EFFECTS OF MUNICIPAL AND COPPER MINE DISCHARGES ON MACROINVERTEBRATES IN TWO MICHIGAN STREAMS

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ABSTRACT

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By

David Z. Skolasinski

The macroinvertebrate population of two northern Michigan streams was examined during the summer, fall and spring (1971-1972) to detect the influence of cultural effluents (sewage treatment plant effluent and municipal runoff) and copper mine discharges on stream organisms.

Cultural influences promoted rigorous and unstable stream conditions which resulted in low species diversity. The adverse effect of the mine discharges was minimal when compared to that of the cultural effluent. Diversity in the mine waters was high and not significantly different from that of an unperturbed area. However, the species assemblage of the unperturbed site tended toward a more intolerant group of organisms.

Lower species diversity values during spring months and in stream sections relatively removed from

human influence, suggested that natural environmental conditions placed a recurring stress on organisms in these areas. Low diversities in perturbed areas were partially attributed to these natural stresses.

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INTRODUCTION

The community structure of benthic macroinvertebrate populations serves as a valuable index of stream conditions because these organisms show a high degree of habitat preference and have low mobility and thus are directly affected by materials entering the environment. Chemical surveys give an indication of the stream conditions only at the time of sampling while benthic macroinvertebrate populations can be indicative of present and past environmental conditions (Wilhm, 1967). Gaufin and Tarzwell (1952) note that these organisms are especially valuable because they can be used to delineate critical conditions of short duration during periods when flows are large, dilution is at a maximum, dissolved oxygen is near saturation, and visual evidence of pollution is at a minimum. In comparing chemical and biological data Butcher (1955) showed that the two differed widely when several types of pollution were involved and concluded that pollution should be defined by biological conditions instead of chemical standards. Benthic invertebrates are, therefore, useful as indicators of both the degree and severity of organic pollution. The effects of pollutants on the benthic macroinvertebrates of a stream are significant because macroinvertebrates are important in aquatic food chains and play an important role in the natural purification of polluted waters (Wilhm, 1970a).

Two concepts, diversity and redundancy, must be considered when evaluating the species diversity of an environment. Diversity is an index of the number of species present per unit area, while redundancy is an expression of the dominance of one or more species and is inversely proportional to the number of species present (Wilhm, 1967). A stable environment of high water quality is characterized by maximum diversity and minimum redundancy.

According to Mathis (1968) polluted streams should have less diversity than non-polluted streams since some species are unable to survive. The remaining species encounter less competition and are able to produce large numbers of individuals if sufficient nutrients are available. Margalef (1961) pointed out that in the event of a sudden increase of nutrients, the different species take full advantage of their respective rates of increase. Because natural waters are relatively free from harmful effluents and provide extremely stable environments the natural communities characteristic of these waters tend toward more complex assemblages of species.

Associations or populations of benthic macro-invertebrates provide a more reliable criterion of organic enrichment than the mere occurrence of a given species (Gaufin and Tarzwell, 1956). This is based on the assumption that actions of the biotic environment and coactions between the biotic components result in a characteristic assemblage of organisms. Gaufin and Tarzwell (1952) note that in using associations of aquatic organisms as indicators of pollution, the absence or much reduced numbers of formerly present clean-water species in an area may be as important, or more so, as numbers of known pollutional forms. However, the absence of clean-water forms should not always be taken as definite indication of pollution. A knowledge of the life histories of the various groups of aquatic insects is often helpful in interpreting the meaning of their distribution. The time of emergence and the time during which they are in the first instars and are very small should always be considered. Analyses based on associations of species, however, usually involve long lists or descriptions of associations which are often cumbersome to use (Wilhm, 1967). Measures which summarize community structure clearly and briefly are much more valuable in evaluating the effects of organic enrichment. Many investigators agree that diversity indices, based on information theory, permit this summarization of large amounts of information about numbers and kinds of organisms (Gaufin and Tarzwell, 1956; Patten, 1962; Wilhm, 1967; Dickman, 1968; Mathis, 1968). These indices do not attempt to explain causal phenomena, but only estimate the amount of information required to define the community structure (Harrel and Dorris, 1968). Wilhm (1966), in discussing the advantages of information theory over methods based on indicator organisms, pointed out that less precise taxonomic distinctions need be made when using information theory. The only data required for community analysis are total number of recognizable taxa in a unit area. The index should, however, be independent of sample size and be associated closely with the wealth of species, since with increasing sample size, the number of individuals increases considerably faster than the number of species.

The present study involves a comparison of species diversity and species abundance of benthic macroinvertebrates in natural stream water and in stream water receiving the effluents from domestic and industrial sources. The study was conducted on the Mineral River and Native Creek, a tributary of the Mineral River, near the White Pine Copper Mine, White Pine, Michigan.

DESCRIPTION OF STUDY AREA

The Mineral River (Figure 1) is approximately 18 km long from its headwaters in the Bergland Hills to its mouth where it empties into Lake Superior. The average gradient is 10.4 m/km. The upper reaches of the river are essentially representative of a natural system although past logging operations in this area have had some effect on the river and the water quality. As a result this part of the river reflects primarily the natural conditions of the river. Near the half-way point the river passes through the community of White Pine where it receives approximately 350,000 gallons of secondary effluent per day from the community's trickling filter sewage treatment plant. In addition, housing development projects in the community and runoff from streets, parking lots and other open areas add an undetermined amount of sediment, oil and associated materials to the river. As the river continues to Lake Superior it is joined by Native Creek approximately 0.4 km from the river's mouth. Native Creek carries the effluents from the copper mine's tailing dams and adds the effects

Figure 1. Map of the Mineral River and Native Creek showing the location of the study sites.

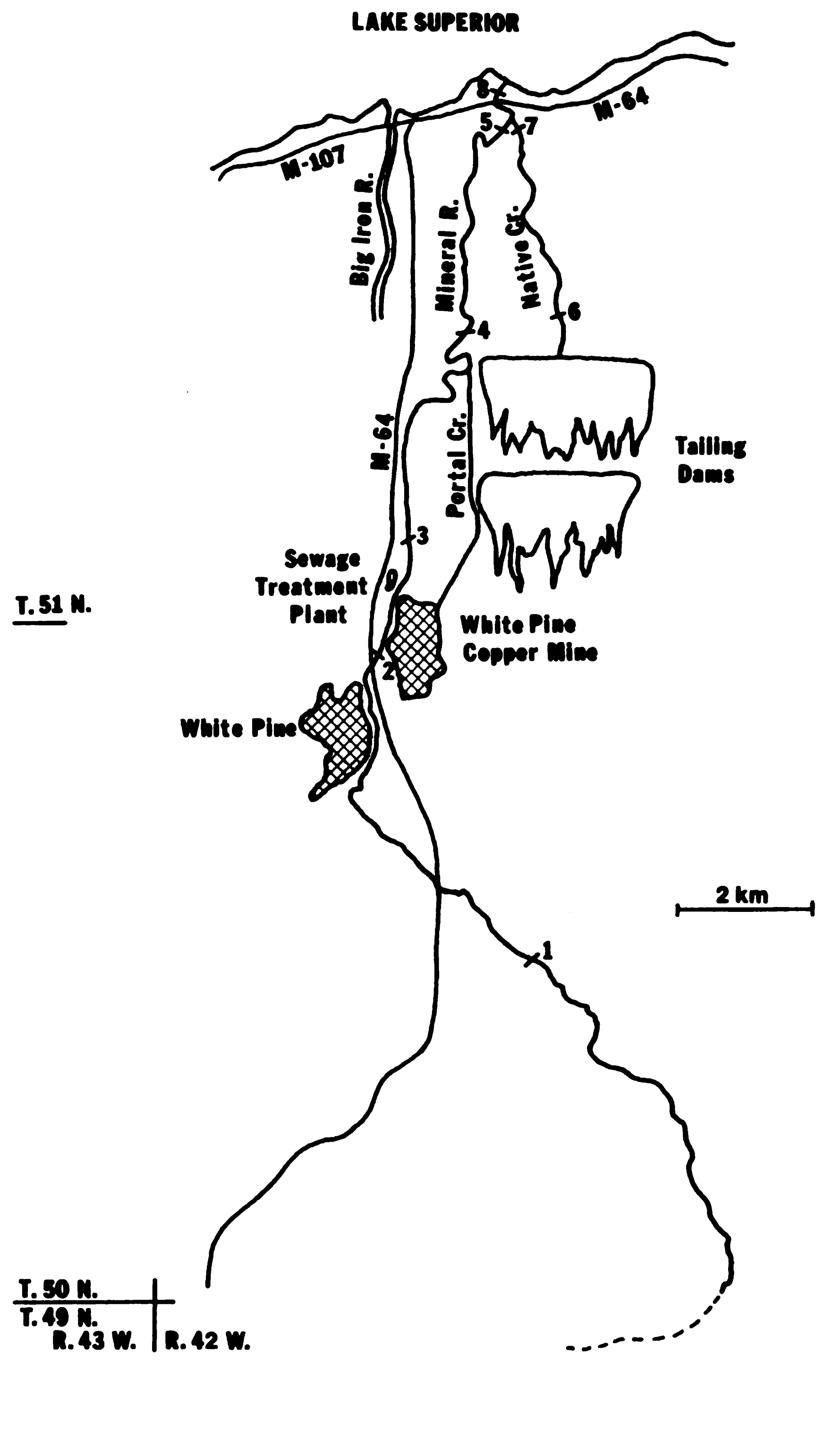
LAKE SUPERIOR
M-107
M-64
Big Iron R.
Mineral R.
Native Cr.
8
5
7
6
4
M-64
Portal Cr.
Tailing
Dams
3
Sewage
Treatment
Plant
T. 51 N.
White Pine
Copper Mine
2
White Pine
2 km
1
T. 50 N.
T. 49 N.
R. 43 W.
R. 42 W.

Figure 1

of the mining operation to the river. A few hundred meters upstream from its mouth the Mineral River widens and flows through a horseshoe-shaped bend where it drops much of its sediment load. Therefore, the cumulative effects of all the factors affecting the water quality are observed at the mouth of the river.

From its headwaters to the community of White Pine the Mineral River changes progressively from 1.5 to 4.5 m in width with a maximum depth of 0.6 m throughout most of the year. The bottom type changes from coarse gravel in the headwaters to a clay-gravel mixture in the intermediate zone and finally into a mixture of clay, large rock and small shale slabs 15-25 cm in diameter, near White Pine. A series of active beaver dams is present in the intermediate area. Overhanging vegetation is prevalent and the surrounding area is heavily wooded primarily with second and third growth maple and aspen which stabilizes the soil and stream banks.

In the area between White Pine and its confluence with Native Creek the river grades from 4.5 to 9.0 m in width with a maximum depth of 1 m throughout most of the year. The bottom type changes from that described above (near White Pine) to a mixture of clay and larger shale slabs downstream. In the area where the river is joined by Native Creek, the bottom type is composed of clay and coarse gravel overlain by large shale slabs up to 1 m in diameter. Less overhanging vegetation is present in this area and the effect of that which is present in the wider sections of the stream is somewhat reduced. This area again is heavily wooded primarily with second and third growth maple but the stream banks are not as well stabilized as a result of greater variability of flow rate.

Native Creek, which begins and parallels the Mineral River from approximately 5 km below White Pine to its confluence with the Mineral River, resembles the corresponding portion of the Mineral River. Flow rate and corresponding water depth, however, are highly variable as a result of the variable discharge rate from the tailing dams.

Drastic physical changes occur in the Mineral River through the last 0.4 km of its length. Immediately after its confluence with Native Creek, the river begins to widen. In the vicinity of the Highway M-64 bridge the river is approximately 24 m wide with a maximum depth of 2.5 m in the main channel throughout most of the year. The bottom is covered by a layer of clay approximately 20 cm thick. Surrounding vegetation is composed of a mixture of maple, aspen and spruce, and stream bank stabilization is reduced.

Eight locations along the river system, chosen for their similarities in physical parameters, were selected for sampling to assess the impact of each major factor exerting a stress on the river.

Site 1 is on the Mineral River approximately 1.5 km upstream from where the river passes under Highway M-64 south (upstream) of White Pine. The river is approximately 4.5 m wide with an average depth of 0.3 m. The bottom consists predominantly of gravel and large rocks 15-25 cm in diameter, intermixed with a relatively small amount of clay. Overhanging vegetation is very abundant and the stream banks are well stabilized.

Site 2 is on the Mineral River between White Pine and the sewage treatment plant, immediately downstream from the point where the river passes under Highway M-64 north of White Pine. The river is approximately 3 m wide with an average depth of 20 cm. The bottom consists largely of clay and rocks 15-25 cm in diameter. Overhanging vegetation is abundant and the stream banks are only moderately well stabilized throughout the area.

Site 3 is on the Mineral River 0.4 km downstream from the sewage treatment plant. The river is approximately 6 m wide with an average depth of 20 cm. The bottom rubble is generally less than 10 cm in diameter and the clay content is at a minimum. Flow rate is increased somewhat as a result of the sewage effluent, overhanging vegetation is abundant and the stream banks are well stabilized.

Site 4 is on the Mineral River approximately 3 km below the sewage treatment plant, adjacent to the north-west corner of the northern-most tailing dam. The stream is approximately 9 m wide with an average depth of 0.3 m. Clay and gravel overlain by shale slabs up to 0.6 m in diameter make up the bottom. Overhanging vegetation is abundant though the stream banks are not well stabilized.

Site 5 is on the Mineral River approximately 0.4 km from Lake Superior, just upstream from where it is joined by Native Creek. The stream is approximately 9 m wide with an average depth of 0.3 m. The bottom consists of clay and gravel overlain by shale slabs up to 1 m in diameter. Overhanging vegetation is abundant and the stream banks are well stabilized.

Site 6 is on Native Creek 0.4 km downstream from the entrance of the tailing dam effluents. The stream is 4.5 m wide and varies in depth from 0.2 to 0.7 m, depending on the rate of discharge from the tailing dams. Clay and gravel overlain by shale slabs up to 0.3 m in diameter make up the bottom. Overhanging vegetation is fairly abundant and the stream banks are quite well stabilized. Except for a buffer zone, however, the area along one side of the stream is open due to earth-moving operations in this area.

Site 7 is on Native Creek 0.4 km upstream from where it joins the Mineral River. The stream is 4.5 m wide and varies in depth from 0.2-0.6 m, depending upon the rate of discharge from the tailing dams. In other respects the site and surrounding area are similar to those described for site 5.

Site 8 is on the Mineral River between the Highway M-64 bridge and the river's mouth. The river is approximately 24 m wide with a maximum depth of 2.5 m in the main channel. A 20-cm layer of clay covers the bottom and overhanging vegetation occurs only intermittently. A narrow margin along the banks of part of the river lacks woody vegetation which subsequently results in reduced stream-bank stabilization.

METHODS AND MATERIALS

Benthic macroinvertebrates were collected during four periods. Three samples from each of the 8 sites were taken during each collection period according to a stratified random design of sampling. A random transect across the stream was sampled at each site though the specific areas sampled were chosen to enhance uniformity in bottom type.

A benthic riffle sampler described by Coffman, Cummins, and Wuycheck (1971) and an Ekman Dredge were used to sample the 7 upstream riffle sites and the one downstream pool site respectively. Once collected, the samples consisting of bottom rubble and organic debris were taken immediately to the laboratory where the organic matter was separated from the rubble. Upon separation the organic matter was washed in a sieve (No. 60 U.S. standard soil series with openings of 0.25 mm) and preserved in 25% formalin. The invertebrates were later removed from the organic debris with the aid of a 10X dissecting microscope, transferred to an ethyl alcohol-glycerin solution, and subsequently identified and counted.

Two related formulas were used to calculate species diversity of benthic macroinvertebrates. One was Brillouin's (1956) formula for information, or diversity per individual:

$$d = \frac{1}{N} (\log_2 \frac{N!}{n_1!\ n_2!\ \ldots\ n_s!})$$

where the total number of individuals of all species in the community (N) and the number of individuals of species i (n_i) are used to measure the diversity (d) of a completely censused collection treated as a population. Sterling's log approximation for factorials, as suggested by Pielou (1969), was used where N was equal to or greater than 200.

Diversity was also determined with Shannon's formula, an approximation of Brillouin's formula, described by Patten (1962):

$$\bar{d} = - \sum_{i=1}^{s} n_i/N \log_2 n_i/N$$

where the total number of organisms (N), number of individuals per species (n_i), and number of species (s) in the community are estimated from samples and used to estimate diversity ($\bar{d}$) of the total population. The index ($\bar{d}$) expresses the relative importance of each species in the community, and reflects the manner in which individuals are distributed among species (Harrel and Dorris, 1968). The range of $\bar{d}$ theoretically varies from zero to any positive number. A value of zero is obtained when all individuals belong to the same species. The maximum value of $\bar{d}$ depends on the number of individuals counted and is obtained when all individuals belong to different species. Wilhm (1970b) demonstrated that $\bar{d}$ rarely exceeds nine and is generally between three and four in clean-water stream areas and less than one in polluted stream areas.

Periodic analysis of the stream water was conducted and seasonal fluctuations in the chemical and physical parameters noted. Analyses for heavy metals (mercury, copper, zinc, lead, cadmium, silver, chromium, manganese, magnesium, aluminum and iron) as well as alkalinity, dissolved oxygen and B.O.D. were conducted by the White Pine Copper Company. Suspended and dissolved solids, turbidity, pH, temperature, hardness and chloride analyses were conducted by the author in accordance with standard methods outlined by American Public Health Association (1965).

Where several heavy metals were present the additive toxicity of the combination of metals was calculated with the formula:

$$\frac{Ca}{La} + \frac{Cb}{Lb} + \ldots \frac{Cn}{Ln} \leq 1$$

where Ca, Cb and Cn are the measured concentrations of the heavy metals in the receiving water, and La, Lb and Ln are the concentrations permissible for each substance individually (National Technical Advisory Committee, 1968). A value greater than 1.0 indicates the toxicity of the combination of metals is greater than the allowable maximum suggested.

RESULTS

Chemical and physical parameters were generally within the range of those of natural stream waters and similar to those present in other rivers in the vicinity (Doonan and Henrickson, 1969; Michigan Water Resources Commission, 1970). Results of chemical and physical analyses appear in Appendix A. A deviation occurred in the area immediately downstream from the copper mine's surface operations (site 4). In this area, chlorides and hardness show a substantial increase in concentration. Portal Creek which carries the mine surface drainage and joins the main river in this area appears to be their source. Periodically, Portal Creek also carries relatively high concentrations of suspended and dissolved solids resulting primarily from surface runoff during periods of precipitation.

Temperature ranges from a minimum of near 0°C during winter to 23°C during summer in the main stream system. This high summer temperature occurs most often in the downstream areas where the shading effect of overhanging vegetation is somewhat reduced. Though diurnal temperature fluctuations were not measured, it is conceivable that during periods of extremely low flow and high ambient temperatures, the water temperature could rise higher than the maximum measured.

Dissolved oxygen at each station generally ranged from 80% to 100% saturation and was usually greater than 7.0 mg/l. Again, however, diurnal fluctuations were not measured. During periods of low flow and high temperatures, early morning minimum concentrations below the sewage treatment plant would undoubtedly be lower.

B.O.D. was usually highest below the sewage treatment plant. During June, 1972 an increase in B.O.D. was noted in Native Creek. Decomposition of vegetation due to flooding in the tailing dams was most likely responsible for the increase. Sewage treatment plant records indicate a 65% removal of B.O.D. from the final effluent.

Heavy metals were present in concentrations naturally occurring in fresh water (Bowen, 1966; Michigan Water Resources Commission, 1972). Results of the heavy metal analyses appear in Appendix B. Among those analyzed, Fe, Al, Cu, Zn, Mn and Mg were found in detectable concentrations. Iron, Cu and Zn were below the maximum allowable concentrations suggested by Newton (1971). (Allowable concentrations of Al, Mn and Mg were not listed.) The additive toxicity of Fe, Cu and Zn, was calculated and their combined concentrations at each site was found to be less toxic than the allowable maximum suggested by the National Technical Advisory Committee (1968). A slight increase in copper concentration below the sewage treatment plant may have been the result of discarded chemical materials entering the sewage system from the mining assay laboratory and other mine facilities.

The number of individuals, number of species, and the Shannon and Brillouin diversity values among the eight sites were compared with the use of Tukey's multiple range test at the 0.05 level. Where diversity was equal to zero, indicating all individuals belonged to the same species, no significant difference was assumed between zero and the next highest diversity value if the difference between this value and zero was less than the Tukey critical value. This assumption was necessary since a value of zero could not be formally entered into the statistical analysis. Discussion of the number of individuals collected is based on all individuals. The number of species and the Shannon and Brillouin diversity values were tabulated and calculated with the omission of data concerning the dipteran family Chironomidae and the class Oligochaeta.

Results indicate that differences among the study sites result from inherent environmental differences among the areas as well as from human perturbation. Diversity was inversely related to the degree of human perturbation present.

The greatest numbers of individuals, as demonstrated by Figures 2 and 3, were collected below the sewage treatment plant and at the mouth of the river. Table 1 indicates that no significant difference was found between these two sites in two of the four collections. In the remaining two collections, while they were significantly different, they ranked close together. No significant difference was identified between the mouth of the river at site 8 and Native Creek. Apparent increased productivity in these areas was attributed to nutrients present in the sewage treatment plant effluent and from addition of lime and decomposition of organic matter in the tailing dams. This apparent increase in productivity from the sewage treatment plant was quite evident at site 4 but fairly well dissipated at site 5. The number of individuals collected at site 5 was low and not significantly different from the densities found at the control site and the rest of the river system, excluding site 3.

The greatest numbers of species, as shown in Table 2, were collected from the control site, Native Creek and site 5. No significant difference was found among these sites in August and October, 1971. In

Figure 2. Density of benthic macroinvertebrates at the eight study sites in July and August, 1971 ($\bar{Y}$ ± 1 SE).

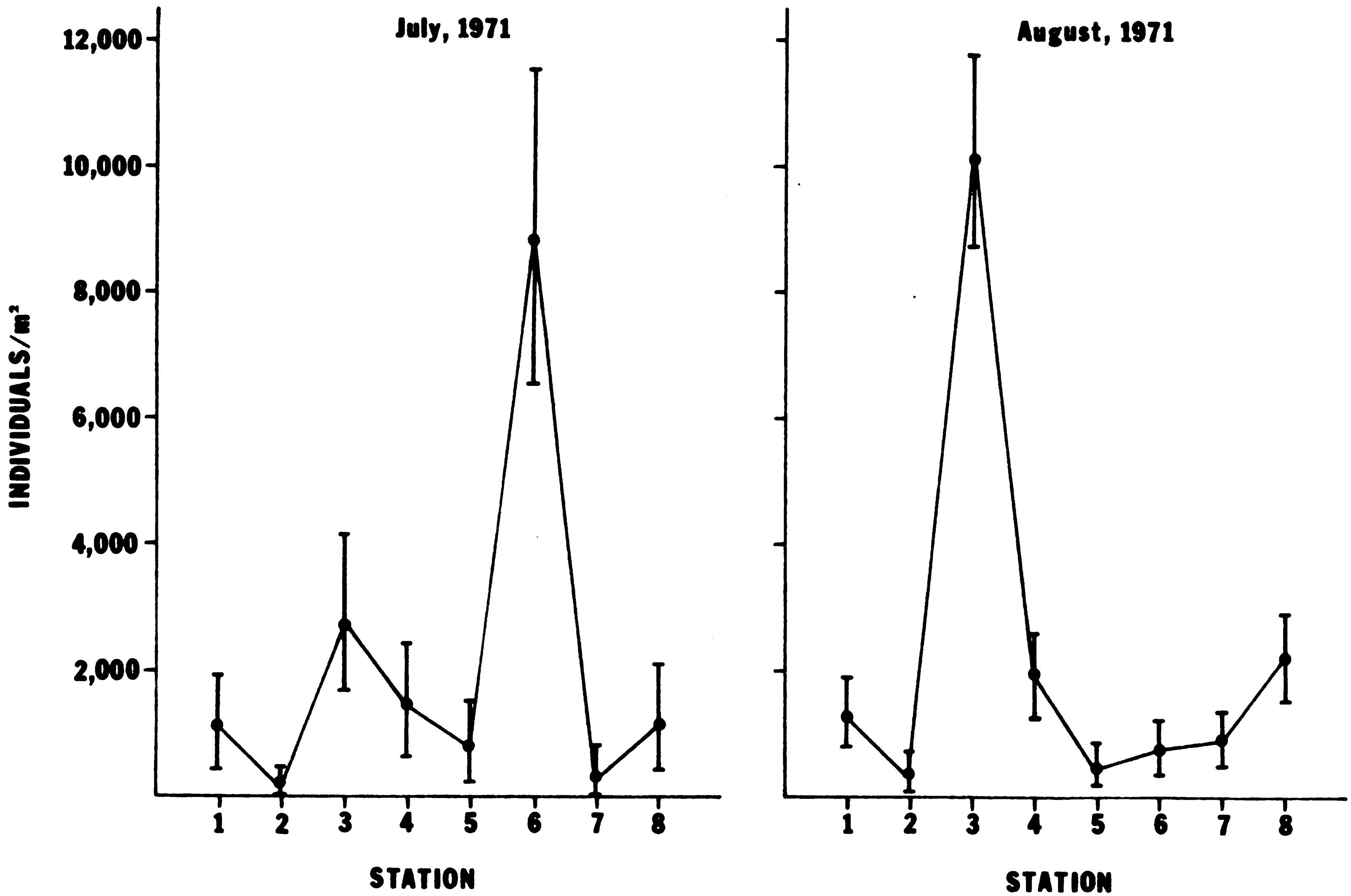
July, 1971
August, 1971
INDIVIDUALS/m²
12,000
10,000
8,000
6,000
4,000
2,000
1
2
3
4
5
6
7
8
STATION
STATION

Figure 2

Figure 3. Density of benthic macroinvertebrates at the eight study sites in October, 1971 and June, 1972 ($\overline{Y} \pm 1$ SE).

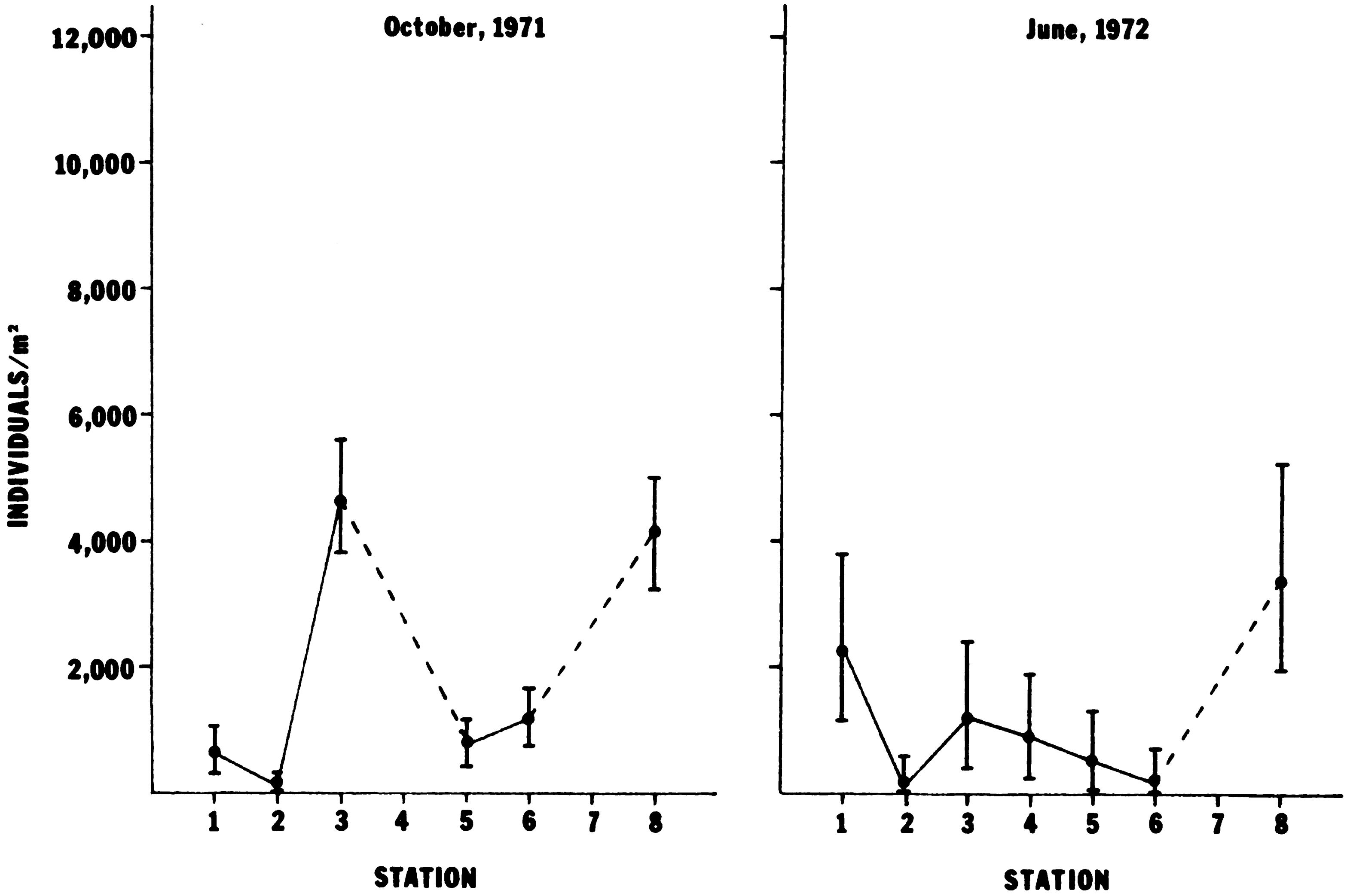
October, 1971
June, 1972
INDIVIDUALS/m²
12,000
10,000
8,000
6,000
4,000
2,000
1
2
3
4
5
6
7
8
STATION
STATION

Figure 3

Table 1. Tukey's multiple range test applied to mean numbers of individuals per ft.^{2} collected in four collections. Means not underscored by the same line are significantly different ($P \leq 0.05$).

July, 1971

Station	2	7	5	1	8	4	3	6
Mean	9.3	27.0	78.0	99.0	106.7	131.7	292.0	694.3
Multiple Range	———	———	———	———	———	———	———	
					———	———	———	———

August, 1971

Station	2	5	6	7	1	4	8	3
Mean	27.0	43.7	72.7	84.0	124.7	177.7	204.0	1022.0
Multiple Range	———	———	———	———	———	———	———	
								———

October, 1971

Station	2	5	1	6	8	3
Mean	9.0	70.0	72.3	112.7	385.3	453.3
Multiple Range	———	———	———	———		
				———	———	
					———	———

June, 1972

Station	2	6	5	4	3	1	8
Mean	10.7	16.7	50.0	85.7	119.3	257.7	509.3
Multiple Range	———	———	———	———	———	———	———

Table 2. Tukey's multiple range test applied to mean numbers of species taken in four collections. Means not underscored by the same line are significantly different (P≤0.05).

July, 1971

Station	8	2	3	5	7	4	6	1
Mean	2.0	2.3	3.0	5.3	5.7	6.3	10.0	13.3
Multiple Range	—	—	—	—	—	—		
				—	—	—	—	
							—	—

August, 1971

Station	8	3	2	4	5	6	7	1
Mean	3.3	4.7	5.0	6.3	7.7	9.3	11.0	11.7
Multiple Range	—	—	—	—	—			
		—	—	—	—	—		
				—	—	—	—	
					—	—	—	—

October, 1971

Station	8	2	3	5	1	6
Mean	2.7	2.7	3.7	6.7	9.0	11.3
Multiple Range	—	—	—	—	—	
				—	—	—

June, 1972

Station	4	2	3	8	6	5	1
Mean	2.0	2.3	2.3	2.7	3.0	4.0	13.3
Multiple Range	—	—	—	—	—	—	
							—

July, 1971 site 5 contained significantly fewer species than the control and Native Creek. In June, 1972 the control contained significantly more species than the rest of the river system while no significant differences was found among the rest of the sites. Numbers of species present in Native Creek and the adjacent section of the Mineral River were not significantly different from each other. Sites 2, 3, 4, 5 and 8, containing the lowest numbers of species, were not significantly different from each other. A constant stress may therefore be acting upon most of the river system to select against many species. A complete listing of numbers of individuals and species collected during the sampling periods at each study site is provided in Appendix C.

The Shannon and Brillouin diversity indices agree strongly although the Shannon values are inherently higher than the Brillouin values (Appendix D). Analyses indicate that diversities at the control, Native Creek, and the section of the Mineral River adjacent to Native Creek are higher than those of the other stations. Tables 3 and 4 show that these sites were not significantly different from each other in July, August and October, 1971. In June, 1972 no significant difference was found among the diversity values for any of the areas downstream from the control while species diversity at the control was significantly higher.

Table 3. Tukey's multiple range test applied to mean species diversity ($\bar{d}$), as calculated by Shannon's formula, in four collections. Means not underscored by the same line are significantly different ($P \leq 0.05$).

July, 1971

Station	8	2	3	5	6	7	4	1
Mean	0.00	.50	.82	1.38	1.50	1.74	1.93	2.90
Multiple Range	———	———	———	———	———	———	———	
				———	———	———	———	———

August, 1971

Station	3	8	2	5	4	6	7	1
Mean	.52	.67	1.59	1.90	1.99	2.14	2.37	2.51
Multiple Range	———	———	———					
			———	———	———	———	———	———

October, 1971

Station	8	3	2	5	1	6
Mean	0.00	.16	.44	1.81	2.20	2.68
Multiple Range	———	———	———			
				———	———	———

June, 1972

Station	4	8	3	2	6	5	1
Mean	0.00	.33	.51	.67	.80	.86	2.97
Multiple Range	———	———	———	———	———	———	
							———

Table 4. Tukey's multiple range test applied to mean species diversity (d), as calculated by Brillouin's formula, in four collections. Means not underscored by the same line are significantly different (P≤0.05).

July, 1971

Station	8	2	3	5	6	7	4	1
Mean	0.00	.30	.55	1.06	1.27	1.32	1.46	2.32
Multiple Range	—	—	—	—	—	—	—	
				—	—	—	—	—

August, 1971

Station	8	3	2	4	5	6	7	1
Mean	.33	.40	1.26	1.56	1.58	1.90	2.06	2.14
Multiple Range	—	—						
			—	—	—	—		
				—	—	—	—	—

October, 1971

Station	8	3	2	5	1	6
Mean	0.00	.12	.29	1.59	1.79	2.24
Multiple Range	—	—	—			
			—	—		
				—	—	—

June, 1972

Station	4	8	3	2	5	6	1
Mean	0.00	.22	.33	.33	.45	.53	2.51
Multiple Range	—	—	—	—	—	—	
							—

The lowest diversity consistently occurs at White Pine (site 2), at the sewage treatment plant (site 3), and near the river's mouth (site 8). Each area reflects the direct effect of human perturbation. The following factors may be responsible for environmental rigor at each site: Municipal surface runoff at site 2; introduced sewage effluent resulting in increased B.O.D. at site 3; and channelization and highway construction at site 8. Figure 4 demonstrates that although conditions in these areas lack stability, they, together with the conditions at the rest of the sites, are quite predictable throughout most of the year.

Though diversity indices indicate that no significant difference exists in the community structure of the upstream control and Native Creek, the insect composition of the two areas is somewhat different (Table 5). The data show that Ephemeroptera were more abundant in the control section while the Trichoptera, Coleoptera and Diptera, exclusive of the Chironomidae, were more prevalent in Native Creek. Gaufin (1958) classifies benthic macroinvertebrates into three categories: 1) intolerant organisms are those restricted to clean-water zones with dissolved oxygen between 75% and 115% saturation; 2) facultative organisms are those found in both clean-water zones and zones of degradation with dissolved oxygen between 40% and 115% saturation; 3) tolerant organisms

Figure 4. Species diversity ($\bar{d}$), as calculated by Shannon's formula, at the eight study sites from July, 1971 to June, 1972.

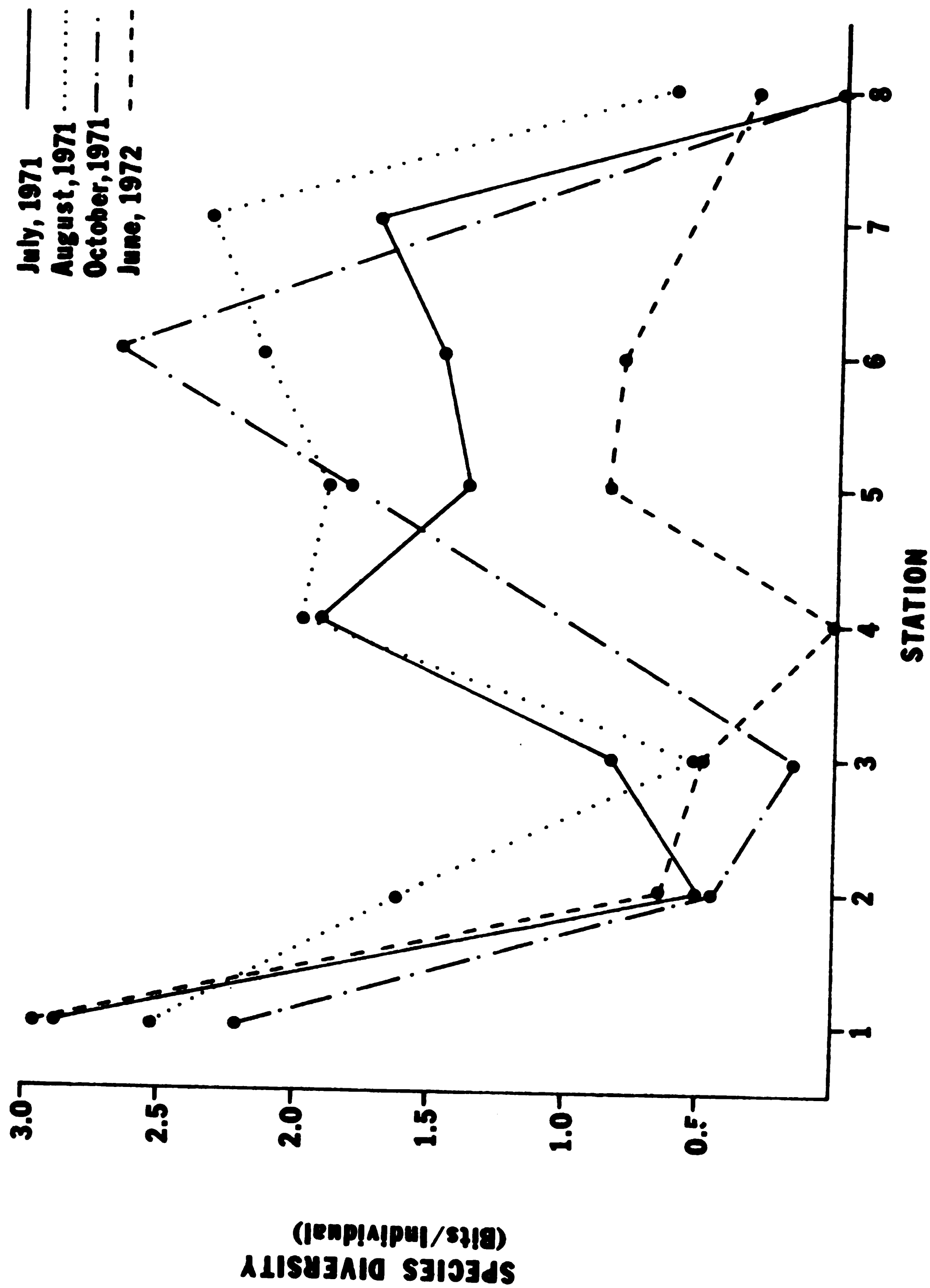
July, 1971
August, 1971
October, 1971
June, 1972
SPECIES DIVERSITY
(Bits/Individual)
3.0
2.5
2.0
1.5
1.0
0.5
STATION
1
2
3
4
5
6
7
8

Figure 4

Table 5. Mean annual percent composition of the dominant orders, exclusive of the dipteran family Chironomidae, at the control and Native Creek (sites 6 and 7).

Station	Ephemeroptera	Trichoptera	Coleoptera	Diptera
Control	18	4	9	11
Native Creek	0	13	18	24

are those most abundant in zones of active decomposition with dissolved oxygen between 1% and 40% saturation. It should be noted that the insect composition of Native Creek consists of a greater percentage of facultative individuals. In the order Trichoptera the genera Hydropsyche and Cheumatopsyche, which are considered facultative, are the most abundant members of the order in the Native Creek community while other genera (Pycnopsyche, Neophylax, Oecetis and Psychomyiid) which are often considered intolerant, are more abundant in the control section. Similar genera of Coleoptera and Diptera, which are predominantly facultative, occur in both areas (Gaufin, 1958; Tennessee Stream Pollution Control Board, 1964; Michigan Water Resource Commission, 1969).

Species diversity generally ranges from 1.0 to 3.0 at sites 1, 4, 5, 6 and 7. Wilhm (1970b) suggests that diversity values within this range are usually indicative of moderate degrees of pollution. However, it must be kept in mind that numbers of species and corresponding densities of the Chironomidae and Oligochaeta were not considered in the diversity determinations. Figure 5 describes the portion of the total number of individuals at each site which belong to the family Chironomidae. This family makes up a moderate to high percentage of the population density in all areas except sites 5, 6 and 7. The number of Oligochaeta were of moderate importance at sites 3 and 8 only. With this additional information diversity at sites 3, 4 and 8 would definitely be increased. It is quite possible that diversity, at least at site 1, would be greater than 3.0 and consequently in the range described by Wilhm (1970b) for clean-water streams.

Electrofishing methods were employed to collect fish to determine the species composition at each site. Most of the species collected throughout the regular sampling areas were members of the Cyprinidae family and of no commercial or sport value. A listing of these species appears in Table 6. These species are generally found under conditions similar to those afforded by the Mineral River (Starrett, 1950; Hubbs and Lagler, 1958).

Figure 5. Percent of the total number of individuals which belong to the family Chironomidae at the eight study sites from July, 1971 to June, 1972.

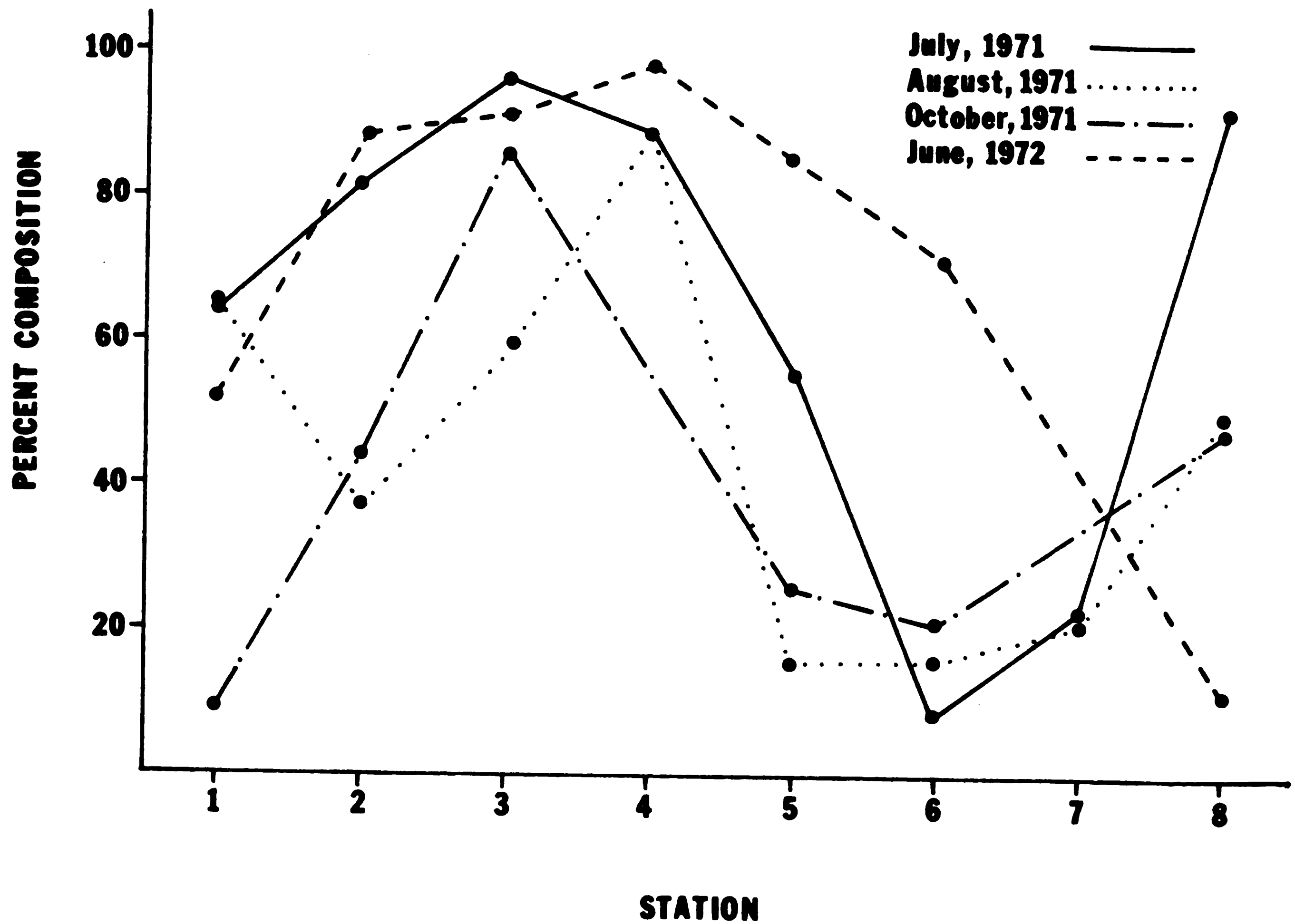
July, 1971
August, 1971
October, 1971
June, 1972
PERCENT COMPOSITION
100
80
60
40
20
1
2
3
4
5
6
7
8
STATION

Figure 5

Table 6. Species of fish collected from the eight study sites in September, 1971 and June, 1972.

Species	1	2	3	4	5	6	7	8
Semotilus atromaculatus (creek chub)	X	X	X	X			X	
Rhinichthys cataractae (longnose dace)	X	X	X	X	X		X	
Rhinichthys atratulus (blacknose dace)	X	X	X	X				
Notropis hudsonius (spottail shiner)								X
Notropis cornutus (common shiner)	X							
Catostomus commersoni (white sucker)	X	X		X	X		X	X
Culaea inconstans (brook stickleback)	X		X			X		
Umbra limi (central mudminnow)			X					
Lota lota (burbot)					X			
Cottus bairdi (mottled sculpin)	X	X						
*Salvelinus fontinalis (brook trout)	X							
Stizostedion vitreum (walleye)								X

*Collected 6.5 km upstream from site 1.

DISCUSSION

Differences in species diversity among the eight study areas suggests that environmental conditions fluctuate to a considerable degree in the various parts of the river system. It is evident that diversity is inversely related to the degree of human perturbation. However, as demonstrated by species diversity in Native Creek, cultural eutrophication can be controlled to provide an environment consistent with the requirements of a well diversified invertebrate population.

Poulson and Culver (1969) suggested that the theoretical major regulators of species diversity are stability, predictability and rigor of the environment. Environments of high species diversity are characterized by high environmental predictability and low variability. Predictability is quite high throughout the Mineral River from season to season although stability appears low where rigor is high.

Precipitation in the Mineral River watershed results in much surface runoff and erosion as a result of loosely held clay soils adjacent to much of the stream.

Though specific flow rates were not measured, highly variable water levels were observed and are illustrated in Appendix E. Spring flooding appears to be responsible for the low diversity throughout most of the river in June, 1972. Wilhm and Dorris (1966) observed a similar reduction in the numbers of species present after heavy rainfall and concluded that the increased flow and scouring effect of dislodged sediments washed many organisms away.

Natural siltation consistently occurs during and after periods of precipitation throughout the spring, summer and autumn months and may be exerting a significant stress within the Mineral River. Figure 1, Appendix E illustrates the apparent magnitude of siltation in one area of the river. Sites 2, 3, 4, 5 and 8 are most affected by this force while sites 6 and 7 are to a lesser extent. The density of the surrounding vegetation at site 1 stabilizes the soils and prevents most erosion.

Gaufin (1958) found that upon settling, fine solids formed a blanket over the stream bottom and over anything else to which they could adhere. The resulting substratum afforded no attachment base for most aquatic invertebrates while its suffocation effect eradicated many organisms previously present. Ellis (1936) stated that silt alters aquatic communities through screening out light, changing heat radiation, and retaining organic materials and other substances which create unfavorable conditions on the stream bottom. Siltation is also responsible for filling in open spaces among the rocks and rubble on the stream bottom and reducing the number of available habitats. Poulson and Culver (1969) found that such reductions in spatial heterogeneity resulted in corresponding reductions of species diversity.

Extremely low and variable water levels in late summer (Figure 2, Appendix E) along with high temperatures may be limiting factors to both invertebrates and fish in the Mineral River and consequently are responsible for low species diversity levels during succeeding seasons. Burton and Odum (1945) indicated that temperature may be one of the most important factors in limiting the distribution of fishes in cool swift streams. Stranding of fish in intermittent ponds is not uncommon during the summer in the Mineral River. Starrett (1951) suggests that this may have adverse effects upon them directly and that reduced space due to low water levels inhibits successful spawning in many fish. The creek chub (Semotilus atromaculatus) was among the most frequently observed species of fish in the Mineral River. The hardiness of this species in drying pools, as mentioned by Shelford (1937), is the apparent reason for its success.

The intolerant mottled sculpin (Cottus bairdi) was present throughout the area from the extreme headwaters to site 2. The brook trout (Salvelinus fontinalis) was absent from sites 1 and 2, though present approximately 6.5 km upstream from site 1. Bailey (1952) found that sculpins and brook trout often occurred in the same areas, while Smith (1972) stated that this was not always the case. Some factors within the tolerance limits of sculpins appear limiting to trout. Low invertebrate diversity and absence of brook trout indicate a rigorous and unstable environment at site 2. All parameters demonstrate that site 1 is the most stable, predictable and least rigorous of the areas studied, though brook trout requirements present in the extreme headwaters are absent at site 1 and all areas downstream from this point.

Chemical and physical parameters do not support the low species diversity found at site 3. The author feels that further analysis is necessary, particularly in determining the magnitude of diurnal oxygen and temperature fluctuations in this area. During late summer when flow rates are at a minimum and temperatures are high, the effluent from the sewage treatment plant is the primary source of water in the river. Septic or near septic conditions may occur, as Gaufin and Tarzwell (1956) suggest, to provide an environment acceptable to only more tolerant species of invertebrates. Although free residual chlorine concentrations downstream from the sewage treatment plant were not measured, they may have been periodically responsible for some reduction of diversity in this area. Zillich (1972) indicates that free chlorine concentrations greater than 0.05 mg/liter are lethal to many species of fish. Although several species of fish were found in the area, their mobility may have afforded a means of escape from periodically harsh conditions. The peak density of individuals found at this site in August, 1971 was the result of peak Chironomidae and Oligochaeta populations (Table 2, Appendix B).

To alleviate the harsh conditions in the Mineral River below the sewage treatment plant, the White Pine Copper Company plans to pump the treated secondary effluent from the sewage treatment plant directly into the tailing dams. This would provide a 60 to 80 day retention time of the sewage effluent within the tailing dams and facilitate a type of tertiary treatment of the sewage effluent. Fertilization of the tailing dams resulting from this operation will also aid in tailing dam reclamation. Operation of this process will be put into practice in the near future.

Site 4 exhibits conditions typical of a recovery zone described by Gaufin and Tarzwell (1956). The population density indicates a reduction in productivity from that present at site 3, while the increased species diversity over that of site 3 is responsive to a more stable and less rigorous environment. The increased levels of chlorides (up to 600 mg/l) in this vicinity appear to have little if any toxic effect on stream organisms. Anderson (1948) reports that concentrations of 3,680 mg/l and 920 mg/l of sodium chloride and calcium chloride respectively, are required for immobilization of *Daphnia magna*, a fairly susceptible invertebrate. The fathead minnow (*Pimephales promelas*), which is relatively intolerant to sodium chloride has a 96-hour median toxicity threshold of 8,700 mg/l (Clemens and Jones, 1954).

Site 5 shows a further decrease in productivity from site 4 while species diversity remains similar. The predominantly large shale slab stream bottom is suspected by the author to have reduced the efficiency of the sampling apparatus. A similar conclusion was made concerning site 7 and to a lesser extent sites 4 and 6. Figure 3, Appendix E illustrates conditions typical of these areas. A greater species diversity than that indicated may therefore exist in these areas.

Conditions in Native Creek, sites 6 and 7, appear to provide an environment of stability approaching that of the control station. However, conditions in Native Creek may be less predictable and more rigorous than those of the control as the species composition of Native Creek contains a lower percentage of intolerant and a greater percentage of facultative organisms than the control. The high population density found in July, 1971 was due to the peak density of <u>Simulium vittatum</u> which composed 70% of the population. By August, 1971 most of the individuals had matured and emerged and were no longer present in the aquatic environment.

Low species diversity at site 8 is not the result of the effluent discharges from the sewage treatment plant and the tailing dams since sites 4, 5, 6 and 7 receive these effluents first and maintain greater species diversity than site 8. Rather, excessive natural siltation, resulting in an unstable and uniform substratum, provides a habitat, as Gaufin (1958) suggests, conducive to only a few invertebrate species adapted to this specific type of environment.

Occasionally a few individuals of species other than those of the family Chironomidae or the class Oligochaeta were collected at this site. These individuals are not members of the community which normally inhabits this area but rather were transported by the current from areas upstream from site 8. Gaufin and Tarzwell (1956) indicate that intolerant species which drift into zones of degradation from nearby tributaries are often able to remain alive for periods sufficient to allow them to emerge as adults. The numbers of such clean-water forms are distinctly limited when compared with the populations of organisms usually found in such areas.

Effluent discharges influence the invertebrate communities in the Mineral River and Native Creek to create rigorous environmental conditions. Compared to the control area, the influence of the tailing dams is minimal while that of the sewage treatment plant is of considerable magnitude. As well as these obvious cultural discharges, the Mineral River system is influenced by flooding, erosion, and natural siltation, alternating with periods of low water. Such natural forces appear to maintain a constant environmental stress evidenced by diversity levels consistently lower than those of the control.

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APPENDICES

APPENDIX A

WATER QUALITY PARAMETERS

Table A1. Water quality parameters at the eight Mineral River and Native Creek study sites on 7/24/71, in mg/liter where applicable.

Parameter	Concentration							
	1	2	3	4	5	6*	7*	8
pH	7.4	7.6	7.1	7.8	8.0	7.8	7.9	7.9
Turbidity	41	9	15	71	57	18	18	27
Solids (Susp.)	37	5	9	66	53	14	13	24
Solids (Diss.)	108	236	202	834	928	214	294	648
Hardness	84	90	92	400	425	90	92	231
Chlorides	1	1	4	380	450	65	70	320
Temp. (°C)	18	18	18	22	18	16	17	19
Diss. Oxygen	7.9		7.4			8.4		9.2
D.O. (% Sat.)	83		78			84		98
B.O.D. (5-Day)	0.7		7.0			0.8		2.8

*Native Creek

Table A2. Water quality parameters at the eight Mineral River and Native Creek study sites and at Portal Creek on 9/8/71, in mg/liter where applicable.

Parameter	Concentration								
	1	2	3	4	5	6*	7*	8	P**
pH	7.1	7.3	7.2	8.0	7.9	7.7	7.7	7.8	7.5
Turbidity	8	12	22	84	88	15	4	82	52
Solids (Susp.)	6	8	12	80	86	14	2	78	41
Solids (Diss.)	120	148	214	136	118	380	364	126	136
Hardness	90	113	81	70	78	179	164	81	68
Chlorides	2	10	154	104	104	400	390	106	60
Temp. (°C)	19	22	19	18	22	23	20	23	--
Diss. Oxygen	10.0		5.0			10.0		9.8	
D.O. (% Sat.)	106		53			115		113	
B.O.D. (5-Day)	6.0		30.0			3.3		3.9	

*Native Creek
**Portal Creek--joins Mineral River between site 3 and site 4

Table A3. Water quality parameters at six of the eight Mineral River and Native Creek study sites and at Portal Creek on 12/29/71, in mg/liter where applicable.

Parameter	Concentration						
	1	2	3	4	6*	8	P**
pH	7.0	7.1	6.8	6.9	9.3	9.0	7.0
Turbidity	13.5	11.5	24.5	300	20.0	49.0	200
Solids (Susp.)	8	3	17	269	9	43	186
Solids (Diss.)	68	66	114	386	318	392	408
Hardness	50	51	62	268	198	163	395
Chlorides	5.0	7.5	10.0	210.0	112.5	165.0	287.5
Temp. (°C)	0.5		1.0		2.0	1.0	
Diss. Oxygen (1:00pm-3:00pm)	12.5		12.8		12.8	13.2	
D.O. (% Sat.)	83		90		93	93	
B.O.D. (5-Day)	2.4		7.6		2.7	3.6	

*Native Creek
**Portal Creek--joins Mineral River between site 3 and site 4

Table A4. Water quality parameters at the eight Mineral River and Native Creek study sites and at Portal Creek on 6/6/72, in mg/liter where applicable.

Parameter	Concentration								
	1	2	3	4	5	6*	7*	8	P**
Copper	<0.005	<0.005	<0.010	0.020	<0.005	<0.005	<0.005	<0.005	<0.005
pH	7.3	7.8	7.5	8.1	8.8	9.8	9.7	9.6	8.3
Turbidity	9.5	6.5	11.5	36.0	27.0	20.0	20.0	27.0	38.0
Hardness	46	44	58	380	468	64	86	132	836
Alkalinity	50	50	64	58	58	44	50	92	46
Chlorides	6.8	100.0	140.0	363.0	457.0	92.8	94.0	145.6	888.8
Temp. (°C)	18.5	21.0	20.0	22.0	19.5	18.0	19.0	19.5	28.0
Diss. Oxygen	8.5		9.2			9.6		8.3	
D.O. (% Sat.)	90		100			100		89	
B.O.D. (5-Day)	1.8		6.4			11.2		6.6	

*Native Creek
**Portal Creek--joins Mineral River between site 3 and site 4

Table A5. Water quality parameters at the eight Mineral River and Native Creek study sites and at Portal Creek on 9/12/72, in mg/liter where applicable.

Parameter	Concentration								
	1	2	3	4	5	6*	7*	8	P**
pH	6.9	7.2	7.2	7.3	7.8	8.3	7.7	7.7	7.4
Turbidity	15.5	11.5	13.5	24.5	36.0	38.5	17.5	40.5	24.5
Solids (Susp.)	10	4	12	20	22	30	8	24	26
Solids (Diss.)	162	188	172	1414	516	324	302	530	3608
Hardness	48	49	62	600	192	102	154	200	2500
Chlorides	1.28	2.88	4.56	568.0	157.2	77.6	32.0	152.4	1912
Temp. (°C) (5:30am-8:00am)	12.0	11.0	12.5	14.0	15.5	15.5	12.0	15.5	16.0
Diss. Oxygen (5:30am-8:00am)	11.0	10.5	11.5	9.5		11.0		10.0	
D.O. (% Sat.) (5:30am-8:00am)	102	95	103	91		109		99	
Temp. (°C) (4:30pm-5:00pm)	16.0		18.0			21.0		18.0	
Diss. Oxygen (4:30pm-5:00pm)	10.2		7.3			13.3		10.5	
D.O. (% Sat.) (4:30pm-5:00pm)	102		77			148		110	

*Native Creek--lower Native Creek, site 7, was not receiving tailing dam effluent at this time

**Portal Creek--joins Mineral River between site 3 and site 4.

APPENDIX B

HEAVY METAL CONCENTRATIONS

Table B1. Concentrations of heavy metals at the eight Mineral River and Native Creek study sites on 7/24/71 in mg/liter.

Parameter	Concentration							
	1	2	3	4	5	6*	7*	8
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron	0.12	0.16	0.04	0.06	<0.01	<0.01	<0.01	<0.01
Aluminum	0.05	0.05	0.05	0.05	0.05	<0.05	<0.05	0.05
Chromium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	<0.005	<0.005	0.020	0.010	<0.005	<0.005	<0.005	<0.005
Manganese	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.01
Magnesium	6.65	6.70	7.10	7.00	7.10	1.50	1.60	5.50
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc	0.010	0.010	0.015	0.015	0.015	0.010	0.010	0.015
Cadmium	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*Native Creek

Table B2. Concentrations of heavy metals at the eight Mineral River and Native Creek study sites on 9/8/71 in mg/liter.

Parameter	Concentration								
	1	2	3	4	5	6*	7*	8	P**
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron	0.15	0.16	0.04	0.07	0.02	<0.01	<0.01	<0.01	0.12
Aluminum	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.10
Chromium	0.05	0.05	0.05	0.05	0.05	<0.05	<0.05	0.05	0.05
Copper	<0.005	<0.005	0.020	0.020	<0.005	<0.005	<0.005	<0.005	<0.005
Manganese	0.03	0.03	0.02	0.01	0.01	0.03	0.03	0.01	0.03
Magnesium	6.90	6.85	7.40	7.30	7.30	1.10	1.15	4.85	5.80
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc	0.010	0.015	0.015	0.015	0.015	0.010	0.010	0.015	0.015
Cadmium	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*Native Creek
**Portal Creek--joins Mineral River between site 3 and site 4

APPENDIX C

SPECIES AND TOTAL NUMBERS OF INVERTEBRATES COLLECTED

Table C1. Species and total numbers of invertebrates collected from the eight study sites on the Mineral River and Native Creek during the period 7/14/71-7/23/71.

Species	TYPE	Number Collected 1	2	3	4	5	6	7	8
OLIGOCHAETA		4			3	21	30	29	32
HIRUDINEA									
Dina sp.							1		
EPHEMEROPTERA									
Ephemera simulans	I	1							
Leptophlebia nebulosa	I	14							
Caenis sp.	F	1							
Tricorythodes sp.		1							
Baetidae	F						6		
MEGALOPTERA									
Sialis sp.	F	1	2	1					
ODONATA									
Cordulegaster sayi		1							
Ophiogomphus sp.		1							
TRICHOPTERA									
Cheumatopsyche spp.	F				15	7	180		
Hydropsyche bifida	F				4	61	71	13	
Hydropsyche slossonae	I				3		17		
Hydropsyche recurvata					3	6			
Hydropsyche cuanis	F				1				
Pycnopsyche sp.	I	3							
Neophylax sp.	I	2	1						
Oecetis sp.	I	6							
Psychomyiid Genus A		2							
COLEOPTERA									
Optioservus spp.	F	5		1		1		10	
Ordobrevia spp.		5		1					
Zaitzevia spp.		4		1		1		8	
Dubiraphia sp.	F	20							
Deronectes sp.		2							
Laccobius sp.	F		1						

Table C1. Continued

Species	TYPE	Number Collected 1	2	3	4	5	6	7	8
DIPTERA									
Tipula sp.	F	1							
Eriocerus longicornis	I	4							
Tabanus sp.	F	16							
Simulium vittatum	F				9		1471		
Atherix variegata	F						2	1	
Palpomyia spp.	F	13	2	26	2	6	4		
Empididae					5		151	1	
Chironomidae	F	190	23	845	351	131	163	19	288
GASTROPODA									
Physa sp.	T						1		

Table C2. Species and total numbers of invertebrates collected from the eight study sites on the Mineral River and Native Creek during the period 8/13/71-9/3/71.

Species	TYPE	Number Collected							
		1	2	3	4	5	6	7	8
OLIGOCHAETA		9	2	1216		16	11	19	288
HIRUDINEA									
Mollibdella grandis							1	5	
Nephelopsis obscura							1		
EPHEMEROPTERA									
Ephemera simulans	I	9							
Leptophlebia nebulosa	I	27							
Caenis sp.		25							
Stenonema sp.	F	1							
MEGALOPTERA									
Sialis sp.	F	2	19	4					
Nigronia sp.						1			
LEPIDOPTERA									
Noctuidae									4
ODONATA									
Cordulegaster sayi			1						
Ophiogomphus sp.			1						
Aeshnidae				3					
TRICHOPTERA									
Cheumatopsyche spp.	F				1		4	1	
Hydropsyche slossonae	I				7	14	11	7	
Hydropsyche cuanis	I				6				
Hydropsyche bifida	F				17	55	23	19	
Hydropsyche recurvata					2	2			
Pycnopsyche sp.	I	2							
Oecetis sp.	I	1	1					1	
Phylocentropis sp.		1							

Table C2. Continued

Species	TYPE	1	2	3	4	5	6	7	8
		Number Collected							
COLEOPTERA									
Optioservus spp.	F	1			1	1	4	32	
Ordobrevia spp.		6						2	
Zaitzevia spp.		3			1	3	0	83	
Dubiraphia sp.	F	35						2	
Berosus sp.	F								4
Carabidae				1					
DIPTERA									
Eriocera longicornis	I	2				2		1	
Antocha saxicola	I					7			
Atherix variegata	F						39	5	
Tabanus sp.	F	3							
Palpomyia spp.	F	11	22	65	5	4			
Empididae	F	1	5	1	17	8	78	16	4
Chironomidae	F	243	30	1778	476	21	34	54	308
GASTROPODA									
Physa spp.	T						2	3	4

Table C3. Species and total numbers of invertebrates collected from six of the eight study sites on the Mineral River and Native Creek during the period 10/19/71-10/23/71.

Species	TYPE	Number Collected					
		1	2	3	5	6	8
OLIGOCHAETA		9		288	45	157	542
EPHEMEROPTERA							
Ephemera simulans	I	15					
Leptophlebia nebulosa	I	19					
Caenis sp.	F	15					
Baetidae	F					1	
MEGALOPTERA							
Sialis sp.	F		1	1			
TRICHOPTERA							
Cheumatopsyche spp.	F				4	8	
Hydropsyche slossonae	I				20	6	
Hydropsyche bifida	F				38	21	
Ochnotrichia riesi					2	1	
Oecetis sp.	I	4					
Psychomyiid Genus A	I	1	1				
COLEOPTERA							
Optioservus sp.	F					1	
Ordobrevia sp.				1			
Zaitzevia spp.		1				5	
Dubiraphia sp.	F	9					
Deronectes sp.		3					
Berosus sp.	F					1	
DIPTERA							
Eriocera longicornis	I	4					
Antocha saxicola	I				22	15	
Tabanus sp.	F	5					
Atherix variegata	I					15	
Pericoma sp.		3					
Palpomyia sp.	F	16	13	96	24	17	12
Simulium vittatum	F					4	
Empididae	F					9	
Chironomidae	F	20	12	1174	55	71	572
GASTROPODA							
Physa sp.	T	2				15	
Helosoma sp.	F	2					
Lymnaea sp.						3	
PELECYPODA							
Sphaerium sp.	T	9					

Table C4. Species and total numbers of invertebrates collected from seven of the eight study sites on the Mineral River and Native Creek during the period 6/7/71-6/14/71.

Species	TYPE	Number Collected						
		1	2	3	4	5	6	8
OLIGOCHAETA		11		22	5	14	1	1336
HIRUDINEA								
Glossiphonia complanata		1						
EPHEMEROPTERA								
Ephemera simulans	I	26						
Caenis sp.	F	33				1		
Stenonema spp.		14	1					
Baetidae	F	3						
PLECOPTERA								
Acroneuria internata	I		1					
ODONATA								
Cordulegaster sayi		1						
Ophiogomphus sp.		1						
TRICHOPTERA								
Hydropsyche bifida	F					5		
Helicopsyche borealis	I	3						
Pycnopsyche spp.	I	4	1					
Psychomyiid Genus A	I	3						
COLEOPTERA								
Optioservus sp.	F	3						
Ordobrevia sp.		4						
Zaitzevia sp.		1						
Dubiraphia sp.	F	3						
Deronectes sp.		4						
Berosus sp.	F			1				
Anchodemus spp.		1		2			1	
Helodidae		1						
DIPTERA								
Eriocera longicornis	I	22					4	
Tipula sp.	F						3	
Tabanus sp.	F	6						
Simulium vittatum	F						5	
Chaoborus sp.								8
Palpomyia spp.	F	24		6	1	1		8
Empididae	F		1					
Chironomidae	F	400	28	327	251	128	36	176
PELECYPODA								
Sphaerium sp.	T	6						

APPENDIX D

SPECIES DIVERSITY

Table D1. Species diversity ($\bar{d}$), as calculated by Shannon's formula, at the eight study sites from July, 1971 to June, 1972.

Date	1	2	3	4	5	6	7	8
July, 1971	2.90	.50	.82	1.93	1.38	1.49	1.74	0.00
August, 1971	2.51	1.59	.52	1.99	1.90	2.14	2.37	.67
October, 1971	2.20	.44	.16	—	1.81	2.86	—	0.00
June, 1972	2.97	.67	.50	0.00	.86	.80	—	.33
Mean Annual Diversity	2.65	.80	.50	1.31	1.49	1.78	2.06	.25

Table D2. Species diversity (d), as calculated by Brillouin's formula, at the eight study sites from July, 1971 to June, 1972.

Date	1	2	3	4	5	6	7	8
July, 1971	2.32	.30	.55	1.47	1.06	1.27	1.32	0.00
August, 1971	2.14	1.26	.40	1.56	1.58	1.90	2.06	.33
October, 1971	1.79	.29	.12	—	1.59	2.24	—	0.00
June, 1972	2.51	.33	.33	0.00	.45	.53	—	.21
Mean Annual Diversity	2.19	.55	.35	1.01	1.17	1.49	1.69	.14

APPENDIX E

PHOTOGRAPHS OF STREAM CONDITIONS

Figure E1. Photograph illustrating natural siltation between site 2 and site 3 on 7/9/71.

Figure E2. Photograph illustrating low flow conditions between site 4 and site 5 on 8/13/71.

Figure E1

Figure E2

Figure E3. Photograph of shale slab stream bottom between site 4 and site 5 on 8/13/71.

Figure E3