THE EFFECT OF INDUSTRIAL AND DOMESTIC POLLUTION ON BENTHIC MACROINVERTEBRATE COMMUNITIES IN TWO NORTHERN IDAHO RIVERS

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NANCY LORRAINE SAVAGE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

ABSTRACT

Benthic macroinvertebrate communities in the Coeur d'Alene and Potlatch Rivers in northern Idaho were analyzed to determine the effect of mine effluents on the structure of these communities. The organisms present in riffles in polluted and unpolluted sections of the rivers were identified, density and biomass were determined, and species diversity was calculated using the Shannon-Wiener function. The diversity value was used to compare community structure between stations and years. Significant differences in diversity were found between control and test stations in both rivers during the two years of study. No significant differences occurred between years at stations in either river.

INTRODUCTION

Wastes from the mines, mills, smelters and towns have been dumped into the South Fork of the Coeur d'Alene River for approximately 85 years. The polluted portion of the river extends from a short distance above Wallace, Idaho on the South Fork to the mouth of the Coeur d'Alene River where it empties into Lake Coeur d'Alene, a distance of 50 miles. Ellis (1932) observed the polluted portions of the river to be nearly devoid of fish, benthic macroinvertebrates and plankton.

Substances introduced into the South Fork of the Coeur d'Alene River as a result of mining consist of rock powder (ranging in size from silt to colloids) and sulfides of heavy metals including Zn, Pb, Fe, Mn, Cu and As. Zinc appears in highest concentrations. Sappington (1970) found in using unpolluted North Fork water that 96-hour TLm values for cutthroat trout fingerlings were 0.09 ppm zinc. Zinc concentrations up to 21 ppm in the South Fork have been recorded during low water periods.

The sediment carried by the river had reduced the channel depth at Medimont (about 15 miles below the confluence of the North and South Forks) from 50 meters in 1883 to 12 meters in 1932 (Ellis 1932). Sediment of this nature destroys the habitat for many benthic invertebrates. Settling ponds constructed since 1932 and during 1969 have substantially reduced this siltation in the river.

In 1968 a proposal to evaluate the biological productivity of the Coeur d'Alene River was approved for support by the Water Resources Research Institute of the University of Idaho. Determination of species diversity of benthic macroinvertebrates was used as an approach to evaluate the effect on the riffle communities of the pollutants entering the South Fork. The project was later expanded to include a similar study on the Potlatch River.

The objectives of this study were (1) to determine any differences that might exist in macrobenthic community structure and diversity in altered and unaltered sections of the Coeur d'Alene and Potlatch Rivers, (2) to compare diversity values between years in the riffle communities of both rivers following the apparent improvement of water quality, (3) to evaluate the Shannon-Wiener diversity measure as a parameter in describing community structure.

METHODS

Collecting Methods

Coeur d'Alene River

Three collection sites in the Coeur d'Alene River were sampled on Sept. 8, 1968 and Sept. 6, 1969. These three sites included zones of heavy pollution, moderate pollution and relatively clean water (Fig. 2). The site on the South Fork near Smelterville received heavy concentrations of heavy metals, organic sewage, and other wastes. The other sites were a broad, shallow riffle at Cataldo about five miles below the confluence of the North and South Forks, and a riffle of comparable size located about five miles above the confluence on the unaltered North Fork.

The Surber square-foot sampler was used to collect benthic organisms. It consists of a frame which encloses one-square-foot of substrate and an attached net into which organisms are washed as the substrate is turned over and stirred. A grid measuring 8 yards by 8 yards was established in the riffle. Stakes were placed at one yard intervals on two sides of the grid. This resulted in a grid of 64 plots which was numbered from 1 to 8 on each side. Twenty-two plots were chosen from a random numbers table and marked on a chart of the grid. A Surber sample was collected from the center of each of the randomly selected plots. Collecting began at the downstream side of the grid and proceeded upstream to avoid disturbing the benthos. The samples were placed in 8 x 12 x 2 inch plastic trays with tight fitting lids. Enough 100% isopropyl alcohol was added to cover the sample.

In the South Fork the grid extended from bank to bank and was 50 feet by 64 feet due to the narrowness of the stream. In the North Fork and Main River, which were much wider, the grid was placed in a riffle near the center of the channel. The grid was placed over as homogeneous an area as possible to minimize the variability in the benthos due to difference in substrate.

Potlatch River

One of the objectives of this study was to compare results of my work with that of Salskov who studied the benthos in the Potlatch River in 1967 using the screen and rake method. This method was used because the stream was too deep in several places during at least part of the year for collecting using the Surber sampler. The bottom of the screen was placed on the stream bed, worked securely into the substrate, and braced against the legs of the collector. A garden rake was worked back and forth over an area two feet wide and six feet long upstream to dislodge benthic organisms from the substrate. These were washed into the screen by the current. The screen and rake method is a relatively inefficient method, missing part of the benthos and allowing some to drift by either side of the screen. It is practical, however, in a deep, torrential stream. Two twelve-square-foot samples were collected at each station. The organisms were removed from the screen by rinsing and picking and placed in 100% alcohol in plastic trays. My collections were made on July 2, 1969 and compared with Salskov's data of June 30, 1967.

Laboratory Analysis of Organisms

In the laboratory I sorted the contents of each tray using an illuminated magnifying lens and a binocular microscope. The organisms were separated from the debris, segregated and identified, and stored in vials with 75% alcohol. Taxa were quantitatively enumerated.

Specific identification of the taxa is not necessary when using a species diversity index. All that is necessary is to count the number of individuals in each taxon in each sample. Specific identification was made for a number of the more common species collected, however.

The following authorities contributed generously of their time in making these identifications: Dr. Merlyn A. Brusven, University of Idaho, Ephemeroptera; Dr. Stanford D. Smith, Central Washington State College, Trichoptera; Dr. Glenn B. Wiggins, Royal Ontario Museum, Trichoptera; and Stanley Jewett, Portland, Oregon, Plecoptera.

One to fifty individuals of each taxon were dehydrated in a drying oven at 85^{o} C for 24 hours and weighed on a Mettler balance (model H-16). The weight of an average individual was then determined and the biomass of each taxon in a sample calculated.

Physical and Chemical Analyses

Standard methods were employed for collecting and analyzing water temperature, pH, alkalinity, and conductivity (Standard Methods 1965). Zinc analyses were performed by the Agricultural Biochemistry Department, University of Idaho. Water depth at each sample site was measured, and width of the river paced or estimated. Notes were taken on the nature of the substrate at each site. Additional physical and chemical data were obtained from Dr. Roy E. Williams and Leroy Mink also working on the Coeur d'Alene River and supported by the Water Resources Research Institute.

Diversity Index

In 1957 Margalef proposed a diversity index derived from the Shannon-Wiener function used in information theory by communication engineers to predict the next letter found in a message.

$$\overline{H} = - \sum p_i \ln p_i \tag{1}$$

$p_i = n_i/N$ = the probability of selecting in sampling an individual of the i^{th} type.

Diversity by this method is interpreted as the degree of uncertainty attached to the specific identity of any randomly selected item (Pielou 1966 b). In a biological community this index relates to the uncertainty involved in predicting which species an animal would be confronted with by the next random encounter (Lloyd, Zar, and Karr 1968). The two components of this diversity index are number of species and species equitability (the distribution of individuals among the species). The diversity is greater when more species are present and when the number of individuals is distributed evenly among the species. The greater the diversity the greater the uncertainty of the identity of the next organism. Maximum diversity (information) occurs when each individual belongs to a different species.

This index has been used increasingly by ecologists including Margalef (1958) with zooplankton, Hairston (1959) with soil arthropods, Patten (1962) with marine phytoplankton, MacArthur (1961, 1964, 1965) and Lloyd and Ghelardi (1964) with birds, and Wilhm and Dorris (1966) with benthic macroinvertebrates. Peilou (1966 a, b) discusses the use of this method in different types of collections. Advantages over other indexes are that it considers the relative abundance, is dimensionless, and is less dependent on sample size (Wilhm and Dorris 1968).

Since formula (1) involves finding the base 2 logarithm of a decimal fraction (n_i/N), calculation is facilitated by modification to:

$$\bar{H} = 3.3219 \left(\log_{10} N - \frac{\sum n_i \log_{10} n_i}{N}\right) \qquad (2)$$

where 3.3219 = conversion factor from $\log_{10}$ to $\log_2$

N = total number of individuals of all species

n_i = number of individuals of the i^{th} species.

Tables are available for finding the values of log N and n log n (Cox 1967, Lloyd *et al*. 1968) and the remaining arithmetic operations can easily be performed with the aid of a calculator. When $\log_2$ is used, diversity is expressed in binary digits (bits). One bit represents the information required to specify one of two equally probable states. As an example, if two species are present each with the same number of individuals (no matter how many), the index would equal 1. The value of this index ranges from 0 in a community of one species to 3 - 4 in a square-foot bottom sample. Diversity has not been defined for a sample or habitat with no organisms present.

Another aspect of this method is the position of the community between maximum and minimum diversity and is called redundancy. Redundancy is inversely proportional to diversity, being greatest (1.00) when diversity is least (0), and least (0), when diversity is greatest (N = m). Redundancy indicates the degree to which one or more species dominate the community. Wilhm and Dorris (1966) found that $\bar{H}$ (2), the diversity per individual, alone or in conjunction with redundancy (R), was the best means of evaluating the benthic community.

DESCRIPTION OF STUDY AREAS

Coeur d'Alene River

The Coeur d'Alene River in northern Idaho lies within the Spokane River drainage basin (Ross and Savage 1967), (Fig. 1 and 2). The headwaters of the Coeur d'Alene are in the Bitterroot Mountains which form the border between Montana and Idaho and are part of the Northern Rocky Mountain Province. The river drains an area of approximately 4000 square miles. The entire North Fork drainage lies in the Coeur d'Alene National Forest. The elevation at the confluence of the North and South Forks is about 2240 feet and the stream gradient between the upper and lower stations is about 8 feet per mile.

Precambrian sedimentary and metamorphic rocks underlie the entire drainage basin except for the few miles from Medimont to the mouth of the river (about 10 miles) where Columbia River basalts of Miocene age cover the basement complex. Alluvial deposits of recent origin make up the stream channels and flood plains in the valleys. In the South Fork valley extensive faulting and subsequent mineralization have resulted in deposition of valuable minerals including lead, zinc, silver and antimony, and smaller quantities of copper, cobalt, and gold. This area is the Coeur d'Alene mining district, the site of a major Idaho industry. The population of the South Fork basin is about 13,000 people. The population is less dense below the confluence and the North Fork basin is virtually unpopulated.

The North Fork site was chosen as a control. Environmental conditions including rock types, precipitation, altitude and temperature as well as water depth and substrate size at the riffles are essentially the same as the South Fork and Main River sites. The width of the river at this point is 150 feet, the average depth in the riffle in both years was 7 inches. The flow rate was 284 cfs on Sept. 8, 1968 and 219 cfs on Sept. 6, 1969. The substrate consisted of medium cobble to pea gravel (Fig. 2, D).

At the South Fork site the stream was 50 feet wide, 12 inches deep in 1968 and 14 inches in 1969. Flow rate was 112 cfs on Sept. 8, 1968 and 102 cfs on Sept. 14, 1969. The substrate consisted of large to medium cobble and a fine sediment overlay which covered the cobble by several inches in 1968 and less than an inch in 1969. This sediment also covers the flood plain of the river (Fig. 2, E). An analysis of the sediment present on the cobble in 1969 showed it to be 25% organic and 75% inorganic material. Observations in 1969 indicated a noticeable decrease in turbidity of the South Fork water at the confluence of the North and South Forks (Fig. 2, B and C).

The Main River site, about five miles below the confluence, near Cataldo, was selected to measure dilution effects of the North Fork upon the South Fork water. The river was approximately 150 feet wide at this location and water depth was 10 inches in 1968 and 6 inches in 1969. Flow rate was 438 cfs. on Sept. 8, 1968 and 338 cfs on Sept. 14, 1969. The substrate consisted of medium cobble to pea gravel with some soft sediment in the stream bed and heavy growth of algae on many of the stones (Fig. 2, A).

Potlatch River

The Potlatch River lies within the Clearwater drainage basin in northern Idaho and drains about 200 square miles (Fig. 1 and 3). Its headwaters are in the Northern Rocky Mountain Province where the predominant rocks are granitic rock of Cretaceous age, part of the Idaho batholith. Below Bovill the river is eroding a channel in Columbia River Basalt which flowed over the area during the late Cenozoic. The portion of the North Fork of the Potlatch included in this study (Stations 1 to 4) cuts the granitic and basaltic rocks alternately. The East Fork drains primarily a granitic area. Station 1 is at an elevation of 2880 feet and station 7 is at an elevation of 2720 feet resulting in a gradient of 17 feet per mile. The population of the entire Potlatch River drainage basin is about 2000 people.

The Simplot clay milling plant near Bovill processes the clay from the disintegrated granitic rock in the area. Wastes from the mill are moved to two settling ponds, one near the plant and one near the river. At the time of this study the lower pond was completely filled with sediment. As a result, waste effluent from the mill was eroding a channel through the sediment and transporting it into the river. Zinc is added to the effluent to combine with and precipitate sulfates. Iron hydroxide precipitates phosphates. The effluent contains zinc and ferrous iron in solution as well as suspended particulate matter. A ferric hydrate flocculent is formed in the stream, possibly from the action of iron precipitating bacteria on the ferrous iron (Salskov 1968). River and substrate characteristics are summarized in Table 1.

Table 1. Characteristics of test and control sites investigated on the Potlatch River.

Station	Width Feet	Depth Inches	Current fps	Substrate	Location
1	12	6	0.5	Sand, gravel, stones to 2 inches diameter.	Control station one-half mile above effluent.
2	Undiluted effluent from settling pond.				
3	12	6	2.5	Small to medium cobble, iron flocculent.	800 feet below effluent.
4	24	8	0.8	Large, angular basalt and gravel.	Six miles below effluent, 50 feet above confluence.
5	22	10	3.0	Large granitic cobble and gravel.	Control station on East Fork 100 above confluence.
6	60	13	5.0	Granite and basalt cobble.	Fifty feet below confluence.
7	80	7	4.0	Granite and basalt cobble.	Nine miles below effluent and six miles below confluence.

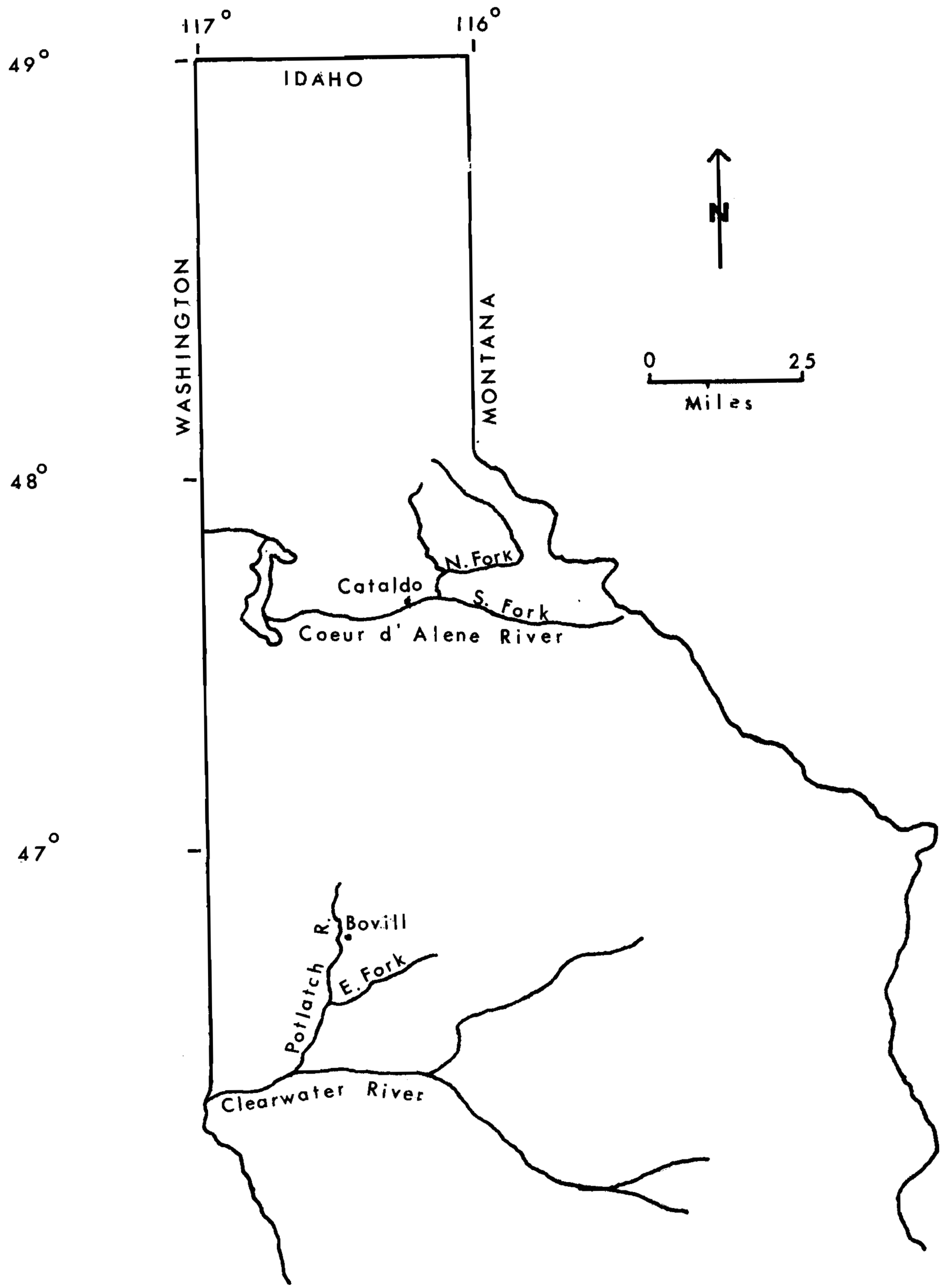
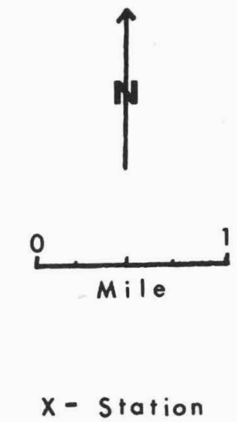


FIGURE 1. COEUR D'ALENE and POTLATCH RIVERS

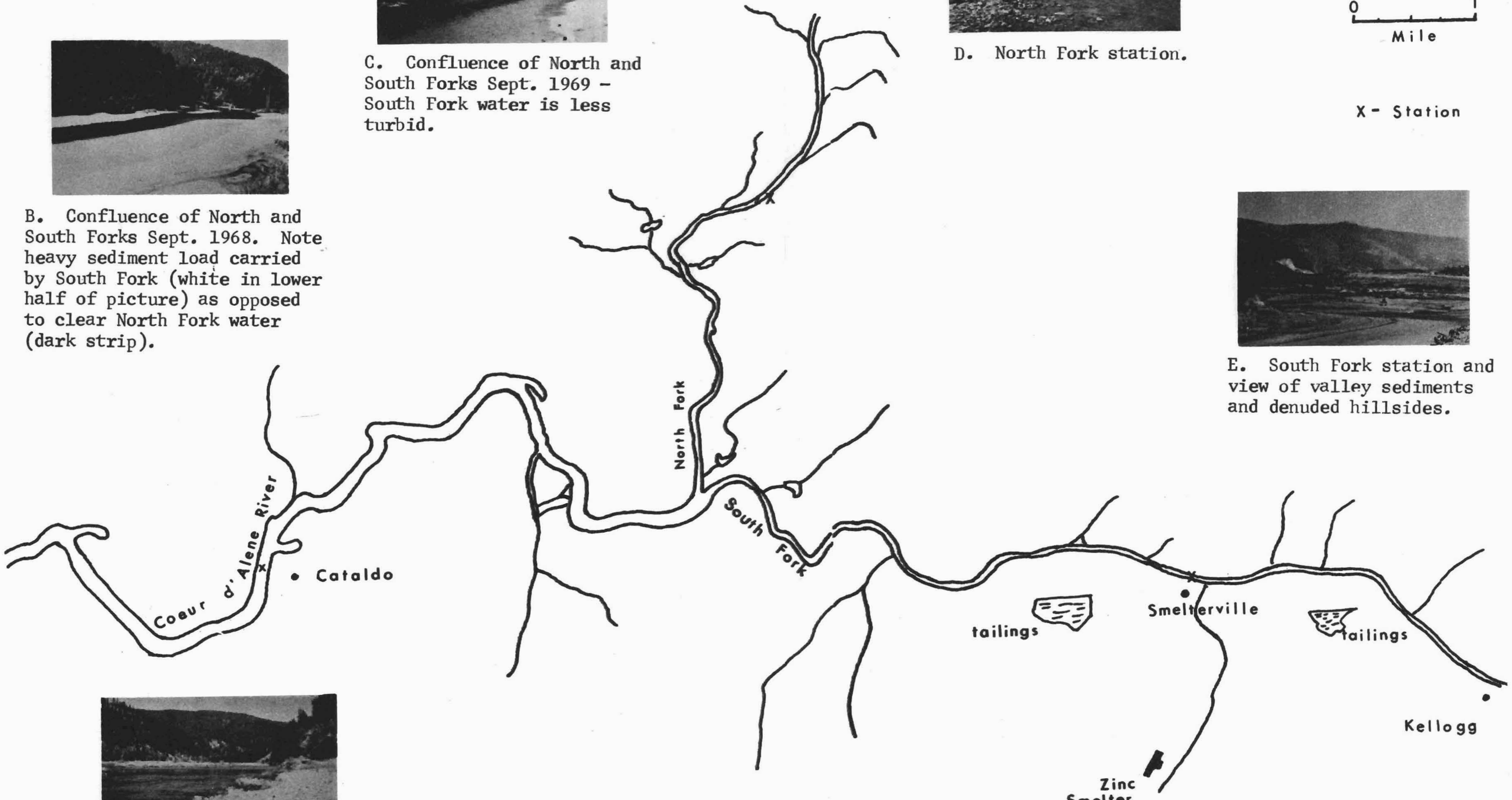
C. Confluence of North and South Forks Sept. 1969 - South Fork water is less turbid.

D. North Fork station.



B. Confluence of North and South Forks Sept. 1968. Note heavy sediment load carried by South Fork (white in lower half of picture) as opposed to clear North Fork water (dark strip).

E. South Fork station and view of valley sediments and denuded hillsides.

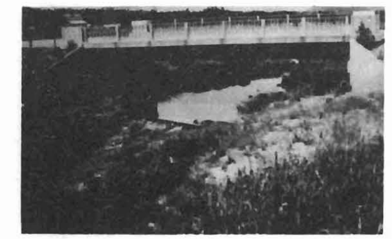


A. Main River station. Note white sediment deposit on exposed rubble.

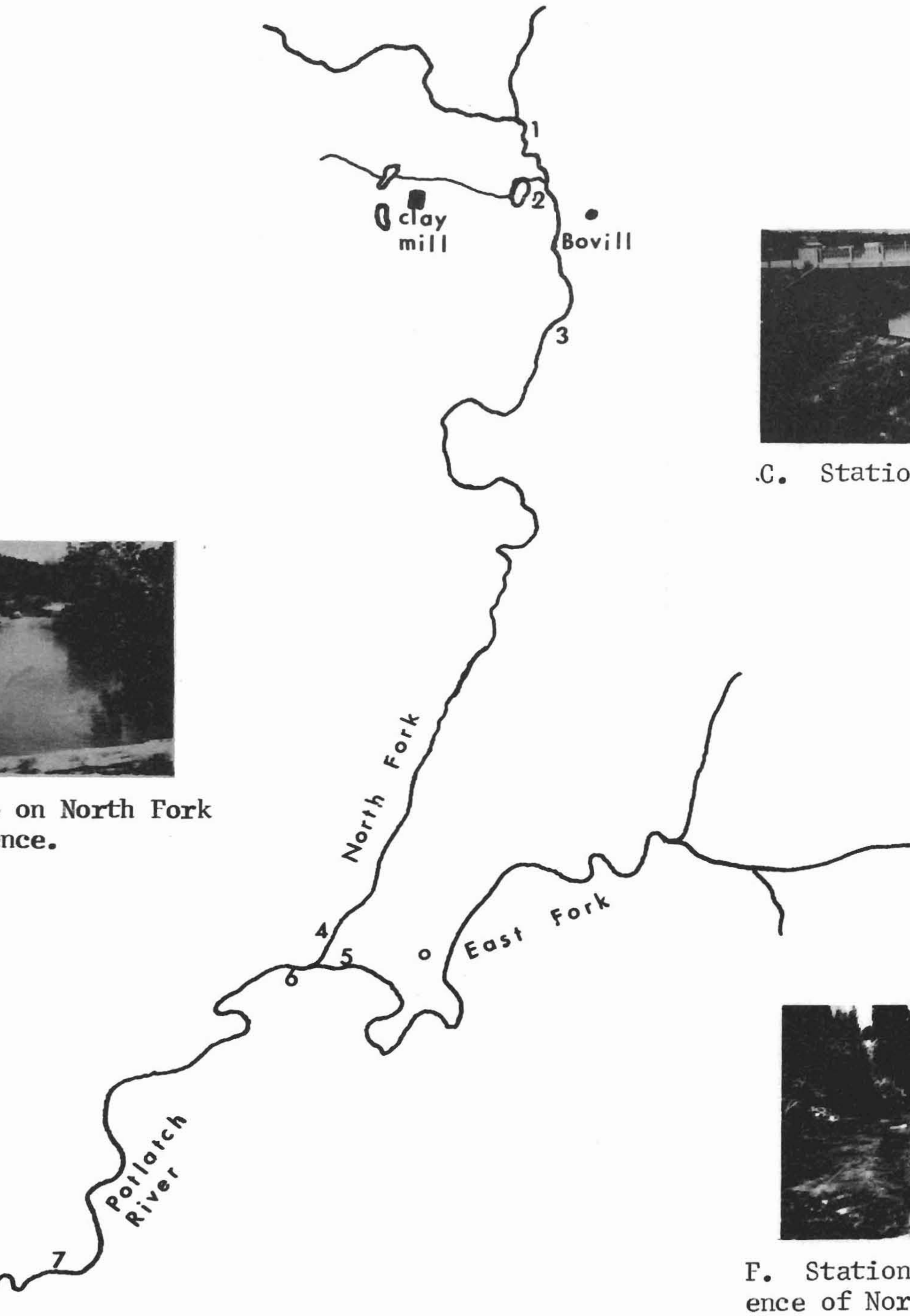
FIGURE 2. COEUR D'ALENE RIVER

A. Control station 1 above effluent.

B. Station 2 - effluent from settling pond.



C. Station 3



D. Station 4 on North Fork above confluence.

E. Control station 5 above confluence on East Fork.

F. Station 6 below confluence of North and East Forks.

G. Station 7

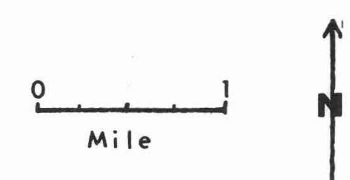


FIGURE 3. POTLATCH RIVER

RESULTS

Coeur d'Alene River

A. Physical and Chemical Factors

A summary of physical and chemical measurements collected on four separate dates is presented in Table 2 and 3. The changes in pH, temperature and dissolved oxygen between the two September dates are negligible. A pH range of 6 to 8 is considered within the tolerance limits of most organisms. All stations except the South Fork in 1968 were within this pH range. Dissolved oxygen was near saturation at all stations and is not limiting. Alkalinity remained about the same except at the South Fork station where it increased from 3 to 20 ppm, approximating that at other sites. Electrical conductivity in 1969 decreased from 420 to 250 micromhos in the South Fork and from 180 to 90 in the Main River. In 1969 turbidity decreased from 490 ppm to 0 in the South Fork and was 0 at all other stations (Table 2).

Zinc concentrations were very high as compared to those of other metal ions sampled (Table 3). Concentrations up to 21 ppm zinc in the South Fork are acutely toxic to life. No significant change was observed in the concentrations of any of the heavy metal ions (Zn, Pb, Cu) between September 1968 and September 1969. The concentrations of Ca and Mg did decrease, however, in 1969.

The data in Table 3 and information on flow rates (Table 2) was obtained from Williams and Mink.

Table 2. Some physical and chemical factors of the Coeur d'Alene River 1968 - 1969

Date	Station	pH	E.C. umhos	Temp. ^oC.	Turb. ppm	Alk. ppm	DO ppm	Flow cfs
Sept. 8, 1968	North Fork	8.0	58	18	0	21	9.2	284
	South Fork	5.6	420	15	490	3	8.8	112
	Main River	7.1	180	16	0	14	8.9	438
Jan. 20, 1969	North Fork	7.1	42	0	0	-	-	1700
	South Fork	6.2	233	1	0	-	-	560
	Main River	6.5	77	0	0	-	-	2310
May 21, 1969	North Fork	6.9	33	10	0	-	9.9	4640
	South Fork	6.2	130	9	0	-	8.9	-
	Main River	6.8	49	8	0	-	8.7	6210
Sept. 6, 1969	North Fork	7.4	50	13	0	28	9.0	219*
	South Fork	6.2	250	15	0	20	8.8	102*
	Main River	7.4	90	14	0	26	8.8	338*

*Sept. 14, 1969

Table 3. Concentrations (ppm) of some metal ions in the Coeur d'Alene River, 1968 - 1969

Date	Station	Zn	Pb	Cu	Mn	K	Ca	Mg	Na	Fe
Sept. 8, 1968	North Fork	0	0	0.05	0.5	-	15.4	6.0	-	0.25
	South Fork	15.05	2.0	0.15	4.3	-	31.7	10.6	-	1.30
	Main River	4.15	0	0	0	-	2.7	2.7	-	0.10
Jan. 20, 1969	North Fork	0.3	0.6	0.3	0.4	-	3.7	2.2	-	0.9
	South Fork	6.5	0.6	0.3	1.7	-	23.0	7.9	-	0.9
	Main River	1.3	0.3	0.4	0.5	-	6.4	3.6	-	0
May 21, 1969	North Fork	0.1	0.4	0.2	0.4	-	0.5	0.4	-	0.6
	South Fork	1.2	0.5	0.4	0.5	-	1.1	0.7	-	0.8
	Main River	0.3	0.4	0.3	0.3	-	0.5	0.4	-	1.0
Sept. 14, 1969	North Fork	<0.1	<0.1	<0.1	1.0	0.4	3.5	2.2	1.5	0.1
	South Fork	21.0	<0.1	<0.1	6.2	2.9	28.0	10.2	12.2	0.2
	Main River	5.3	<0.1	<0.1	2.1	1.3	10.7	5.2	5.3	0.2

B. Community Structure

The taxa and number of individuals for each sample in the North Fork and Main River are presented in Table 4-6. A few organisms were found at the South Fork station in 1969 whereas none were collected there in 1968. The North Fork site is an example of a productive and diverse riffle community. In 1968 seven species including Trichoptera (*Lepidostoma* sp. and *Hydropsyche* sp.), Ephemeroptera (*Ephemerella* sp. C and *Baetis tricaudatus*), Diptera (Chironomidae A), and Elmidae (*Zaitzevia* sp. and *Heterlimnius* sp., adults and larvae) were observed in 100% of the samples (Table 5).

Six species including Trichoptera (*Glossosoma* sp.), Ephemeroptera (*Pseudocloeon* sp., *Rhithrogena* sp. and two species of *Ephemerella*) and Diptera (Chironomidae B) were found in 90% to 95% of the samples.

Two species were observed in 80% to 85% of the samples. These were Ephemeroptera (*Cinygma* sp.) and Diptera (*Atherix* sp.). Of 30 species present in the riffle a total of 15 were present in more than 80% of the samples. Such a large number of common species is evidence of a relatively homogeneous community (Raunkaier 1934).

Of the total number of organisms in the riffle in 1968, 67% were Trichoptera, 14% Ephemeroptera, 10% Diptera, 5% Coleoptera, and 3.6% Plecoptera. These aquatic insects accounted for 99.6% of the benthic organisms and 87% of the species present. The remaining taxa included Hydracarina (water mites) and small gastropods and pelecypods (Sphaeriidae). This miscellaneous group contributed less than 0.1% of the biomass.

The data on numbers, biomass, and diversity of the riffle communities is summarized in Table 8. A mean number of 405 ± 137 organisms per square-foot was present in the North Fork in 1968. This amount is indicative of an above average level of fish food organisms (Madsen 1935). This range in numbers (117 - 614) in a single riffle is consistent with the results of other investigators (Needham and Usinger 1956, Egglishaw 1969) and is indicative of a contagious (clumped) distribution. It is this variability that makes quantitative sampling of stream macrobenthos by present methods difficult. A large sample must be taken to achieve statistically significant estimates of numbers and biomass (Needham and Usinger 1956, Hales 1961).

The diversity values for each sample are listed in Table 9. The range for the North Fork in 1968 was 2.083 to 3.345 (average 2.970). Wilhm and Dorris (1968) have proposed that a diversity value of three or more indicate an unpolluted stream condition, one to three a moderately polluted situation, and less than one a heavily polluted zone. They based these criteria on work performed on streams in the Midwest where the overall productivity differs considerably from montane situations such as the Coeur d'Alene and Potlatch Rivers.

In 1969 the species composition of the riffle was essentially unchanged, while relative abundances varied considerably from the previous year (Table 6). Two species, Trichoptera (*Lepidostoma* sp.) and Ephemeroptera (*Paraleptophlebia heteronea*), were found in 100% of the samples. Two species, Ephemeroptera (*Cinygma* sp.) and Diptera (*Atherix* sp.), were present in 90% to 95% of the samples. Two others were found in 80% to 85% of the samples. These were Plecoptera (*Claasenia sabulasa*) and Elmidae (*Zaitzevia* sp.).

Thus only six of 31 species occurred in 80% or more of the riffle samples. The composition by groups was Trichoptera 53%, Ephemeroptera 15%, Coleoptera 13%, Diptera 12%, Plecoptera 4%, and miscellaneous 3%. These figures represent a decrease in the number of trichopterans and an increase in all other groups from 1968. Aquatic insects represented 97% of the total number of benthic organisms and 87% of the species present. Planarians were found in the 1969 sample increasing the numbers and biomass of the miscellaneous group slightly.

A mean number of 268 $\pm$ 192 organisms per square foot (Table 8) was found in 1969. Density differences between the two years resulted from a reduction in numbers of two trichopterans (Hydropsyche sp. and Glossosoma sp.). One ephemeropteran (Rhithrogena sp.), which made up 12% of the mayfly population in 1968, was not collected in 1969.

The diversity values (Table 9) range from 2.518 to 3.591, a smaller range than in 1968 (1.073 and 1.262). The average diversity was 3.035. The higher average for 1969 reflects the increased equitability in distribution of individuals among the species.

In the Main River only chironomids were found in 1968. The diversity value for a one species community is zero since there is no diversity. At the same station in 1969 there were three species of aquatic insects including Elmidae adults (riffle bettle), Atherix sp., a dipteran of the family Rhagionidae (snipe flies), as well as the chironomids. About 97.5% of the total number of benthic organisms were chironomids, 22% more than in 1968. This large percentage resulted in a low diversity value of 0.214.

In the South Fork, chironomids appeared in the samples collected in 1969 where none had been found in 1968. The numbers and biomass were low and the diversity was 0 (Table 8). The chironomids present in the North Fork appeared to differ from those present in the Main River and South Fork. The taxonomy of these immature midges is difficult, making positive identification questionable. The chironomid larvae found in the Main River and South Fork of the Coeur d'Alene were green in color. The white forms observed in the North Fork and Potlatch were a ubiquitous group, found in nearly all samples. The average number per square foot was 25 in the North Fork for both years. The average in the Main River was 125 in 1968 and 168 in 1969. This was the only group present in the South Fork in 1969 with an average of 36 per square foot.

Duncan's Multiple Range test was applied to those Coeur d'Alene stations with diversity values greater than 0. The diversity in the North Fork was not significantly different between 1968 and 1969 ($P \leq .05$). The North Fork diversities were significantly greater than the Main River value, however (Table 4).

Table 4. Results of Duncan's Multiple Range test on Coeur d'Alene stations.

Station		Diversity	
North Fork	1968	2.970	a*
North Fork	1969	3.035	a
Main River	1969	0.214	b

*Those means with different letter suffixes differ significantly ($P \leq .05$)

Table 5. Number of individuals per taxon for each sample

Taxon	Sample 1	2	3	4	5	6
Trichoptera						
Lepidostoma sp.	126	101	127	97	31	78
Hydropsyche sp.	2	141	148	7	162	60
Glossosoma sp.	141	12	6	15	19	75
Apatania sp.	19			6		
Plecoptera						
Claasenia sabulasa (Banks)	1	1	1			1
Isogenus sp.	5	2	3		3	
Arcynopteryx parallela (Frison)		1	8		1	
Alloperla sp.			1	1	1	
Pteronarcys californica (Newport)						
Pteronarcella sp.			2			
Ephemeroptera						
Ephemerella sp. A	1	5	5	1	5	3
Ephemerella sp. B	1	6	4	1	2	4
Ephemerella sp. C	2	27	35	6	4	7
Ephemerella sp. D		1				3
Paraleptophlebia heteronea (McDunn)		3	4	1		
Baetis tricaudatus (Dodds)	1	34	19	3	8	12
Pseudocloeon sp.		35	32	3	15	6
Rhithrogena sp.		7	20	2		6
Cinygma sp.	7	5	3	12	3	1
Diptera						
Atherix sp.	11			12	8	7
Chironomidae A	8	11	27	5	7	18
Chironomidae B	60	16	20	20	28	3
Simulium sp.		2	1		1	
Tipula sp.	4		2			1
Coleoptera (Elmidae)						
Zaitzevia sp.	4	5	4	2	5	4
Heterlimnius sp.	11	8	16	4	12	13
Hydracarina	7	2		1		
Collembola						
Pelecypoda			1			
Gastropoda						
Total	411	427	490	200	316	302

in the North Fork of the Coeur d'Alene River, Sept. 8, 1968.

Sample																
7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
406	105	254	75	51	57	132	203	85	44	35	41	80	72	53	112	2365
61	97	70	21	111	26	59	69	95	15	1	144	80	67	48	81	1565
30	83	2	244	70	368	5	4	342	157	32	1	69	107	127		1909
	5	2	28	1	12	2		2	15	10	2	1	14	5	2	126
1	1	1	2		3	2	1	2	2		1		1	5		26
	1	8	2	4	3		9	2	3	2	1	7	5		1	45
12	1	14		1		2	4	1		1	1	3	2		14	68
	1	3	2		6		2	2	3	3	1		7	3	2	38
						1	1							1		3
																2
5	2	5		6	3	8	3	3		1	9	7	4	6	4	86
5	5	4	2	2	5	4	3	1			8	6	4	5	4	76
8	20	14	1	11	1	10	11	8	3	1	8	13	7	3	8	208
1		3	1	2	2	2		4				4			1	24
	1		1			1	4	2	1	1		1	6	1	8	35
5	29	25	6	20	12	13	18	20	5	2	14	4	10	10	8	278
11	15	28	5	6	16	16	28	7	2	3	20	14	27	10	20	319
15	4	20	8	6	3	2	9	7	3	1	3	9	12	8	8	153
	5	6	4		2	12	15	1	5	6	3	1			4	95
2	9	4	1	6	1	4	8	4	2		12	3	3	2	5	104
13	37	20	30	10	9	31	36	75	17	5	12	35	14	17	43	480
12	5	22	25	6		14	20	3	3		6	3	6	5	25	302
				6	1						2	1				14
	1			1	2	3		11	1			2				28
4	5	1	12	9	5	2	3	21	10	3	4	8	8	5	3	127
23	13	13	26	28	16	8	12	53	25	5	11	16	27	22	10	367
	1		3	4				4	4	2						28
									1							1
										1				2		4
							1								1	2
614	446	519	499	362	554	333	466	755	321	117	304	367	403	338	365	

Table 6. Number of individuals per taxon for each sample

Taxon	Sample					
	1	2	3	4	5	6
Trichoptera						
Lepidostoma sp.	171	80	30	2	22	200
Hydropsyche sp.	8	14	1		5	1
Glossosoma sp.	30	40			9	24
Apatania sp.	36	2	1		5	26
Brachycentridae					1	
Plecoptera						
Claasenis sabulasa (Banks)	2	2		1	1	1
Isogenus sp.	2	2	1			2
Arcynopteryx parallela (Frison)	4					
Arcynopteryx aurea (Smith)		2			1	9
Alloperla sp.	13	8				21
Pteronarcys californica (Newport)						
Ephemeroptera						
Ephemerella sp. A	1	3			1	1
Ephemerella sp. B	9	6	1		5	13
Ephemerella sp. C	4	6		1		9
Paraleptophlebia heteronea (McDunn)	6	7	3	2	4	28
Baetis tricaudatus (Dodds)				2	1	1
Pseudocloeon sp.	2	5			1	1
Centoptilum sp.	1	1				
Cinygma sp.	10	12	4	1	3	50
Diptera						
Atherix sp.	4	6	2	2	6	4
Chironomidae	11	25	15	3		50
Simulium sp.		1		1		
Tipula sp.	4				1	3
Tipulidae		1		20	2	
Heleidae						2
Coleoptera (Elmidae)						
Zaitzevia sp.	2	2	1	1	1	14
Heterlimnius sp.	2	3				2
larvae	25	36	1	1	12	34
Hydracarina	12	3				8
Mollusca		1				
Planaria			3		7	2
Ostracoda						
Total	359	270	65	15	107	507

in the North Fork of the Coeur d'Alene River, Sept. 6, 1969.

Sample																
7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
240	44	27	125	25	275	3	200	100	100	85	110	15	37	85	47	2113
3	5		2		2	1	23	3	12	4	24		6			114
11			111	2	15	6	50	3	56	25	85			69	106	642
5		2	5		18		54		23	11	39		2	21	16	266
1														2		4
1	5		1	1	2	1	3	3	2	2	2	1		1	1	33
7				1	5			3		5	2				3	33
5	2		2						1	1						15
				1	2		11	1	4	1	7			3	3	48
3	4	2	6		3		10	1	11		14			7	9	112
							1									1
						3			2	1	2			3		17
4	2	1	9	3	3		6	7	3	4	9			3		88
7	5	4		2	6		11	6	16	7	14		2	4	9	113
16	22	1	9	10	19	1	28	14	18	4	12	6	6	7	19	242
	1	4					3	2	1	1		3	2		4	31
1			1		1		5	1		3	3			3	1	28
											1					3
29	14	3	29	11	30		27	22	25	14	27	6	7	15	22	359
8	12	2	2		13	1	10	6	15		9	1	8	2	4	117
75	40	2	10	10	40		65			15	70	12	25		60	528
							2									4
1			1				1								4	15
1		1							1		2			1		29
				2							2	1				7
8	6		4	2	5	1	13	10	8	6	13			4	11	112
2	1	1	2		2		7	2	5	2	5			1	3	40
85	33	7	25	21	55	2	56	26	35	15	22	6	19	10	88	614
2	3		3				10	1	3		8	1	1	5	5	65
1	1							1			1				3	8
5	5						5	5	5			2			4	43
									1							1
523	209	52	348	92	503	19	602	217	438	207	485	51	117	248	475	

Table 7. Number of individuals per taxon for each sample in the Main Coeur d'Alene River, Sept. 8, 1968 and Sept. 6, 1969.

Sample Number	1968 Chironomidae	1969 Chironomidae	*Atherix*	Elmid	Total
1	15	15	1	1	17
2	20	40	1	1	42
3	20	50		2	52
4	25	60		1	61
5	25	90	7		97
6	32	100	1	1	102
7	40	100	1	1	102
8	42	100	6		106
9	43	130	13		143
10	61	150	5		155
11	66	160	2		162
12	73	170	3		173
13	74	190	3		193
14	75	190	5	2	197
15	89	200	4		204
16	90	200	5	1	206
17	105	210	2		212
18	213	250	6	1	257
19	364	260	1		261
20	365	280	1		281
21	425	300	9	1	310
22	600	500	4	1	505
Total	2862	3695	80	13	3788

Table 8. Numbers, biomass, and diversity of benthic organisms in riffle communities of the Coeur d'Alene River.

Station	Mean N	S.D.	95% Conf. Limits	Range	Total m	Mean m	Mean Biomass mg./sq.ft.	Average $\bar{H}$
1968								
North Fork	405	137	355 - 465	117 - 614	30	21	136	2.970
South Fork	-	-	-	-	-	-	-	-
Main River	125	160	55 - 195	15 - 600	1	1	23	0
1969								
North Fork	268	192	183 - 353	19 - 602	31	18	86	3.035
South Fork	36	-	-	-	1	1	6	0
Main River	176	109	127 - 223	17 - 500	3	2.4	30	0.214

N = number of organisms
m = number of species
$\bar{H}$ = diversity
S.D. = standard deviation

Table 9. Diversity Index* values for riffle community samples in the Coeur d'Alene River.

Sample Number	North Fork 1968	North Fork 1969	Main River 1969
1	2.621	3.039	0.638
2	3.056	3.521	0.033
3	3.162	2.571	0.166
4	2.870	3.189	0.206
5	2.694	3.617	0.322
6	3.010	3.245	0.249
7	2.628	2.754	0.163
8	3.199	3.398	0.239
9	2.834	2.711	0.030
10	2.697	2.634	0.129
11	3.232	2.930	0.159
12	2.083	2.518	0.076
13	3.076	2.827	0.219
14	3.023	3.405	0.123
15	2.747	2.754	0.090
16	2.770	3.036	0.116
17	3.166	3.109	0.379
18	2.883	3.591	0.139
19	3.289	2.731	0.312
20	3.345	2.767	0.575
21	3.053	3.043	0.063
22	3.196	3.329	0.159
Mean	2.970	3.035	0.214

* $\overline{H} = -\sum p_i \ln p_i$

Potlatch River

A. Physical and Chemical Factors

Results of some physical and chemical measurements collected July 2, 1969, and during July 1967, from the Potlatch River are listed in Table 10. The 1967 data were based on work performed by Salskov (1968) and most values are monthly averages. The two samples differ only slightly in dissolved oxygen, temperature, pH, and alkalinity. Information on zinc ion concentrations for July, 1967 was not available for all stations; however, Salskov reported readings in excess of 1 ppm at stations 3 and 4 with a decrease downstream. Zinc content in the river on July 2, 1969 differed little from that in July, 1967. Analysis of water samples collected in October, 1969 showed 125 ppm zinc at the effluent, 17 ppm at station 3 and 7 ppm at station 4. Water levels were much lower at this time than during the July collecting period.

B. Community Structure

A list of macroinvertebrate species and numbers of individuals is compiled in Table 11 for 1969. No collections of organisms were made at station 2 which was the undiluted effluent water. Large areas were sampled in the Potlatch River (approximately 12 square-feet) as compared to the Coeur d'Alene samples (one-square-foot). Two samples were collected at each station.

Chironomidae was the only taxon observed at all stations. At station 1, an average of 700 chironomid larvae was counted per sample (Table 11). This station is below a pole mill and receives some organic

Table 10. Physical and chemical factors in the Potlatch River for July, 1967 (Salskov 1968) and July 2, 1969.

Station	DO ppm		Temp. °C.		pH		Alkalinity ppm		Zinc ppm	
	1967	1969	1967	1969	1967	1969	1967	1969	1967	1969
1	5.2	5.9	19	19	6.6	7.6	30	20	-	0.008
2	2.8	-	20	-	3.5	5.2	0	4	-	4.85
3	5.4	9.3	20	20	5.8	7.2	24	18	-	2.25
4	7.6	8.8	25	17	7.3	7.5	16	20	-	1.55
5	7.4	9.0	20	18	8.0	7.8	32	26	-	0
6	8.4	6.6	20	19	7.6	7.5	35	22	-	0
7	8.4	9.9	25	15	8.2	7.8	33	22	-	0.45

Table 11. Number of individuals per taxon for each station and sample - Potlatch River 1969

	1-1	1-2	3-1	3-2	4-1	4-2	5-1	5-2	6-1	6-2	7-1	7-2
Trichoptera												
Lepidostoma sp.		1	1									
Hydropsyche sp.	1						66	66		25		
Glossosoma traviatum							34	87	1	1		
Brachycentridae						1						
Helicopsychidae							2		1			
Plecoptera												
Pteronarcys californica							2	9				
Arcynopteryx sp.							6	15			10	2
Isoperla sp.	1	1										
Setipalpia								1		1	1	
Ephemeroptera												
Heptegenia elegantula	68	11					20	11	2	1	5	
Epeorus sp.							46	57		2		
Paraleptophlebia debilis	118	25	1									
Tricorythodes sp.	3	4								2		
Ephemerella (simplex)	13	3					17	20	1	2		
Ephemerella (bicolor)								1				
Pseudocloeon sp.								3				
Baetis sp.	22	4					46	12		3		
Baetis bicaudatus									1			
Diptera												
Tipula sp.	103	76					2	3	4	3	1	
Antocha sp.		500					3	2		2		
Chironomidae	1000		14	15	100	50	11	5	23	15	150	60
Simulium sp.					3	5		1	4	6	58	19
Atherix sp.					1		2	3		1		1
Chaoborinae										1		

Table 11--Continued

	1-1	1-2	3-1	3-2	4-1	4-2	5-1	5-2	6-1	6-2	7-1	7-2
Hemiptera												
Corixidae		1										
Odanata												
Ophiogomphus sp.		1										
Species B								1				
Coleoptera												
Elmidae	2	6					13	51		3	3	1
Haliplidae	8	7			1							
Pyralidae								1				
Crustacea												
Astacus sp.	2	1					2	2				
Gammarus sp.	1	3										
Mollusca												
Sphaeriidae	3	1										
Ancylidae	3	1										
Hydracarina	12	2										1
Oligochaeta	5	6							2			
Nematoda	4						3	3				
Total	1369	655	16	15	105	56	275	84	39	68	144	174

material from the bark removing process. At station 3 the chironomids were essentially the only insect present. The single trichopteran and ephemeropteran observed there were probably adventitious individuals. At station 4, chironomids averaged 75 per sample. They were present in low numbers at the most diverse stations (5 and 6) and increased again at station 7.

Four species including Ephemeroptera (*Heptegenia* sp.), Diptera (*Tipula* sp. and *Simulium* sp.) and Coleoptera (Elmidae) were found in 58% of the samples. The Simulidae, Rhagionidae and Haliplidae found at station 4 are organisms that exhibited a wide tolerance for changing conditions of water quality (Gaufin and Tarzwell 1956).

Twenty-two species were observed at station 5, 21 at station 1 and 18 at station 6 (Table 12). Nine species were collected at station 7, five at station 4 and three at station 3. Aquatic insects accounted for 66% of the species and 93% of the numbers at station 1, 91% of the species and 98% of the numbers at station 5, and 95% of the species and 98% of the numbers at station 6. Crayfish (*Astacus* sp.) were found at stations 1 and 5 adding considerably to the biomass.

The diversity values demonstrate the same relationship between stations for both years (Table 12). The greatest diversity of species is found at control station 5 and the least at station 3 nearest the effluent. Control station 1 probably is not as productive an area as control station 5 where the volume of flow is greater. No increase in diversity occurred in 1969 except at control station 5 and station 7 where the effects of pollution are minimal.

Duncan's Multiple Range test was used to compare diversity values for stations and years (Table 12). Station 3 had a significantly lower diversity value than all other stations. The diversity at stations 4 and 7 was significantly less than at stations 5 and 6. This indicates a general reduction in pollution downstream from the effluent. There was no significant difference in diversity indexes between years, leading one to infer that no improvement has occurred in the aquatic communities at any of the sites since 1967.

Table 12. Diversity values for each station in the Potlatch River in 1967 and 1969 and mean numbers of organisms per station, 1969. Duncan's Multiple Range test applied to stations both years.

Station	1967[a] Diversity	Diversity	Numbers (N)	Species (m)	*
1	2.069	1.515	1012	21	ab
3	0.149	0.334	16	3	c
4	0.721	0.450	81	5	bc
5	2.687	3.174	314	22	a
6	2.644	1.814	53	18	a
7	0.259	1.228	156	9	bc

[a]Recalculated from Salskov's data.

*Those stations with different letter suffixes differ significantly ($P \leq .05$).

DISCUSSION

The structure of an ecological community may be described by the numbers and biomass of species present and by their relative abundance and distribution. Relative abundance, or the manner in which organisms are distributed among species, is measured by species diversity. In this study I utilized taxon numbers, diversity indexes and biomass to describe the structure of riffle communities.

The diversity or number of species of plants or animals in a community usually increases during succession. Niches increase in number and narrow in scope. Each tends to become occupied by a single species in accordance with the principle of competitive exclusion (Patten 1962). Diversity ($\overline{H}$) is an index of succession. The diversity in a community is a function of increase in variety of niches, productivity, biomass, and complexity of the food chain. A high diversity is associated with a stable, unpolluted, successionally mature community (Patten 1962).

Addition of small amounts of organic matter to an oligotrophic stream may actually increase productivity with a consequent increase in diversity. On the other hand, large amounts of organic material, the addition of heavy metal ions or large sediment loads such as those which occur in the Coeur d'Alene and Potlatch Rivers, alter benthic communities and reduce diversity.

Wilhm and Dorris (1966), working on a stream receiving domestic and oil refinery effluents, found that species diversity (as determined by the Shannon-Wiener function) was a better measure of stream conditions than traditional parameters (numbers of taxa, indicator species, density, or biomass).

To best describe a natural or polluted aquatic ecosystem, a number of different biotic communities should be investigated. These would include the aufwuchs or plant-animal associations on the rocky substrate, protozoan assemblages in pool areas, fish populations, and macroinvertebrates inhabiting riffles. Patrick (1961) has attempted to inventory aquatic communities on a large scale by employing teams of biologists, chemists and statisticians.

I chose to use benthic macroinvertebrates that inhabit riffle areas because they are relatively sedentary and more easily identified than diatom assemblages collected from rock surfaces. Chemical tests of the water alone reveal water quality conditions only at that point in time. The diversity of benthic invertebrates, on the other hand, reflects past as well as present conditions.

The species represented in riffle communities vary considerably throughout the year depending on the time of hatching and emergence of the various aquatic insects that comprise most of the fauna. In Convict Creek, California, Kennedy (1967) observed maximum numbers and biomass between October and June. Other investigators have observed maximum biomasses in spring, early winter, or winter at various locations. Pronounced variation in numbers may occur between years, apparently as a result of changes in environmental factors such as temperature and volume of flow. Kennedy observed a 41% increase in the aquatic invertebrates the second year of his study. Air and water temperatures were 0.5 F warmer, and volume of flow was 21% greater the second year.

In the North Fork of the Coeur d'Alene I found a 34% reduction in density and a 37% reduction in biomass the second year. Several species

(*Hydropsyche* sp., *Glossosoma* sp., *Baetis* sp., and *Pseudocloeon* sp.) which had been very abundant in 1968 showed a considerable decrease in 1969 (Tables 5 and 6). Other taxa increased in 1969 (*Cinygma* sp., *Alloperla* sp., *Paraleptophlebia* sp., and Elmidae). Diversity increased slightly due to an increase in equitability.

Chironomids were the most abundant invertebrates in the polluted zones of the Coeur d'Alene and Potlatch Rivers. An exact count of the number of species of chironomids present was not made because of the difficulty in identifying immature forms. I was able to separate two species from the North Fork by differences in the head capsules. These midge larvae have small worm-like bodies with no external respiratory structures; gas exchange is by cutaneous respiration. They feed on, and form pupal cases from, organic matter such as was present in the South Fork. These insects are not smothered or otherwise harmed by a limited amount of fine sediment that would bury and destroy forms with gills and delicate appendages. These adaptations enabled them to survive the conditions of pollution present in the South Fork and main Coeur d'Alene River.

Another insect present in nearly all samples from the Coeur d'Alene River in 1969 was the larva of the snipe fly *Atherix* sp. This is the only aquatic genus of the family Rhagionidae. It lacks external appendages and breathes by cutaneous respiration. This predaceous form probably feeds on the midge larvae.

The third insect present in small numbers (Table 7) in the Main River in 1969 was a species of riffle beetle of the family Elmidae. These beetles are common in the moderate to fast water of riffles while most other aquatic beetles occur in the quiet water of stream margins, eddies or pools. They utilize atmospheric oxygen by rising to the surface and collecting a bubble of air which is held under the elytra. The elmids feed on algae and mosses which were abundant in the Main River riffles.

Black fly larvae (Simulium sp.), mosquito larvae (Chaoborinae), and an air breathing beetle (Haliplidae) were present at station 4 in the Potlatch River in addition to the chironomids. These forms have been reported in polluted sections of drainages where dissolved oxygen levels are low (Gaufin and Tarzwell 1956). Chaoborinae have a caudal respiratory tube with which they penetrate the surface tension membrane and utilize atmospheric oxygen, whereas Simulium attaches itself to the rocky substrate by a caudal suction disc and breathes by means of respiratory filaments on the thorax.

Little is known about the effects of heavy metal ions on macroinvertebrates. Warnick and Bell (1969) investigated acute toxicity of some heavy metals to three aquatic insects. The organisms, a trichopteran, a plecopteran and an ephemeropteran, were unaffected by concentrations up to 64 ppm of most metals after 16 days exposure. The most sensitive organisms were mayflies in the genus Ephemerella which showed a 24-hour TLm of 0.32 ppm of copper but survived for 10 days at 16 ppm zinc. These aquatic insects are less sensitive to heavy metal ions, apparently, than are most fish. Copper was present at all stations in the Coeur d'Alene at concentrations of less than 0.1 ppm and zinc at 21 ppm in the South Fork on the sampling dates included in this study (Table 3). Benthic organisms absorb significant amounts of metal ions which are transferred through the food chain (Warnick and Bell 1969).

Of the physical and chemical factors measured in this study, turbidity, and the resulting siltation, was probably the most important limiting factor in preventing colonization of the riffles in the Coeur d'Alene River. Chironomids were found in the South Fork and *Atherix* sp. and Elmidae colonized the Main River following a decrease in turbidity in 1969. This change could easily be reversed. Monitoring these riffle communities will reveal whether or not the change is continuing. Dissolved oxygen and food materials were abundant. Given a stable substrate and lack of toxic conditions, this river could probably support a more diverse benthic fauna.

On the other hand, analysis of the Potlatch River revealed that the environmental situation is essentially the same as it was in 1967. If improvements had been accomplished by treatment of the clay mill effluent, they were not reflected in improved macrobenthic communities. Statistical tests showed that the 1969 diversities were not significantly different from those of 1967.

Another purpose of this study was to compare diversity, as measured by the Shannon-Wiener function, with that calculated by traditional methods. The number of species (m) is the simplest measure of species diversity. In the North Fork of the Coeur d'Alene River and the control stations in the Potlatch River, the large number of species present was an adequate indicator of clean water conditions. However, m is not a particularly sensitive measure, and if gradual deterioration of water quality should occur, it would be more quickly revealed by a change in $\bar{H}$ than by a decrease in m. As an example, there were 22 species present and an $\bar{H}$ of 3.174 at station 5 while at station 1, with 21 species, the $\bar{H}$ was only 1.515. The $\bar{H}$ values indicate that there was a large difference in productivity between the two stations, whereas $\underline{m}$ does not reveal this. In the main Coeur d'Alene River in 1969, $\underline{m}$ was small (three species), but the distribution of the individuals among the species was so unequal that the $\bar{H}$ value was only 0.214. If the individuals had been distributed equally among the three species, $\bar{H}$ would have been about 1.5.

One more instance where $\bar{H}$ contributes unique information was at stations 3 and 4 of the Potlatch River in 1967. There, two species were present at both stations, but the number of individuals was greater at station 3. The $\bar{H}$, however, was lower at station 3 (0.149) than at station 4 (0.721), reflecting the fact that a majority of the individuals belonged to one species. A different situation existed at stations 1 and 6 in 1969 where $\underline{m}$ was slightly larger and N was much larger at station 1, while $\bar{H}$ was larger at station 6. The $\bar{H}$ value, then, represents an additional parameter useful in describing community structure.

A more accurate description of a community is attained by including numbers or biomass than by $\bar{H}$ alone. For example, a community of 10 species with an n_i of 10 would have the same $\bar{H}$ value as a community of 10 species with an n_i of 100 or 1000 (each would be 3.32). $\underline{M}$ would be the same in each case also, but N and biomass would reveal important additional information.

Sample size is a problem when dealing with species diversity measures. Hairston and Byers (1954), working with soil arthropods, found that variation in sample size affected all diversity indexes used. They attributed this to the spatial distribution of organisms, specifically the clumping of rare species. MacArthur (1965) states that the diversity measure $\overline{H}$ is less dependent on sample size than is species count since rare species add little to $\overline{H}$.

Pielou (1966 b) summed N and n_i for a patchy population of sessile organisms, increasing the sample size until an asymptote was reached. At this level, the effect of new rare species and more individuals of common species balance each other. Thus $\overline{H}$, at the asymptotic level, was a good estimate of true community diversity. Pielou found 95% of the asymptotic $\overline{H}$ after 5 square-meter samples in a tract of woodland. Wilhm and Dorris (1968), working with macrobenthos in a stream, found the asymptote was reached by the fourth Surber square-foot sample. A small sample size is desirable when many collecting sites are included in a study.

After sorting and counting the 22 square-foot samples from the North Fork of the Coeur d'Alene in 1968, I accumulated the N and n_i values for each sample and constructed a curve after the method of Pielou. Since a definite asymptote was not reached with a sample of this size, I was unable to predict the minimum number of samples necessary to describe the community. In both 1968 and 1969, 95% of the total diversity of 22 samples from the North Fork was not reached until 18 samples were analyzed (Table 13, Fig. 4). However, the asymptotic level of the curve was not attained, and, after considering the results, I did not feel justified in reducing the number of samples in 1969.

The large number of samples necessary to describe this community is consistent with the findings of Needham and Usinger (1956). They observed that a minimum of 73 square-foot samples were necessary to obtain significant figures at the 95% level of significance on the number of organisms in a riffle community in Prosser Creek, California.

My study has shown significant differences between test and control stations in both the Coeur d'Alene and Potlatch Rivers. The untreated wastes contaminating these waters has greatly altered the composition of the benthic communities. There was no significant improvement during the two years of study in either river although a slight improvement in diversity at the Coeur d'Alene test stations may indicate a trend toward recovery there.

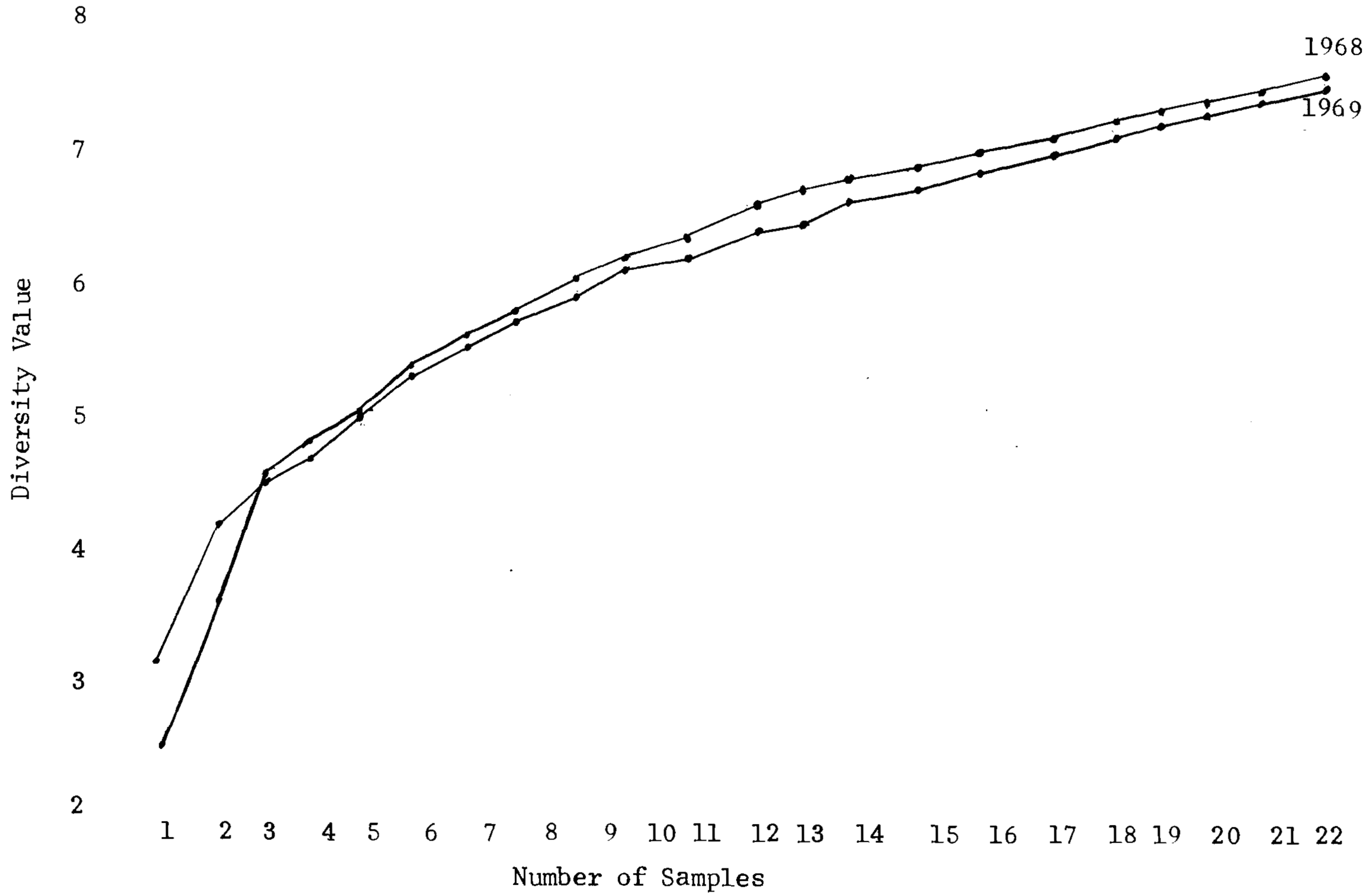
The Shannon-Wiener function proved to be a useful method in describing diversity in the benthic communities studied. If a small number of samples are collected and the diversities averaged, the riffle community can be adequately described by this method. The number of species, density and biomass are other parameters useful in describing benthic communities.

Small changes in the community structure including changes in number of species and species equitability are revealed in a change in $\bar{H}$. The $\bar{H}$ values can be compared statistically and significant differences identified.

Table 13. Accumulated diversity values for the North Fork of the Coeur d'Alene River from collections made on Sept. 8, 1968 and Sept. 6, 1969.

Sample	1968	1969
1	2.624	3.036
2	3.860	4.228
3	4.551	4.531
4	4.893	4.644
5	5.179	5.069
6	5.461	5.332
7	5.591	5.464
8	5.847	5.727
9	6.006	5.817
10	6.136	6.016
11	6.275	6.066
12	6.348	6.142
13	6.471	6.175
14	6.597	6.368
15	6.674	6.474
16	6.767	6.601
17	6.823	6.707
18	6.913	6.866
19	7.016	6.909
20	7.119	6.966
21	7.195	7.052
22	7.278	7.155

Figure 4. Accumulated Diversity for Twenty-two Samples from the North Fork of the Coeur d'Alene River, 1968 and 1969.



SUMMARY

1. Collections of macrobenthos were made from riffles in the North Fork, South Fork, and main Coeur d'Alene River on Sept. 8, 1968 and Sept. 6, 1969 and at 6 stations in the Potlatch River on July 2, 1969. Standard water chemistries, tests, and measurements of physical factors were also made at all collecting sites.
2. The organisms collected were sorted, counted and weighed. Individuals were identified to taxon (in some cases to species).
3. Species diversity values ($\overline{H}$), using the Shannon-Wiener function derived from information theory, were determined for each sample and the average was calculated for each station for each year. Biomass and density were also estimated.
4. The $\overline{H}$ values were compared using Duncan's Multiple Range Test. Significant differences at the 5% level were found between polluted and unpolluted stations in both rivers. No significant differences were found between years at sites in either river.
5. An attempt was made to predict optimum sample size in the North Fork of the Coeur d'Alene River using accumulated $\overline{H}$ values. No conclusive results were obtained as a definite asymptote was not reached after 22 sample values were accumulated.
6. Adaptations for survival in insects present in zones of moderate to heavy pollution in both rivers, and the effects of various types of pollution on aquatic insects were discussed.
7. It was concluded that siltation had been the main limiting factor in preventing the colonization of riffles in the South Fork and

main Coeur d'Alene River by macrobenthic fauna. Zinc ion concentrations were high enough, however, during times of low water in the South Fork (below the zinc smelter) to be acutely toxic to most macroinvertebrates.

8. In the Potlatch River, iron flocculent had destroyed the benthic habitat at station 3, and zinc ion concentrations had been high enough during low water periods to be a probable limiting factor. These factors may have affected the benthic community at station 4 also.

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