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# THE IMPACT OF LOGGING ON BENTHIC COMMUNITY STRUCTURE IN SELECTED WATERSHEDS OF THE OLYMPIC PENINSULA, WASHINGTON

by

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Contribution toward the Final Report of the
Clearwater Effects of Logging Contract

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# ABSTRACT

Logging practices change the physical characteristics of streams, either through introduction of fine sediments caused by erosion, or by canopy removal, which may increase water temperature or decrease allocthonous detrital input. The aquatic insect community responds to the presence of fine inorganic sediment by changes in species composition or population size. In this study, conducted on the Olympic Peninsula, Washington, benthic samples were collected in 25 streams whose watersheds had varying intensities of logging. In addition, measurements of gravel composition, amount of shade, riparian vegetation, discharge, ratio of organic to inorganic material, and water quality were taken. Logging intensity was measured by the kilometers of road per basin area, and by the percentage of basin area logged. Insects were enumerated, weighed and identified to functional group. Linear correlation analysis and stepwise multiple correlation analysis were applied to determine if the dominant environmental conditions affecting insect community composition could be the direct result of logging practices. Density and biomass of scrapers was found to be negatively correlated with the presence of fine gravels. Differences in abundance and biomass were not correlated to the same environmental characteristics, and neither could be attributed to the effects of logging alone. Within-stream variability was greater than between-stream variability to the extent that differences in community size or structure could not be causally related to logging.

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# INTRODUCTION

Many studies have shown that logging practices can cause perturbations to the physical characteristics of streams. Investigations by Anderson (1971), Brown and Krygier (1971), Fredrickson (1970), Megahan and Kidd (1972) and Cederholm, Reid and Salo (1980) indicate that construction of logging roads can result in a significant increase in the amount of fine sediment deposited in streams, either through road surface erosion or landslides. Additional effects of logging on the aquatic environment may result in an increase in water temperature and incident light, and a decrease in allochthonous detrital input, as a result of canopy removal. Changes in the shape of the hydrograph may occur as well. The effects of logging on the stream environment are summarized in reviews by Gibbons and Salo (1973) and Iwamoto et al. (1978).

It has been shown that the aquatic insect community responds to the presence of fine inorganic sediment. These responses may be observed as increases or decreases in insect numbers and biomass, or as changes in species composition. In lotic systems a greater number of insects are found in eroding than in depositional areas. Minshall and Minshall (1977), Cordone and Kelly (1960), Sprules (1947), Cummins (1966), Pennak and Van Gerpen (1947) and Newlon and Rabe (1977) have all shown that there is a differential preference on the part of some members of the macroinvertebrate community for areas of rubble and cobble, rather than for fine inorganic gravel. By introducing insects to artificial substrate of different sizes, either with or without an embedding layer of silt, Cummins and Lauff (1969) have shown that various insect species have differential tolerances for substrates of different size. Literature reviews by Hynes (1970) and Milner and Scullion (1980) address the effects of sediment and bedload movement on the insect community in more detail. The results of these investigations suggest that logging practices may produce changes in the benthic community by introducing fine sediment into the aquatic environment. The number of insects may be reduced by the grinding action produced by bedload movement, or by loss of cobble surface area by the filling in of interstices.

Martin (1976) concluded that on the Olympic Peninsula, an area of extremely high annual precipitation, there was no detectable differences in insect community structure in logged and unlogged streams. However, this study was conducted within only one watershed with a limited range of environmental perturbations. Research by Hawkins (1979) in Oregon has found that by removing streamside canopy the resultant increase in light increases algal production and the number of benthic herbivores which masks the effects of sediment introduction as a result of logging. Erman, Newbold and Roby (1977) have shown that in logged streams without buffer strips, more abundant but less diverse insect populations results. Gut content analysis indicates that allochthonous leaf material is the most important food source for primary consumers (Minshall 1967). The spatial distribution of the benthic community has a strong correlation with the amount of detrital debris present (Eggleshaw 1964). These studies suggest that logging may have differential impact on benthic organisms based on individual feeding regimes. Through analysis of gut contents, Cummins (1973) and Merrit and Cummins (1978) devised a system of classification of insects based on characteristic feeding mechanisms. Insects are partitioned into one of five functional groups: (1) shredders - herbivores and detritivores, (2) collectors - filter feeders and detritus gatherers, (3) scrapers - feeding on algae and attached periphyton (4) engulfers-predators, (5) parasites.

The objective of this study was to determine whether the cumulative effects of logging (i.e., sediment deposition, canopy removal, changes in organic detritus) correlate with changes in abundance of the benthic community structure of Olympic Peninsula streams.

## DESCRIPTION OF STUDY AREA

The western slopes of the Olympic Peninsula, located in the extreme northwest corner of Washington State (Fig. 1), have a mean annual precipitation of 300 to 400 mm. Twenty-five streams were chosen, based on the intensity of logging and road-building in each watershed. The intensity of logging road building was based on kilometers of road per basin area. The streams were located in seven different major watersheds which ranged in logging intensity from wilderness area (0 percent) to areas with 92 percent of the drainage basin logged (Table 1). Stream size ranged from first to seventh order, and low flow discharge varied from less than 28 liters/sec to greater than 10,900 liters/sec.

## METHODS

### Benthic Sampling

Benthic samples were taken between July 21, 1980 and August 22, 1980. One riffle in each stream was sampled. Riffles were chosen on the basis of whether they were suitable for salmon spawning, and if the depth and site of substrate were such that the benthic sampler could be employed. Bottom fauna were sampled with a modified Neill cylinder (Neill 1938). This cylinder (Fig. 2) samples 0.1 $m^2$, and had a trailing net with a mesh size of 223 microns. It

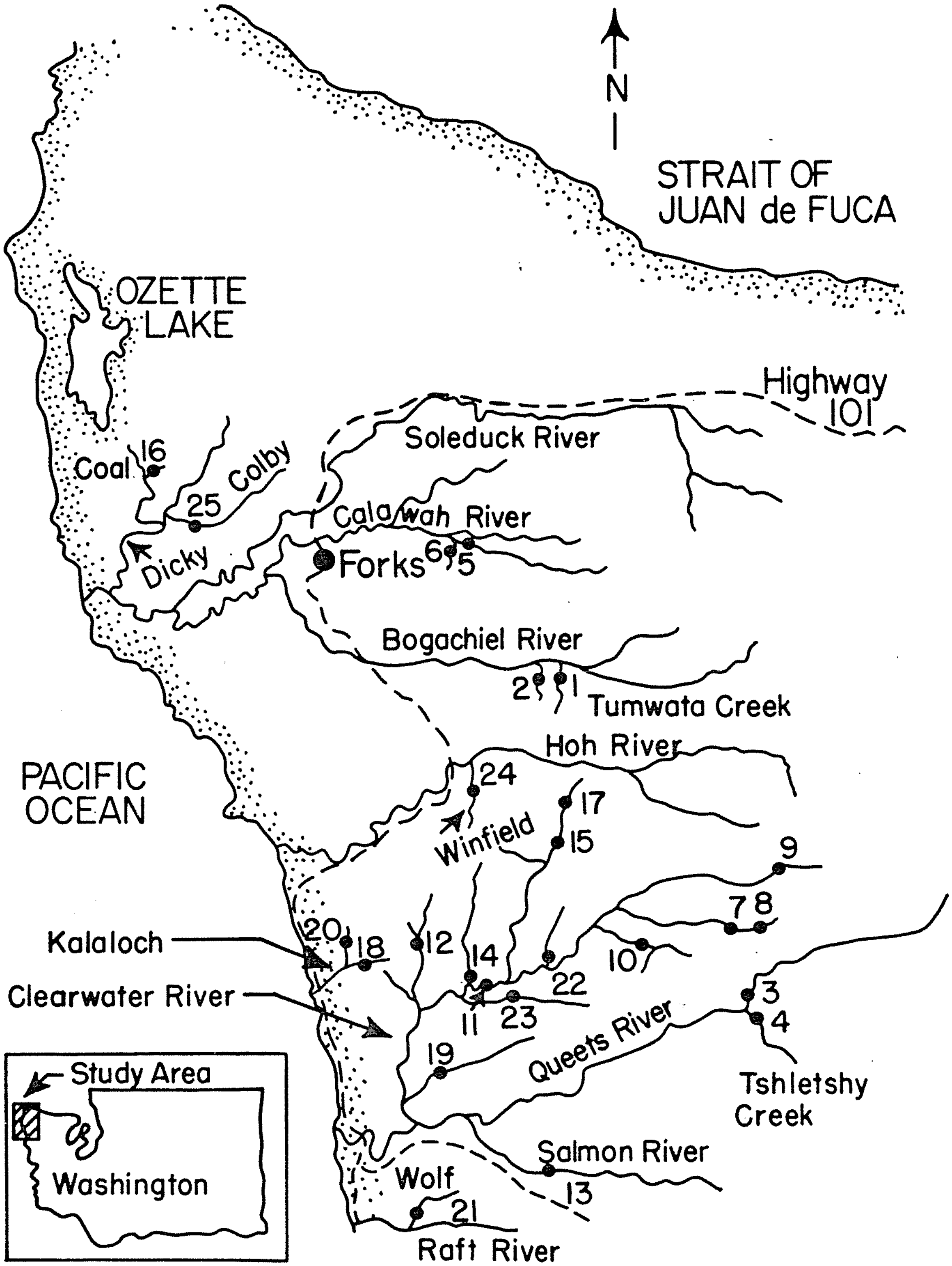
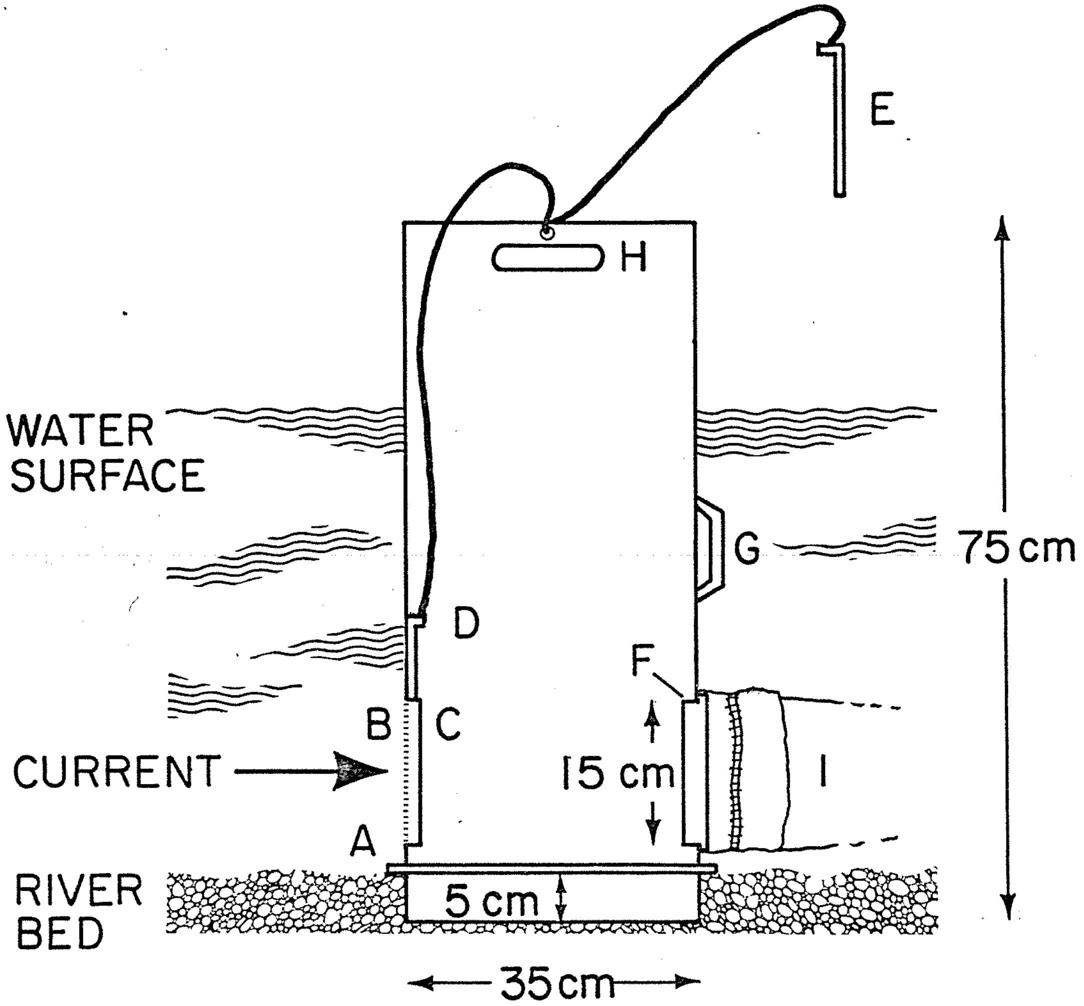


Figure 1. Study area. Identification of stream numbers are found in Table 1.

Table 1. Streams surveyed and associated logging intensity.

| Stream | % basin area logged | Road kilometers/ basin area | Stream identification number |
|---|---|---|---|
| Tumwata Creek | 0 | 0.0 | 1 |
| Bogachiel Tributary | 0 | 0.0 | 2 |
| Upper Queets River | 0 | 0.0 | 3 |
| Tshletshy Creek | 0 | 0.0 | 4 |
| South Fork Calawah River | 0 | 0.0 | 5 |
| Boundary Creek | 8 | 1.11 | 6 |
| Lower Solleks River | 15 | 2.01 | 7 |
| Upper Solleks River | 21 | 2.08 | 8 |
| Upper Clearwater River | 31 | 2.83 | 9 |
| Stequaleho Creek | 32 | 4.12 | 10 |
| Lower Clearwater |  | 4.68 | 11 |
| Miller Creek | 35 | 5.00 | 12 |
| Middle Fork Salmon | 36 | 5.57 | 13 |
| Shale Creek | 38 | 3.62 | 14 |
| Lower Snahapish River | 45 | 5.81 | 15 |
| Coal Creek Tributary | 46 | 6.77 | 16 |
| Upper Snahapish River | 47.5 | 5.60 | 17 |
| East Fork Kalaloch River | 50 | 5.13 | 18 |
| Hurst Creek | 56 | 4.25 | 19 |
| West Fork Kalaloch River | 56 | 6.90 | 20 |
| Wolf Creek | 62 | 4.38 | 21 |
| Bull Creek | 62 | 6.00 | 22 |
| Christmas Creek | 62 | 6.60 | 23 |
| West Winfield Creek | 77 | 6.89 | 24 |
| Colby Creek | 92 | 4.80 | 25 |



| | |
|---|---|
| A | Flange |
| B | Screen over front opening |
| C | Track for sliding door |
| D | Sliding door with attached cord (in track) |
| E | Rear sliding door (hung outside cylinder for flushing) |
| F | Rear opening with flange |
| G | Carrying handle |
| H | Handle for rotating cylinder |
| I | Trailing net |

(adapted from Neill, 1938)

Figure 2. Neill cylinder.

is pushed into the substrate until the projecting bottom flange was flush with the surface of the substrate. The two doors were then opened, with the ensuing rush of water flushing organisms into the net. Large stones were washed in the cylinder to remove any attached insects. A metal probe 15 cm long was then inserted into the substrate and the gravel stirred to dislodge any insects remaining. The doors are then closed. The stirring and flushing procedure was repeated two more times. Insects were removed from the net and preserved in 70 percent ethyl alcohol until analyzed. Four samples were taken in each riffle in a line perpendicular to the thalweg. In the laboratory, a modification of the Williams and Williams (1974) technique for staining insects with rose bengal was used to aid in sorting. Insects were separated from debris under 10X magnification, subsampled so there were at least 250 in each sample, then counted and identified to family or genera when possible. From each family 75-100 insects less than 3 mm were measured to the nearest 0.10 mm. These lengths were used to calculate the mean length of insects less than 3 mm for each family. All insects greater than 3 mm were measured to the nearest 0.10 mm. Biomass calculation based on length was determined by methods used by Martin (1976). In this case, the modified biomass formula is:

$$1 \text{ mm weight} = \frac{\pi \cdot \left( \frac{D:L}{2} \right)^2 \cdot 1.05}{1000}$$

D:L = average weighted diameter-to-length ratio for a given taxon. The mean specific gravity of aquatic insects is 1.05 (Hynes and Coleman 1968). The weight of each individual is calculated and the total biomass is equal to the sum of the weights of all individuals found in the sample.

Functional group classification follows that of Merrit and Cummins (1978). The most abundant genus of each family was used to determine the

Table 2. Functional groups of observed taxa.
c = collection-gathers sh = shredders sc = scrapers
eng = engulfers par = parasites

| Taxa | Functional group |
|---|---|
| Ephemeroptera | |
| Baetidae | c |
| *Baetis* | |
| Ephemerellidae | c |
| *Ephemerella* | |
| Heptageniidae | sc |
| *Epeorus* | |
| Siphlonuridae | c |
| *Ameletus* | |
| Leptophlebiidae | c |
| *Paraleptophlebia* | |
| Potomanthidae | c |
| *Potomanthus* | |
| Plecoptera | |
| Perlidae | eng |
| *Acroneuria* | |
| Chloroperlidae | c |
| *Alloperla* | |
| Nemouridae | sh |
| *Nemoura* | |
| Capniidae | sh |
| *Capnia* | |
| Leuctridae | sh |
| *Leuctra* | |
| Perlodidae | eng |
| *Isoperla* | |
| Peltoperlidae | sh |
| *Peltoperla* | |
| Trichoptera | |
| Rhyacophila sp. | eng |
| Glossosomatidae | sc |
| *Glossosomatinae* | |
| Limnephilidae | sh |
| Hydropsychidae | c |
| Psychomyiidae | c |
| Philoptomidae | c |
| Hydroptilidae | par |
| Brachycentridae | c |
| *Brachycentrus* | |

Table 2 continued.

| Taxa | Functional group |
|---|---|
| Lepidostomatidae | sh |
| *Lepidostoma* | |
| Polycentropodidae | eng |
| Diptera | |
| Dixidae | c |
| *Dixa* | |
| Tipulidae | eng |
| *Antocha* | |
| Chironomidae | c |
| Simuliidae | c |
| Ceratopagenidae | eng |
| Empididae | eng |
| Dolichopodidae | eng |
| Psychodidae | c |
| Deuterophlebiidae | sc |
| Coleoptera | c |
| Elmidae | sh |
| Dytiscidae | par |
| Staphlinidae | eng |
| Hydrophilidae | eng |
| Collembola | c |
| Mites | par |

functional group category for the entire family (Table 2). When identification was not possible, the dominant functional group for that family was used. There are inherent problems in this method, in that different larval instars may have alternate feeding mechanisms, and all genera of a particular family may not belong to the same functional group. The small size of most aquatic insects found on the Olympic Peninsula (85 percent are less than 3 mm) makes identification of insect to genera or species quite difficult. Therefore, the functional group for each family was categorized according to the dominant genus greater than 5 mm. Sampling only during July and August would favor those genera that grow to 5 mm by this time, and discriminate against those that have already emerged, or have slower growth rates.

## Substrate Analysis

Gravel samples were collected by a technique similar to that of Cederholm and Lestelle (1974). Six samples were collected in each stream, two in each of three consecutive riffles. Multiple samples were taken to overcome problems associated with heterogeneity within riffles. One of these riffles was sampled for benthic organisms. For gravel samples a stainless steel McNeil cylinder (Fig. 3) was rotated into the substrate to a depth of 20-25 centimeters, and the contents were removed and stored in a bucket. A plunger was then inserted to retain fine suspended sediment and all water remaining in the cylinder was added to the bucket. Gravel was separated into different size categories by washing and shaking them through 10 Tyler sieves of descending size mesh (53.8 mm, 26.9 mm, 13.2 mm, 6.7 mm, 3.35 mm, 1.70 mm, 0.85 mm, 0.425 mm, 0.21 mm, 0.106 mm). Material passing through the smallest

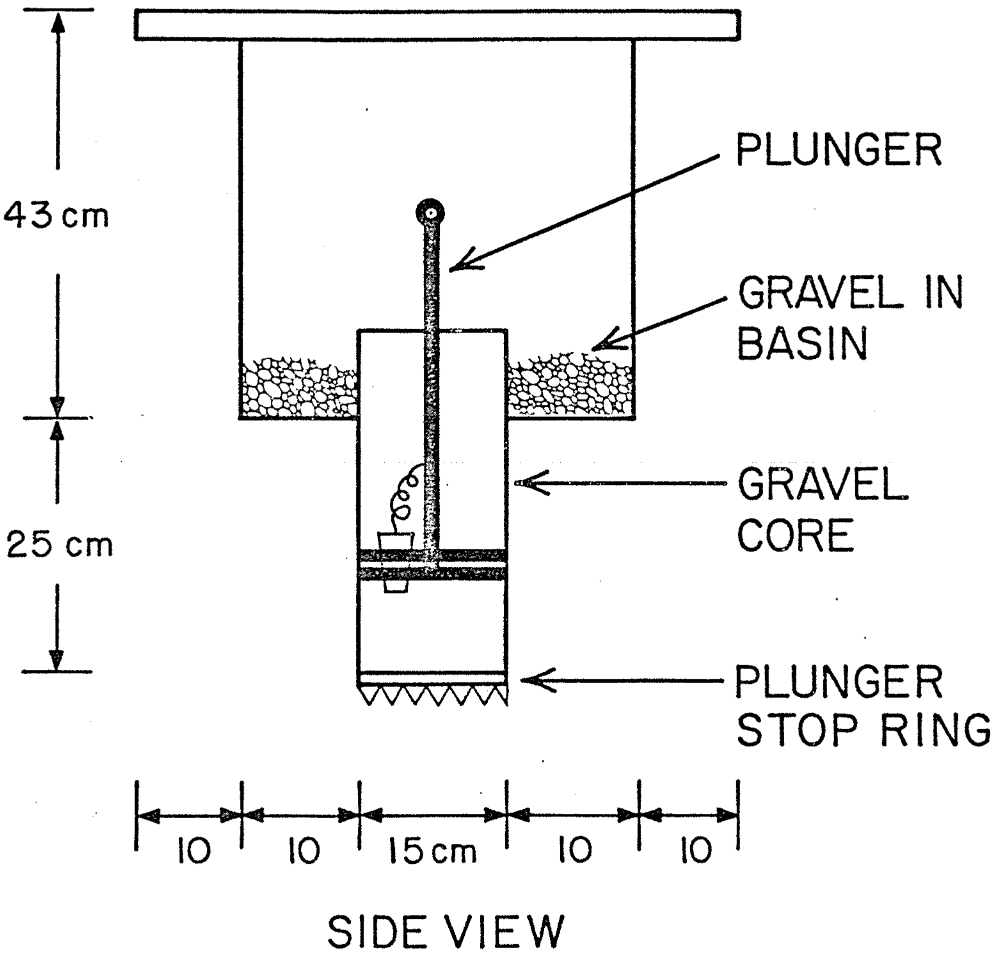


Figure 3. The McNeil gravel sampler.

sieve settled into a graduate cylinder for one hour and was then measured volumetrically. Those gravels retained in the sieves were measured volumetrically as well, and the percent composition of the total sample passing each sieve was calculated. The regression analysis of Shirazi and Seim (1979) was used to calculate mean geometric diameter. This analysis also made it possible to estimate the particle diameters at various percentiles of the gravel size distribution. The particle diameters at the 5, 16, 84 and 95 percentiles were used in this analysis to represent particle size distributions.

## Logging Intensity

Logging activity in each watershed was measured planimetrically using aerial photographs. Intensity was defined as percentage of basin area logged, and ratio of logging road kilometers to basin area.

## Organic Analysis

A measurement of the ratio of organic to inorganic material was determined in each riffle where an insect sample was taken. Formalin was added to each bucket containing sediment gathered by the McNeil cylinder to preserve organic material for future analysis. All debris, both organic and inorganic, smaller than 4.76 mm was retained for analysis. The remaining material was grouped into size classes by washing through Tyler sieves, sizes 2.362 mm, 1.00 mm, 0.295 mm and 0.106 mm. The material retained on each sieve was then oven-dried at 60 C for 48 hrs in pre-weighed porcelain crucibles, or in 800 mm Pyrex beakers. The samples were cooled to room temperature and weighed to the nearest .1 mg. Samples were then burned in a muffle furnace at 500 C for 4 hrs, cooled to room temperature, and again weighed to the nearest .1 mg. The weight of the organic component was determined from weight lost upon ignition. The ratio of organic to inorganic materials for a given mesh size was then calculated.

## Shade Measurement

The degree of shading of each riffle sampled for insects was done in two ways. (1) A 35-mm camera with a 28-mm wide-angle lens was positioned at the midpoint of a riffle by placing it on a bucket 38 cm in height. The camera was leveled using a pocket level, and a photograph was taken with the lens in a horizontal position. By using a digital planimeter and the photographic print the area of the picture not consisting of trees or branches was determined. (2) Stream aspect was noted, and overhead canopy was visually estimated. By taking into account aspect and any geographic points that may obscure sunlight, such as a steep cliff next to the bank, the amount of shading was categorized into one of five groups: 0 percent, 25 percent, 50 percent, 75 percent and 100 percent.

## Discharge Measurement

Transects were set perpendicular to the thalweg in each stream, and the width was measured. Depending on stream width, the depth was measured in three to seven locations, and cross-sectional area was determined. At each point where the depth was measured, water velocity was measured at 0.6 of the depth using a midget Bentzel current speed tube or a Price current meter. The product of cross-sectional area and velocity is equal to the discharge.

## Riparian Vegetation

A visual inspection of the streamside vegetation was made to estimate the ratio of coniferous to deciduous plants growing alongside the riffle. The ratios were broken into groups of 100:0, 75:25, 50:50, 25:75 and 0:100.

## Water Quality

Water samples were taken in 500-ml plastic bottles at sites upstream from riffles being sampled, so that disturbance of the streambed would be minimal. The water was analyzed for conductivity, $NO_3^-$, $NH_4^+$ and $PO_4^{-3}$.

## Substrate Score

The substrate within the Neil sampler was analyzed using a modification of the technique of Sandine (1974). The dominant particle in the Neil cylinder was determined to be within one of 6 size intervals: (1) <1.5 mm, (2) 1.5-6.35 mm, (3) 6.35-25.4 mm, (4) 25.4-63.4 mm, (5) 63.5-152.4 mm, (6) >152.4 mm. The degree of embeddedness of this material was then estimated to be (1) 100 percent, (2) 75 percent, (3) 50 percent, (4) 25 percent, (5) 0 percent. For example, a value of 100 percent embeddedness was given when the dominant particle size was almost completely covered by smaller gravel sizes, so that there were few interstices observed. The size of the embedding material was determined to be one of the six gravel sizes listed above, usually at some size less than the dominant one. Based on the studies by

Hynes (1970), Cordone and Kelly (1960) and Sprules (1947), the quality of the substrate was evaluated in relation to insect preferences. Dominant size (1-5) was multiplied by a weighted factor (.6-1.0 as embeddedness decreased) and this value was then multipled by a weighted factor (.1-.5 as embedding material size increased). This final value was used as an overall substrate score. For example, if the dominant particle size was 6.35-25.4 mm, and it was 75 percent embedded by particles of 1.5-6.35 mm, the rating for this substrate would be 3 x .2 x .2 = 0.12. This rating system provides a relative scale for the various substrate compositions encountered; the higher the value of the score, the better the substrate in terms of interstices and surface area and the lower the amount of fine material.

## Hydrologic Measurements

Measurements of hydrologic data were taken from Rittmueller (1983 in preparation). Three measurements were used in the correlation analysis (1) Road yield of fine sediments entering the streams over a 24 month period, (2) Boundary layer shear stress, a measurement of the hydrologic energy generated along the surface of the streambed, (3) Recurrence of bed movement, a theoretical approximation based on bank full discharge and gradient. This is an evaluation of the stability of the stream bottom.

## Statistical Analysis

Elliot (1981) has determined through statistical analysis that the distribution of benthic macroinvertebrates is contagious and is best described as a negative binomial distribution. In order to apply normal statistics, all numbers and biomass measurements were converted by a log (X+1) transformation. Percent composition of functional groups was transformed using an arcsin transformation, as values could only be between 0 and 100. Analysis of variance tests, and the Student-Newman-Keuls test were applied to determine if significant differences between streams for numbers, biomass, or composition existed. Pearson correlation analysis, and stepwise multiple correlation analysis were applied to determine which environmental factors had the most dominant effect in structuring the insect community.

# RESULTS

## Numbers and Biomass

Mean total numbers of insects were found to range from 4400 ± 3866 insects/m$^2$ in Boundary Creek, to 33080 ± 16154 insects/m$^2$ in lower Clearwater River (x ± 95 percent confidence interval) (Table 3). Due to the small mesh size used these values are higher than those reported in other studies but are in agreement with Martin (1976), who used a similar size mesh. Analysis of variances indicates that there are significant ($p \leq .05$) differences between streams with regard to the total number of insects present. The results of the Student-Newman-Keuls multiple range test are indicated by the heavy bars in the upper part of Fig. 4. There are four groups of which two do not overlap. The 95 percent confidence intervals are quite large indicting the presence of considerable variability between samples within a riffle. Due to this variability, there were streams with means that could not be relegated to only one group. This leads to the possibility that in fact greater and more distinct differences do exist between streams, but they are not distinguishable (a type II error). The amount of variability was not constant among streams.

No detectable relationships were found to exist between logging activity and mean total number of insects based on the intensity of logging within a watershed, measured as percent of basin area cut, or road kilometers per basin area within the watershed. The groups calculated by the multiple range test were not in any way partitioned by intensity of logging. Correlation analysis did not detect any significant relationships between any of the physical or biotic measurements that were potentially subject to perturbation by logging

Table 3. Mean number and biomass (mg) per square meter ± 95 percent confidence interval for all streams sampled.

| | Number | Biomass (mg) |
|---|---|---|
| Colby | 23350 ± 7480 | 3598.30 ± 2646.62 |
| Stequaleho | 7190 ± 4255 | 12861.55 ± 27639.59 |
| Bull | 15805 ± 7240 | 1824.75 ± 1018.55 |
| S. F. Calawah | 15553 ± 8095 | 2063.20 ± 1077.07 |
| Hurst | 9475 ± 2497 | 1318.42 ± 631.87 |
| Salmon | 8185 ± 2852 | 1974.90 ± 3113.06 |
| Coal Cr. Tributary | 12080 ± 3406 | 1011.60 ± 566.18 |
| Tseletshy | 16860 ± 8646 | 7316.80 ± 7877.18 |
| E. F. Miller | 12755 ± 13820 | 5596.97 ± 13511.82 |
| Shale | 14875 ± 10314 | 3685.02 ± 3981.17 |
| Upper Solleks | 17750 ± 8093 | 6490.40 ± 6696.92 |
| Boundary | 4415 ± 3866 | 983.72 ± 731.88 |
| Christmas | 16960 ± 8192 | 4286.80 ± 4431.48 |
| W. F. Kalaloch | 12270 ± 4506 | 2095.60 ± 1272.16 |
| Bogachiel Tributary | 12810 ± 3251 | 3814.20 ± 3917.28 |
| Queets | 8450 ± 10998 | 5861.20 ± 5647.04 |
| Upper Clearwater | 16840 ± 6187 | 3846.50 ± 5415.06 |
| Lower Clearwater | 33080 ± 16154 | 7772.70 ± 1461.35 |
| Lower Snahapish | 21030 ± 16504 | 6846.20 ± 5040.30 |
| W. Winfield | 13690 ± 4992 | 2977.30 ± 5565.16 |
| Upper Snahapish | 15230 ± 4800 | 2142.20 ± 644.27 |
| Tumwata | 9020 ± 3458 | 3107.50 ± 3252.03 |
| Wolf | 12440 ± 5178 | 987.30 ± 649.52 |
| E. F. Kalaloch | 11070 ± 2566 | 1436.80 ± 360.45 |
| Lower Solleks | 16775 ± 14096 | 14232.80 ± 17839.48 |
| Mean | 14321 ± 6025 | 4325.04 ± 3817.00 |

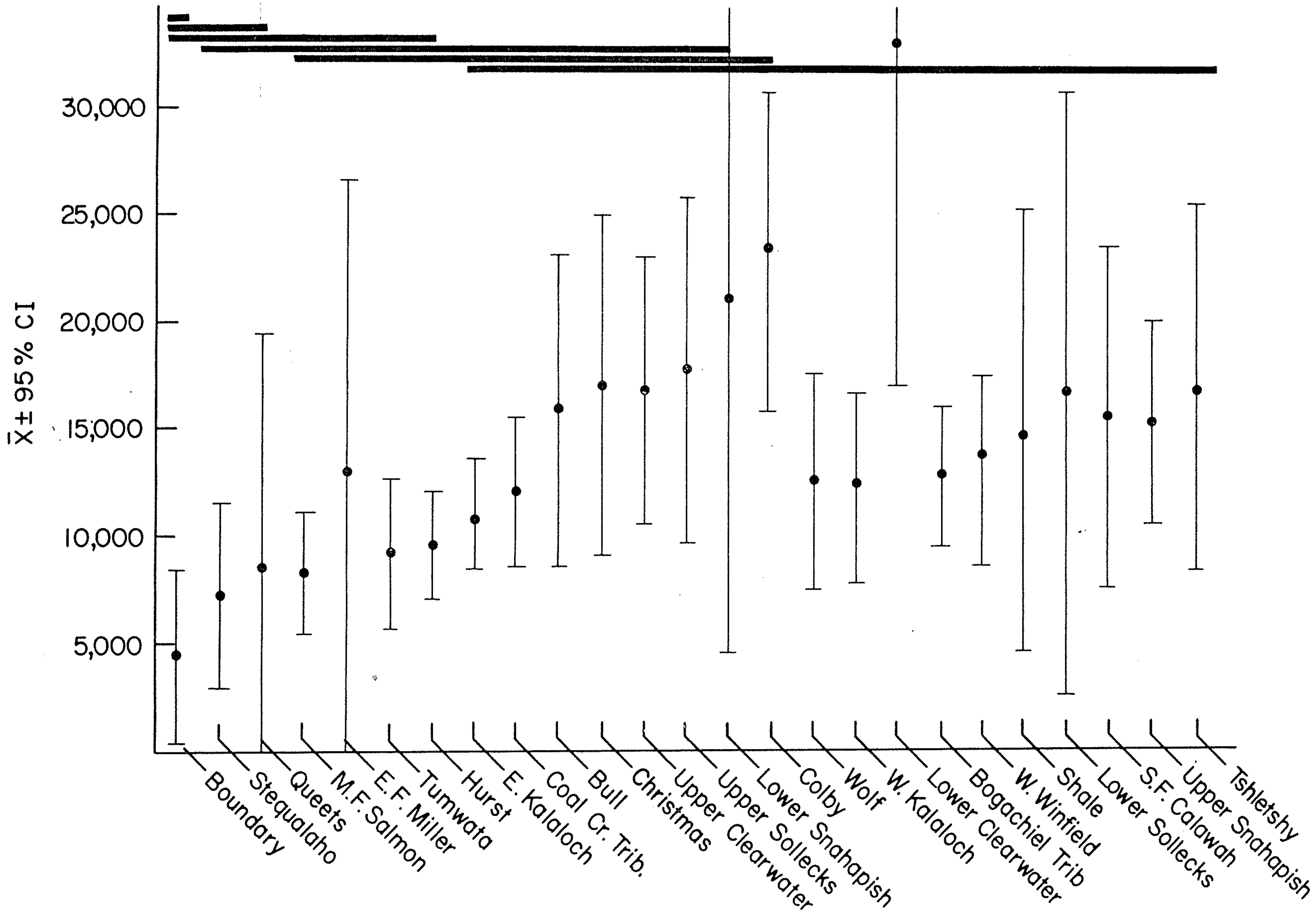


Figure 4. Mean number of insects per square meter ± 95% confidence interval for all streams. Bars in upper part of figure indicate which groups of streams are significantly different as determined by the Student-Newman Keuls multiple range test.

(i.e., shade, percent of fine sediment, ratio of organic to inorganic material, riparian vegetation) and total number of insects.

Mean total biomass of benthic invertebrates ranged from 983 ± 732 mg/m$^2$ in Boundary Creek, to 14232 ± 17839 mg/m$^2$ in lower Solleks River (Table 3). Analysis of variance testing indicates that there is no detectable difference in total biomass among any of the 25 streams. This is in part due to the great variability found between samples in the same riffle. Correlation analysis again failed to detect any significant correlation between intensity of logging, or environmental perturbation subject to effects of logging, and mean total biomass of insects.

## Benthic Community Composition

The composition of the insect community was determined by calculating the percentage contribution of each functional group with regard to the total number and biomass for each stream. With the exception of Stequaleho Creek, the funtional group composition of all streams was strikingly similar when analyzed in terms of numbers (Fig. 5). The dominant group in Stequaleho Creek was parasites, while in all other streams, collectors comprised the dominant functional group with respect to density. This group accounted for a minimum of 70% of the total benthic community. Parasites were the second most abundant group in 19 of 25 streams ranging from 1 to 41 percent and shredders were generally the third most abundant, comprising from 1 to 14 percent of the total.

Engulfers and scrapers were always a small part of the total, contributing in every case less than 10 percent, and usually less than 5 percent.

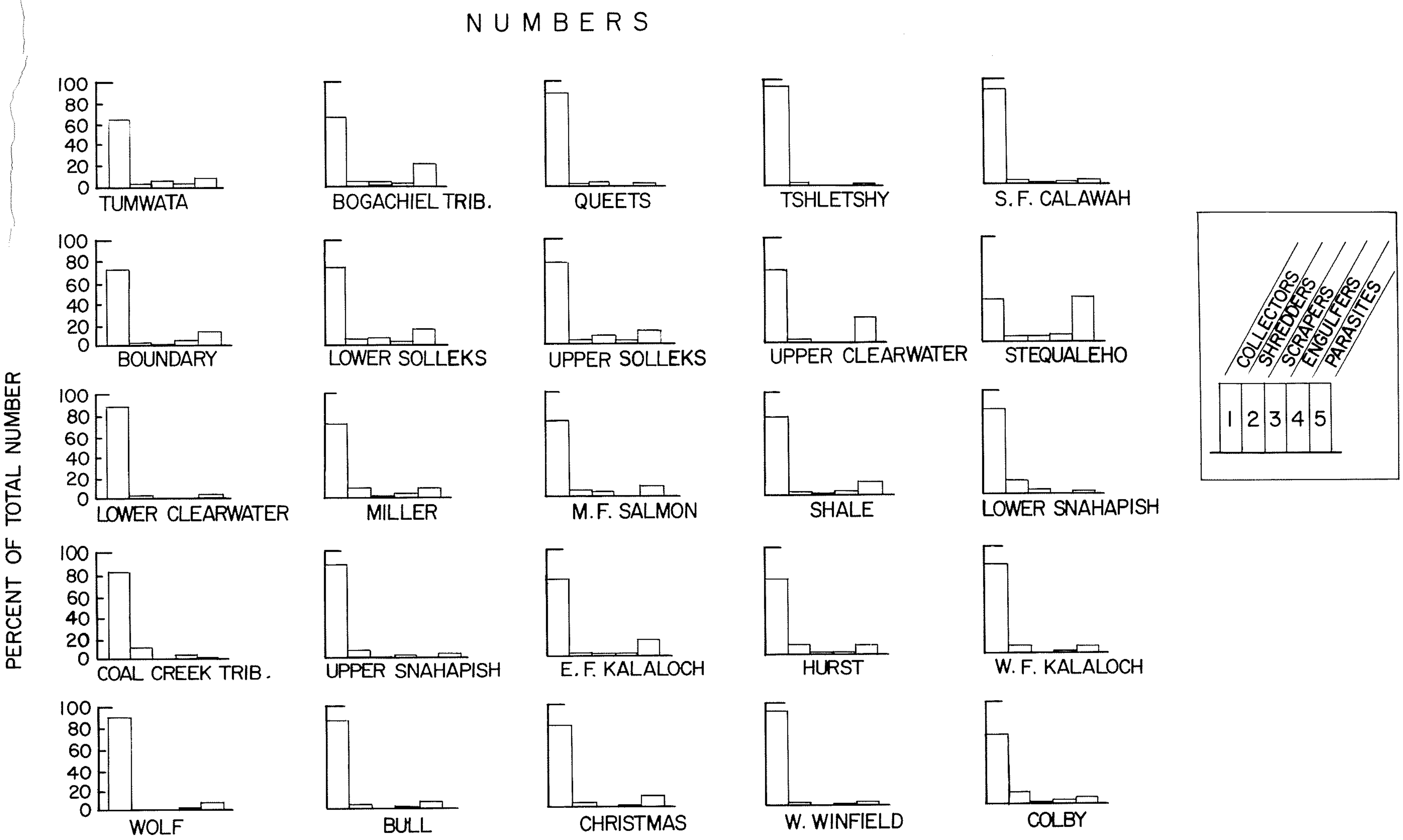


Figure 5. Benthic community composition calculated as percent of total number contributed to be each functional group.

Inspection of the graphs in Figure 5 demonstrates that streams with markedly different land use show suprisingly similar community profiles. Upper Snahapish River (46.5 percent logged) and the Queets River (0 percent logged) have almost identical profiles as do Upper Solleks River (21 percent) and Bogachiel Tributary (0 percent) and Wolf Creek (62 percent) and Tumwata Creek (0 percent). Furthermore, streams with equal portions of basin logged such as Bull Creek and Wolf Creek (62 percent) show differences in profile.

Although there appear to be detectable differences among the biomass profiles of these streams (Figure 6) (for example, compare Colby and Shale Creeks) analysis of variance tests indicates that there is no significant difference in percent of total biomass for each functional group between streams except for shredders and parasites. This can be explained by the tremendous variability within samples. Since 97 percent of all insects found on these Olympic Peninsula streams are less than 6 mm (Martin, personal communication) a few large individuals will greatly increase the biomass estimate within that sample, which increases the variability between groups within a riffle. Furthermore, if a few large individuals are found within one group, that will cause that particular group to have the largest percent biomass. Biomass profiles are therefore quite subject to sampling error, and differences that appear to exist among streams may not be real.

Results of Pearson correlation analysis examining the statistically significant relationships between functional groups and individual stream characteristics are presented in Tables 4 and 5. These tables show only those relationships found to be statistically significant. No significant relationships were found to exist between a specific parameter and mean density, abundance of collectors, or biomass of engulfers. This is due in part to the large variability associated with these groups. The remaining

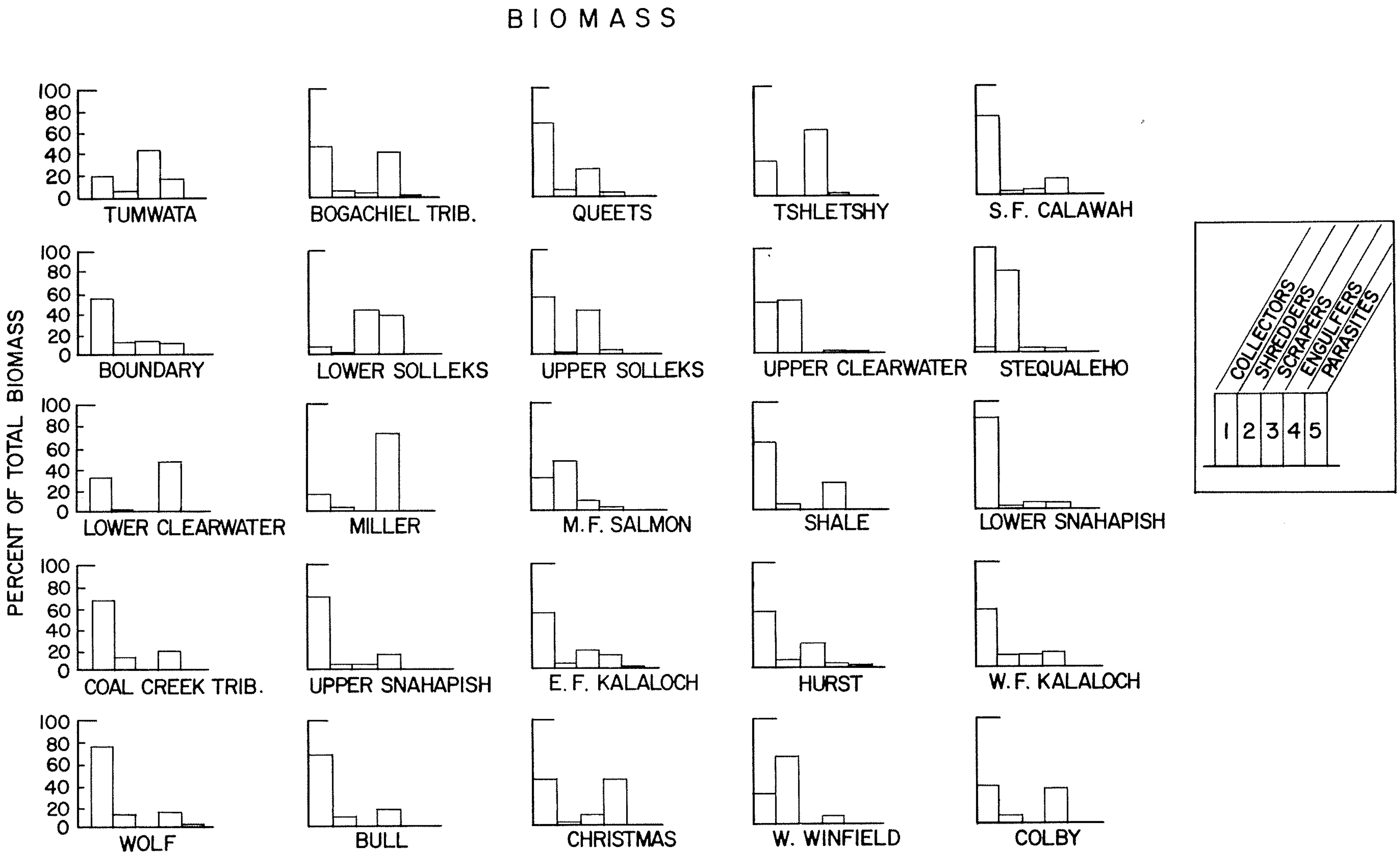


Figure 6. Benthic community composition calculated as percent of total biomass contributed to by each functional group.

Table 4. Correlation analysis showing significant relationships ($P \leq .05$) between mean density of each functional group and stream characteristics. Values presented are R values. D5 through D95 are geometric diameter measurements of gravel sizes at the fifth through ninety-fifth percentiles.

| | Functional Groups | | | | |
|---|---|---|---|---|---|
| Independent Variable | Collectors | Shredders | Scrapers | Engulfers | Parasites |
| Shade | | | | | .50 |
| Substate Score | | | | -.56 | |
| Road Yield (2 yr.) | | .61 | | | |
| Recurrence of bed movement | | | .44 | | |
| Boundary Layer Shear Stress | | .56 | | | .45 |
| Gravel % <26.90 mm | | .46 | | | |
| 13.20 mm | | .42 | | | |
| 6.70 | | .41 | | | |
| 3.35 mm | | .16 | | | |
| .85 mm | | .58 | -.44 | | |
| .425 mm | | .55 | -.47 | | |
| .106 mm | | .48 | -.54 | | |
| D5 | | -.55 | | | |
| D16 | | -.57 | | | |
| D50 | | -.57 | | | |
| D84 | | -.57 | | | |
| D95 | | -.56 | | | |

Table 5. Correlation analysis showing significant relationships ($P \leq .05$) between biomass of each functional group and stream characteristics. Values presented are R values.

| | Functional Groups | | | | |
|---|---|---|---|---|---|
| Independent Variable | Collectors | Shredders | Scrapers | Engulfers | Parasites |
| Discharge | .44 | | | | |
| Shade | | | .67 | | |
| Substrate score | .56 | -.48 | | | |
| % Basin area logged | | | | | -.40 |
| Road yield (2 yr.) | | | | | -.41 |
| Recurrence of bed movement | | | .48 | | |
| Gravel % < 13.20 mm | -.41 | | -.41 | | |
| 6.70 mm | -.45 | | -.44 | | |
| 3.35 mm | | | -.43 | | |
| .85 mm | | | -.44 | | |
| .425 mm | | | -.51 | | |
| .106 mm | | | -.42 | | |

correlations explain only a small part of the variability, as indicated by the low R values. The scraper functional group is the only one found to have a significant correlation with both density and biomass and fine sediment. A significant ($P \leq .05$) negative relationship is found between scrapers and gravel with diameters of less than .85 mm to .106 mm. This would indicate that the introduction of fine sediments is limiting scraper production. Scraper density has the strongest correlation with gravel sizes less than .106 mm ($R = -.54$).

There appears to be a positive relationship between gravel composition and density of shredders, but there is no preference for large sizes over small sizes, as observed by the positive correlations for gravel diameters at both ends of the spectrum. This is observed as well for the geometric diameter measurements at various percentiles. An increase in D5, the diameter of which 5 percent of the sample is smaller than, indicates decreasing amounts of fine materials. An increase in D95 would indicate increasing fines. Positive relationships between density of shredders are found for both. Furthermore, introduction of fine sediments from road surfaces is found to be positively related to abundance of shredders. Other weak but significant relationships are found to exist, but no clear explanation of these relationships can be made. Most puzzling is the positive relationship between biomass of scrapers and shade. An increase in shade would be expected to reduce algal production, with a concomitant reduction in scraper production. However, the opposite relationship was found to exist.

Stepwise multiple correlation analysis was performed to determine the combination of environmental factors responsible for the variability between streams in terms of total numbers and biomass, and numbers and biomass for each functional group. The results of this analysis are presented in Tables 6 and 7. No significant relationships are found to exist between total abundance, abundance of collectors, and any group of stream variables. Total biomass can be explained in part by some factor associated with gravel, since biomass decreases with increasing amounts of fine material. The percent of the total gravel sample less than .425 mm, and the diameter of gravel at the 95 percentile explain 36 percent of the variability in biomass. No doubt, these are both indicators of a single, undefined, factor.

The strongest relationship found was for biomass of shredders, whereby 67 percent of the variability was explained by the amount of shade, percent of basin area logged, and gravel diameter at the ninety-fifth percentile. However, it is unclear why the grouping of these particular characteristics result in such a strong correlation.

The abundance of shredders is found to be associated with fine gravels, as seen by the inclusion of road yield and percent fines less than .425 mm. Hydrologic factors enter into the relationship as well, as seen by the negative correlation with boundary layer shear stress. If would appear that some facet of hydrologic events may be in part responsible for abundance of scrapers.

With the exception of scrapers, no clear interpretations of the factors found to explain functional group variability can be made. For example, it is unclear why substrate score, amount of organic material, and percentage of basin area logged would jointly explain 43 percent of the variability in density of engulfers. It must be kept in mind that given the large variance associated with the samples, and the large number of variables entered into the correlation, undoubtedly some of the correlations will be spurious.

Finally, note that in most cases some factor associated with gravel composition is found to explain part of the variability associated with a

Table 6. Multiple correlation analysis between density and significantly correlated parameters ($P \leq .05$).

| Functional group | Environmental Factor | Simple R | Multiple $R^2$ | Significance |
|---|---|---|---|---|
| Total density | No significant relationships found | | | |
| Collectors | No significant relationships found | | | |
| Shredders | Road yield | .61 | .37 | .007 |
| | Boundary layer shear stress | -.56 | .59 | .001 |
| | % gravel <.425 mm | -.54 | .64 | .002 |
| Scrapers | % gravel <.106 mm | -.54 | .64 | .022 |
| | Recurrence of bed movement | .44 | .28 | .005 |
| | % gravel <13.20 mm | -.13 | .51 | .002 |
| Engulfers | Substrate Score | -.56 | .31 | .016 |
| | Ratio of organic/ inorganic <.106 | .10 | .38 | .027 |
| | % Basin area logged | -.35 | .43 | .045 |
| Parasites | Shade | .50 | .25 | .034 |
| | Boundary layer shear stress | .48 | .40 | .021 |
| | % Basin area logged | -.32 | .53 | .011 |

Table 7. Multiple correlation analysis between biomass and significantly correlated parameters ($P \leq .05$).

| Functional group | Environmental Factor | Simple R | Multiple $R^2$ | Significance |
|---|---|---|---|---|
| Total biomass | % gravel <.425 mm | -.33 | .11 | .137 |
| | Gravel size at 95th percentile | -.27 | .36 | .014 |
| Collectors | % gravel <.335 mm | -.58 | .33 | .012 |
| | Ratio of organic/ inorganic <.295 mm | -.16 | .42 | .016 |
| | Substrate score | .56 | .52 | .015 |
| Shredders | Substrate score | -.48 | .23 | .044 |
| | % gravel <.335 mm | .08 | .32 | .053 |
| | Road yield | .14 | .43 | .042 |
| Scrapers | Shade | .67 | .45 | .002 |
| | % Basin area logged | .31 | .60 | .001 |
| | Gravel size at 95th percentile | .08 | .67 | .001 |
| Engulfers | Gravel size at 95th percentile | -.30 | .09 | .216 |
| | Ratio of organic/ inorganic <1.0 mm | .27 | .29 | .073 |
| | % Gravel <.850 mm | .05 | .43 | .041 |
| Parasites | Road yield | -.41 | .17 | .089 |
| | % Basin area logged | -.40 | .42 | .015 |
| | % Gravel <.850 mm | -.15 | .49 | .020 |

functional group. However, no clear relationships are found to exist between logging activity and total abundance or biomass, or functional group composition. The percentage of the basin area logged is found to enter into the equation explaining biomass of scrapers, but in light of the positive correlation with shade previously discussed, the mechanisms of this relationship is uncertain.

## DISCUSSION

The results of this study indicate that there was no detectable effects on the insect community in terms of total number or biomass, or abundance of any functional group as a direct result of logging intensity, measured as percent of basin area logged, or as road miles per basin area. Biomass of parasites was found to have a negative correlation with percentage of basin area logged, but it is uncertain whether this is a causal relationship. This is in contrast to studies by Hawkins et al. (1982) who reported an increase in abundance of predators in streams with open canopies. This relationship, although significant, is quite weak, with $R^2 = .16$. Cederholm et al. (1980) showed a positive relationship between fine sediment input to streams and traffic levels on logging roads. A significant negative relationship was found between abundance and biomass of scrapers and fine sediment which may be attributed to the effects of logging. Scrapers eat algae and periphyton attached to rocks and an increase in fine material can make this food unavailable. The negative relationship may be the result of the food supply being covered, or the movement of fine bedload scraping the algae from rocks. This small material can also be an unstable medium for periphyton growth. There appears to be some relationship between gravel composition and abundance of shredders. No preference for particular gravel sizes are seen, which is surprising in light of work by Martin (1976) who demonstrated an increase in the amount of fine organic matter associated with increases in fine gravels. No relationship with the presence of fine organic materials was found for number or biomass of this functional group.

No strong relationships were found with collectors, the most dominant functional group. It was impossible to determine whether this was due to the variability between samples, or the lack of sensitivity in sampling techniques. A measure of the variability can be calculated from Table 3. Using the method suggested by Elliot (1971), an estimate of the error can be calculated. K is a measure of the clumping of organisms and can be estimated by the following equation:

$$K = \frac{\bar{x}^2 - s^2/n}{s^2 - \bar{x}}$$

for a population with a negative binomial distribution. The percent precision (D percent) of a sample measured as the mean $\pm$D percent is:

$$D + \frac{1}{n\bar{x}} + \frac{1}{nk}$$

n = the number of samples

x = the mean of those samples

Using Upper Solleks River as an example, it was found that the mean density based on four samples taken within a single riffle had an associated error of 87 percent. To calculate the number of samples needed to be taken to estimate the mean with a standard error equal to 20 percent of the mean, the following equation may be applied:

$$n = \frac{t^2}{D^2} \left( \frac{1}{\bar{x}} + \frac{1}{K} \right)$$

In this case, D = 0.2 and t is the Student's t distribution equal to a 95 percent probability of calculating the mean ± 40 percent. For Upper Solleks River, 76 samples would be needed to calculate the mean with a tolerable error of 20 percent. These calculations demonstrate the large variability found within these streams, and the problems inherent in this type of analysis.

The total variability of insect abundance and biomass is the variability within a stream plus the variability among streams. If logging activity was the dominant factor in determining community size or structure, then variability among streams should be greater and multiple range tests should partition streams according to logging intensity; however, this was not found to be the case.

It is possible that there is a continuum of differences that exist as a result of timber harvest, but within stream variability overshadows these effects. Community structure and abundance is a function of specific hydrologic regimes and the resultant microhabitats available. The west coast of the Olympic Peninsula sustains a tremendous amount of rainfall each year, ranging from 300-400 mm. The high flows due to storm events encountered during the winter may scour the streambed to the extent that it resets the insect community to a low level each year, hence the relative abundance of univoltine life histories. Furthermore, the extreme high flows may act to obscure the effects of logging related activity. Siltation resulting from road surface erosion may be flushed quickly enough to preclude any changes in invertebrate abundance. The weak correlations found with sediment suggest that fine gravel does not have a causal effect on the insects, but rather may mirror the hydrologic regime in the particular stream. Martin (unpublished data) found that the numbers of benthic insects are lowest in March through

June, that is, the period immediately following the events of winter. It was with the idea that the effects of logging may be secondary to hydrologic regimes that measurements of boundary layer shear stress, recurrence of bed movement, and road yield of sediments over a 24 month period were used in the correlation analysis. Unfortunately, these measurements of hydrologic factors produced weak correlations at best.

A final problem that may have acted to obscure any clear cut relationships may be the result of the wide range of stream types evaluated. These streams ranged from pristine, old growth forests to very intensively logged areas. The interactions of a multitude of factors that could not be adequately assessed (temperature, shape of the hydrograph, or proximity of roads for example) may act to blur any relationships that exist. A more intensive evaluation of similar streams with only one or two differences in environmental characteristics may have yielded more fruitful results.

# LITERATURE CITED

Anderson, H. W. 1971. Relative contributions of sediment from source areas and transport processes. In J. T. Krygier and J. D. Hall (editors), Symposium Forest Land Uses and Stream Environment, Oregon State Univ., Corvallis. 55 pp.

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

Cederholm, C. J., and L. C. Lestelle. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington. Fisheries Research Institute, University of Washington, FRI-UW-7404.

Cederholm, C. J., L. M. Reid and E. O. Salo. 1980. Cumulative effects of logging road sedimentation on salmonid populations in the Clearwater River, Jefferson County, Washington. Proceedings from the conference Salmon-Spawning Gravel: A Renewable Resource in the Pacific Northwest? October 6-7, 1980. Seattle, WA, State of Washington Water Research Center. Rep. No. 39. 284 pp.

Cordone, A. J., and D. W. Kelly. 1960. The influence of inorganic sediment on the aquatic life in streams. California Dept. of Fish and Game, 47:189-228.

Cummins, K. W. 1966. A review and future problems in benthic ecology. In K. W. Cummins, C. A. Tryon and P. T. Hartman (editors), Organism-Substrate Relationships in Streams, Spec. Publ. Pyatuning Laboratory of Ecology, University of Pittsburgh, 4:2-51.

Cummins, K. W. 1973. Trophic relations of aquatic insects. Ann. Rev. Ent.

18:183-206.

Cummins, K. W., and G. H. Lauff. 1969. Influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia 34:145-181.

Egglishaw, H. J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. J. Animal Ecol. 33:463-476.

Elliot, J. M. 1971. Statistical analysis of samples of benthic invertebrates. Freshwater Biological Association, Scientific Publication No. 25.

Erman, D. C., J. D. Newbold and K. B. Roby. 1977. Evaluation of streamside buffer strips for protecting aquatic organisms. California Water Resource Center, University of California, Davis. Contribution 165, ISSN 0575-4941.

Fredrickson, R. L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. U.S.F.S Res. paper PNW and Range Exp. Sta., No. PN 10-104.

Gibbons, D. R., and E. O. Salo. 1973. An annotated bibliography of the effects of logging on the western United States and Canada. U.S.D.A. Forest Service General Technical Report PNW-10.

Hawkins, C. 1979. Relative effects of sediment and canopy removal on stream communities. Abstracts to presentations at the NCAS 1 West Coast Regional Meeting, p. 54.

Hawkins, Charles P., Michael L. Murphy, and N. H. Anderson. 1982. Effects of Canopy, Substrate Composition, and Gradient on the Structure of Macroinvertebrate Communities in Cascade Range Streams in Oregon. Ecology 63(6) 1840-1856.

Hynes, H. B. N. 1970. The ecology of stream insects. Ann. Rev. Entomol. 15:25-42.

Hynes, H. B. N., and M. J. Coleman. 1968. A simple method of assessing annual production of stream benthos. Limnol. Oceanogr. 13(4):569-573.

Iwamoto, R. N., E. O. Salo, M. A. Madej and R. L. McComas. 1978. Sediment and water quality: a review of the literature including a suggested approach to water quality criteria. EPA Region 10 Contract No. WY-6-99-0825-J.

Martin, D. J. 1976. The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington. M.S. Thesis, College of Fisheries, University of Washington.

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

Merrit, R. W., and K. W. Cummins (eds.). 1978. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Company, Iowa.

Milner, N. J., and J. Scullion. 1980. Review of effects of natural and artificial flow patterns and sediment dynamics on benthic invertebrates and salmonids in Upland Rivers, University of Wales, Institute of Science and Technology.

Minshall, G. W. 1967. Role of allochthonous detritus in the trophic structure of a woodland springbrook community. Ecology 45:138-149.

Minshall, G. W., and J. N. Minshall. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain (U.S.A.) stream. Hydrobiologia 55:231-239.

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

Newlon, T. A., and F. W. Rabe. 1977. Comparison of macroinvertebrate samplers and the relationships of environmental factors to biomass and diversity varability in a small watershed. Idaho Water Research Institute, University of Idaho, Research Technical Completion Report, Project A-049-IDA.

Pennak, R. W., and E. D. VanGerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28:42-48.

Rittmueller, J. F. 1983. (In Press) Effects of Logging Roads on Spawning Gravels in Western Washington Streams. M.S. Thesis, Western Washington University.

Sandine, M. F. 1974. Natural and simulated insect substrate relationships in Idaho batholith stream. M.S. Thesis, University of Idaho.

Shirazi, M. A. and W. K. Seim. 1979. A stream systems evaluation - an emphasis on spawning habitat for salmonids. Corvallis Environmental Research Laboratory, Office of Research and Development, EPA-600/3-79-108.

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin National Park, Ontario. Univ. Toronto Stud. Biol. Serv. 56:1-81.

Williams, D. D., and N. E. Williams. 1974. A counterstaining technique for use in sorting benthic samples. Limnol. Oceanogr. 19(1):152-154.

Appendix Table 1

Functional Group Composition Mean Number/.1 $m^2$ and Percent of Total.

| | Collectors | | Shredders | | Scrapers | | Engulfers | | Parasites | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream | Mean | PCT | Mean | PCT | Mean | PCT | Mean | PCT | Mean | PCT |
| Colby | 1651 | 72.0 | 313 | 13.6 | 71 | 3.1 | 88 | 0.1 | 267 | 11.2 |
| Stequaleho | 315 | 44.3 | 35 | 5.0 | 32 | 4.6 | 38 | 5.4 | 290 | 40.8 |
| Bull | 1331 | 86.0 | 59 | 3.8 | 4 | 0.2 | 32 | 2.1 | 121 | 7.8 |
| S.F. Calawah | 1350 | 88.5 | 30 | 1.9 | 35 | 2.3 | 37 | 2.5 | 74 | 4.8 |
| Hurst | 684 | 74.2 | 79 | 8.6 | 12 | 1.4 | 13 | 1.4 | 133 | 14.4 |
| M.F. Salmon | 628 | 77.4 | 33 | 4.1 | 50 | 6.2 | 13 | 1.6 | 86 | 10.6 |
| Coal Creek Trib. | 973 | 81.6 | 150 | 12.6 | 4 | 0.3 | 42 | 3.5 | 24 | 2.0 |
| Tshletshy | 1485 | 93.1 | 41 | 2.6 | 38 | 2.4 | 13 | 0.8 | 18 | 1.1 |
| Miller | 927 | 74.0 | 147 | 11.7 | 21 | 1.7 | 40 | 3.2 | 117 | 9.4 |
| Shale | 1125 | 77.8 | 39 | 2.7 | 20 | 1.4 | 53 | 3.7 | 208 | 14.4 |
| Upper Solleks | 1363 | 78.6 | 36 | 2.1 | 77 | 4.4 | 41 | 2.4 | 218 | 12.6 |
| Lower Solleks | 1221 | 73.9 | 48 | 2.9 | 79 | 4.8 | 48 | 2.9 | 256 | 15.5 |
| Boundary | 319 | 72.9 | 12 | 2.7 | 7 | 1.5 | 25 | 5.8 | 74 | 17.0 |
| Christmas | 1375 | 82.9 | 64 | 3.9 | 17 | 1.0 | 36 | 2.2 | 167 | 10.1 |
| W.F. Kalaloch | 1028 | 85.3 | 69 | 5.7 | 7 | 0.6 | 29 | 2.4 | 72 | 6.0 |
| Bogachiel Trib. | 777 | 62.5 | 69 | 5.6 | 69 | 5.6 | 42 | 3.3 | 283 | 22.8 |
| Queets | 759 | 90.9 | 22 | 2.6 | 34 | 4.1 | 4 | 0.5 | 15 | 2.0 |
| Upper Clearwater | 1213 | 72.9 | 26 | 1.6 | 15 | 0.9 | 14 | 0.8 | 395 | 23.7 |
| Lower Clearwater | 2942 | 92.5 | 29 | 0.9 | 32 | 1.0 | 35 | 1.1 | 143 | 4.5 |
| Lower Snahapish | 1661 | 80.4 | 291 | 14.1 | 54 | 2.6 | 17 | 0.8 | 42 | 2.0 |
| W. Winfield | 2152 | 92.7 | 26 | 1.9 | 14 | 1.0 | 21 | 1.5 | 38 | 2.8 |
| Upper Snahapish | 1283 | 85.2 | 146 | 9.7 | 2 | 0.1 | 19 | 1.3 | 55 | 3.6 |
| Tumwata | 639 | 72.3 | 32 | 3.6 | 85 | 9.6 | 33 | 3.7 | 95 | 10.7 |
| Wolf | 1009 | 88.5 | 13 | 1.1 | 0 | 0.0 | 29 | 2.5 | 89 | 7.8 |
| E.F. Kalaloch | 828 | 76.2 | 43 | 3.9 | 24 | 2.2 | 20 | 1.8 | 172 | 16.0 |

Appendix Table 2

Functional Group Composition - Mean Biomass mg/.1 $m^2$ and Percent of Total.

| Stream | Collectros | | Shredders | | Scrapers | | Engulfers | | Parasites | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | PCT | Mean | PCT | Mean | PCT | Mean | PCT | Mean | PCT |
| Colby | 145.7 | 40.5 | 60.3 | 16.8 | 5.5 | 1.5 | 146.0 | 40.6 | 2.2 | 0.6 |
| Stequaleho | 96.8 | 7.5 | 1084.3 | 84.3 | 59.9 | 4.7 | 41.3 | 3.2 | 3.8 | 0.3 |
| Bull | 124.7 | 68.4 | 16.8 | 9.2 | 0.4 | 0.2 | 39.0 | 21.3 | 1.6 | 0.9 |
| S.F. Calawah | 157.2 | 76.8 | 5.6 | 2.7 | 7.3 | 3.6 | 33.5 | 16.3 | 1.0 | 0.5 |
| Hurst | 72.8 | 55.9 | 15.2 | 11.6 | 33.5 | 25.8 | 6.9 | 5.3 | 1.7 | 1.3 |
| M.F. Salmon | 68.5 | 34.7 | 94.0 | 47.6 | 20.5 | 10.4 | 13.3 | 6.7 | 1.1 | 0.6 |
| Coal Creek Trib. | 66.2 | 65.4 | 13.3 | 13.2 | 3.1 | 3.1 | 18.2 | 18.0 | 0.3 | 0.3 |
| Tshletshy | 262.4 | 35.9 | 1.5 | 0.2 | 453.1 | 61.9 | 14.5 | 2.0 | 0.2 | 0.0 |
| Miller | 111.7 | 20.0 | 12.6 | 2.2 | 2.0 | 0.3 | 432.4 | 77.3 | 1.0 | 0.2 |
| Shale | 239.9 | 65.1 | 14.7 | 4.0 | 4.8 | 1.3 | 106.3 | 28.9 | 2.8 | 0.7 |
| Upper Solleks | 353.7 | 54.5 | 11.6 | 1.8 | 262.4 | 40.4 | 18.5 | 2.9 | 2.9 | 0.4 |
| Lower Solleks | 161.5 | 11.3 | 12.9 | 0.9 | 661.1 | 46.4 | 585.8 | 41.2 | 2.0 | 0.1 |
| Boundary | 54.0 | 54.8 | 14.6 | 14.9 | 15.5 | 15.8 | 13.3 | 13.5 | 1.0 | 1.0 |
| Christmas | 190.8 | 44.5 | 7.5 | 1.7 | 39.0 | 9.1 | 189.14 | 44.1 | 2.2 | 0.5 |
| W.F. Kalaloch | 121.4 | 57.9 | 25.4 | 12.1 | 28.3 | 13.5 | 33.5 | 16.0 | 1.0 | 0.4 |
| Bogachiel Trib. | 183.4 | 48.1 | 18.1 | 4.7 | 13.7 | 3.6 | 162.5 | 42.6 | 3.7 | 1.0 |
| Queets | 396.9 | 67.7 | 23.9 | 4.1 | 142.8 | 24.4 | 22.3 | 3.8 | 0.2 | 0.0 |
| Upper Clearwater | 173.1 | 45.0 | 198.8 | 51.7 | 2.8 | 0.7 | 4.7 | 1.2 | 5.2 | 1.4 |
| Lower Clearwater | 280.4 | 36.1 | 16.0 | 2.1 | 71.0 | 9.1 | 408.0 | 52.5 | 1.9 | 0.2 |
| Lower Snahapish | 600.7 | 87.7 | 12.8 | 1.9 | 31.1 | 4.5 | 39.4 | 5.6 | 0.6 | 0.0 |
| W. Winfield | 87.4 | 29.4 | 189.4 | 63.6 | 2.4 | 0.8 | 18.1 | 6.1 | 0.5 | 0.2 |
| Upper Snahapish | 158.1 | 73.8 | 9.1 | 4.3 | 8.0 | 3.7 | 38.4 | 17.9 | 6.6 | 0.0 |
| Tumwata | 71.2 | 22.9 | 36.2 | 11.6 | 142.8 | 45.9 | 59.4 | 19.1 | 1.3 | 0.4 |
| Wolf | 75.9 | 76.8 | 9.7 | 9.9 | 0.0 | 0.0 | 12.0 | 12.1 | 1.2 | 1.2 |
| E.F. Kalaloch | 81.2 | 56.5 | 9.6 | 6.7 | 30.6 | 21.3 | 20.0 | 13.9 | 2.3 | 1.6 |