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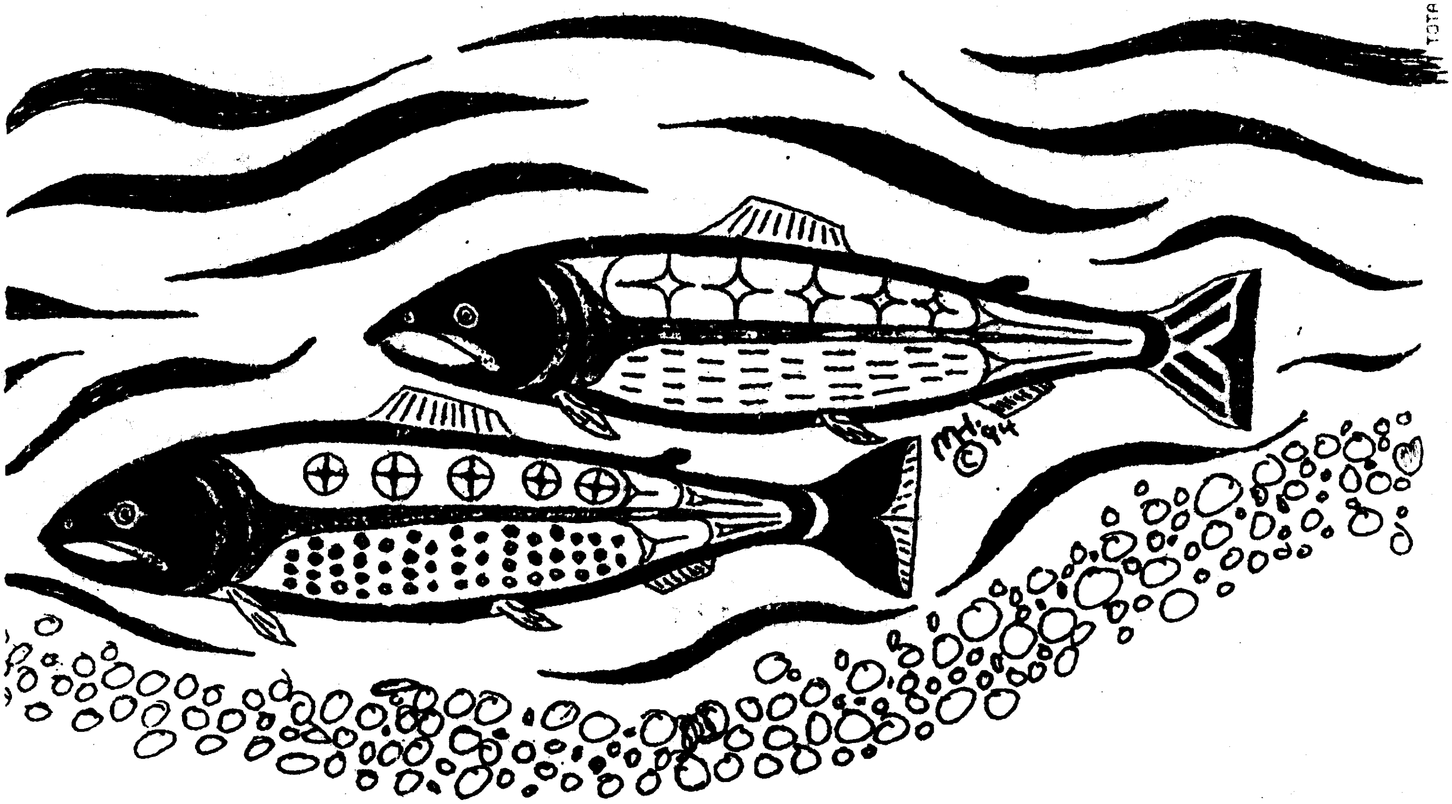

Spawning Gravel Quality, Watershed Characteristics and Early Life History Survival of Coho Salmon and Steelhead in Five North Olympic Peninsula Watersheds

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Centennial Clean Water Fund &
Section 205J Clean Water Act

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ABSTRACT

We evaluated the effects of managed and natural watershed characteristics on Salmonid spawning gravel quality and early life history in five North Olympic Peninsula watersheds. The percentages of four classes of fine sediment (<0.106, 0.85, 2.0, 3.35 mm) were not strongly correlated to parameters associated with managed watersheds. However, sediment levels <0.85 mm in spawning gravel were consistently above levels considered harmful to incubating Salmonid embryos. Lack of correlation between land use and sediment composition are probably related to the inability to quantitatively assess the impacts of historic logging activities, the influence of a unique sedimentary lithology, and the lack of pristine watersheds in the study area. Both land management activities and natural watershed characteristics were positively correlated to stream geometry, particularly bankfull width and depth. Survival of incubating coho and steelhead eggs was highly variable (0 to 53%) and did not correlate with measures of spawning gravel quality or inter-gravel dissolved oxygen. When fine sediments (<0.85 mm) exceeded 13%, Salmonid survival dropped drastically. This suggests the existence of a threshold over which survival is very low. We observed significant aggradation and degradation of channel beds during Salmonid survival tests. Such events likely influence Salmonid early life history and may be related to both past and present land management activities manifested through changes in channel form and sediment yield.

INTRODUCTION

The relationship between land management practices, non-point source pollutants and beneficial uses has received increasing scrutiny from researchers and resource management agencies. In Washington, these concerns have largely focused on the question of the cumulative impact of historic and modern watershed management practices on Salmonid fishes.

On the Olympic Peninsula, the dominant land use for the past century has been forestry. Forest management activities have been shown to accelerate the delivery of coarse and fine sediments to stream channels (Brown 1983; Hartmann & Scrivener 1990). Historic records indicate that logging activities on the Olympic Peninsula began in the late nineteenth century and accelerated in magnitude by the early twentieth century (Fish 1983). Early logging techniques were extremely destructive to stream habitats. Railroad logging, steam donkeys, and log floats were common practices, and resulted in altered stream morphology, and massive sediment delivery (Seddell & Luchessa 1982). By the 1940's truck logging was adopted as the preferred method for harvest. This system required the construction of many miles of road, and allowed access to steep, unstable areas of watersheds. Road construction techniques were initially primitive and often caused catastrophic landslide and debris flow events (Cederholm et al. 1981; Swanson et al. 1987). Roads also act as conduits of water and sediment to streams (Megahan & Kidd 1972).

While modern forestry practices are generally conducted with greater sensitivity to aquatic resources, they do not necessarily account for ecological processes, fluvial sediment transport and cumulative watershed effects (Bisson et al. 1987). Road densities are often high, older road systems and railroad grades may be poorly maintained, harvest rates may be rapid, and riparian vegetation may be altered. On the Olympic Peninsula, natural watershed characteristics are conducive to accelerated erosion (SCS 1984). Sedimentary rocks, primarily sandstones and siltstones are typically poorly indurated, and rapidly decompose through chemical weathering associated with the regions heavy rainfall, and disaggregate by abrasion during transport events (Benda 1993). Streambank and floodplains composed of these friable materials are weakly resistant to erosion and react rapidly to channel changing disturbances (variations in flow and sediment discharge), both natural and management related. As a result, significant sediment aggradation within the lower, low gradient reaches of many channels suggest that these processes continue to affect channel transport behavior and capacity.

Rivers maintain a natural or background level of sediment from erosion from various sources within the watershed. The amount of sediment stored in the stream channel may be described as:

Storage = Inputs - Transport Capacity

This concept is referred to as the dynamic equilibrium principle (Mackin 1948). When the transport capacity of a river is exceeded, a stream channel responds by storing sediments. Areas of deposition generally occur in low-energy environments of less than 3% gradient, typically along the sides of the channel (bars), back eddies, and pools (Jackson & Beschta 1982). These areas, especially pool tailouts, are actively selected by salmonids for incubating their eggs. Aggradation of fine sediments within these areas affects the incubation success of embryonic salmonids (Koski 1966; Irving & Bjornn 1984; Everest et al. 1987). Reduced water exchange within the gravel due to excessive fine sediments can lower oxygen levels or raise metabolite concentrations such that mortality occurs. Alevins may also be physically trapped so that they are unable to emerge from the gravel. Many detailed reviews have been written on this subject (Cordone & Kelley 1961; Hall 1984; Sorensen et al. 1977; Iwamoto et al. 1978; Chapman & McLeod 1987).

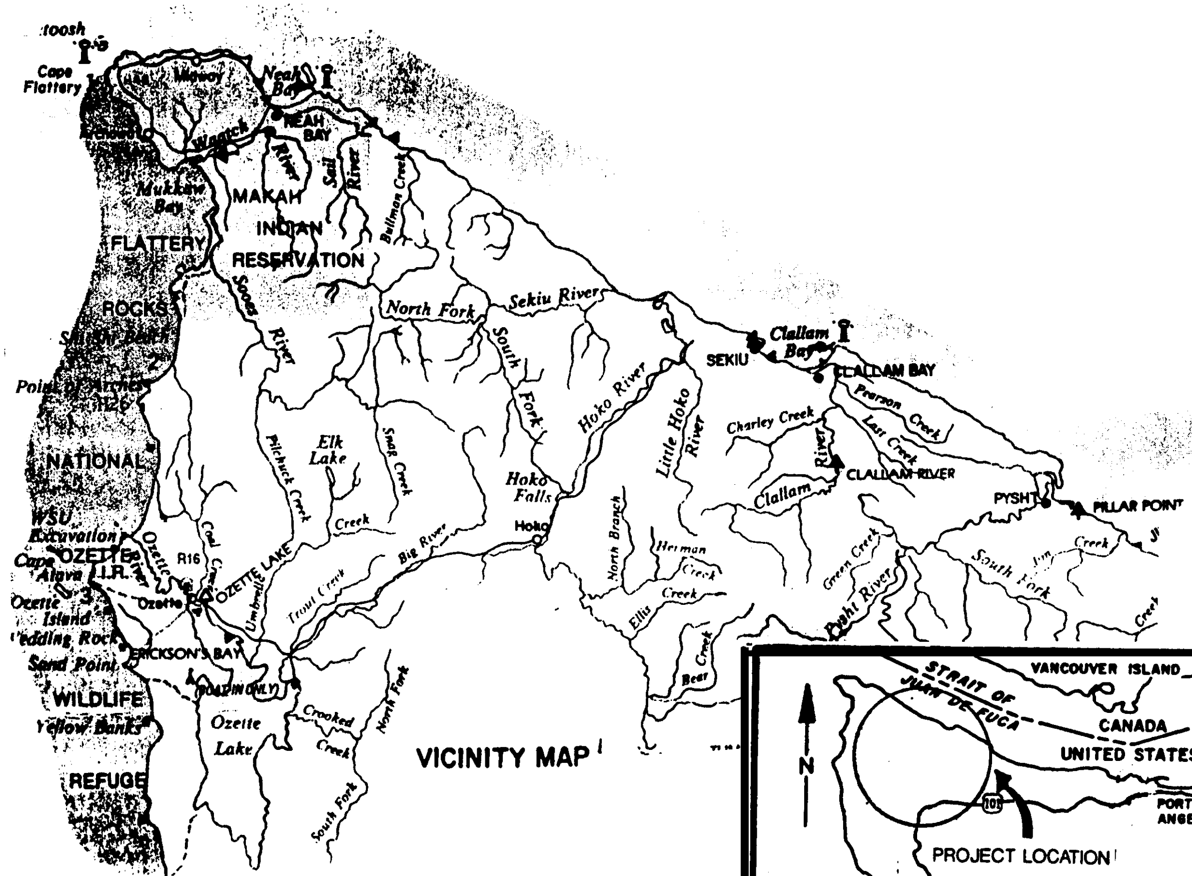
Although research on the effects of fine sediment on Salmonid reproductive success dates to the 1920's (Harrison 1923), the dynamics of this relationship have proven elusive. Chapman **(1988)** in a critical review of the subject, pointed out that many studies were flawed because: 1) laboratory studies failed to duplicate the complexity of substrate conditions found in natural streams, and 2) in-situ evaluations were not conducted within the egg pocket of a salmon redd. In addition, researchers have failed to standardize methodologies. This has complicated efforts at quantifying the relationship between sediment and salmon early life history.

The purpose of this study was to develop and demonstrate a new method for assessing cumulative impacts of sedimentation on salmonids. We measured the relative condition of the spawning gravel in five watersheds on the northern coastal region of the Olympic Peninsula. Sediment values were then compared to natural and anthropogenic basin characteristics of each of the five watersheds to explain gross sedimentation processes. Finally, we measured in-situ early life history survival of two species of salmon within two study watersheds using an artificial redd technique developed by the Idaho Division of Environmental Quality (Burton et al. 1990). The technique has been tested by King & Thurow (1991) who found that although the exact morphology of natural redds is difficult to mimic, dissolved oxygen levels, temperatures and fine sediments in artificial redds were not significantly different from those encountered in natural redds. Three hypotheses were developed:

- H_1: amounts of inter-gravel fine sediment within spawning areas of streams is inversely correlated to inter-gravel dissolved oxygen levels.
- H_2: survival of incubating salmon eggs is inversely correlated to levels of fine sediment in spawning gravel.
- H_3: the level of fine sediment found in spawning gravel reflect one or a host of effects, natural or man-induced, occurring at the basin level.

STUDY AREA

The study area included five watersheds on the Northern Olympic Peninsula of the Washington coast (Figure 1). The Pysht Clallam, Hoko and Sekiu rivers flow northeasterly and terminate in the Strait of Juan de Fuca (Strait). These systems originate in a series of low hills paralleling the Strait and share a common



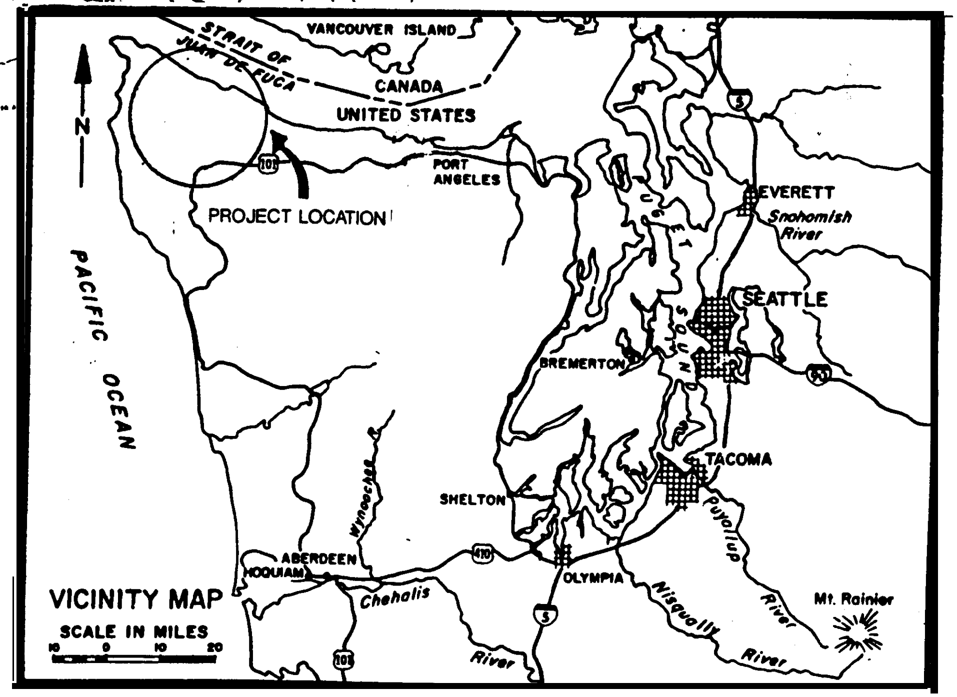


Figure 1. Study area, North Olympic Peninsula, Washington.

geology, soil type, topography, size, channel network, climate, and land management histories. The Twin River Formation (Tabor & Cady 1978) is moderately faulted, dominated by a 5000 m thick sequence of massive to thin-bedded sedimentary rocks (to 5000 m) of a marine origin. Dominant rocks are poorly indurated and moderately to highly weathered sandstones, Siltstones, mudstones, and conglomerate. The Twin River Formation is overlain in places by unconsolidated silts, sands, and gravel of the Quaternary continental glaciation. Bedload gravel compositions of channels downcutting through these outwash deposits include granite and other erosion resistant rock types not native to the Olympic Peninsula (Adams 1988). Climatic conditions are cool maritime. Annual precipitation averages 152-254 cm, the majority occurring between October and May. Study streams support anadromous stocks of chum (Oncorhynchus keta), coho (0. kisutch), and chinook salmon (0. tshawytscha), steelhead (0. mykiss), and cutthroat trout (0. clarki). Several stocks including Pysht coho, Hoko chinook, and Sekiu steelhead are currently classified by fisheries managers as critical or depressed (SASS1 1993). Degraded freshwater habitat is suspected of contributing to their status.

The Lake Ozette drainage represented a basin of special concern to the Makah Tribe. A sockeye salmon (0. nerka) population historically utilized the numerous tributaries of Ozette Lake (Dlugokenski et al. 1980). This distinct stock no longer utilizes tributary habitats and has declined to the point of being a candidate for listing under the Endangered Species Act (Nehlsen et al. 1992). Degradation of spawning gravel quality and elevated temperatures within tributaries of Lake Ozette has been identified as a cause for their decline (Dlugokenski et al. 1980). The geology of the Lake Ozette basin differs from the other study watersheds. Tabor and Cady (1978) classify this area as part of the Western Olympic Assemblage. Glacial deposits from the Cordilleran ice sheet (15,000 years BP), composed of rock clasts foreign to the Olympic Peninsula are dominant.

MATERIALS AND METHODS

Particle size Distribution

Watershed and sub-basin (>2.4 km^2) hydrologic boundaries were delineated on 1:24,000 USGS topographic maps. Ten to twenty-two sample- sites were selected for particle size distribution analysis within each watershed (Figures 2-6). Tributary sites were located in low gradient areas (<2%), with known Salmonid spawning activity, usually near their confluence with main-stem rivers. Main-stem sites were located along a gradient from the river mouth towards headwaters.

Bulk sediment samples were collected within the wetted stream channel using a stainless steel McNeil coring device (150 mm diameter; 254 mm depth). The McNeil cylinder has minimal bias and is applicable to a wide variety of sampling conditions (Grost et al. 1991). At each site, 5 to 10 samples were collected over a minimum of three separate riffle habitat areas during low flow conditions (May to October) in 1991 and 1992. Preference was

Figure 2. Location of McNeil core sample sites and egg basket sites, Pysht River.

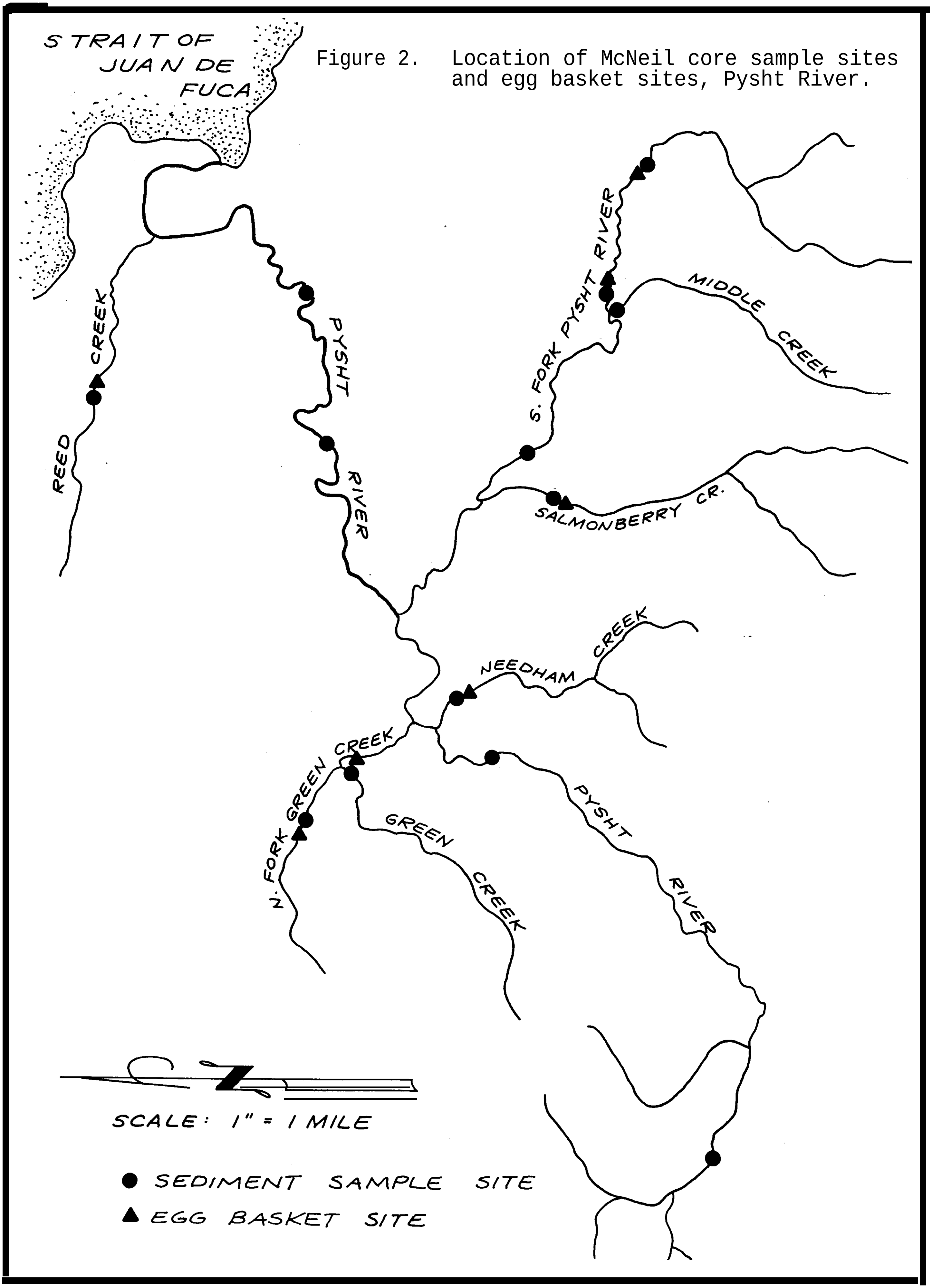
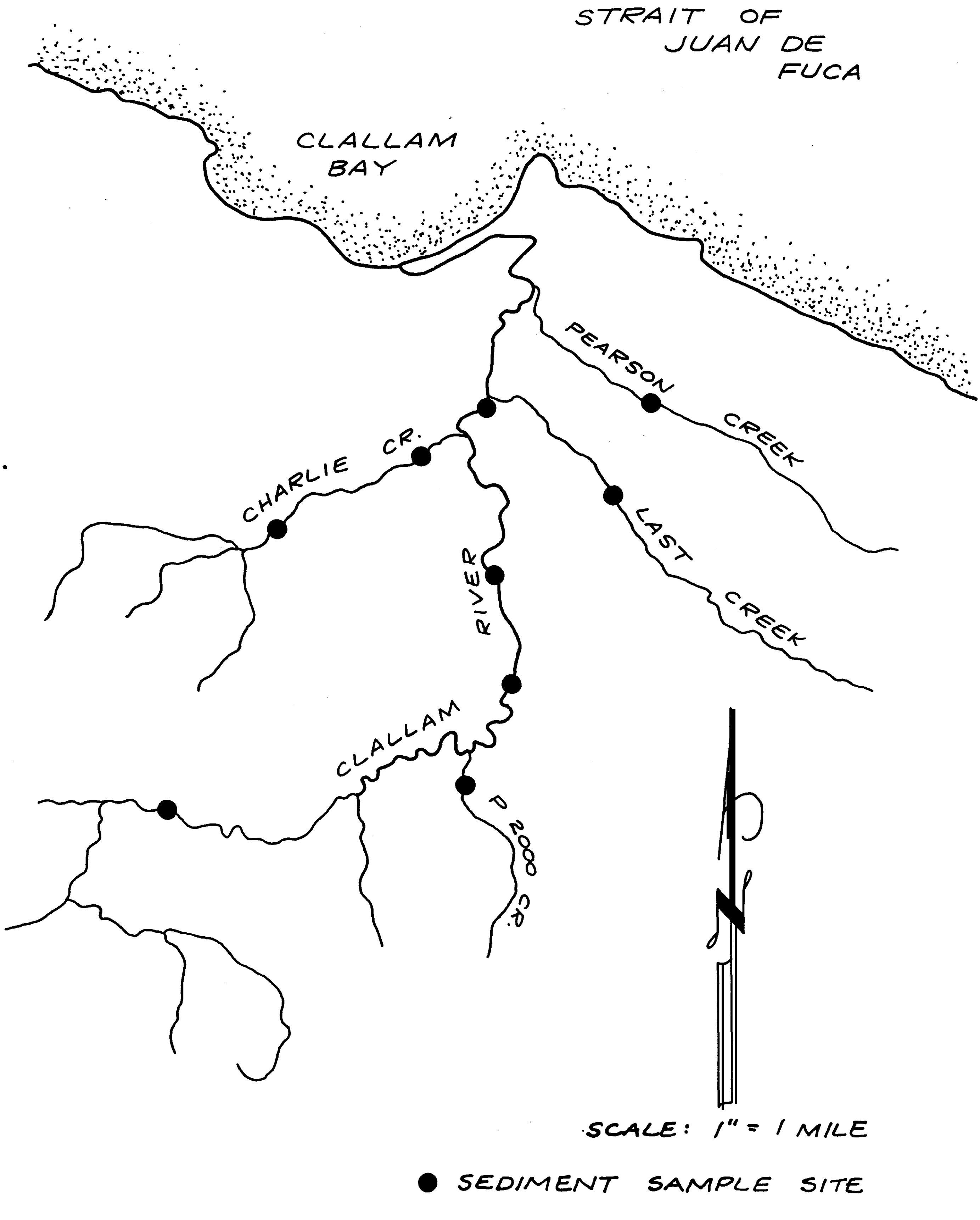


Figure 3. Location of McNeil core sample sites, Clallam River.



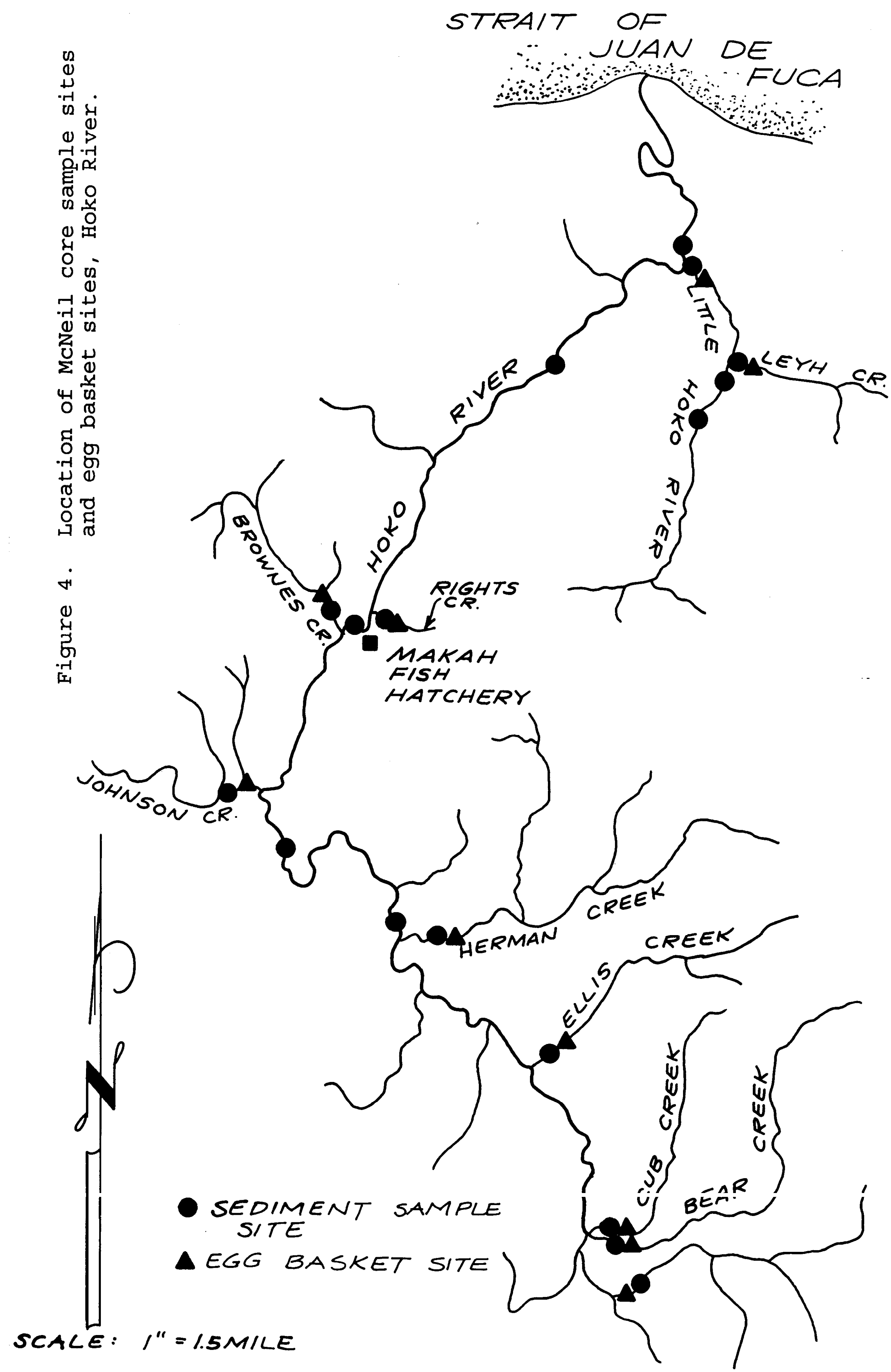


Figure 4. Location of McNeil core sample sites and egg basket sites, Hoko River.

Figure 5. Location of McNeil core sample sites, Sekiu River.

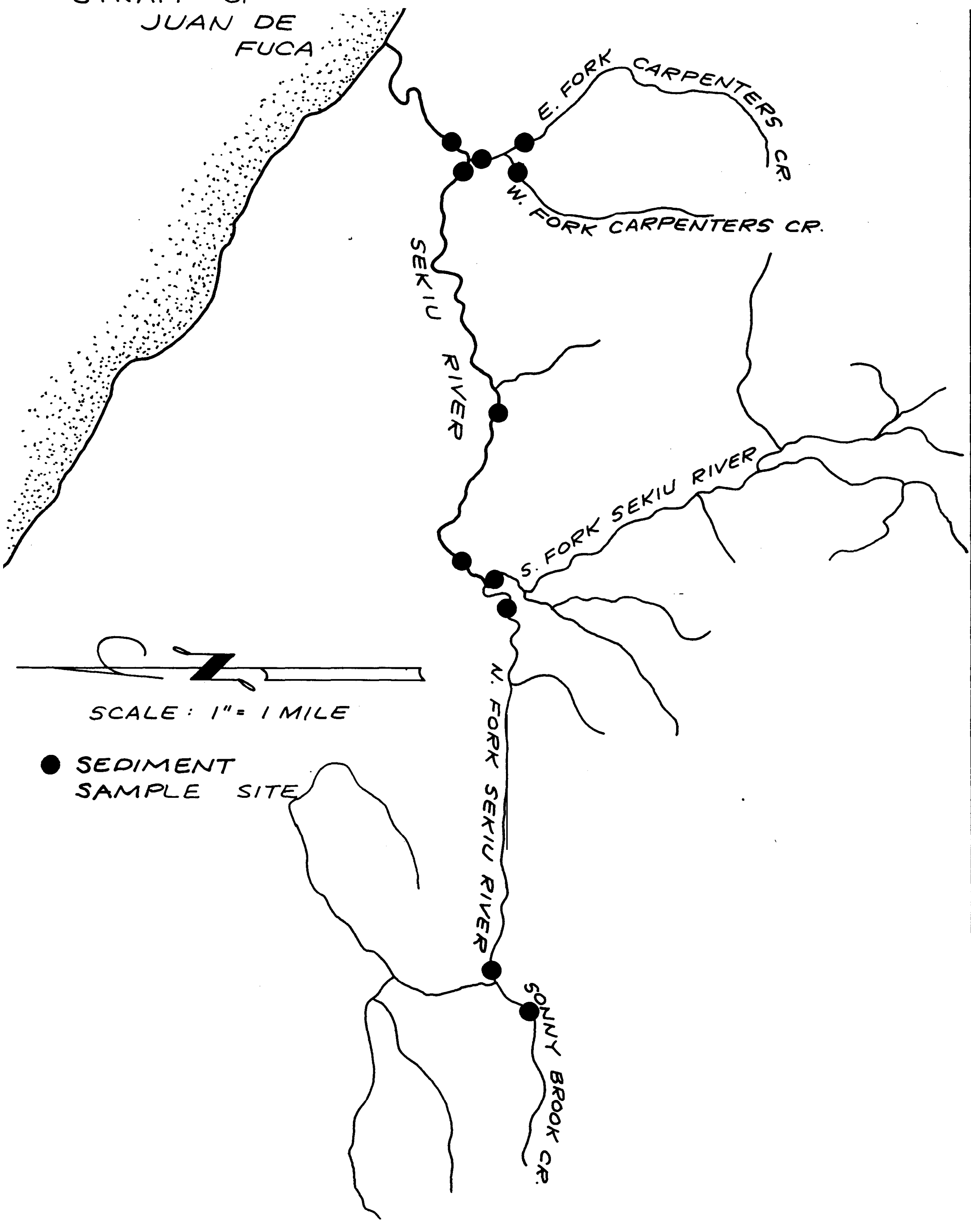
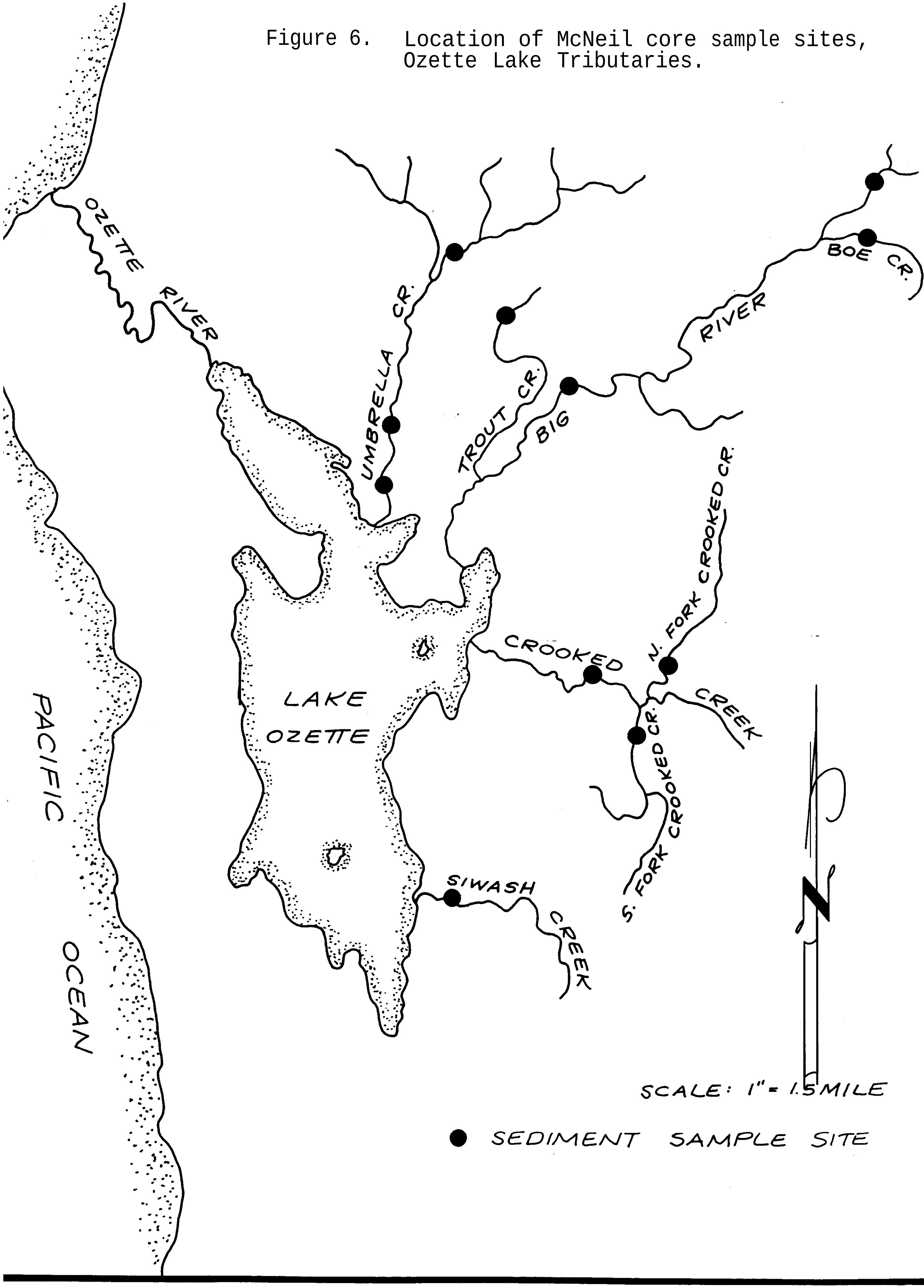


Figure 6. Location of McNeil core sample sites, Ozette Lake Tributaries.



given to known spawning redd sites, but if unavailable, then areas that met the following habitat use criteria for spawning coho salmon (Reiser & Bjornn 1979) were sampled:

(a) water depth .10 to .53 m

(b) unarmored gravel to cobble sized substrate

(c) pool tailouts or glide habitats

Collected bulk samples were placed in individual 5-gallon buckets, fitted with lids, labelled and transported to a sediment analysis laboratory at Neah Bay. Individual samples were placed in 52.5 x 32.2 x 10.1 cm stainless steel pans, and oven-dried at 50°C for 12 to 24 hours. Air-cooled samples were then mechanically shaken for 10 minutes through a series of sieves with the following opening sizes: 75.0, 26.5, 9.5, 3.3, 2.0, 0.85 and 0.106 mm. Material retained by each screen was weighed on a-Ohaus Solution Balance (20 kg capacity) to the nearest 0.5 gram. Sample weights were totalled and percentages of each size class calculated. The geometric mean diameter (D_g) (Platts et al. 1979) and the fredle index (f_i) (Lotspeich & Everest 1981) were also calculated These indices of gravel quality have been closely correlated to Salmonid survival to emergence for several species (Chapman & McLeod 1987; Young et al. 1991).

Watershed Characterization

A watershed characterization was compiled for each of the five watersheds. An inventory had been previously completed for the Pysht River (Jones & Stokes Associates 1991). Inventories within the other four basins were modeled after this approach. Aerial photographs, U.S.G.S. topographical maps, geological maps, G.I.S. systems, information from private and public landowners, and field verifications were used to create maps of each of the systems. Base maps (1:24000) containing topographic, stream, and road layers were provided by the Olympic Region, Department of Natural Resources, Geographic Information System (GIS) for each watershed. Aerial photographs (1991) were used to verify and update road information, as well as to classify vegetation. Vegetation was broadly grouped under four age-class categories: open (O-10 years), young (11-20 years), pre-commercial (20-40), commercial (40-80), and mature (>80 years). The area of each vegetation class was measured with a polar planimeter. Watershed variables measured for each sub-basin are listed in Table 1.

Salmonid Egg-to-Alevin Survival

An assessment of in-situ incubation success of two species of Salmonid eggs was conducted in tributaries of the Pysht and Hoko rivers. The use of egg baskets placed in artificial redds within the stream allowed a measure of survival of eggs under relatively natural conditions (Burton et al. 1992). This technique is being evaluated by the State of Idaho for assessing the impacts of non-point source pollution on Salmonid spawning. Harvey (1989) recommended that a minimum criteria of >6mg/l IGDO be maintained for protection of Idaho streams that support salmonids. We tested this technique in the Hoko River and selected tributaries during a pilot study in 1989-90 and found that basket loss due to aggradation was high in mainstem habitats. This result influenced the selection of sites in which baskets were placed in this study, usually in stable tributary locations.

Table 1. List of Independent Watershed Variables Measured for the Pysht, Clallam, Hoko, Sekiu, and Ozette Lake Drainages.

INDEPENDENT VARIABLES	DEPENDENT VARIABLES
Watershed Scale	
Watershed Area	% Fines <0.106 mm
Geology	% Fines <0.85 mm
Soil Type	% Fines <2.0 mm
Watershed Disturbance Index	% Fines <3.35 mm
Drainage Density	% Substrate <9.5 mm
Road Density	% Substrate <26.5 mm
Direct Road Entries	% Substrate <75.0 mm
Vegetation Age-Class	Fredle Index
<10 years	Geo. Mean Particle Size
10-20 years	
20-40 years	
40-80 years	
>80 years	
Relief Ratio	
Road Length	
Watershed Length	
Stream Scale	
Wetted Depth	
Bankfull Width	
Bankfull Depth	
Width/Depth Ratio	
Stream Power	
Gradient	
Length Primary Channel	
Length Secondary Channel	

During the winter of 1990-91, 45 baskets were placed in known spawning regions of the Pysht River system. Because native stock was unavailable from the Pysht River, coho salmon eggs and milt were collected at the Lower Elwha S'Klallam hatchery facility on the Elwha River for use in the Pysht River. Steelhead eggs and milt were collected from naturally returning adults at the Makah Tribal Fish Hatchery on the Hoko River. Forty-three baskets were deployed in the Hoko River and its tributaries during the winter of 1991-1992. During the winter of 1992-93, an additional **13** baskets were placed in the Hoko River drainage using coho eggs collected at the Makah Hatchery. A controlled rearing experiment was also established at the Lower Elwha S'Klallam Hatchery using Elwha coho to evaluate the affect of the basket technique. We placed screened gravel (2.0-5.0 cm diameter), in a hatchery raceway, with a stable flow of 5 gal/minute, and placed 10 baskets in constructed redds within the raceway.

During field trials, each basket contained gravel representative of that site along with 100 freshly fertilized Salmonid eggs. Artificial redds were constructed using shovels to mimic a female salmon's digging and cleaning of the gravel. Each basket was then placed in the downstream portion of the pocket at an average target depth of 26 cm (range 20-46 cm). An oxygen monitoring tube was placed horizontally behind the basket and perpendicular to the flow, the whole unit then covered with gravel dug directly upstream of the pocket. Oxygen monitoring tubes consisted of a 19 cm length of well screen (3.2 cm diameter, 0.002 cm slot) within which was placed a 21 cm length of plastic aquarium pipe (0.95 cm diameter). Three sets of four equidistant holes were drilled into the aquarium pipe to sample water along the length of the well screen pipe. A 2.0 m length of Tygon tubing was connected to the aquarium pipe, the lower 25 cm being buried with the basket, and the remaining length exposed at the substrate water interface downstream of the basket (Hoffman 1986). Inter-gravel dissolved oxygen (IGDO) and water temperature were sampled bi-weekly at each of the baskets via the oxygen monitoring tube using a peristaltic pump. Water samples were tested with a portable oxygen and temperature meter (YSI model 57) at the site. The eggs within the baskets were allowed to develop to the alevin stage. We monitored stream temperature and development of hatchery eggs to predict hatching and emergence timing. Prior to estimated emergence dates, baskets were excavated from the gravel, and egg/alevin survival enumerated. Dead eggs were fixed, stained and preserved in Stockards[1] solution to determine age at mortality. Gravel within each basket was processed as described previously for the core samples.

Statistical Analysis

Particle size distribution data was entered on electronic spreadsheets using a IBM Personal Computer and Lotus l-2-3 software. Descriptive statistics were generated by site and by watershed. Graphical presentation of selected particle size variables by sub-basin was accomplished using Notched Box Plots. Inferential tests of spatial and temporal differences between sub-

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l/ 5% formalin, 4% glacial acetic acid, 6% glycerin, 85% water.

basins were performed using, one-way ANOVA and Tukey's HSD test (Sokal & Rohlf 1969).

Particle size distribution was compared to watershed characteristics at the sub-basin level using correlation and regression techniques (Sokal & Rohlf 1969). Step-wise multiple regression analysis was used to explain the variation between particle size distribution (dependent variable) and significant independent variables obtained in the correlation matrix.

Linear regression was used to test the difference obtained by the dry sieving (gravimetric) technique and that of the wet sieving (volumetric) methodology. A sub-sample of twenty separate bulk samples obtained from the Pysht, Clallam, Hoko, and Sekiu rivers was processed volumetrically, then dried and reprocessed gravimetrically.

RESULTS

Particle Size Distribution (PSD)

A total of 564 (190 main-stem\374 tributary) McNeil Core samples were collected during low flow periods of 1991 and 1992: 135 (23.9%) in the Pysht River, 70 (12.4%) in the Clallam River, 162 (28.7%) in the Hoko River, 90 (15.9%) in the Sekiu River, and 107 (18.9%) in tributaries of Lake Ozette. Cumulative particle size distributions were approximately log-normal (Figure 7). Nearly log-normal distributions are generally typical for mountainous channels and are characterized by low cumulative percentages of sand-sized particles <3.35 mm and rubble-sized particles >26.5 mm. Inspections of particle size distributions for tributaries showed similar trends. In main-stems, a comparison of particle size distribution along a longitudinal gradient from upstream to downstream revealed little difference between sites. Only the lowest sites on the Pysht (RM 3.5) and Hoko rivers (RM 3.5) were significantly different from their respective upstream sites (Figure 8). Theoretical sediment-transport relationships predict that in similar bedrock lithologies, as stream order increases (and gradient decreases), mean diameter of particles will decrease (Leopold et al. 1964). Summary PSD data is listed by site in Appendix 1.

Variation in PSD

Variability between sites was highly significant. We used one-way ANOVA, and the Tukey HSD test to discriminate differences between tributary and main-stem sites between basins. Significant ($p<0.05$) F-values were obtained for all size classes, as well as the Geometric mean and Fredle Index (Table 2). Within site variability was evaluated through the coefficient of variation. This statistic is used to describe the amount of variation in populations with different means. For percent fines <0.85 mm, the coefficient of variation ranged from 29.9% (Sekiu River) to 75.1 (Upper Hoko River), and averaged 41.2 for all sites. As particle size increased, the coefficient of variation tended to decrease at both tributary and main-stem sites. The highest coefficient of variation values were consistently observed in particles <0.106 mm,

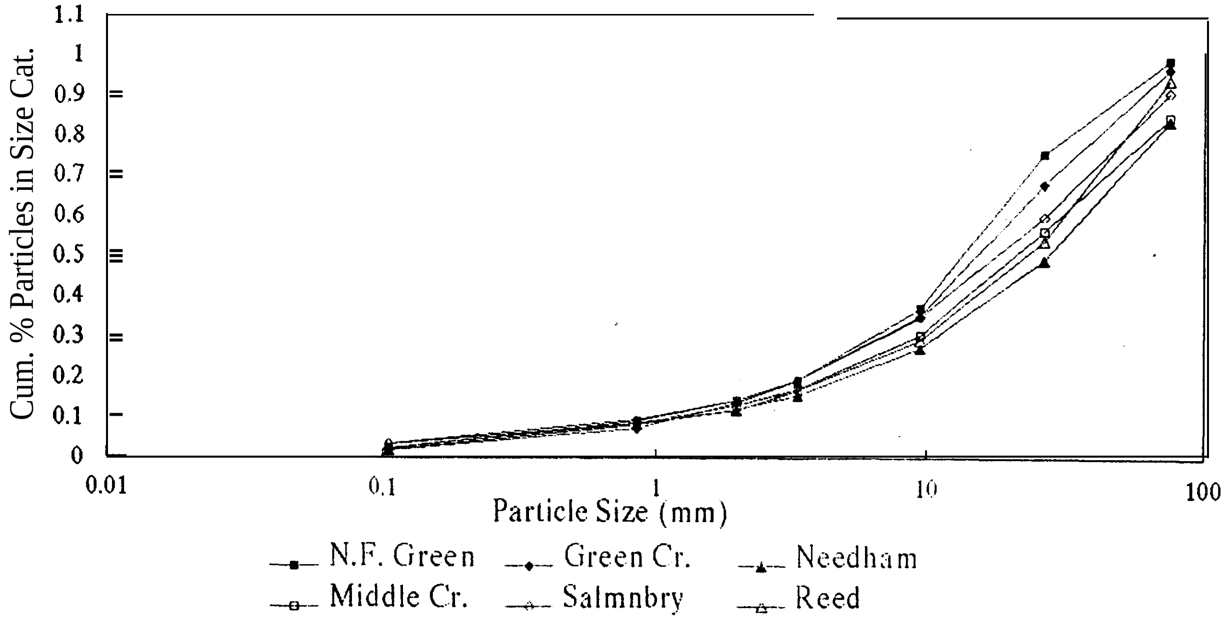


Figure 7. Cumulative Particle Size Distribution for representative tributaries, North Olympic Peninsula, Washington.

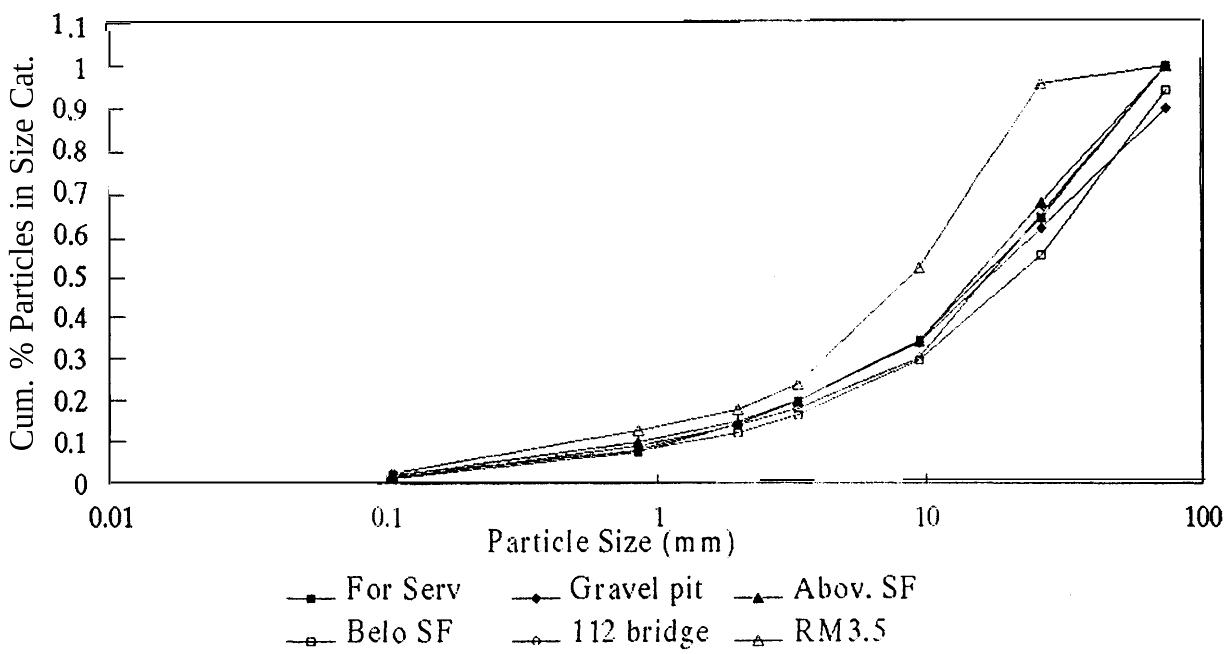


Figure 8. Cumulative Particle Size Distribution from sampling sites in the Pysht River Mainstem, North Olympic Peninsula, Washington.

which averaged 61.2% for all sites.

To assess the temporal variability in sediment distributions, we compared the particle size distributions of eleven randomly selected paired samples collected from the Clallam River, Charlie Creek, and the W.F. Carpenter's Creek during the summer and winter of 1992. No significant differences were detected for fines <0.85 mm (t=0.0l, p=.012), Fredle Index (t=0.15, p=.116), and geometric mean particle size (t=0.39, p=.280).

Table 2. Results of ANOVA and Tukey HSD tests for fine sediment in tributary and main-stem sites, North Olympic Peninsula, Washington.

PARAMETER	F-VALUE	SIGNIFICANT PAIRS	TUKEY HSD
<0.106 mm	10.56	Ozette Tr.> Clallam Tr.	0.006
		Pysht Tr. > Hoko Tr.	0.000
		Pysht Tr. > Little Hoko	0.006
<0.85 mm	3.54	Clallam Tr. > Little Hoko	0.052
		Clallam Tr. > Upper Hoko	0.011
<3.35 mm	3.63	Ozette Tr. > Little Hoko	0.001
		Sekiu > Little Hoko	0.002
		Sekiu > SF Pysht	0.002
Fredle Index	3.72	Little Hoko > Sekiu	0.044
Geometric Mean	3.00	Little Hoko > Sekiu	0.001

Geometric Mean/Fredle Index

Fredle Index values were low (mean=4.9, S.D.=2.8) throughout the study area. Geometric mean (D_g) particle size and Fredle Indices showed that small, but statistically significant differences between main-stem and tributaries exist (Figure 9). We used notched box plots to provide a simple graphical summary of a batch of data (McGill et al. 1978). On each box, the median is marked by the center vertical line. The upper 75th and lower 25th percentiles are represented by the top and bottom of the rectangle. Thus, the box illustrates the spread of the bulk of the data (the central 50 percent). If the intervals around two medians do not overlap, you can be confident at the 95% level that the two population medians are different. The solid line represents tails of the data distribution, while isolated circle are outlying data points.

Fine Sediment

We compared the cumulative percentages of four sediment size classes (<0.106, <0.85, <2.0 and <3.35 mm) between and within the five study basins (Figure 10). These sizes were chosen because previous research has indicated significant correlation between Salmonid egg survival and volume of various sizes of fine sediments in spawning gravel. For fine sediment less than 0.85 mm, the category currently thought to be most relevant from a regulatory standpoint, gravimetric values ranged from 0.39 to 20.92%, and 0.76 to 26.79% in tributaries and main-stem sites, respectively (Tables 3 & 4). Mean percentage fine sediment for all sites (n=564) was 9.00% (3.71% standard deviation).

We found significant differences between the results obtained by gravimetric (dry) and volumetric (wet) processing. As sieve size decreased, the difference between methodologies became greater. The relationship between methodologies for fines <0.85 mm

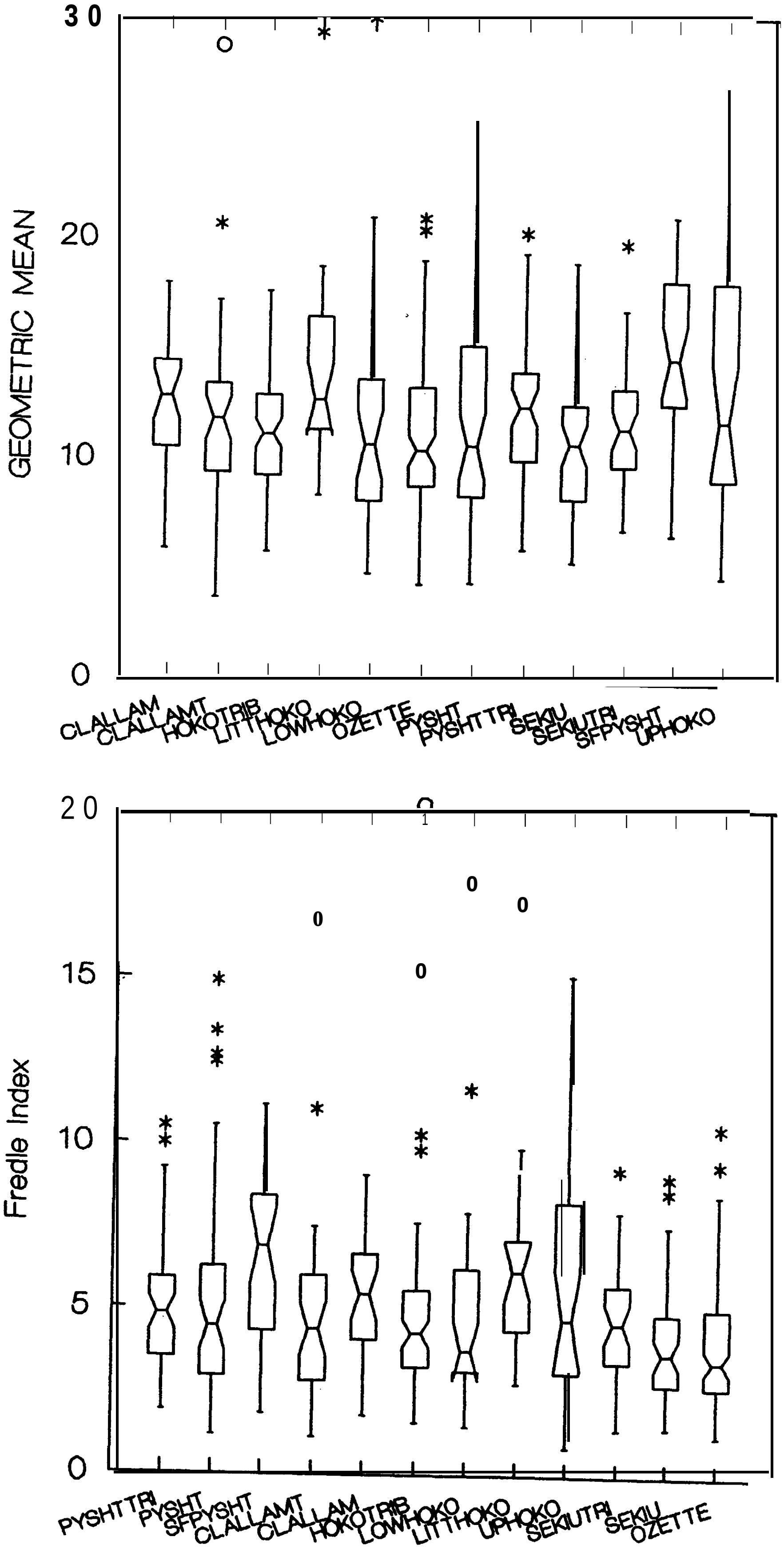


Figure 9. Box Plot representations of Geometric mean (D) particle size and Fredle Index (f_i) values for mainstem and tributaries, North Olympic Peninsula Washington.

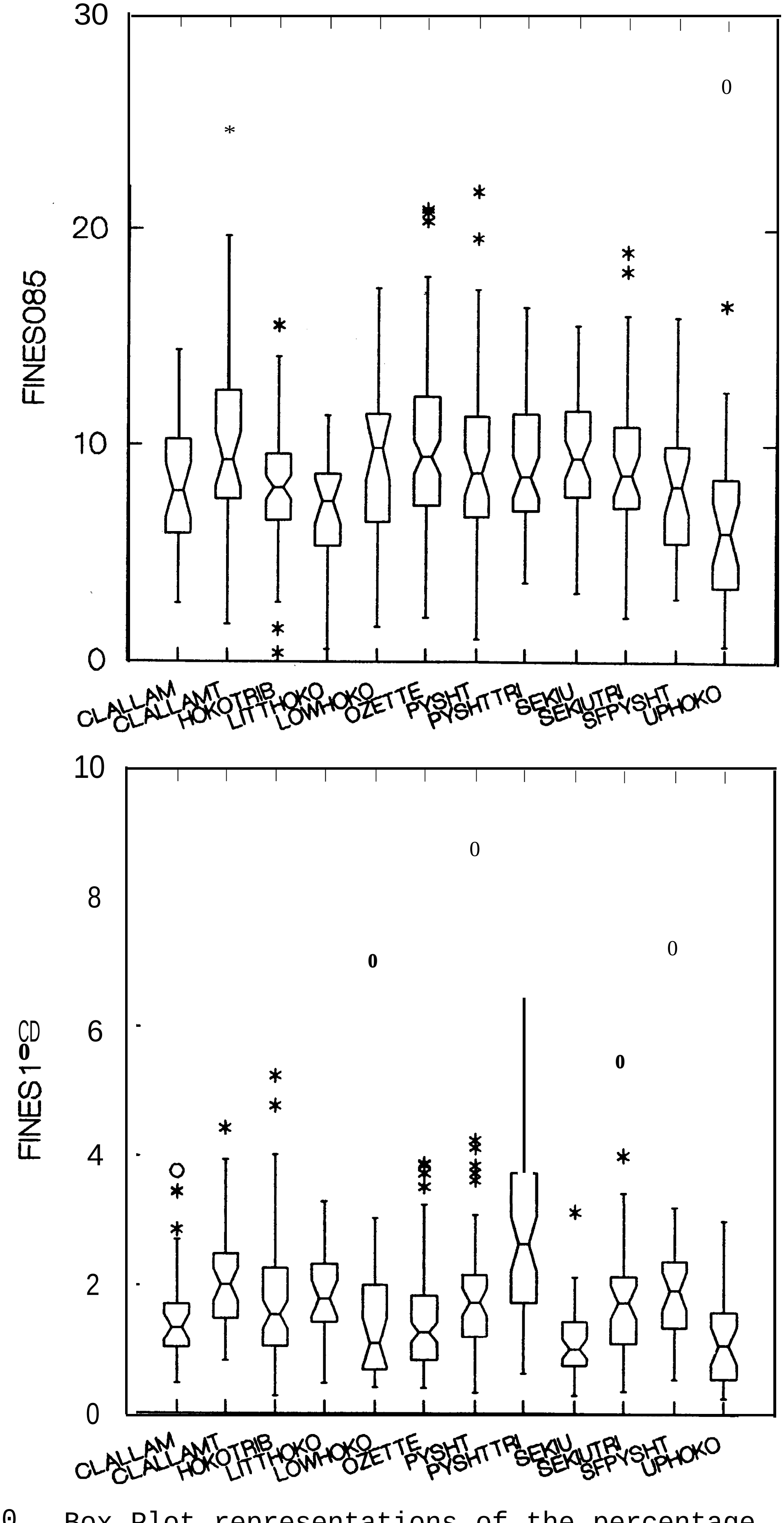


Figure 10. Box Plot representations of the percentage of fine sediments <0.106 and <0.85 mm for mainstem and tributaries, North Olympic Peninsula, Washington.

is depicted in Figure 11. The gravimetric process described less than 50% of the fine sediment obtained by the volumetric process. We developed correction factors for each size class used in the study (Table 5).

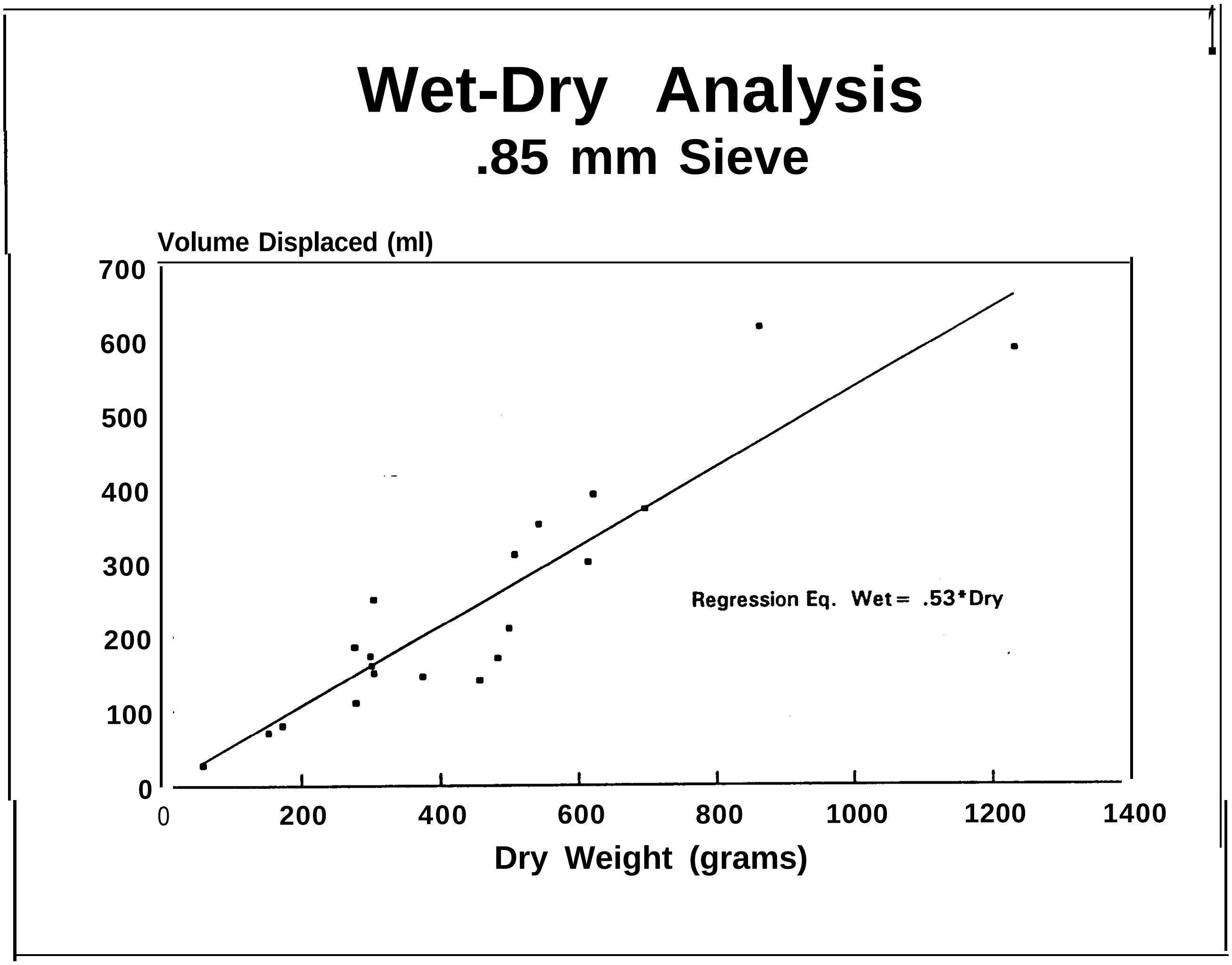


Figure 11. Regression relationship between gravimetric and volumetric processing results, fines <0.85 mm, North Olympic Peninsula, Washington.

Table 3. Mean percentages of four size classes of fine sediment collected in tributaries of the Pysht, Clallam, Hoko, Sekiu rivers, and Lake Ozette, Washington. All values gravimetric (dry) process.

STREAM	Cumulative Percent Fines (mm) <0.106	<0.85	<2.0	<3.35
PYSHT				
Middle	3.14	10.41	15.62	20.48
Salmonberry	3.81	10.53	15.81	21.42
Reed	3.62	9.00	12.31	17.86
Green	1.88	7.61	13.95	19.74
NF Green	2.34	9.09	14.29	19.41
Needham	2.17	10.11	14.61	18.92
CLALLAM				
Last	1.96	11.86	19.70	25.97
Pearson	3.75	16.85	21.78	26.10
U.Charlie	2.34	8.75	12.47	16.66
L.Charlie	1.96	10.34	15.84	20.25
P2000	1.46	7.21	14.84	20.99
HOKO				
Brownes	1.57	8.00	15.01	21.82
Rights	2.51	10.45	**16.96**	23.38
Johnson	1.47	8.26	15.26	22.29
Ellis	1.05	7.51	13.76	19.69
Herman	1.10	6.09	10.38	15.37
Cub	2.63	9.91	18.32	26.48
Bear	1.95	8.80	14.62	20.36
Leyh	2.13	6.72	10.36	13.89
SEKIU				
SFork	2.72	8.15	13.75	19.00
Sonnybrook	1.73	11.14	18.15	23.95
EFCarpenter	2.52	12.00	16.94	22.51
WFCarpenter	1.44	5.46	9.36	14.54
OZETTE				
Siwash	1.85	13.86	19.96	26.14
U.Umbrella	1.86	9.73	18.08	25.20
M.Umbrella	0.75	9.74	18.36	23.84
L.Umbrella	1.12	9.55	17.68	24.19
U.Big River	2.15	9.77	16.08	22.45
L.Big River	0.85	9.78	17.59	22.98
Trout	0.96	8.07	16.38	22.20
Boe	1.08	8.04	15.96	21.58
NFCrooked	2.48	13.53	20.63	27.25
SFCrooked	1.42	9.64	15.62	20.80
Crooked	1.26	7.65	11.28	15.65

Table 4. Mean percentages of four sizes of fine sediment in mainstem sites of the Pysht, Clallam, Hoko, and Sekiu rivers, Washington. All values gravimetric (dry) process.

Stream	Cumulative Percent Fines (mm) <0.106	<0.85	<2.0	c3.35
PYSHT				
RM 14.5	1.31	7.27	13.99	19.46
RM 9.7	1.79	9.10	15.66	21.99
RM 7.4	2.02	9.72	14.89	19.62
RM 7.2	2.47	8.20	12.57	17.10
RM 5.2	1.33	9.03	13.75	17.63
RM 3.5	2.45	12.44	17.48	23.65
SF RM0.5	2.35	8.13	12.35	16.80
SF RM4.8	1.37	6.66	10.14	14.61
SR RM5.9	2.34	9.56	12.80	16.03
CLALLAM				
RM 9.5	1.03	4.80	10.36	15.96
RM 5.4	1.23	7.40	12.39	17.25
RM 4.5	2.53	10.16	15.10	20.04
RM 2.8	1.43	12.62	18.91	25.06
HOKO				
RM 21.3	1.72	10.58	18.20	24.64-
RM 15.6	1.00	5.51	11.65	17.87
RM 12.7	0.63	4.67	10.60	16.73
RM 9.8	1.81	8.65	14.57	19.64
RM 5.6	1.15	7.64	13.56	19.10
RM 3.5	1.64	10.94	15.95	21.59
LHoko RM0.2	1.95	6.86	9.28	12.92
LHoko RM1.5	2.02	7.82	12.38	17.35
LHoko RM1.8	1.40	6.43	11.13	15.94
SEKIU				
RM 8.3	0.97	6.65	12.00	17.28
RM 5.5	1.40	9.78	18.38	25.11
RM 5.2	1.04	8.14	16.02	23.41
RM 3.7	1.25	8.70	14.51	21.03
RM 1.5	1.15	10.54	16.95	23.52
RM 1.0	0.98	10.77	16.08	20.73

Table 5. Linear regression models for predicting volumetric (wet) from gravimetric (dry) values of eight sediment size classes.

SIEVE SIZE	CONSTANT	COEFFICIENT	F-VALUE	P
<0.106	0.00	1.962	149.3	0.001
>0.106	0.00	0.626	194.8	0.000
0.85	0.00	0.532	401.1	0.000
2.0	0.00	0.589	625.9	0.000
3.35	0.00	0.457	444.5	0.000
9.5	0.00	0.375	340.5	0.000
26.5	0.00	0.444	622.3	0.000
>75.0	0.00	0.387	690.6	0.000
Geometric Mean	0.00	0.983	16.7	0.001
Fredle Index	0.00	1.017	37.1	0.000

Watershed Characterization

Geologic conditions in the four north facing (Strait) watersheds **(Pysht,** Clallam, Hoko, & Sekiu) were dominated by uplifted marine sediments, modified by glacial out-wash. Ozette Lake tributaries are primarily glacial out-wash in origin (Tabor & Cady 1978). Little variation was seen in soil types: uplands were dominated by Palix loams on the hill slopes, and Ozette and Tealwhit silt loams along the valleys. These soils exhibit medium runoff rates, moderate permeability, and are described as muddy and soft when wet, and unstable on steep slopes (SCS 1984).

Each of the watersheds were divided into sub-basin tributaries ranging in size from 2.4 to 19.5 km^2. Mainstem sites drained as much as 176.1 km^2. Tributaries and mainstem sites were classified according to stream order, and ranged from first to fifth order. Average channel gradients ranged from 2.5% to 9.3% for main-stems and 2.8% to 24.4% for tributaries. Site gradients, where core samples were collected were always less than 2%.

Road densities in 61 sub-basins averaged 2.34 km/km^2 (range 0.029 to 4.06 km/km^2). On a watershed perspective, average road densities were as follows: Sekiu (2.86 km/km^2), Hoko (2.45 km/km^2), Ozette (2.2 km/km^2), Pysht (1.69 km/km^2), and Clallam (1.68 km/km^2). Vegetation age class distribution was more variable between sub-basins, but was generally described as a mix of open (<10 years old), pre-commercial (20-40 years old), and commercially mature (40-80 years old) forest cover. Aside from the upper Pysht basin where 17.4% of the vegetation was greater than 80 years old, little vegetation in this age class was found in the study area. Watershed variables are summarized for each sub-basin in Appendix 2 (Available from Authors).

We developed a Watershed Disturbance Index (WDI) for 43 tributary sites using -- road density, the percentage of hydrologically immature vegetation (<40 years old), and presence of mass wasting to describe sub-basins where the most severe land use impacts have occurred. Hydrologic immaturity criteria were based on studies by Harr (1986) in the rain-on-snow zone, and Grant (In Press) in low elevation rain dominated watersheds. Road density information was developed from sediment yield studies in the Clearwater River[2] (Cederholm & Reid 1987). Recent mass wasting activity was determined from an inspection of 1990 aerial photos. The WDI, which can have values ranging from 1 to 15, was calculated

[2]The authors recognize the danger that extrapolation of these results to other watersheds represents. We feel that until other estimates are developed the data provided represents a conservative estimate of the effects of road density on sediment yield.

as follows:

Road Density <2.0 km/km² = 1
Road Density 2.0 to 3.0 km/km² = 2
Road Density >3.0 km/km² = 3
0-19.9% Vegetation < 20 years = 1
20-39.9% Vegetation < 20 years = 2
40-59.9% Vegetation < 20 years = 3
60-79.9% Vegetation < 20 years = 4
Extensive Mass Wasting History? yes = 3 no = 0

Where:

WDI = Road Density * Vegetation Score + Mass Wasting History

Seventeen of 43 (39.5%) of the tributaries had WDI scores of greater than seven (high impact). Ten tributary basins (23.2%) had WDI scores of greater than ten (severe impact) (Table 6). Because historical- information is limited, primarily to the aerial photo record from 1960 to the present, this index only assesses the most recent watershed impacts (last 2-3 decades).

Watershed Correlation Analysis

We used correlation analysis on 27 variables thought to influence gravel composition in North Olympic Peninsula streams (Table 7). The composition of fine sediment in spawning gravel was generally not related to land management variables measured in this study. In the Clallam basin, there was a strong inverse relationship between fine sediment and management activities. In some basins (Sekiu, Clallam) we were able to relate sediment composition to natural features such as gradient and watershed relief. We consistently found a positive relationship between channel geometry as described by bankfull width, bankfull depth and width-depth ratio, and both natural features and measures of roading intensity and vegetation age-class. Both factors were approximately equal in importance.

Multiple regression models were developed for all sites combined using the most significant relationships obtained from the correlation analysis (Table 8). Models with significant multicollinearity (Tolerance >0.0l) were rejected. The models suggest a close relationship between stream geometry and both measures of natural and managed characteristics. Among natural features, watershed size and the length of first and second order channels consistently were selected through stepwise regression runs.

Salmonid Egg to Alevin Survival

During 1991-92, 32 of 45 (71.1%) egg baskets were recovered in the Pysht River coho salmon survival simulation. The remainder had either been lost or were found downstream of the site. Survival to alevin stage was poor in the Pysht River. Only one live alevin was recovered out of the original 4500 eggs planted (0.02%). Dead eggs recovered from baskets in the Pysht had survival to the eyed stage as high as 22% in the South Fork, though average survival to the eyed stage was only 2.8% *(5.5%* standard deviation). In contrast, survival (range 0-58%, mean=25.7%) of coho in the Hoko river during 1992-93 was much higher. We recovered 7 of 13 (53.8%) baskets planted, with the majority lost in the Little Hoko River.

Table 6. Watershed Disturbance Index (WDI) Scores for North Olympic Peninsula Tributaries.

Basin	Stream	Score
PYSHT	Green	15
	NF Green	5
	South Fork (4)	3.7
	Salmonberry	4
	Middle	4
	Needham	2
	Reed	1
CLALLAM	Charlie (2)	6
	Last	2
	Pearson	3
	Unamed (#19.0140)	1
HOKO	Rights	9
	Brownes	15
	Ellis	11
	Herman	11
	Leyh	9
	Johnson	8
	Little Hoko (2)	6
	Bear	9
	Cub	6
SEKIU	South Fork	15
	Sonnybrook	15
	EF Carpenter	11
	WF Carpenter	11
	NF Sekiu (2)	6
OZETTE	Umbrella (3)	12
	SF Crooked	8
	Trout	8
	Siwash	8
	Crooked River	3
	Big (2)	13
	NF Crooked	2
	Boe	3

(#) = Number of sites/drainage. Score represents mean from all sites.

Table 7. Results of correlation analysis for five North Olympic Watersheds. Only significant pairs (p<0.05) listed.

WATERSHED	VARIABLES	PEARSON (r)
Clallam	W\D Ratio-# Direct Entry Roads	0.917
	W\D Ratio-Length Primary Channels	0.945
	W\D Ratio-Length Secondary Channels	0.845
	W\D Ratio-Road Length	0.933
	W\D Ratio-Watershed Area	0.926
	Fines<2.0 mm-Relief Ratio	-0.655
	Geometric Mean-Relief Ratio	0.723
	Fines<2.0 mm-Road Density	-0.589
	Finesc3.35 mm-Road Density	-0.650
	Fines<0.85 mm-Relief Ratio	-0.668
	Vegetation<20 years-Fines <0.85 mm	-0.640
	Vegetation<20 years-Fines <2.0 mm	-0.690
	Vegetation<20 years-Fines <3.35	-0.650
Sekiu	Bankfull Width-# Direct Entry Roads	0.907
	Bankfull Width-Length Primary Channels	0.928
	Bankfull Width-Length Secondary Ch.	0.913
	Bankfull Width-Road Length	0.909
	Bankfull Width-Watershed Area	0.922
	Vegetation<10 years-Geometric Mean	0.618
	Fines <0.106 mm-Road Density	0.420
	Gradient-Finesc0.85 mm _	-0.320
	Gradient-Finesc2.0 mm	-0.460
	Gradient-Finesc3.35 mm	-0.480
	Gradient-Finesc9.5 mm	-0.540
Ozette	W/D Ratio-Road Density	0.610
	W/D Ratio-Road Length	0.779
	W/D Ratio-Vegetation<20 years	0.683
	W/D Ratio-Watershed Area	0.653
	W/D Ratio-Length Secondary Channel	0.751
	Fredle Index-Watershed Relief	0.495
Pysht	Bankfull Width-# Direct Entry Roads	0.940
	Bankfull Width-Road Length	0.860
	Bankfull Width-Watershed Area	0.867
	Bankfull Width-Watershed Relief	0.800
	Gradient-Finesc0.85 mm	-0.363
Hoko	W/D Ratio-# Direct Entry Roads	0.870
	W/D Ratio-Road Length	0.818
	W/D Ratio-Watershed Area	0.810
	W/D Ratio-Watershed Relief	0.541
	Gradient-Fines<O.106 mm	-0.636

Table 8. Results of stepwise multiple regression model runs for five North Olympic Peninsula watersheds. (All regressions significant $p<0.01$)

WATERSHED	MODEL	r^2
Ozette		
Bankfull W/D	= 11.05 + (0.001) Length Secondary Channels + (0.15) % Vegetation c 20 Years.	0.75
Bankfull W/D	= 12.1 + (0.126) % Vegetation c 20 Years + (0.127) Road Length.	0.72
Pysht		
Bankfull Width	= 0.339 - (0.12) # Direct Entry Roads + (0.178) Watershed Area + (0.32) Watershed Relief.	0.57
Hoko		
Bankfull Width	= 9.78 + (0.56) # Direct Entry Roads - (0.39) Road Length) + (0.77) Watershed Area.	0.95
Sekiu		
Bankfull W/D	= 1.0 + (0.37) # Direct Entry Roads - (0.90) % Vegetation c 20 Years - (0.45) Length Primary Channel.	0.95
All Sites		
Bankfull W\D	= 1.0 + 0.12 (# Direct Entry Roads) - (0.02) (Road Length) + (0.005) Watershed Area.	0.47

In the Hoko River steelhead survival simulation, 38 of the original 43 (88%) baskets were recovered at their original placement site. Survival to alevin stage in the Hoko River ranged from 0 to 53.5%, and averaged 14.9 (17.4% standard deviation). Conversely, egg to alevin survival rates of the hatchery raceway reared egg baskets ranged from 10-89% with an average survival of 37.6% (27.3% standard deviation). Of those dead eggs recovered, most appeared to have died in the early stages of development.

Egg survival to the eyed stage was not highly correlated to the percent fines (<0. 85 mm) found in the baskets for Pysht coho (r=0.026), Hoko coho (r=0.13) or Hoko steelhead (r=0.ll). Maximum survival to eyed stage was only 13% for sites containing 10% fines or greater. Geometric Mean particle and Fredle Index explained between 10-20% of the variation in survival in both trials. Summary egg basket results are shown in Table 9.

Dissolved oxygen measurements taken from the artificial redd proved to be highly variable (Figure 12). Minimum intergravel dissolved oxygen explained 9% and 0.4% of the variation in egg survival in the Pysht and Hoko rivers, respectively. Some baskets exhibited oxygen levels low enough to cause mortality to developing eggs (<5mg/L). These depressions were typically observed following the first major storm event after placement. At IGDO levels between 5-8 mg/l, survival was variable with no clear trend. When IGDO levels exceeded >9mg/l, survival was generally good.

Table 9. Numbers of egg baskets lost, and percent survival to eyed, and alevin stages in Hoko and Pysht River survival tests.

Site	%Baskets Lost	%Survival to Eyed	%Survival to Alevin
Hoko Steelhead			
Leyh	20	9.7	9.7
L. Hoko	40	16.0	16.0
Rights	0	35.3	33.3
Ellis	0	13.2	13.2
Herman	28	6.8	6.8
Bear	40	36.3	35.3
Cub	0	7.0	3.6
Pysht			
Green	50	1.7	0.3
Needham	25	4.2	0.0
SF(RM 4.8)	28	10.0	0.0
SF(RM 5.9)	14	0.3	0.0
Salmonberry	0	0.0	0.0
Reed	56	0.0	0.0
NF Green	28	2.3	0.0
Hoko Coho			
Rights	66	---	11.0
Leyh	20	---	3-2.7
L. Hoko	80	---	1.0

Sediment distributions were generally similar between the egg baskets and McNeil core samples, although the egg baskets typically lacked particles >75 mm (Figure 13). Paired t-tests of the baskets and associated core sites in the Pysht River, using fines <0.85 mm (p=0.39), Fredle index (p=0.82), and geometric mean (p=0.90) were not found to be statistically different at the 95% level. During Hoko steelhead trials, fine sediments <0.85 mm were found to be significantly different (p=0.98), while the Fredle Index (p=0.77) and Geometric mean (p=0.91) were not. This difference was attributed to differences in timing that subjected steelhead eggs to fewer storm events of the magnitude able to transport bedload.

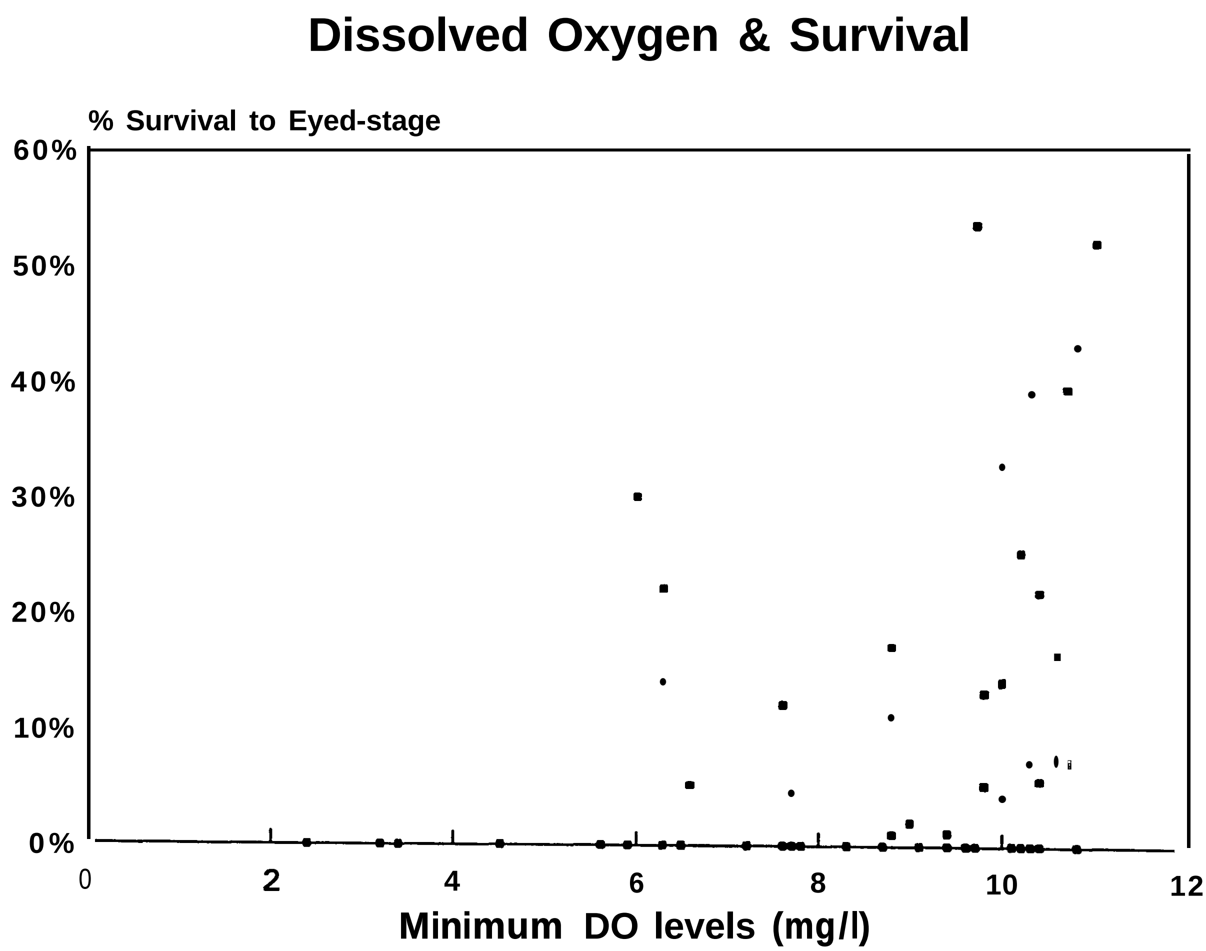


Figure 12. Minimum Intergravel Dissolved Oxygen Levels (IGDO) versus survival to eyed stage for steelhead and coho salmon in artificial redds, North Olympic Peninsula, Washington. (Note most Zero values from Pysht River Coho Simulation)

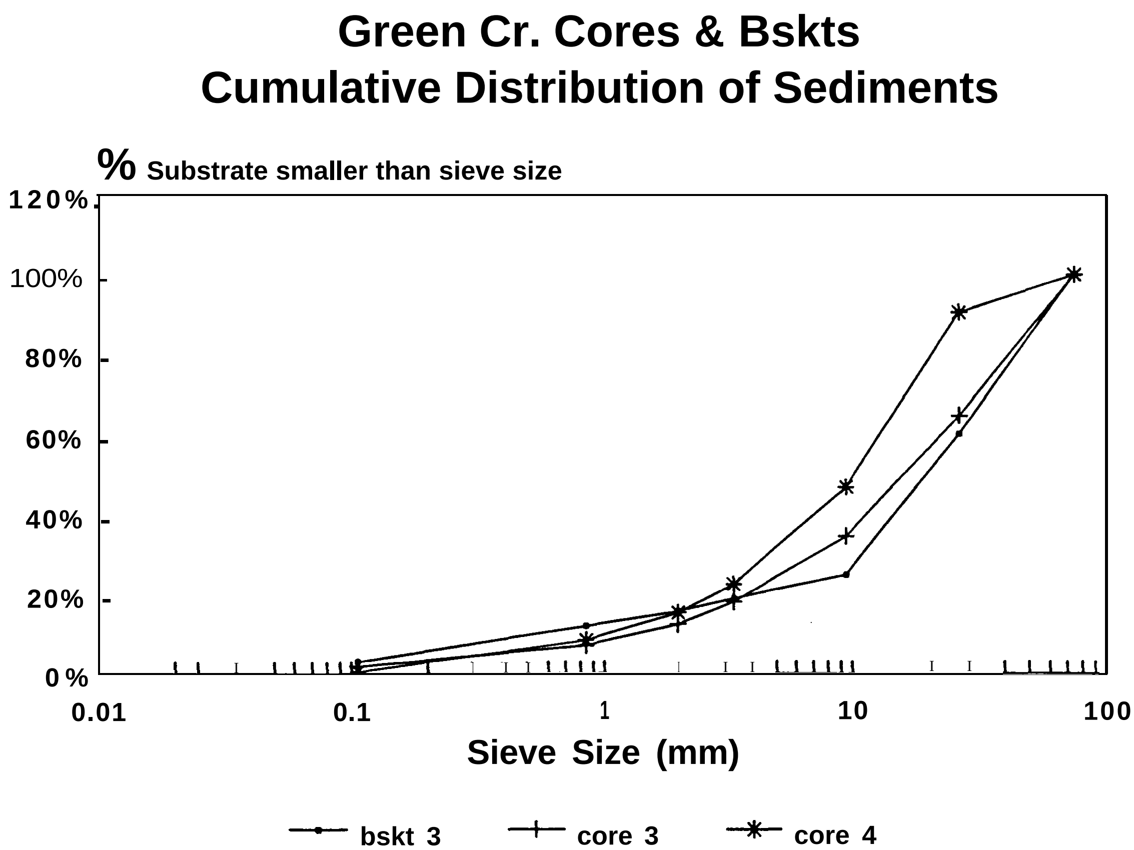


Figure 13a. Cumulative Particle Size Distribution for egg baskets and adjacent natural redds, Green Creek, North Olympic Peninsula, Washington.

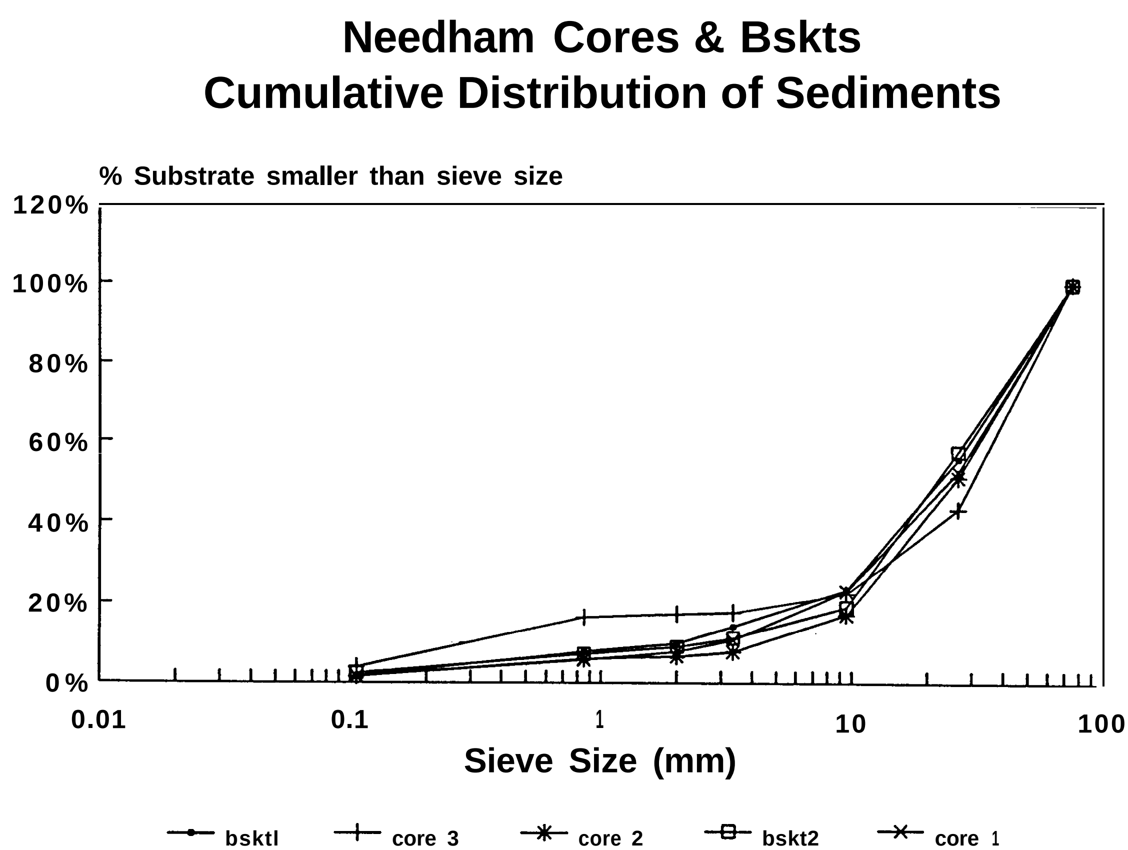


Figure 13b. Cumulative Particle Size Distribution for egg baskets and adjacent natural redds, Needham Creek, North Olympic Peninsula, Washington.

DISCUSSION

Fine Sediment

Fine sediment levels were consistently high in both mainstem and tributary spawning habitats. In Washington streams, Peterson et al. (1992) recommended the adoption of target conditions where no more than 11% (volumetric) of the particle size distribution be comprised of sediment <0.85 mm. By this standard, we found only 1 tributary that met the target condition. Seventeen tributaries exceeded 17% fine sediment <0.85 mm.

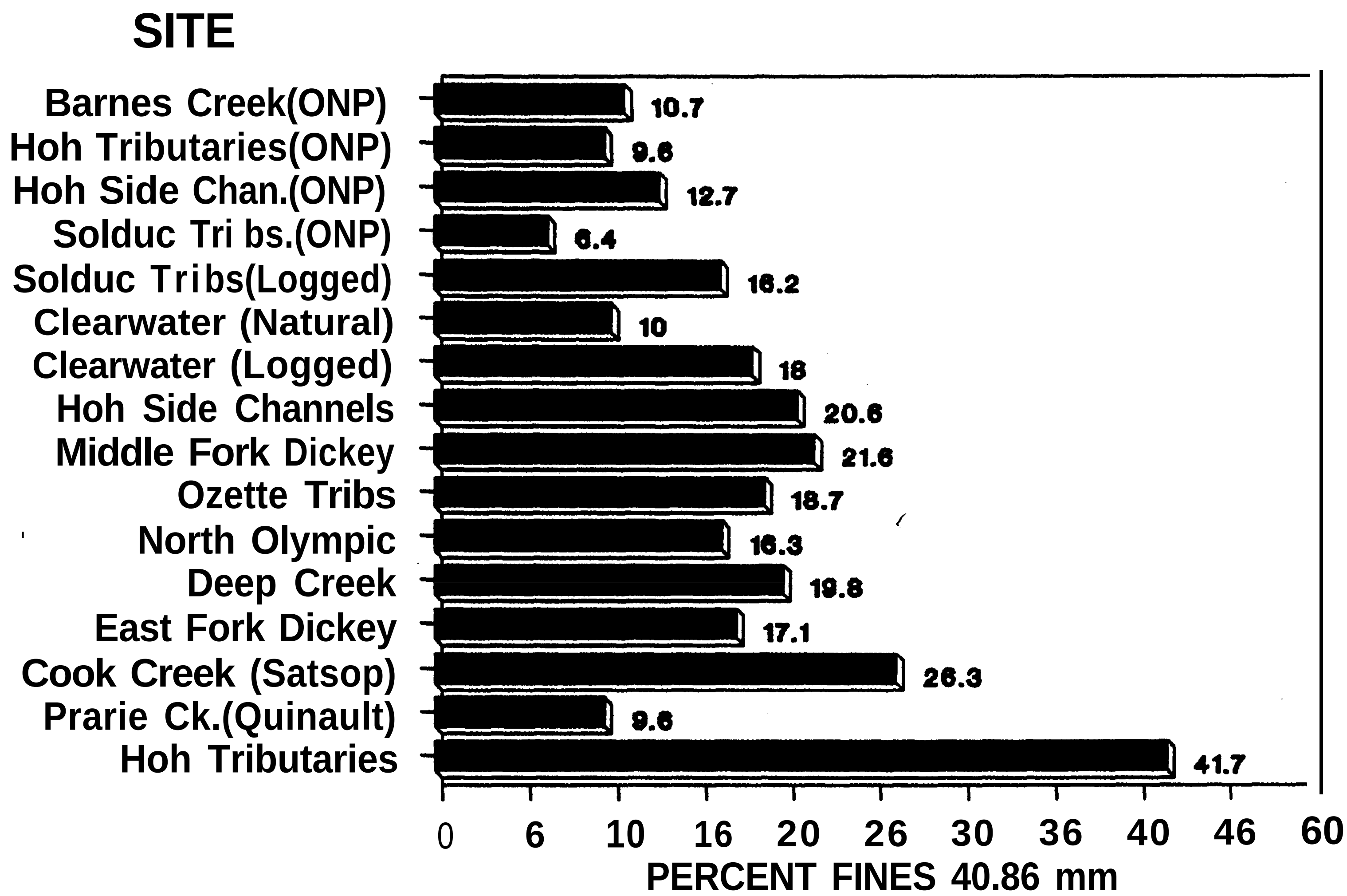
The high levels of fines encountered may be partly attributable to the lithology (sandstones, siltstones, mudstones) of the study area. Benda (1993) estimated the breakup (attrition) of bedload to suspended load using tumbling mill experiments on colluvium excavated from a debris flow deposit located in Green Creek (Pysht). The results indicated that the rocks were the least resistant to physical abrasion compared to other available samples from western Washington. He further speculated that the effects of adding landslide debris to the volume of channel bedload were not significant in Green Creek because 80% of the landslide derived bedload may break into suspended load after 3 kilometers of travel. However, Benda (1993) through a sediment budget approach, estimated that approximately 90% of landslide derived sediments introduced to Green Creek during the last four decades still were found to be stored within the valley floor. Such deposits represent a potentially persistent source of fine materials that may be transported into Salmonid habitat as weathering and remobilization occur.

Other watersheds have been observed with high fine sediment fractions in the transport load. Duncan & Ward (1985) found that the amount of sediment <2.0 mm in southwestern Washington streams was closely related to the lithologic composition of the soils. Koski (1966) found average fine sediment (<0.833 mm) levels of 26.2% in a unlogged coastal Oregon stream. Additionally, Adams & Beschta (1980) reported that fine sediment <1.0 mm in **21** Oregon Coast Range streams ranged from **10.6%** to 49.3%, and 10.6% to 29.4% in managed and unmanaged sedimentary basins, respectively. We were unable to statistically test the relationship of soils and geologic composition to fine sediment levels found in channel samples in this study because of a lack of quantitative data. Existing data bases (Tabor & Cady 1978; SCS 1980) were either at too large a scale **(1:12500)** or incomplete. SCS (1980) did report that some soil series found in the study area contained a high percentage of clay particles (up to 50%).

We could not identify a tributary within the dominant geology (Twin River Formation) of the North Olympic Peninsula that could be considered as having a natural background sediment level to facilitate a control for this study. All drainages have either been previously logged and roaded. The lowest percentage of fines <0.85 mm found in the study was 4.8% on the Clallam River (RM 9.5). Though impacted by mass wasting associated with mid-slope roads built in the 1950's, this site has sufficient stream power to transport bedload to downstream areas. Conversely, in areas of lower stream power, sediment levels have probably not changed appreciably in last 10-20 years. Samples collected in Umbrella Creek (Dlugokenski et al. 1980) in 1979 showed that fines <0.6 mm averaged 17.8%. This value is approximately equal to the average of **18.1%** collected in three sites in this study.

Analysis of gravel samples collected in other Olympic Peninsula Rivers indicates that sediment levels in the study area are similar to those in other intensively managed watersheds and about half those found in a variety of Olympic National Park streams (Figure 14). Samples collected from three basins (Salmonberry, Middle & Bullman Creeks) with primarily commercially mature (40-60 years) forest cover were fairly typical for the study area as a whole (average 9.6% gravimetric). Each of these systems historically have had large scale logging operations and associated mass wasting whichmakes interpretation of these results difficult.

In 1993, crude sediment budget analyses were conducted in Green Creek and the North Fork of Green Creek, tributaries to the Pysht River. In both systems mass wasting associated with earlier logging and road construction was the dominant contributor of sediment. In Green Creek, Benda (1993) found that sediment production during the last **43** years ranged between 20-12,032 $m^3/km^2/year$. Average sediment transport was estimated at only **121** $m^3/km^2/year$, leaving approximately 90% of the colluvium that originated from mass wasting in storage along the valley floor (Benda 1993). In the North Fork of Green Creek, Calder-Shaw (1993) observed that the channel is currently down-cutting through 0.5-4.0



All value8 wet(volumetric) of equivalent

Figure 14. Percent fine sediment <0.85 mm reported from spawning gravels for managed and unmanged streams on the Olympic Peninsula, Washington.

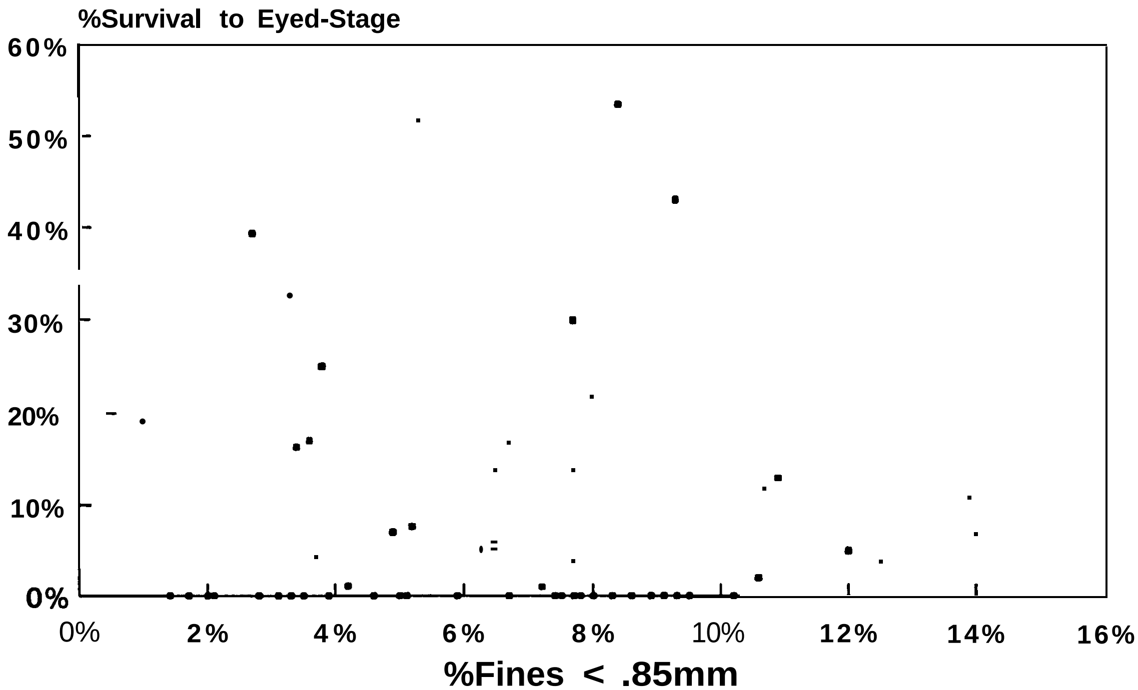
m of mass-wasting and debris-flow deposits generated following earlier harvest in the basin. The persistent sediment deposits observed in both systems are undoubtedly a contributor of fine sediments to spawning gravel and a possible explanation for the highly unstable channel banks, evidence of frequent lateral channel migration and significant aggradation observed within Green Creek.

Recovery time of watersheds following a mass-wasting event is extremely slow and are largely a result of geomorphic processes, and human management activities. Platts et al. (1989) showed that sediment levels in the South Fork Salmon River initially decreased rapidly, but did not recover to natural levels, 20 years after implementing a logging moratorium. Borman & Likens (1979) projected century long patterns in recovery of logged watersheds, largely incumbent on the replacement of stable large debris and reestablishment of natural sediment loads. Given the level of historic disturbances in the study drainages, combined with short timber rotations, and the lack of long-term watershed management plans, it is unlikely that recovery will occur for several centuries.

Salmonid Egg to Alevin Survival

Survival within egg baskets was highly variable in the field trials and appeared not to correlate with sediment levels except in the most extreme cases, where fines <0.85 mm, and <0.106 mm exceeded **13%** and 2.5% respectively (Figure 15). This result suggests a threshold level over which survival is very low. For

Egg Basket Survival
Pysht & Hoko



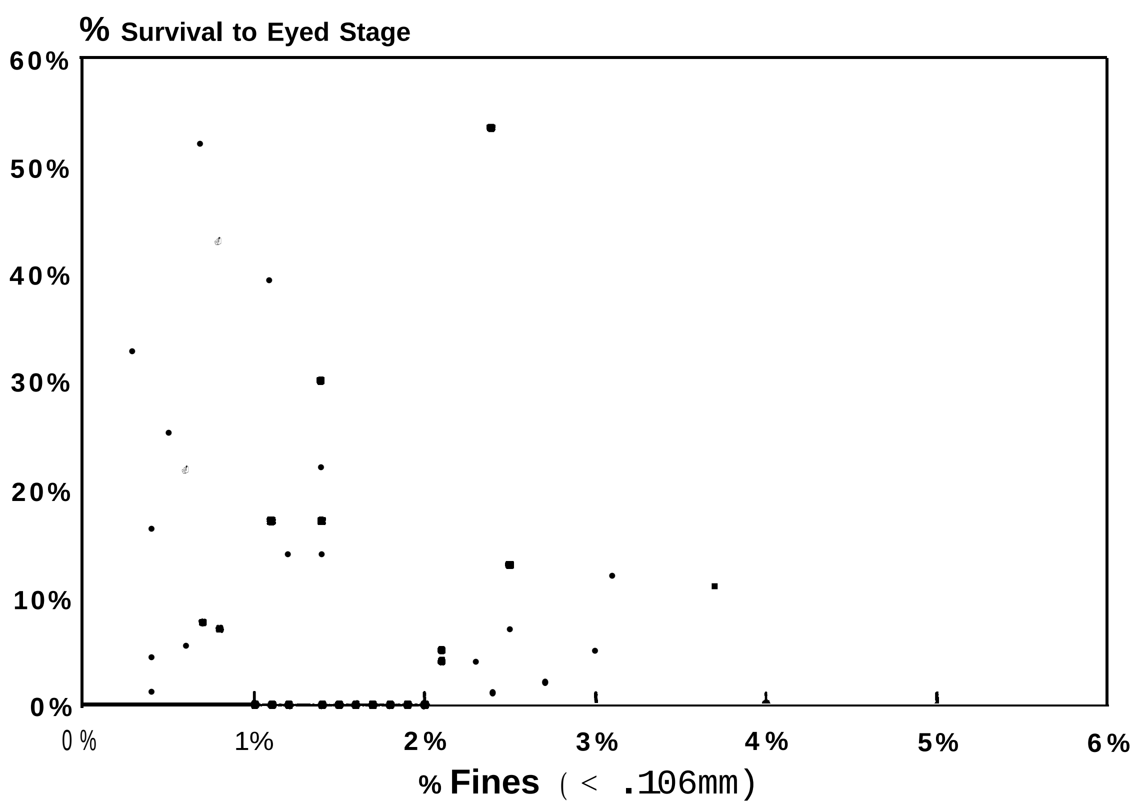


Figure 15. Survival of coho and steelhead to the eyed stage versus percentage of fine sediment (<0.106 & <0.85 mm) in an artificial redd, North Olympic Peninsula, Washington.

chinook salmon in the South Fork Salmon River, Idaho, Burton et al. (1992) reported that embryo survival dropped rapidly when the percentage of fine sediments <6.03 mm exceeded 20-25%. In contrast, the majority of survival to emergence studies show either a linear or curvilinear relationship between increasing fines and Salmonid embryo survival (Chapman & McLeod 1987; Peterson et al. 1992). Under high sediment levels other factors may be operating to affect egg development.

We observed significant bed aggradation (to 21.8 cm) and degradation (>30 cm) and accompanying channel changes during storm events at various sites, particularly during the Pysht coho salmon simulations. Monitoring conducted in the Pysht River during 1989-91 (Steve Ralph, Unpublished Data, University of Washington) showed significant shifts in bed elevation and channel form (Figure l-6). Significant 9(>0.33 m> channel aggradation and degradation was observed at **15** of 27 (55%) transects. Bed movement of this magnitude has been shown to be detrimental to incubating Salmonid embryos. Several researchers (McNeil 1966; Tripp and Poulin 1986) found that scour was highly variable, but frequently exceeded mortality from fine sediments alone. Stream-bed instability has been shown to limit chinook survival in southern Oregon streams. Nawa et al. (1990) found that 75% of the redds they monitored were either scoured or buried by bed movements. Because of differences in hydrograph, coastal (west of the Cascade Mountains) salmon stocks, particularly those that spawn in early fall and winter, are at a greater risk of the detrimental impacts of scour than those

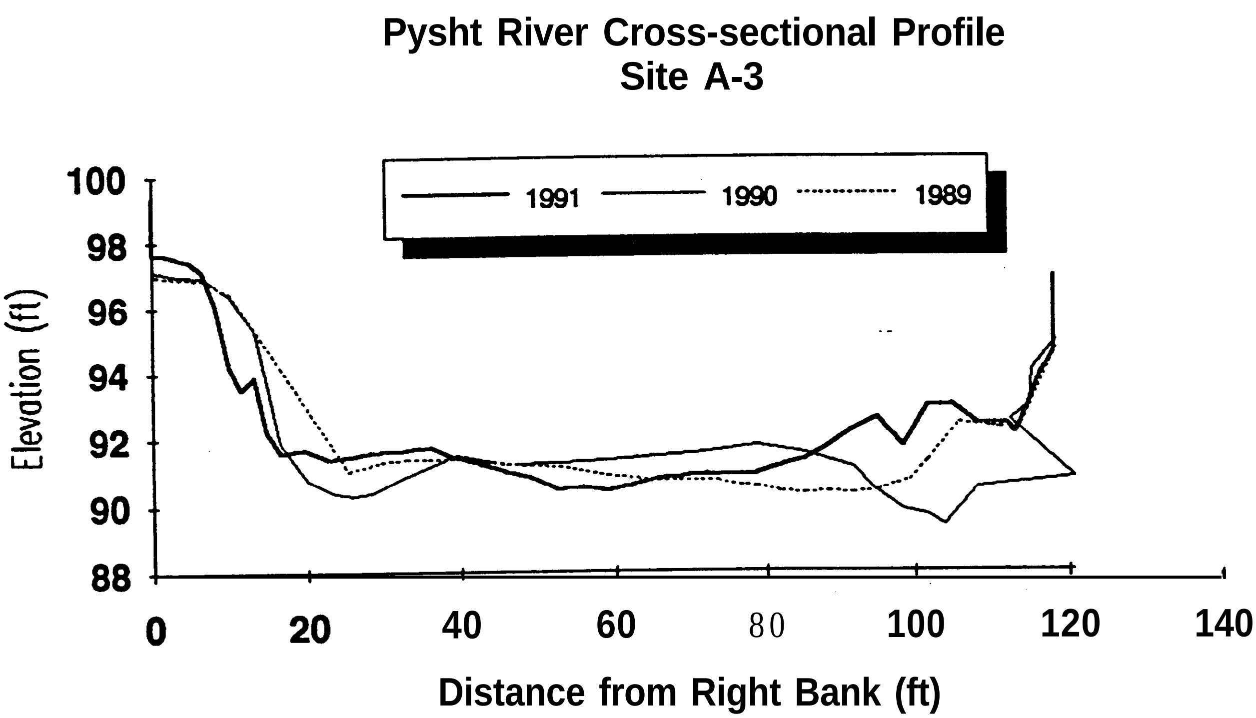


Figure 16. Changes in cross sectional profile (elevation) 1989-1991, Pysht River, Washington. Data provided by Steve Ralph (UW).

east of the Cascade Range. In an analysis of peak flows, Amerman & Orsborn (1987) found that streams on the North Olympic Peninsula were most likely to have peak flows between mid-November and early February. Therefore, winter and summer steelhead stocks, because of a later run timing (March-June), are less vulnerable to the detrimental impacts of scour. This observation also has implications for other users of the egg basket technique. The relationship between forestry practices and depletion of large woody debris and maintenance of habitat complexity in streams has been well documented (Grette 1985; Maser et al. 1988). The relationship between large woody debris and channel instability, particularly on depth of scour is less well understood. Hartmann & Scrivener (1990) noted that abundant and stable large woody debris was a common feature in natural Vancouver Island, British Columbia streams. Large woody debris volumes appear to be decreasing dramatically in logged watersheds of the Northwest (Ralph et al. 1993). In a resurvey of 28 Olympic Peninsula streams (Grette 1985; McHenry et al. In Preparation) found significant reductions in large woody debris loading in one decade. The implications of these results to basin scale cumulative effects are significant.

Despite attempts at providing egg baskets with a range of gravel quality, we found no significant differences between the particle size distributions of gravel in baskets and surrounding substrate collected with the McNeil core. This result would indicate that fine sediments are highly mobile and are able to infiltrate salmon redds. This may be particularly true in clay dominated geologies. Einstein (1968) reported that in channels with abundant silt and little sand-sized particles, silt was able to infiltrate all but the smallest interstitial spaces, and fill the stream bed from bottom up. Lisle and Lewis (1992) found that in Jacoby Creek, California, coho salmon redds were "planed off' by flows high enough to transport bedload sediment, thus losing any hydraulic benefit provided by redd topography. Lisle (1979) also noted that particles >0.25-4.0 mm quickly infiltrated spawning gravel. Such changes in bed dynamics would tend to negate the potential benefits of gravel cleaning provided by actively spawning salmon during the redd construction process.

These observations point to a mechanical stress acting on the eggs, such as physical abrasion by sands and silts passing along and through the channel bed. Dissolved oxygen readings tended to corroborate these findings, since dissolved oxygen levels remained high in the majority of baskets, even those with zero survival. Burton et al. (1990) found that dissolved oxygen in natural chinook redds never approached levels that would cause mortality (<6/mg/l) in the South Fork Salmon River. In watersheds impacted by agricultural activities IGDO may be more significant. Maret et al. (1990) found that in Rock Creek, Idaho up 40% of IGDO measurements were below 6.0 mg/L, and that survival of brown trout eggs increased at IGDO levels above 8.0 mg/L.

The very low survival (<1%) of coho salmon in the Pysht River was a concern. Because survival to eyed stage only averaged 2.8%

there was concern about experimentally induced mortality associated with the basket technique, poor fertilization success or possibly the use of non-native Elwha coho stock. Fertilization success was determined to be high (>90%), and therefore not related to the observed low survival in-situ. The results of the controlled raceway experiment (10-89% survival) and the success of the technique in different geographic (Burton et al. 1990; Maret et al. 1993) locations support the validity of the technique. We were unable to assess the effects of possible stock adaptations to substrate differences in particle size distribution. Several reviewers speculated that genetic differences as a result of adaptations to differences in lithology between the Elwha River (basalt) and the Pysht River (sedimentary) might bias the results. The higher survival observed for Hoko coho may support this hypothesis. This theory deserves additional testing as we were unable to find any pertinent references in the literature.

Watershed *Geomorphology*

We were unable to correlate fine sediment levels at the watershed level. Adams & Beschta (1980) determined that on a watershed basis fine sediment was primarily controlled by watershed geomorphology and land-use history, while at the reach level, sinuosity and bank-full discharge were most critical. The lack of correlation in this study between dependent measures of gravel quality and watershed level parameters was probably due to the following factors: **1)** a low range of fine sediment values between sub-basins, 2) the inability to accurately measure lithologies **and** soil types at the subbasin level, and 3) the inability to **quantify** historical disturbances in the watersheds.

We found that both land use and natural watershed features influenced stream geometry. Land management alters the shape of a channel through aggradation or degradation associated with changes in volume or timing of sediment delivery and high flows (MacDonald et al. **1991).** The consistent pattern observed between drainages suggests land management activities that affect hydrologic regimes are manifested in altered channel conditions within the study area. Grant (1988) noted that an increase in channel width could result from an increase in peak flow. However, the limited understanding of hydrologic change and mass wasting histories in the study area may mask our complete understanding of the relationship between accelerated sedimentation and channel form characteristics. Beschta (1985) found that sediment delivery and not peak flows caused the most pronounced changes in channel form characteristics. In Washington, regulators currently only recognize the affects of clearcut harvest on increased runoff in the rain-on-snow zone above 3000' elevation. Predicting the impacts of forestry on changes in water yield in low elevation coastal watersheds has proven difficult. However, there is increasing evidence that extensive clearcut harvesting in low elevation Pacific Northwest watersheds may be causing increases in peak flows. Such increases may be significant to channel form, particularly when sediment yield has been increased, and inputs of large woody debris drastically altered. It is likely that in the majority of intensively managed watersheds on the Olympic Peninsula, channel adjustments have already occurred. In such cases it will be difficult if not impossible to determine any affects of increases in peak flow.

CONCLUSIONS & RECOMMENDATIONS

* High sediment levels were found in spawning gravel throughout the study area. We were not able to correlate the percentages of four size classes of fine sediment and two indices of gravel quality to either natural or managed watershed characteristics.

* We found significant variation in particle size distribution both between and within subbasins. At the stream level variation was greater between sampled habitat units rather than within.

* Fine sediment levels are consistently higher in managed stream systems than in unlogged streams on Olympic Peninsula; This relationship appears consistent regardless of differences in local geologies.

* North Olympic Peninsula watersheds have high average road densities, and are often dominated by vegetation age classes of less than 20 years. These features correlate to measures of channel form such as bankfull width.

* To fully understand sediment dynamics in North Olympic Watersheds mass wasting histories should be determined. Available information indicates that mass wasting from historic logging and road construction practices has contributed the majority of bedload sediment within the region.

* Survival of Coho from egg to alevin was extremely poor in the Pysht River. Survival of steelhead from egg to alevin was also poor in the Hoko River. Sediment levels did not correlate with either survival or inter-gravel dissolved oxygen except at higher levels.

* At high sediment levels (>13% fines <0.85 mm), a threshold condition exists, above which survival drops rapidly. This result is consistant with other similar studies.

* Channel instability appears to be a significant limiting factor for the early life history of salmonids. The relationship between channel instability, channel bedload transport, and Salmonid early life history needs further research. The depletion of large woody debris from channels as a result of management,activities has exacberated this problem.

* Monitoring on the effects of scour on early life history of salmonids should be pursued. We recommend utilizing scour chains and bed monitors (Nawa & Frissell 1993) in conjunction with surveyed cross sections, and artificial egg baskets.

* The use of artificial egg baskets appears to be a valid evalualtion technique. However, because of the susceptibility to scour, the technique may be most applicable in small tributaries (West of the Cascades).

* We found significant differences between the results obtained by volumetric and gravimetric processing. In geologies with a high clay content, water retention is a potentially significant source of error when using the volumetric method. Similarly, mechanical **breakdown** of sediments during processing is also a concern when using the gravimetric process.

* The Watershed correlation approach used in this study may have greater utility when applied to areas that have a greater range of managed and unmanaged (controls) subbasins. The lack of controls in this study clouded conclusions concerning background levels of fine sediment.

* Research on the possible genetic adaptations of different Salmonid stocks to differences in fine sediment may prove useful in improving the relationship between measures of gravel quality and early life history survival.

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