roughness.

6. The Clearwater River system drains a 145 square mile watershed, is presently unglaciated, and flows 45 miles before entering the Queets River 35 miles south of Forks, Washington.

7. The principal salmonid species are coho and chinook salmon and steelhead and cutthroat trout.

8. The climax vegetation consists of Western Hemlock, White Fir, Sitka Spruce, and Western Red Cedar.

9. The Clearwater watershed is under intensive old growth timber management by the DNR and private companies, and the U.S. Forest Service.

10. Presently, the Clearwater watershed area is approximately 35% logged in the clearcut manner and 70% roaded.

11. The Stequaleho Creek landslides (The Debris Torrent and Yahoo Lake landslides) occurred in May 1971 in the headwaters of two steep tributaries. The volume of sediment entering Stequaleho Creek was estimated to be 20,000 cubic yards. The Yahoo Lake landslide reactivated in the spring of 1973.

12. Stequaleho Creek landslide-affected spawning gravels with mean % fines < 0.850 mm for the second through sixth summers (1972-1976) after the Debris Torrent and Yahoo Lake landslides were 10.91%, 9.91%, 9.00%, 12.01%, and 11.60%; compared to 7.78%, 7.49%, 9.50%, 7.63%, and 9.41% in the control areas, respectively.

13. The mean percentages of materials < 0.850 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, 1973, 1975, and 1976, but not in 1974.

14. The sampling locations at ST-3-B, located in Stequaleho Creek between the two landslides, had mean percentages of fines of 6.72% in 1972; 21.20% in 1973; 17.62% in 1974; no gravel to sample in 1975; and 8.74% in 1976. During the reactivation of the Yahoo Lake landslide in early 1973, heavy sediment was deposited on the upstream side of a large logjam created by the Debris Torrent Slide. This sediment was washed downstream in 1974-1975 when the logjam broke up.

15. Clearwater River landslide-affected spawning gravels with mean % fines < 0.850 mm for the second through sixth summers (1972-1976) after the Debris Torrent and Yahoo Lake landslides were 9.21%, 9.24%, 8.69%, 6.32%, and 12.16%; compared to 7.78%, 7.49%, 9.50%, 7.63%, and 9.41% in the control areas, respectively.

16. The mean percentages of fine materials < 0.850 mm in spawning gravels of the mainstem Clearwater River were found to be significantly (5% level) higher than the controls in the landslide-affected areas (below Stequaleho Creek mouth) in 1972, 1973, and 1976, but not in 1974 and 1975.

17. Gravel samples collected over a 6-year period at three control sites (Cl-1, SO-1, ST-2-A) have shown a gradual build-up of fine sediments (% <0.850 mm) in spawning gravels since logging road construction began.

18. Approximately 1,000 spawning gravel samples collected from 44 basins were correlated with percent of basin logged, miles of road per square mile of basin, and percent of basin area in roads. The spawning gravel sediment sizes that correlated strongest with the above three variables were total materials < 0.850 mm's with r^2 values of 0.44685, 0.42688, and 0.47200, respectively.

19. Numbers of redds of adult coho and chinook salmon and steelhead trout in tributaries and the mainstem Clearwater River were recorded for the years 1972-1978. It was determined that the numbers in Stequaleho Creek were variable from year to year, but generally corresponded in numbers with the other tributaries.

20. During 1975 and 1977 we carried out two laboratory stream experiments to test the effects of fines (% < 0.850 mm) on the survival to emergence of coho salmon eggs. In both years the relationship between these two variables yielded a significant inverse relationship (5% level), $r^2 = -0.696$ in 1975 and $r^2 = -0.692$ in 1977.

21. In an experiment to test the effects of a logging road-caused landslide in the East Fork of Miller Creek, we found that the coho salmon eggs planted in the unaffected (control) area two years after the slide

occurred survived to hatching at an average rate of 57.4%, while in the affected zone the mean survival rate was 24.7%. The survival to the button-up stage of development was 25.6% in the control and 2.3% in the landslide-affected zone.

DISCUSSION AND CONCLUSIONS

Spawning gravel compositions deleterious to salmonid egg survival can occur if soil disturbance from logging roads is allowed to take place without restrictions. Such was the case in 1971 when two massive landslides occurred in Stequaleho Creek, a tributary of the Clearwater River.

During the six year period of observation since the Yahoo Lake and Debris Torrent landslides the spawning gravels of Stequaleho Creek, the main Clearwater River, and other tributaries have been monitored. On the average, the levels of fine sediment (<0.850 mm) have increased in Stequaleho Creek from 8.36% in the control areas to 10.69%, and from 8.36% to 9.12% in the Clearwater River below Stequaleho Creek. These changes represent increases of +2.33% and +0.76% in Stequaleho and the Clearwater River, respectively. This does not include the apparently extreme high levels of sediment observed in the year of the landslides (1971). There are still some sediments stored behind organic debris and across gravel bars throughout the floodplain of upper Stequaleho. These data indicate that a large amount of flushing has occurred since the initial landslides. There is also evidence that although recovery to near natural levels occurred in two of the winters, there are still some sediments to come down from upstream areas.

Our studies of other spawning areas within the Clearwater River-drainage indicate that there is a subtle accumulation of fine sediments occurring in areas of heavy road use. It appears that sediments are accumulating in spawning gravels of areas that are in logged areas that are at least 15% clearcut, with 1.5 miles of road per basin square mile covering 2% of the drainage area. The relative amount of road surface area in a basin has the strongest positive correlation with this sediment build-up.

Platts and Megahan (1975) in their work on the South Fork Salmon River of Idaho found that accumulation of sediments occurs when the supply exceeds a rivers energy to transport it. They also found that when the supply of sediments was stopped, through restrictions in logging, that spawning-bed sedimentation levels decreased rapidly.

According to Dunne and Leopold (1978) a stream that carries a sediment load can be considered a transporting machine that, like all other machines, can be characterized by the relation:

Rate of doing work = available power x efficiency

The available power over a unit area of stream-bed is proportional to the product of the discharge rate times the stream gradient. The efficiency factor is related to the frictional forces existing in the channel (i.e. bed roughness, log jams). From this theory one can imagine the relative sediment flushing potentials of a hypothetical stream say: with a smooth cement bottom compared to a stream with a gravel bottom; and compared to a stream with a gravel bottom and large accumulations of logs and associated debris. The more resistance to flow, the more chance for sediment to be deposited and stored in a streambed. Stequaleho Creek has a relatively steep gradient (2-4%) and a high maximum-minimum flow ratio (400-500:1). These two factors in combination have provided this stream with the energy to flush the large quantities of sediment caused by the original landslides.

The major question that still remains, however, is when a watershed such as the Clearwater is experiencing multiple logging road related sediment inputs throughout the basin (Fiksdal 1974 A & B) how soon does the supply of sediment exceed the energy available in the basin needed to flush it?

Our studies in the East Fork of Miller Creek documented that high sediment levels in spawning areas downstream of a road related landslide were still significantly causing coho egg mortality two years after the slide occurred. The East Fork of Miller Creek is a relatively flat gradient stream (1-2% gradient) and is characterized by heavy accumulations of large organic debris. These debris accumulations were found to be holding back large quantities of sediment apparently caused by the landslide. It was later concluded that sediment from landslides would have a much greater retention time within this spawning tributary compared to Stequaleho Creek. This kind of sediment accumulation therefore has the potential to effect several more generations of spawners.

In conclusion, it appears that the Yahoo Lake and Debris Torrent landslides have had a significant but short-term influence on the spawning gravel composition of Stequaleho Creek. After two winters the sedimentation rates were essentially returned to background levels and this was related to this streams physical ability to flush sediments to downstream areas. Other tributaries, however, possessing less stream power, retain greater amounts of fine sediments for longer periods of time. It is this basin-wide variation in potential for subtle accumulations of fine sediments in downstream spawning gravels that remains our main concern.

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APPENDICES

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

A thesis submitted in partial fulfillment

of the requirements for the degree of

MASTER OF SCIENCE

University of Washington

1975

Approved by ______________________________
(Chairperson of Supervisory Committee)

Program Authorized
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ABSTRACT

During the summers of 1973 and 1974, the populations of juvenile salmonids and other teleosts were censused at 20 different 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 two-, three-, and four-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 into 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 zero 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

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ABSTRACT

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; however, 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 fifty percent 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 percent of the total production, the predators contributed 18 to 29.2 percent 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

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ABSTRACT

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. Percent of gravel <0.850 mm was defined as "poor gravel" while the percent 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.

Behavioral, Physiological and Lethal Effects of Suspended Sediment on Juvenile Salmonids

by

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of the requirements for the degree of

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University of Washington

Abstract

BEHAVIORAL, PHYSIOLOGICAL AND LETHAL EFFECTS OF SUSPENDED SEDIMENT ON JUVENILE SALMONIDS

By Charles C. Noggle

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Studies were conducted to assess the effects of suspended sediment upon juvenile salmonids in the stream environment. Static bioassay tanks were used to determine 96 hour LC50's, changes in gill histology, and changes in blood physiology. Two experimental stream designs were used to relate sediment concentrations to avoidance behavior.

Results indicate seasonal changes in the tolerance of salmonids to suspended sediment. Bioassays conducted in summer produced LC50's less than 1,500 mg/ℓ, while autumn bioassays showed LC50's in excess of 30,000 mg/ℓ. Histological examination of gills revealed structural damage by suspended sediment. Blood chemistry showed elevated blood glucose levels at sublethal suspended sediment concentrations. Experiments conducted with a turbid artificial stream and clear tributary indicated a reluctance by the fish to leave their established territories. Studies conducted with a Y-shaped stream showed a preference for turbid water at medium concentrations and slight avoidance at high concentrations.

THE EFFECTS OF FOREST DEBRIS REMOVAL ON A POPULATION OF RESIDENT CUTTHROAT TROUT IN A SMALL HEADWATER STREAM

by

Lawrence Charles Lestelle

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of the requirements for the degree of

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University of Washington

Abstract

THE EFFECTS OF FOREST DEBRIS REMOVAL ON A POPULATION OF RESIDENT CUTTHROAT TROUT IN A SMALL HEADWATER STREAM

By Lawrence Charles Lestelle

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Logging along small streams can sometimes deplete the stream environment of natural forest debris, e.g., logs and stumps, due to indiscriminate yarding and cleanup measures. An experiment was conducted to determine effects of overcleaning a stream course of forest debris on a resident salmonid population. The study was conducted in two headwater streams of the Clearwater River, Washington during 1972 and 1973.

Stream clearance had little or no effect on numbers and biomass of cutthroat trout immediately after alteration and prior to winter. Subsequently, large reductions did occur over winter 1972-1973 but these losses were short-term. A decline in numbers of overwintering trout was apparently associated with environmental instability brought on by the removal of large forest debris from the stream channel. Within one year of debris alterations, the population had returned to pretreatment levels. The physical characteristics of the stream were also largely restored to pretreatment conditions within one year of debris removal.

APPENDIX TABLE I

APPENDIX TABLE I

HURST CREEK #1   N = 10

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	1.8	33.2	42.0	14.7	5.1
s^2	33.9	137.0	89.1	18.5	5.7
St dev	5.8	11.7	9.4	4.3	2.4
SE Mn	1.8	3.7	3.0	1.4	0.8
95 Con	4.2	8.4	6.7	3.1	1.7

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	98.2	65.0	23.0	8.3	3.2
s^2	33.9	165.7	30.0	8.3	1.1
St dev	5.8	12.9	5.5	2.9	1.0
SE Mn	1.8	4.1	1.7	0.9	0.3
95 Con	4.2	9.2	3.9	2.1	0.7

HURST CREEK #2   N = 10

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	5.1	40.2	36.4	11.8	4.2
s^2	157.7	52.5	73.3	23.4	4.5
St dev	12.6	7.2	8.6	4.8	2.1
SE Mn	4.0	2.3	2.7	1.5	0.7
95 Con	9.0	5.2	6.1	3.5	1.5

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	94.9	54.8	18.4	6.8	2.3
s^2	157.7	182.9	49.4	6.6	1.6
St dev	12.6	13.5	7.0	2.6	1.3
SE Mn	4.0	4.3	2.2	0.8	0.4
95 Con	9.0	9.7	5.0	1.8	0.9

APPENDIX TABLE I
(Continued)

HURST CREEK #3   N = 16

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	2.7	40.1	35.6	10.7	7.6
s^2	35.5	56.3	17.6	20.5	13.6
St dev	6.0	7.5	4.2	4.5	3.7
SE Mn	1.5	1.9	1.0	1.1	0.9
95 Con	3.2	4.0	2.2	2.4	2.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.3	57.2	21.6	10.8	3.2
s^2	35.4	70.4	49.3	18.1	4.2
St dev	5.9	8.4	7.0	4.3	2.0
SE Mn	1.5	2.1	1.8	1.1	0.5
95 Con	3.2	4.5	3.7	2.3	1.1

SHALE CREEK #1   N = 17

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	10.3	38.9	33.0	10.1	5.6
s^2	176.3	106.4	120.0	11.1	3.8
St dev	13.3	10.3	11.0	3.3	2.0
SE Mn	3.2	2.5	2.7	0.8	0.5
95 Con	6.8	5.3	5.6	1.7	1.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	89.8	50.9	17.5	7.8	2.2
s^2	176.3	173.7	30.0	10.4	2.3
St dev	13.3	13.2	5.5	3.2	1.5
SE Mn	3.2	3.2	1.3	0.8	0.4
95 Con	6.8	6.8	2.8	1.7	0.8

APPENDIX TABLE I
(Continued)

SHALE CREEK #2 N = 15

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	13.1	34.2	28.9	13.8	6.9
s^2	311.9	89.9	59.1	39.3	3.1
St dev	17.7	9.5	7.7	6.3	1.8
SE Mn	4.6	2.4	2.0	1.6	0.5
95 Con	9.8	5.2	4.2	3.5	1.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	86.9	52.7	23.8	10.0	3.2
s^2	311.9	222.1	67.8	8.1	3.4
St dev	17.7	14.9	8.2	2.8	1.8
SE Mn	4.6	3.8	2.1	0.7	0.5
95 Con	9.8	8.2	4.6	1.6	1.0

W. F. MILLER CREEK #1 N = 14

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	2.5	24.2	39.6	17.5	8.8
s^2	57.0	222.5	115.9	45.3	10.5
St dev	7.5	15.0	10.8	6.7	3.2
SE Mn	2.0	4.0	2.9	1.8	0.9
95 Con	4.4	8.6	6.2	3.9	1.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.5	73.3	33.8	16.2	7.4
s^2	56.9	301.8	62.8	24.0	9.2
St dev	7.5	17.4	7.9	4.9	3.0
SE Mn	2.0	4.6	2.1	1.3	0.8
95 Con	4.4	10.0	4.6	2.8	1.7

APPENDIX TABLE I
(Continued)

W. F. MILLER CREEK #2 N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	12.8	30.4	30.2	13.6	8.5
s^2	262.0	182.6	21.3	4.3	12.7
St dev	16.1	13.5	4.6	2.1	3.6
SE Mn	6.6	5.5	1.9	0.8	1.5
95 Con	17.0	14.1	4.8	2.2	3.7

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	87.2	56.8	26.5	13.0	4.5
s^2	262.0	79.2	36.8	22.8	2.5
St dev	16.2	8.9	6.1	4.8	1.6
SE Mn	6.6	3.6	2.5	1.9	0.6
95 Con	17.0	9.3	6.4	5.0	1.7

W. F. MILLER CREEK #3 N = 21

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	1.8	29.8	39.4	17.4	8.5
s^2	21.7	52.5	57.0	19.7	2.3
St dev	4.7	7.2	7.6	4.4	1.5
SE Mn	1.0	1.6	1.6	1.0	0.3
95 Con	2.1	3.3	3.4	2.0	0.7

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	98.2	68.5	29.1	11.7	3.1
s^2	21.7	83.5	24.4	4.2	1.9
St dev	4.7	9.2	5.0	2.1	1.4
SE Mn	1.0	2.0	1.1	0.4	0.3
95 Con	2.1	4.2	2.3	0.9	0.6

APPENDIX TABLE I
(Continued)

E. F. MILLER CREEK #1   N = 14

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	3.0	38.8	30.3	11.7	10.8
s^2	61.0	55.0	46.7	15.2	6.1
St dev	7.8	7.4	6.8	3.9	2.5
SE Mn	2.1	2.0	1.8	1.0	0.7
95 Con	4.5	4.3	4.0	2.3	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.1	58.3	28.0	16.3	5.5
s^2	61.0	89.2	17.8	15.3	5.2
St dev	7.8	9.4	4.2	3.9	2.3
SE Mn	2.1	2.5	1.1	1.0	0.6
95 Con	4.5	5.4	2.4	2.3	1.3

E. F. MILLER CREEK #2   N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	34.0	35.5	13.2	13.0
s^2	0.0	61.0	55.6	33.5	8.5
St dev	0.0	7.8	7.5	5.8	3.0
SE Mn	0.0	3.2	3.0	2.4	1.2
95 Con	0.0	8.2	7.8	6.1	3.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	66.0	30.5	17.3	4.3
s^2	0.0	61.0	42.0	7.5	3.5
St dev	0.0	7.8	6.5	2.7	1.9
SE Mn	0.0	3.2	2.6	1.1	0.8
95 Con	0.0	8.2	6.8	2.9	2.0

APPENDIX TABLE I
(Continued)

E. F. MILLER CREEK #3 N = 4

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	27.7	38.3	18.3	11.3
s^2	0.0	78.4	46.8	9.0	4.4
St dev	0.0	8.9	6.8	3.0	2.1
SE Mn	0.0	4.4	3.4	1.5	1.0
95 Con	0.0	14.1	10.9	4.8	5.3

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	72.3	34.1	15.8	4.5
s^2	0.0	78.4	14.0	4.2	2.0
St dev	0.0	8.9	3.7	2.1	1.4
SE Mn	0.0	4.4	1.9	1.0	0.7
95 Con	0.0	14.1	6.0	3.3	2.3

E. F. MILLER CREEK #4 N = 21

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.3	34.2	36.1	12.1	9.6
s^2	56.8	142.6	75.4	18.8	22.3
St dev	7.5	12.0	8.7	4.3	4.7
SE Mn	1.6	2.6	1.9	0.9	1.0
95 Con	3.4	5.4	4.0	2.0	2.2

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	95.7	61.4	25.4	13.2	3.6
s^2	56.8	196.4	47.8	19.0	3.3
St dev	7.5	14.0	6.9	4.4	1.9
SE Mn	1.6	3.1	1.5	1.0	0.4
95 Con	3.4	6.4	3.1	2.0	0.9

APPENDIX TABLE I
(Continued)

CHRISTMAS CREEK #1 N = 4

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	8.2	37.3	31.9	11.9	8.2
s^2	89.7	48.5	44.8	22.0	10.2
St dev	9.5	6.9	6.7	4.7	3.2
SE Mn	4.7	3.5	3.3	2.3	1.6
95 Con	15.0	11.1	10.6	7.4	5.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	91.8	54.5	22.6	10.6	2.4
s^2	89.7	135.2	65.6	16.0	0.7
St dev	9.5	11.6	8.1	4.0	0.9
SE Mn	4.7	5.8	4.1	2.0	0.4
95 Con	15.1	18.5	12.9	6.4	1.4

CHRISTMAS CREEK #2 N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	7.9	26.1	37.2	12.0	9.0
s^2	42.2	62.0	22.3	4.0	1.7
St dev	6.5	7.9	4.7	2.0	1.3
SE Mn	2.7	3.2	2.0	0.8	0.5
95 Con	6.8	8.3	5.0	2.1	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	92.1	66.0	28.8	16.8	7.8
s^2	42.2	9.2	18.3	14.7	7.5
St dev	6.5	3.0	4.3	3.8	2.7
SE Mn	2.7	1.2	1.7	1.6	1.1
95 Con	6.8	3.2	4.5	4.0	2.9

APPENDIX TABLE 1
(Continued)

CHRISTMAS CREEK #5   N = 14

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	3.0	27.0	38.1	12.8	15.0
s^2	36.5	100.3	44.2	12.4	48.5
St dev	6.0	10.0	6.7	3.5	7.0
SE Mn	1.6	2.7	1.8	0.9	1.9
95 Con	3.5	5.8	3.8	2.0	4.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.0	70.0	32.0	19.1	4.1
s^2	36.5	65.7	100.9	53.2	4.7
St dev	6.0	8.1	10.0	7.3	2.2
SE Mn	1.6	2.2	2.7	2.0	0.6
95 Con	3.5	4.7	5.8	4.2	1.2

SNAHAPISH RIVER #1   N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.4	28.7	45.2	13.1	6.7
s^2	47.2	337.9	49.5	46.2	13.5
St dev	6.9	18.4	7.0	6.8	3.7
SE Mn	2.8	7.5	2.9	2.8	1.5
95 Con	7.2	19.3	7.4	7.1	3.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	95.6	66.9	21.6	8.6	1.9
s^2	47.2	226.3	110.6	15.7	0.8
St dev	6.9	15.0	10.5	4.0	0.9
SE Mn	2.8	6.1	4.3	1.6	0.4
95 Con	7.2	15.8	11.0	4.2	0.9

APPENDIX TABLE I
(Continued)

SNAHAPISH RIVER #2 N = 10

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	1.1	42.5	31.9	12.1	9.5
s^2	12.7	161.3	21.4	30.1	23.8
St dev	3.6	12.7	4.6	5.5	4.9
SE Mn	1.1	4.0	1.5	1.7	1.5
95 Con	2.5	9.1	3.3	3.9	3.5

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	98.9	56.4	24.5	12.5	3.0
s^2	12.7	139.5	111.6	38.0	6.8
St dev	3.6	11.8	10.6	6.2	2.6
SE Mn	1.1	3.7	3.3	2.0	0.8
95 Con	2.5	8.4	7.5	4.4	1.8

SNAHAPISH RIVER #3 N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	8.2	35.4	31.3	10.9	10.2
s^2	402.4	198.5	38.5	11.5	45.3
St dev	20.1	14.1	6.2	3.4	6.7
SE Mn	8.2	5.8	2.5	1.4	2.7
95 Con	21.1	14.8	6.5	3.6	7.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	91.8	56.5	25.2	14.2	4.0
s^2	402.4	212.9	98.4	47.5	1.6
St dev	20.1	14.6	9.9	6.9	1.2
SE Mn	8.2	6.0	4.1	2.8	0.5
95 Con	21.0	15.3	10.4	7.2	1.3

APPENDIX TABLE I
(Continued)

SNAHAPISH RIVER #4 N = 8

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	40.3	36.2	11.8	9.0
s^2	0.0	125.8	42.9	13.1	5.8
St dev	0.0	11.2	6.6	3.6	2.4
SE Mn	0.0	4.0	2.3	1.3	0.9
95 Con	0.0	9.4	5.5	3.0	2.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	59.7	23.5	11.7	2.7
s^2	0.0	125.8	37.2	8.5	1.3
St dev	0.0	11.2	6.1	2.9	1.1
SE Mn	0.0	4.0	2.2	1.0	0.4
95 Con	0.0	9.4	5.1	2.4	0.9

SNAHAPISH RIVER #5 N = 14

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.4	46.4	33.1	6.4	5.8
s^2	66.3	115.1	95.7	12.8	5.9
St dev	8.1	10.7	9.8	3.6	2.4
SE Mn	2.2	2.9	2.6	0.9	0.7
95 Con	4.7	6.2	5.6	2.1	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	95.7	49.2	16.1	9.7	3.9
s^2	66.3	163.3	35.0	10.8	1.5
St dev	8.1	12.8	5.9	3.3	1.2
SE Mn	2.2	3.4	1.6	0.9	0.3
95 Con	4.7	7.4	3.4	1.9	0.7

APPENDIX TABLE I
(Continued)

BULL CREEK #1 N = 20

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	6.3	35.8	36.1	10.9	5.7
s^2	96.1	130.0	63.7	13.7	4.5
St dev	9.8	11.4	8.0	3.7	2.1
SE Mn	2.2	2.5	1.8	0.8	0.5
95 Con	4.6	5.3	3.7	1.7	1.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	93.7	57.9	21.9	10.9	5.3
s^2	96.1	134.4	35.3	10.4	1.9
St dev	9.8	11.6	5.9	3.2	1.4
SE Mn	2.2	2.6	1.3	0.7	0.3
95 Con	4.6	5.4	2.8	1.5	0.7

STEQUALEHO CREEK #1 N = 34

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	3.8	38.1	37.8	10.9	6.4
s^2	53.4	112.6	90.4	19.8	10.8
St dev	7.3	10.6	9.5	4.4	3.3
SE Mn	1.3	1.8	1.6	0.8	0.6
95 Con	2.5	3.7	3.3	1.5	1.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	96.2	58.1	20.3	9.5	3.1
s^2	53.4	160.1	63.2	22.9	3.2
St dev	7.3	12.7	8.0	4.8	1.8
SE Mn	1.3	2.2	1.4	0.8	0.3
95 Con	2.5	4.4	2.8	1.7	0.6

APPENDIX TABLE I
(Continued)

STEQUALEHO CREEK #2   N = 43

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	5.3	38.8	36.2	12.7	5.0
s^2	110.1	148.9	62.6	24.5	3.4
St dev	10.5	12.2	7.9	5.0	1.8
SE Mn	1.6	1.9	1.2	0.8	0.3
95 Con	3.2	3.8	2.4	1.5	0.6

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	94.7	55.8	19.7	6.9	2.0
s^2	110.1	124.6	36.6	6.2	1.3
St dev	10.5	11.2	6.1	2.5	1.1
SE Mn	1.6	1.7	0.9	0.4	0.2
95 Con	3.2	3.4	1.9	0.8	0.3

STEQUALEHO CREEK #3   N = 38

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	2.8	40.9	37.1	10.4	8.5
s^2	40.9	98.6	43.2	13.5	6.8
St dev	6.4	9.9	6.6	3.7	2.6
SE Mn	1.0	1.6	1.1	0.6	0.4
95 Con	2.1	3.3	2.2	1.2	0.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.2	56.3	19.3	8.9	2.4
s^2	40.9	94.5	27.7	9.3	1.6
St dev	6.4	9.7	5.3	3.0	1.2
SE Mn	1.0	1.6	0.9	0.5	0.2
95 Con	2.1	3.2	1.7	1.0	0.4

APPENDIX TABLE I
(Continued)

STEQUALEHO CREEK #4   N = 19

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	2.4	33.6	42.1	13.2	6.7
s^2	38.8	85.1	86.6	14.5	6.4
St dev	6.2	9.2	9.3	3.8	2.5
SE Mn	1.4	2.1	2.1	0.9	0.6
95 Con	3.0	4.4	4.5	1.8	1.2

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	97.6	63.9	21.8	8.6	1.9
s^2	38.8	159.6	26.2	7.3	1.6
St dev	6.2	12.6	5.1	2.7	1.3
SE Mn	1.4	2.9	1.2	0.6	0.3
95 Con	3.0	6.1	2.5	1.3	0.6

STEQUALEHO CREEK #5   N = 29

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.2	30.4	37.9	13.0	11.1
s^2	101.6	187.7	162.9	16.4	124.0
St dev	10.1	13.7	12.8	4.1	11.1
SE Mn	1.9	2.5	2.4	0.8	2.1
95 Con	3.8	5.2	4.9	1.5	4.2

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	95.8	65.4	27.5	14.5	3.4
s^2	101.6	199.2	238.3	181.9	9.6
St dev	10.1	14.1	15.4	13.5	3.1
SE Mn	1.9	2.6	2.9	2.5	0.6
95 Con	3.8	5.4	5.9	5.1	1.2

APPENDIX TABLE I
(Continued)

STEQUALEHO CREEK #6   N = 35

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	7.6	24.8	44.2	13.7	7.5
s^2	208.5	113.8	135.2	18.7	8.9
St dev	14.4	10.7	11.6	4.3	3.0
SE Mn	2.4	1.8	2.0	0.7	0.5
95 Con	5.0	3.7	4.0	1.5	1.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	92.4	67.6	23.4	9.7	2.2
s^2	208.5	254.6	52.5	12.7	0.9
St dev	14.4	16.0	7.2	3.6	1.0
SE Mn	2.4	2.7	1.2	0.6	0.2
95 Con	5.0	5.5	2.5	1.2	0.3

STEQUALEHO CREEK #7   N = 47

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.0	30.3	40.7	14.6	7.9
s^2	77.3	95.9	71.3	25.6	6.9
St dev	8.8	9.8	8.4	5.1	2.6
SE Mn	1.3	1.4	1.2	0.7	0.4
95 Con	2.6	2.9	2.5	1.5	0.8

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	96.0	65.7	25.0	10.4	2.5
s^2	77.3	113.3	48.4	13.2	2.4
St dev	8.8	10.6	7.0	3.6	1.6
SE Mn	1.3	1.6	1.0	0.5	0.2
95 Con	2.6	3.1	2.0	1.1	0.3

APPENDIX TABLE I
(Continued)

STEQUALEHO CREEK #8 N = 46

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.0	30.6	35.7	17.7	8.3
s^2	76.3	143.1	67.5	60.6	8.4
St dev	8.7	12.0	8.2	7.8	2.9
SE Mn	1.3	1.8	1.2	1.1	0.4
95 Con	2.6	3.6	2.4	2.3	0.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	96.0	65.3	29.6	11.9	3.6
s^2	76.3	159.7	96.6	13.3	2.7
St dev	8.7	12.6	9.8	3.6	1.6
SE Mn	1.3	1.9	1.5	0.5	0.2
95 Con	2.6	3.8	2.9	1.1	0.5

SOLLEKS RIVER #1 N = 29

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	9.5	31.8	38.1	12.5	5.0
s^2	163.9	149.5	160.7	19.2	5.0
St dev	12.8	12.2	12.7	4.4	2.2
SE Mn	2.4	2.3	2.4	0.8	0.4
95 Con	4.9	4.6	4.8	1.7	0.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	90.5	58.7	20.7	8.1	3.2
s^2	163.9	147.8	34.2	9.8	1.3
St dev	12.8	12.2	5.8	3.1	1.2
SE Mn	2.4	2.3	1.1	0.6	0.2
95 Con	4.9	4.6	2.2	1.2	0.5

APPENDIX TABLE I
(Continued)

SOLLEKS RIVER #2 N = 28

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	5.1	25.2	48.4	12.1	6.7
S^2	137.0	162.9	270.1	56.4	15.7
St dev	11.7	12.8	16.4	7.5	4.0
SE Mn	2.2	2.4	3.1	1.4	0.7
95 Con	4.5	4.9	6.4	2.9	1.5

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	94.9	69.8	21.3	9.3	2.5
S^2	136.0	308.1	90.2	19.5	2.0
St dev	11.7	17.6	9.5	4.4	1.4
SE Mn	2.2	3.3	1.8	0.8	0.3
95 Con	4.5	6.8	3.7	1.7	0.5

SOLLEKS RIVER #3 N = 34

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	5.4	31.1	44.5	12.5	4.5
S^2	109.6	227.8	314.3	32.9	9.7
St dev	10.5	15.1	17.7	5.7	3.1
SE Mn	1.8	2.6	3.0	1.0	0.5
95 Con	3.6	5.3	6.2	2.0	1.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	94.6	63.5	19.0	6.5	2.0
S^2	109.6	302.6	68.3	10.5	1.5
St dev	10.5	17.4	8.3	3.2	1.2
SE Mn	1.8	3.0	1.4	0.6	0.2
95 Con	3.6	6.1	2.9	1.1	0.4

APPENDIX TABLE I
(Continued)

CLEARWATER RIVER #1 N = 27

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	4.6	23.7	47.1	16.3	6.1
s^2	97.6	105.3	178.6	36.7	4.6
St dev	9.9	10.3	13.4	6.1	2.1
SE Mn	1.9	2.0	2.6	1.2	0.4
95 Con	3.9	4.1	5.3	2.4	0.8

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	95.4	71.7	24.6	8.3	2.2
s^2	97.6	195.4	49.2	5.9	0.7
St dev	9.9	14.0	7.0	2.4	0.8
SE Mn	1.9	2.7	1.4	0.5	0.2
95 Con	3.9	5.5	2.8	1.0	0.3

CLEARWATER RIVER #2 N = 22

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	3.7	29.0	42.4	16.5	7.0
s^2	45.7	152.6	144.7	17.2	7.9
St dev	6.8	12.4	12.0	4.1	2.8
SE Mn	1.4	2.6	2.6	0.9	0.6
95 Con	3.0	5.5	5.3	1.8	1.2

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	96.3	67.2	24.8	8.3	1.3
s^2	45.7	164.3	24.8	10.7	0.7
St dev	6.8	12.8	5.0	3.3	0.9
SE Mn	1.4	2.7	1.1	0.7	0.2
95 Con	3.0	5.7	2.2	1.5	0.4

APPENDIX TABLE I
(Continued)

CLEARWATER RIVER #3 N = 25

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	5.6	34.8	33.9	17.0	6.3
s^2	73.1	48.5	135.6	95.9	5.0
St dev	8.6	7.0	11.6	9.8	2.2
SE Mn	1.7	1.4	2.3	2.0	0.4
95 Con	3.5	2.9	5.0	4.0	0.9

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	94.4	59.6	25.7	8.7	2.4
s^2	73.1	106.4	116.7	6.6	1.5
St dev	8.6	10.3	10.8	2.6	1.2
SE Mn	1.7	2.1	2.2	0.5	0.3
95 Con	3.5	4.3	4.5	1.1	0.5

CLEARWATER RIVER #4 N = 39

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	9.1	33.4	32.6	15.3	7.3
s^2	211.5	166.0	46.7	65.4	6.3
St dev	14.5	12.9	6.8	8.1	2.5
SE Mn	2.3	2.1	1.1	1.3	0.4
95 Con	4.7	4.2	2.2	2.6	0.8

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	90.9	57.5	24.9	9.6	2.2
s^2	211.5	139.4	76.8	10.2	1.6
St dev	14.5	11.8	8.8	3.2	1.3
SE Mn	2.3	1.9	1.4	0.5	0.2
95 Con	4.7	3.8	2.8	1.0	0.4

APPENDIX TABLE I
(Continued)

CLEARWATER RIVER #5   N = 73

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	3.8	41.7	33.0	13.7	5.8
s^2	57.1	59.5	74.0	48.3	8.8
St dev	7.6	7.7	8.6	7.0	3.0
SE Mn	0.9	0.9	1.0	0.8	0.3
95 Con	1.8	1.8	2.0	1.6	0.7

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	96.2	54.4	21.4	7.7	1.8
s^2	57.1	77.1	78.9	10.3	1.7
St dev	7.6	8.8	8.9	3.2	1.3
SE Mn	0.9	1.0	1.0	0.4	0.2
95 Con	1.8	2.1	2.1	0.8	0.3

CLEARWATER RIVER #6   N = 61

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.8	29.3	52.2	8.0	7.2
s^2	10.7	203.0	129.3	56.3	28.9
St dev	3.3	14.2	11.4	7.5	5.4
SE Mn	0.4	1.8	1.5	0.9	0.7
95 Con	0.8	3.6	2.9	1.9	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	99.3	70.0	17.8	9.8	2.6
s^2	10.7	233.4	105.6	28.3	2.6
St dev	3.3	15.3	10.3	5.3	1.6
SE Mn	0.4	2.0	1.3	0.7	0.2
95 Con	0.8	3.9	2.6	1.4	0.4

APPENDIX TABLE 1
(Continued)

CLEARWATER RIVER #7   N = 17

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.5	45.0	31.1	7.0	11.5
s^2	4.0	82.8	28.3	11.3	6.0
St dev	2.0	9.1	5.3	3.4	2.4
SE Mn	0.5	2.2	1.3	0.8	0.6
95 Con	1.0	4.7	2.7	1.7	1.3

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	99.5	54.6	23.5	16.5	4.9
s^2	4.0	66.1	21.2	12.7	4.2
St dev	2.0	8.1	4.6	3.6	2.0
SE Mn	0.5	2.0	1.1	0.9	0.5
95 Con	1.0	4.2	2.4	1.8	1.1

S. F. HOH RIVER TRIBUTARY   N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	51.5	34.4	11.1	2.7
s^2	0.0	349.4	163.1	43.7	4.0
St dev	0.0	18.7	12.8	6.6	2.0
SE Mn	0.0	7.6	5.2	2.7	0.8
95 Con	0.0	19.6	13.4	6.9	2.1

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	48.5	14.1	3.1	0.4
s^2	0.0	349.4	71.5	4.3	0.0
St dev	0.0	18.7	8.5	2.1	0.1
SE Mn	0.0	7.6	3.5	0.8	0.1
95 Con	0.0	19.6	8.9	2.2	0.1

APPENDIX TABLE I
(Continued)

S. F. HOH RIVER   N = 19

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	35.7	37.9	18.1	7.2
s^2	0.0	102.7	61.1	26.5	9.0
St dev	0.0	10.1	7.8	5.1	3.0
SE Mn	0.0	2.3	1.8	1.2	0.7
95 Con	0.0	4.9	3.8	2.5	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	64.4	26.4	8.3	1.1
s^2	0.0	102.7	26.1	11.0	0.3
St dev	0.0	10.1	5.1	3.3	0.5
SE Mn	0.0	2.3	1.2	0.8	0.1
95 Con	0.0	4.9	2.5	1.6	0.3

TSHLETCHY CREEK   N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	43.7	33.2	17.1	4.8
s^2	0.0	29.3	8.4	8.7	1.8
St dev	0.0	5.4	2.9	2.9	1.3
SE Mn	0.0	2.2	1.2	1.2	0.5
95 Con	0.0	5.7	3.0	3.1	1.4

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	56.3	23.1	6.0	1.2
s^2	0.0	29.3	15.0	2.4	0.3
St dev	0.0	5.4	3.9	1.5	0.5
SE Mn	0.0	2.2	1.6	0.6	0.2
95 Con	0.0	5.7	4.1	1.6	0.5

APPENDIX TABLE I
(Continued)

BOB CREEK N = 6

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	43.7	42.1	9.3	3.5
s^2	0.0	98.8	13.7	51.1	8.2
St dev	0.0	9.9	3.7	7.1	2.9
SE Mn	0.0	4.1	1.5	2.9	1.2
95 Con	0.0	10.4	3.9	7.5	3.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	56.3	14.2	4.9	1.4
s^2	0.0	98.8	106.7	10.5	0.3
St dev	0.0	9.9	10.3	3.2	0.5
SE Mn	0.0	4.1	4.2	1.3	0.2
95 Con	0.0	10.4	10.8	3.4	0.6

HARLOW CREEK N = 5

Percentage sediment retrieved by each sieve size

	77 mm	26.9 mm	3.36 mm	0.850 mm	0.105 mm
Mean	0.0	13.4	66.2	10.8	7.5
s^2	0.0	57.7	33.7	64.5	2.6
St dev	0.0	7.6	5.8	8.0	1.6
SE Mn	0.0	3.4	2.6	3.6	0.7
95 Con	0.0	9.4	7.2	10.0	2.0

Percentage sediment smaller than (LT) each sieve

	LT 77 mm	LT 26.9 mm	LT 3.36 mm	LT 0.850 mm	LT 0.105 mm
Mean	100.0	86.6	20.4	9.6	2.0
s^2	0.0	57.7	56.1	2.9	0.6
St dev	0.0	7.6	7.3	1.7	0.8
SE Mn	0.0	3.4	3.4	0.8	0.3
95 Con	0.0	9.4	9.3	2.1	1.0