BENTHIC MACROINVERTEBRATE DIVERSITY IN THREE DIFFERENTIALLY PERTURBED MICHIGAN STREAMS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
SCOTT JON REGER
1973

~~3 '75~~ 01

~~JUN~~ C 80

~~JUN 2~~ 18

~~JUN~~ 179

~~JAN~~ 239

~~1 15 77~~ 355

~~JAN 15 1980~~ 661

~~72~~ 127

84 140

154

~~MAY 97~~ 86

~~N 25~~ 309

12-23-92 337

ABSTRACT

BENTHIC MACROINVERTEBRATE DIVERSITY IN THREE
DIFFERENTIALLY PERTURBED MICHIGAN STREAMS

By

Scott Jon Reger

The macroinvertebrate community structures of three Michigan streams were examined through an annual cycle. Study sites were located above and below known sources of human disturbance on each stream. Taxonomic composition, standing crops, and diversity of both numbers of individuals and biomass were used in an attempt to describe the effects of cultural development on the streams.

Macroinvertebrate diversity indices calculated using numbers of individuals were found to be more sensitive than other indicators of human perturbation, particularly when comparing sections of any given stream. The city of Grayling's sewage treatment plant's conversion to land disposal resulted in increased diversity of the lower Au Sable River from an earlier study. This change was not noticeable by direct measurement of chemical water quality parameters.

Nutrient enrichment appeared to result in an increased production of macroinvertebrates, followed closely by a decreased diversity of the community. Factors other than enrichment also were shown to be important in controlling the composition and diversity of the communities. Most important of such factors were substrate types and stability and variation in discharge; these may or may not have been a result of human activity in the watersheds.

BENTHIC MACROINVERTEBRATE DIVERSITY
IN THREE DIFFERENTIALLY PERTURBED
MICHIGAN STREAMS

By

Scott Jon Reger

A THESIS

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1973

ACKNOWLEDGEMENTS

I extend my sincere gratitude to several people who not only helped in the preparation of this work, but also helped further my overall education:

Dr. Kenneth W. Cummins for his invaluable help in attacking the many problems that arose in the course of this study with his knowledge and experience in stream ecology, and for making available his time, equipment, and staff to help with the identification of organisms.

Dr. Niles R. Kevern for his overall guidance in my course of study, his help with this manuscript, and for making funds, equipment, and encouragement available whenever I needed them.

Dr. Robert C. Ball for his consultation and encouragement, and for providing the facilities of the Institute of Water Research when necessary.

Dr. Terry A. Haines, project director, for helping with the logistics of the field work, continued consultation, and providing me with other data from the project. I would also like to thank all those who helped gather field data; particularly Dr. Wayne L. Smith, Dr. Adam T. Szluha, and Chris Schmitt.

Dr. Richard A. Cole has been most helpful in my gaining understanding of stream community ecology, and the many hours he has spent discussing this project with me are most appreciated.

Several people have given laboratory assistance, but I want to extend thanks especially to Jon Lauer, Chris Brand, Jane Kotenko, Larry Waterworth, Kirk Johnson, and Carolyn Goldberg.

For help in the identification of organisms I would like to express special thanks to Jack Wuycheck, Robert Peterson, Robert King, and Milton Ward.

This study was supported (in part) by funds from Grant 14-31-0001-3153, provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964 and (in part) by the National Science Foundation Institutional Grant for Science, both administered by the Institute of Water Research, Michigan State University. Funds and equipment were also provided by the Department of Fisheries and Wildlife and Agricultural Experiment Station, Michigan State University. Use of the Michigan State University computing facilities was made possible through support, in part, from the National Science Foundation.

TABLE OF CONTENTS

LIST OF TABLES

List of Tables (con't.)

LIST OF FIGURES

INTRODUCTION

Throughout recent history, man has caused stream degradation to occur at an accelerated rate due to changes in agricultural practices and increased industrialization and associated urbanization. One of the more important changes in streams has been enrichment with nutrients from decomposing organic matter in the stream or in sewage treatment plants. Evaluation of the gradual changes in aquatic communities in response to such enrichment is necessary if we are to develop indicators of stream degradation that can be used to properly manage the disposal of such wastes. Sensitive indicators of enrichment are essential if we are to be able to detect and predict degradation of our waterways at an early stage in the process.

Hooper (1969) has pointed out the importance of developing indices that will provide a common language for documenting and assessing rates of change in our aquatic communities. Macroinvertebrate populations are often used as an index of stream conditions because they effectively integrate conditions over time and are responsive to critical conditions of short duration that other sampling might miss (Gaufin and Tarzwell, 1956; Gaufin, 1958; Hynes, 1960). The community structure of benthic macroinvertebrates has thus been widely used as one such indicator. Diversity indices, particularly that of Shannon (Shannon and Weaver, 1949), have become one of the more popular ways of describing such communities (Hooper, 1969; Warren, 1971). Such indices are considered among the best and most sensitive indicators of ecological change (Wilhm and Dorris, 1968; Hooper, 1969; Warren, 1971).

Species diversity was first used by Wilhm and Dorris (1966) to examine the effects of organic effluents in a stream. Harrel and Dorris (1968) used this method to study a stream system within a single drainage basin. Mathis (1968) compared diversity in three unpolluted mountain streams. Mathis and Dorris (1968) investigated the effects of oilfield brine on the diversity of a stream. Gislason (1971) successfully used species diversity of macroinvertebrates collected from artificial substrates to show differing levels of human perturbation on four sites in the same three streams as the present study. He also suggested that seasonal instability in the indices occurred before a reduction in the mean value of the index with increased degradation.

One of the purposes of this study was to compare the effects of apparent different levels of human disturbance on species diversity of macroinvertebrates. In particular, it was desired to see how the sensitivity of macroinvertebrate diversity indices compared to other indicators of stream enrichment. To help minimize other influences, the sites were located both above and below known nutrient sources; this had not been done in the previous study. Also, natural substrates were sampled to see if they produced results different than those found with artificial substrates, particularly in regard to the seasonal instability which may have been an artifact of the particular substrate used. A final objective was to see if the use of biomass units, rather than numbers of individuals, in Shannon's formula gave a better indication of the level of human perturbation.

SITE DESCRIPTION

Six sites were selected on three streams in the lower peninsula of Michigan (Figures 1-3). The sites were chosen to represent a wide range of apparent human disturbance in the watersheds.

Certain chemical parameters were studied throughout the course of this project (Tables 1 and 2). Physical parameters and substrate conditions during the summer were also recorded (Table 3). In general, the four more northern sites were similar, while differing from the Red Cedar sites. The lower Au Sable site showed marked diurnal dissolved oxygen fluctuations during the summer, which were attributed to macrophyte growths. The lower Red Cedar site had highly variable dissolved oxygen levels, much higher nutrient levels than the other sites, and heavy metal and pesticide residues. Both the Red Cedar sites were subject to highly variable discharge rates.

Upper Jordan

The upper Jordan runs through uninhabited state forest land, where, in order to preserve the nearly pristine conditions, camping is prohibited along the banks of the stream. Recreational use is limited to occasional wading fishermen. The stream bed is predominately sand with numerous fallen logs and occasional silt deposits. *Chara vulgaris* is the predominate plant in the silt. *Fontinalis sp*. grows on the marl concretions on many of the logs. Sculpin and brown trout are the predominate fish.

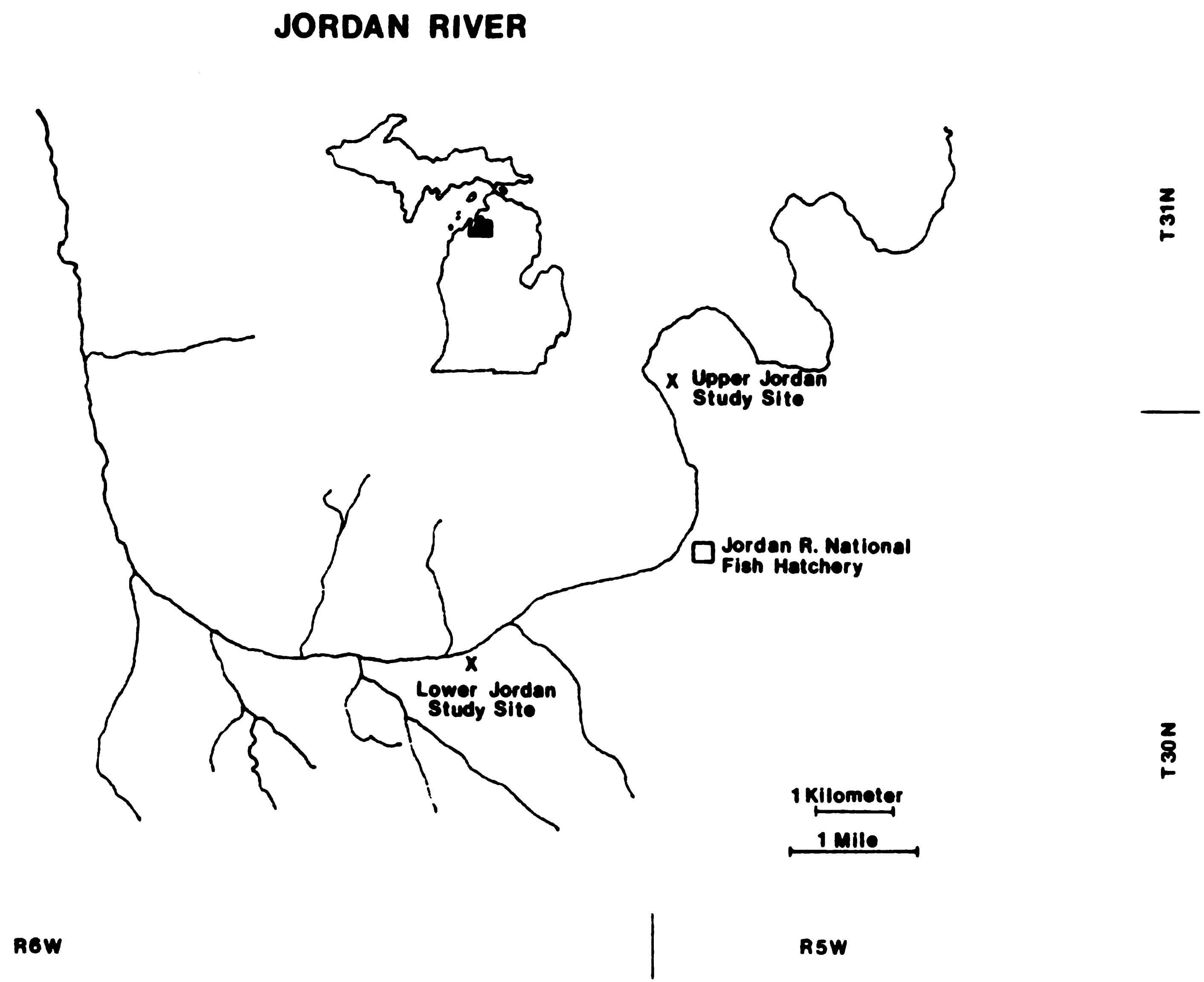

Figure 1. Map of the Jordan River showing the location of the study sites.

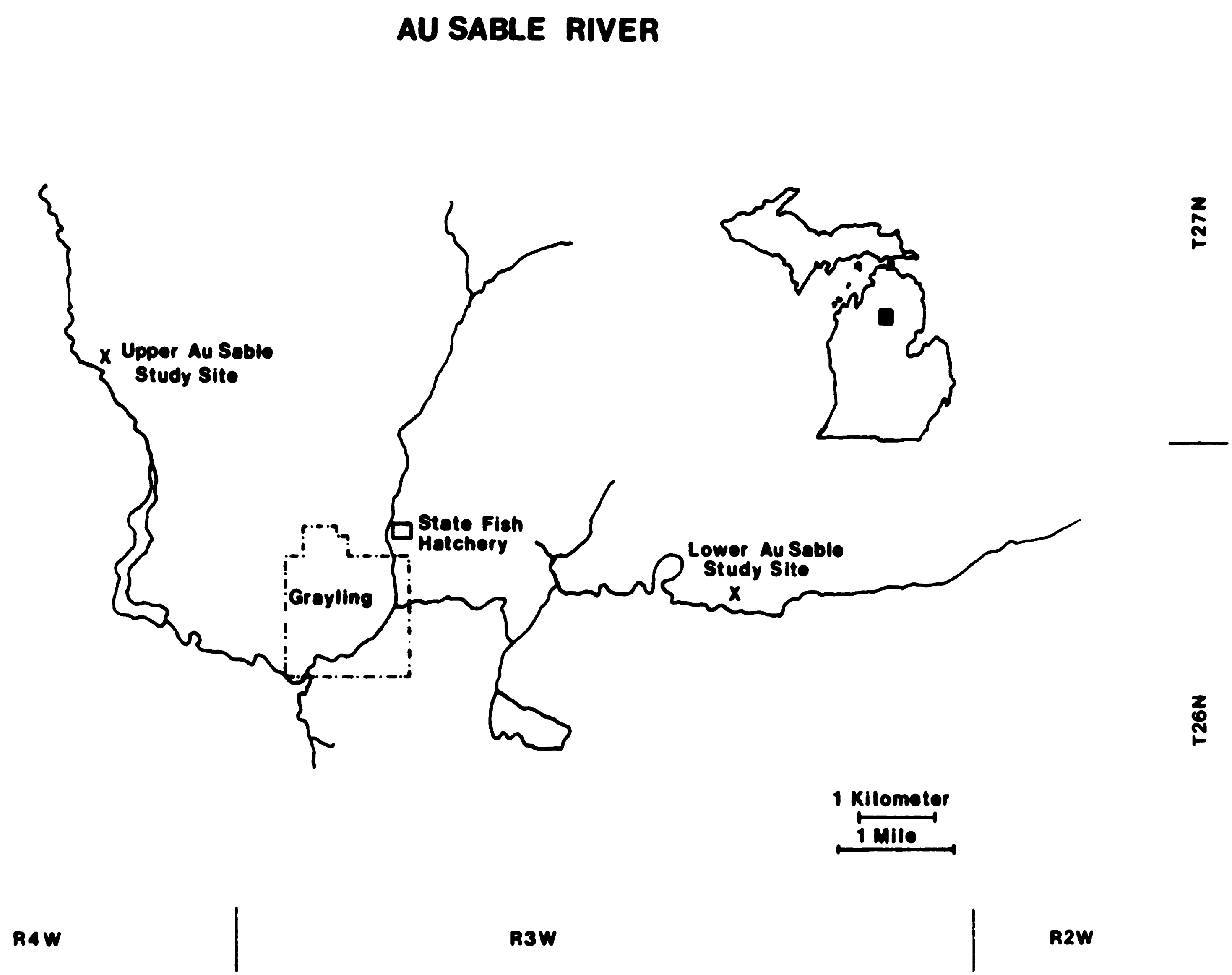

Figure 2. Map of the Au Sable River showing the location of the study sites.

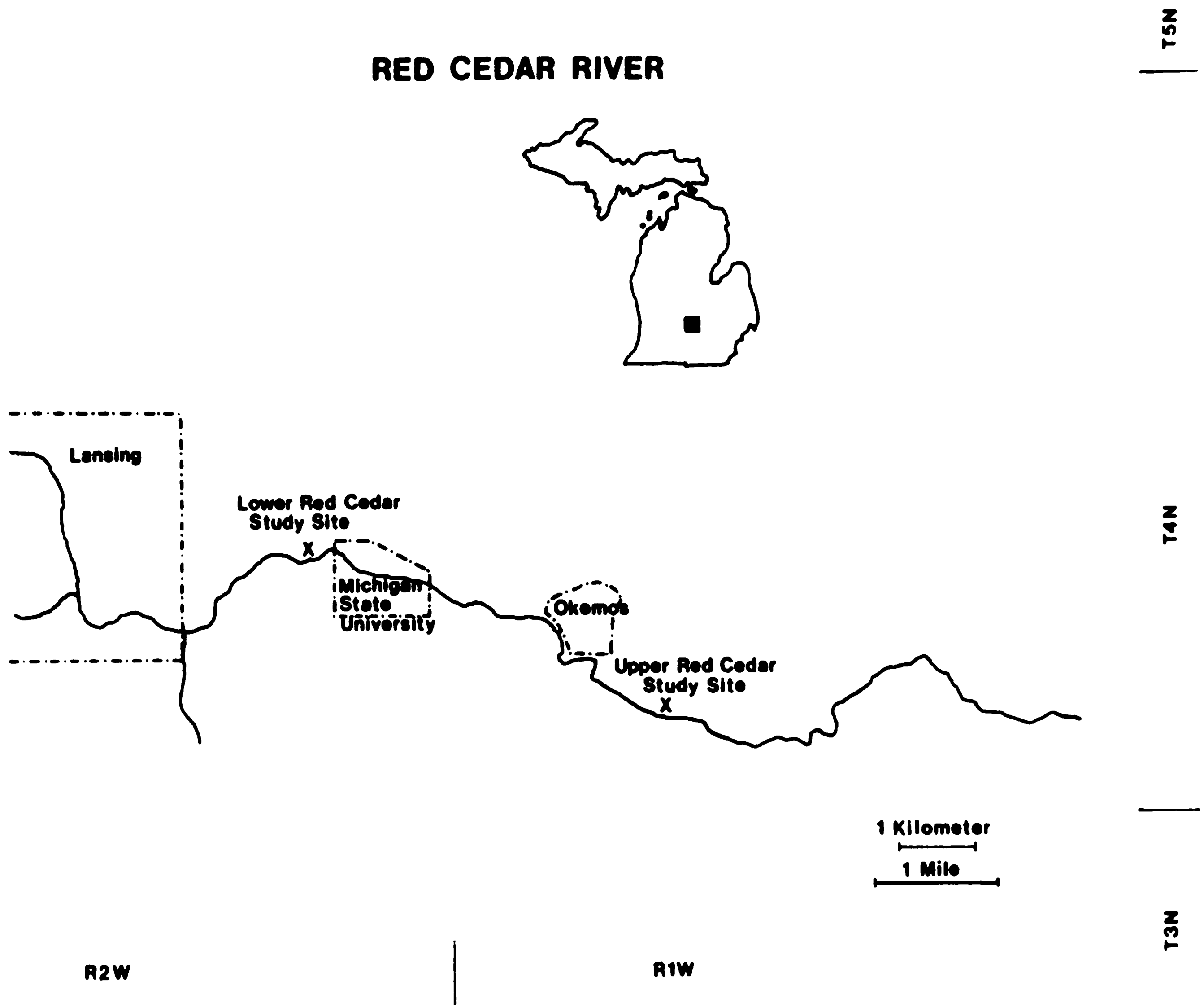

Figure 3. Map of the Red Cedar River showing the location of the study sites.

Table 1. Chemical water quality parameters investigated in 1971-1972 at the study sites. (Results are expressed as means and ranges () in mg/l).

Site	Alkalinity	Hardness	Total Solids	Nitrate Nitrogen	Total Phosphorus	Chlorides
Upper Jordan	159 (60-201)	171 (97-208)	203 (186-227)	0.89 (0.60-1.30)	0.03 (0.01-0.07)	1.5 (0.1- 3.6)
Lower Jordan	142 (55-176)	161 (92-186)	211 (196-234)	1.22 (0.97-1.45)	0.03 (0.01-0.07)	1.6 (0.6- 3.0)
Upper Au Sable	135 (40-173)	144 (63-167)	178 (120-228)	0.11 (0.00-0.37)	0.04 (0.01-0.07)	5.0 (2.0- 9.6)
Lower Au Sable	131 (52-171)	141 (92-161)	180 (122-226)	0.09 (0.00-0.22)	0.04 (0.01-0.08)	4.9 (4.0- 7.5)
Upper Red Cedar	247 (68-285)	311 (198-421)	483 (430-547)	1.15 (0.08-3.12)	0.15 (0.06-0.26)	37.9 (10.1- 99.4)
Lower Red Cedar	239 (68-300)	323 (198-407)	501 (395-635)	1.09 (0.12-3.83)	0.16 (0.08-0.27)	46.6 (26.8-103.8)

Table 2. Maximum and minimum water temperatures (°C) and dissolved oxygen concentrations (mg/l) in 1971-1972 at the study sites.

Date	Upper Jordan		Lower Jordan		Upper Au Sable		Lower Au Sable		Upper Red Cedar		Lower Red Cedar	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
WATER TEMPERATURES C												
5/71			12.0	6.0			11.0	7.0	18.0	13.5	19.0	14.0
6/71	20.0	12.0	15.5	11.2	18.5	15.0	19.2	17.0	22.5	19.5	25.0	22.0
7/71	18.5	10.0	14.5	10.0	20.5	15.6	20.5	17.0	21.5	16.0	23.0	19.0
8/71	16.0	9.0	14.0	9.0	20.5	14.0	21.0	16.0	22.0	16.0	23.0	18.5
10/71	11.5	8.0	9.5	7.5	16.5	14.0	18.0	15.3	16.0	12.0	16.5	13.0
6/72	20.5	10.5	17.0	10.0	16.0	9.0	17.0	11.0	21.0	18.0	22.0	19.0
DISSOLVED OXYGEN MG/L												
5/71			11.5	9.5			11.0	8.5	7.7	5.0	7.5	5.0
6/71	9.5	8.0	13.0	9.5	12.0	7.5	13.0	4.0	7.0	4.3	6.2	3.4
7/71	10.0	8.0	10.7	8.5	10.0	7.5	11.5	7.0	9.1	5.5	6.8	4.5
8/71	10.5	8.5	11.0	9.5	10.5	8.0	12.5	5.0	10.0	5.5	9.0	3.8
10/71	11.5	9.5	12.5	11.5	10.0	7.2	12.5	6.0	10.5	5.0	8.0	6.0
6/72	10.5	8.0	10.5	8.5	10.0	6.5	10.5	7.5	11.5	7.2	9.0	7.0

Table 3. Physical characteristics of the study sites during the summer of 1971.

	Upper Jordan	Lower Jordan	Upper Au Sable	Lower Au Sable	Upper Red Cedar	Lower Red Cedar
average width (m)	17.98	29.11	11.58	18.41	16.67	17.37
average depth (cm)	37.6	36.6	42.7	48.8	36.6	42.7
average discharge	1.84	2.72	1.56	2.12	1.56	5.66
(m^3/sec.)					(0.85-3.76)	(0.57-18.68)
in July 71	1.53	2.65	1.70	2.04	1.90	1.90
Total colonizable substrate in the site (1000's of m^2)	10.96	8.92	6.50	9.48	7.43	8.08
% composition (in July-August, 1971)*						
gravel	0	0	<u>49</u>	<u>72</u>	<u>23</u>	8
sand	<u>57</u>	<u>67</u>	<u>36</u>	<u>17</u>	<u>64</u>	<u>55</u>
silt	<u>7</u>	1	<u>10</u>	3	10	<u>35</u>
log	<u>36</u>	<u>32</u>	5	8	3	2
with plant	15	3	17	39	18	18

*Those underlined represent substrates regularly sampled.

Lower Jordan

The lower Jordan site receives the effluents of the Jordan River National Fish Hatchery. It is slightly wider, somewhat more open, has fewer logs, and lacks the silt deposits found in the upper site, which it otherwise resembles.

Upper Au Sable

The upper Au Sable site receives some nutrients from the town of Frederick and occasional cottages. Some canoeing and fishing constitute the recreational usage. The substrate is largely gravel and sand with frequent silt deposits along the edges. *Potomogeton spp*. grows extensively in the silt, and to a lesser extent in the sand, seasonally. Predominate fish are brook trout, sculpin, and darters.

Lower Au Sable

The lower Au Sable receives effluents from the municipal sewage treatment plant of Grayling, a state fish hatchery, and numerous homes and cottages along the banks. Early in the course of this study the Grayling sewage treatment plant completed conversion to a land disposal system. Extensive use is made of the stream by canoeists and fishermen. The substrate is largely gravel with some sand. *Potomogeton spp*. and *Elodea sp*. grow in both substrates, *Potomogeton filiformis* becoming very dense over large areas in the summer and fall, causing diurnal dissolved oxygen levels to occasionally fall below 5 ppm. Brown trout and sculpin are the predominate fish, with many other species occurring, some only seasonally.

Upper Red Cedar

There is considerable agricultural development, including feedlots, several small towns, and a metal plating plant located above the upper

Red Cedar site. Substrate is largely sand and some gravel. A large area of the sand has seasonal growths of *Potomogeton spp*. Diurnal dissolved oxygen fluctuations are pronounced in warm months, but rarely fall below 5 ppm. There is considerable flooding in the spring and occasionally at other times. Characteristic fish are golden redhorse, rock bass, and bluntnosed minnow, but a great variety of other species, including smallmouth bass, occur in smaller numbers.

Lower Red Cedar

More agricultural land, several subdivision developments, and the towns of Okemos and East Lansing-Michigan State University also add effluents and runoff above the lower site. The substrate is mostly sand with large silt and organic deposits occurring along the edges and at the bottom of the deeper pools during the periods of low flow. Heavy growths of *Potomogeton spp*. occur seasonally in the sand. Dissolved oxygen levels are highly variable and fluctuate diurnally during the warm mouths, occasionally falling below 1 ppm under extreme conditions. Drastic fluctuations in flow occur with runoff, which in combination with the unstable substrate produce a drastic scouring effect. All fish populations are unstable, but many species occur at times, white suckers being predominate.

MATERIALS AND METHODS

After preliminary studies were made to determine the major substrates, the two or three major types, as mentioned in the site description, were sampled monthly in triplicate. Where macrophyte growths occurred in a substrate, some of the samples were taken in an area where the plants were growing. Because of the large number of macroinvertebrates collected, the number of samples analyzed completely for species diversity calculations was restricted to those from one month for each season.

Gravel was sampled with a modified Surber sampler; this consisted of adding a 0.5 mm mesh net front and sample collection bag to the riffle benthos sampling device described by Coffman, Cummins, and Wuycheck (1971). The sample area is dug up to a depth of 10 cm and washed thoroughly. Log samples were taken by carefully enclosing a portion of a log in a bag of the same material used in the Surber, cutting off, and removing. Sand and silt samples were taken with an Ekman dredge mounted on a pole. Samples were taken to a depth of at least 10 cm whenever possible.

Samples were sieved through a #30 U.S. standard sieve (0.595 mm openings) to remove small particulate matter, and preserved in formalin. The samples were later washed, placed in an enamel pan, and the invertebrates removed by hand under an illuminated magnifier. The invertebrates were then separated and identified as far as possible under a dissecting microscope. Each taxa was then counted and wet weights taken, except no weights were taken for clams and snails. Formalin preserved weights are generally considered to have less than 5% loss from live weight (Ball, 1973a; Waters, 1973; Winberg, 1971). Howmiller (1972), while reporting greater losses, found formalin to show less weight loss than other common preservatives.

Diversity indices using both numbers of individuals and biomass were calculated on a Control Data 6500 Computer. The index used is that of Shannon, as described by Wilhm and Dorris (1968), using sample data to estimate the population diversity. The formula is:

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

where N = the total number of individuals; n_i = the number of individuals per taxa; s = the number of taxa; and $\bar{d}$ = the estimate of population diversity. Values range from 0 to any positive number. Wilhm (1970) has shown that diversity index values rarely exceed nine, and are usually between three and four for clean water streams and below one in polluted conditions.

In communities with habitats containing organisms with clumped distribution a method of estimating the actual population diversity has been presented by Pielou (1966), and modified by Mawson and Godfrey (1971). It consists of plotting the diversity indices of all possible combinations of samples. Wilhm and Dorris (1968) and Warren (1971) have shown that pooling an adequate number of samples achieves essentially the same results. Three to five samples were shown to be necessary to accurately estimate population diversity. The six or nine samples used in this study thus should give a good estimate of the true population diversity.

This particular index has several attributes that should be noted. It makes possible the objective comparison of community structure between different streams in different geographical areas (Mathis, 1968). It takes relative abundance into account and thus is less affected by rare species which might be missed in sampling. It is independent of sample size. It is dimensionless, thus any appropriate units describing each species contribution to the community can be used. This is important in light of the fact that biomass is often considered to be a more accurate way of assessing the ecological impact of a species on the community (Wilhm and Dorris, 1968; Wilhm, 1968). The use of biomass units substitutes a continuous for a discrete variable, but redefines diversity in biomass terms, and thus is related more closely to energy distribution among species (Wilhm, 1968). The present study has used an estimate of live weights in the calculation of diversity. It has been suggested that dry weights or ash-free dry weights are better, and that production values are better yet in assessing the contribution of a species to the community (Dickman, 1968). However, production values are at best, estimates, and require more information than available to date in this study (Waters, 1969).

An index of the evenness of distribution, or species equitability, E, was calculated using MacArthur's (1965) method. If all species are equally abundant, $\bar{d} = \log_2 s$, and $s = 2^{\bar{d}}$. The ratio $2^{\bar{d}}/s$, or equitability, is thus a measure of the relative evenness of distribution, with maximum and minimum values of 1 and 0, respectively.

Water samples were collected monthly, and sediment and fish samples twice annually at each of the sites. Twenty-four hour continuous monitoring of dissolved oxygen and temperature were carried out at each site monthly except during winter. Chemical analyses were determined by the Institute of Water Research Water Quality Laboratory at Michigan State University. Pesticide residue analyses were made by the Pesticide Research Center, Michigan State University.

RESULTS

Jordan River

Direct measurement of nutrient levels and other water chemistry parameters did not reflect the effect of the Jordan River National Fish Hatchery (Tables 1 and 2). The high levels of nitrate and apparent increase at the lower station were shown by Szluha (1971) to come from groundwater. He calculated that 898 kg/yr of phosphorus and 4,173 kg/yr of nitrogen were contributed annually by the hatchery effluents, mostly in pulses when raceways were cleaned. These made up 28.3% and 5.0% of the annual budgets of these elements, respectively, in the Jordan River. He showed that periphytic growth was increased by the nutrient additions, but that primary productivity was well within normal ranges throughout the system, and that the oxygen balance of the stream was not effected significantly. Oxygen fluctuations were somewhat greater at the upper site (Table 2), apparently as a result of the more marked temperature fluctuations. The large amount of groundwater entering between the sites has a moderating effect on temperature and oxygen levels at the lower site. The increased discharge did not increase depth or velocity noticeably, but took the form of a wider channel (Table 3).

Both sites were characterized by an abundance of trichopteran, ephemeropteran, and chironomid taxa; the lower site showed considerably fewer taxa (Table 4). This may be, in part, a result of the less stable sand and lack of macrophytes. Both sites had large numbers of ephemerellids, baetids, tipulids (*Antocha sp.*), and tantytarsan midges. The upper station

Table 4. Number of taxa collected at the study site during each season and overall total.

	Summer	Fall	Winter	Spring	Total
Upper Jordan	51	56	54	54	87
Lower Jordan	33	30	50	36	63
Upper Au Sable	75	56	56	48	99
Lower Au Sable	63	56	49	43	90
Upper Red Cedar	51	56	73	18*	102
Lower Red Cedar	31	20	13	10	39

*No gravel samples taken due to high water.

also had large numbers of sphaerids (Pisidium sp.), amphipods (Hyallela azteca), and hydropsychids (Hydropsyche spp.). The lower station had fewer sphaerids, more Gammarus fasciatus than Hyallela azteca, Cheumatopsyche sp. rather than Hydropsyche spp., and had large numbers of diamesian and orthoclad chironomids, brachycentrids, simuliids, and tubificids as well (Appendices 1 and 2).

The lower site had far greater productivity than the upper site, both in terms of numbers of individuals and biomass (Tables 5 and 6). This is true of both the log and sand substrates (Appendix 9). Seasonal patterns appear to be similar at both stations but fluctuations are greater at the lower. While a fair amount of the increased production was due to taxa common at both sites, a large contribution is made by the simulids, brachycentrids, orthoclad chironomids, and particularly the tubificids, which were relatively infrequent at the upper site.

The lower site showed less diversity than the upper one, especially as numbers of individuals. The lower site also exhibited a greater seasonal variation in diversity (Tables 7 and 8). The lower diversity is apparently due to the increased production of the taxa mentioned above, especially in the sand substrate (Appendix 9). The diversity on logs is similar at both stations despite the increased production at the lower site (Appendices 7 and 9).

The hatchery effluents had an effect on the macroinvertebrate community of the Jordan River. While some of the changes are due to changes in the character of the substrate, a most important factor in the distribution of communities (Thorup, 1964; Hynes, 1970), this also may be related to human disturbance in the watershed resulting from earlier logging operations. The instability of the sand makes the logs a most important habitat, as is often the case where other stable substrates are rare

Table 5. Productivity as standing crops in number of individuals per square meter at the study sites during each season and annual means (± 1 S.E.).

	Summer	Fall	Winter	Spring	Annual Mean
Upper Jordan	4846	2996	9849	6909	6150 ± 1469
Lower Jordan	7701	9793	40225	40598	24579 ± 9151
Upper Au Sable	8918	2493	2683	2991	4272 ± 1552
Lower Au Sable	15722	17000	12266	10751	13935 ± 1458
Upper Red Cedar	3098	4553	10770	6029*	6113 ± 1664
Lower Red Cedar	3887	99906	79696	105580	81015 ± 15104

*No gravel samples taken due to high water.

Table 6. Productivity as standing crops in grams per square meter at the study sites during each season and annual means (± 1 S.E.).

	Summer	Fall	Winter	Spring	Annual Mean
Upper Jordan	7.24	8.49	13.81	12.80	10.59 ± 1.60
Lower Jordan	14.30	22.23	98.19	47.48	45.55 ± 18.92
Upper Au Sable	25.68	13.99	12.76	15.81	17.06 ± 2.94
Lower Au Sable	39.54	54.17	46.18	21.41	40.32 ± 6.98
Upper Red Cedar	50.21	46.29	78.07	7.28*	45.46 ± 14.56
Lower Red Cedar	36.74	72.40	57.09	72.94	59.79 ± 8.52

*No gravel samples taken due to high water.

Table 7. Shannon diversity indices and equitability in terms of numbers of individuals at the study sites during each season and annual means (± 1 S.E.).

		Summer	Fall	Winter	Spring	Annual Mean
Upper Jordan	$\bar{D}$	3.98	4.01	4.09	4.09	4.04 ± 0.03
	E	0.31	0.29	0.32	0.32	0.31
Lower Jordan	$\bar{D}$	3.63	2.88	3.79	2.01	3.08 ± 0.41
	E	0.38	0.25	0.28	0.11	0.26
Upper Au Sable	$\bar{D}$	4.48	4.52	4.49	4.02	4.38 ± 0.18
	E	0.30	0.41	0.40	0.34	0.36
Lower Au Sable	$\bar{D}$	4.16	4.03	4.25	3.28	3.93 ± 0.22
	E	0.28	0.29	0.39	0.23	0.30
Upper Red Cedar	$\bar{D}$	3.96	3.72	3.95	3.01*	3.66 ± 0.22
	E	0.31	0.24	0.21	0.45	0.30
Lower Red Cedar	$\bar{D}$	1.67	0.54	0.38	0.61	0.80 ± 0.29
	E	0.10	0.07	0.10	0.15	0.11

*No gravel samples taken due tc high water.

Table 8. Shannon diversity indices and equitability in terms of biomass at the study sites during each season and annual means (± 1 S.E.).

		Summer	Fall	Winter	Spring	Annual Mean
Upper Jordan	$\bar{D}$	3.55	3.58	4.00	3.89	3.76 ± 0.11
	E	0.23	0.21	0.30	0.27	0.25
Lower Jordan	$\bar{D}$	3.70	3.24	3.65	2.86	3.36 ± 0.20
	E	0.39	0.32	0.25	0.20	0.29
Upper Au Sable	$\bar{D}$	4.10	3.48	3.84	3.45	3.72 ± 0.16
	E	0.23	0.20	0.26	0.23	0.23
Lower Au Sable	$\bar{D}$	3.96	3.87	4.15	3.95	3.98 ± 0.06
	E	0.25	0.26	0.36	0.36	0.31
Upper Red Cedar	$\bar{D}$	1.05	1.50	2.64	1.78*	1.74 ± 0.46
	E	0.04	0.05	0.09	0.19	0.09
Lower Red Cedar	$\bar{D}$	2.31	0.66	0.53	0.43	0.98 ± 0.45
	E	0.16	0.08	0.11	0.13	0.12

*No gravel samples taken due to high water.

(Hynes, 1970), and increases the importance of the relatively stable areas where silt collects and macrophytes grow. Attempted colonization from these areas also could account for higher diversity in nearby sand areas in the upper site (Hynes, 1970).

While the diversity on logs was essentially the same at both stations, production was greatly enhanced by increased enrichment here as well as in the sand. Some change in community composition were noted in both substrates. These changes, especially those due to the increase in filter feeding simulids and hydropsychids, and detrital feeding brachycentrids, chironomids, and oligocheates, in response to the hatchery effluents are the same as have been reported by the Michigan Water Resources Commission (1969) using Hester-Dendy artificial substrates. The completion of settling basins for the hatchery effluents should alleviate the problem.

Au Sable River

Direct measurement of nutrient levels and other water chemistry parameters did not reflect the input from the town of Grayling and the State Fish Hatchery (Table 1). Nor did they reflect the removal of the Grayling sewage treatment plant's effluent from the stream. Periphytic production was higher at the lower station and was more stable at both sites than in the other two rivers (Ball, 1973b). The lower section was wider and deeper than the upper, and had considerably less silt and detrital deposition areas, possibly as a result of the increased flow (Table 3). The enrichment of the lower site produced a substantial macrophytic growth, and this resulted in a marked diurnal oxygen fluctuation during the summer months (Tables 2 and 3).

Both sections were characterized by an abundance of trichopteran and chironomid taxa. The upper site also had a large number of ephemeropteran and gastrapod taxa. Both stations supported a large number of taxa (Table 4). Both sections had large numbers of amphipods (*Gammarus fasciatus*), hydropsychids, elmids, simulids, and chironomids of the tribes Chironomini and Tantytarsini. The upper site also had large numbers of orthoclad chironomids. The lower site had large numbers of diamesian chironomids, glossosomatids (*Agapetus illini*), isopods (*Asellus militaris*), and tubificids as well (Appendices 3 and 4).

The lower section exhibited a greater production both in numbers of individuals and especially in biomass (Tables 5 and 6). This was true of both the sand, where the difference was greatest in numbers of individuals, and the gravel, where the difference was greatest in biomass (Appendix 9). While much of this increased production was from taxa common to both sites, the lower had significant contributions from isopods, diamesian chironomids, and tubificids which were unimportant at the upper.

The lower section had slightly lower diversity when calculated using numbers of individuals but appears to possibly have had a slightly higher diversity when using biomass (Tables 7 and 8). These differences occurred mostly in the sand substrate, particularly in areas of macrophyte growth (Appendix 7) where large numbers of smaller organisms, such as chironomids and tubificids, lowered the diversity in terms of numbers of individuals but not in terms of biomass. Neither section showed much seasonal variation in diversity (Tables 7 and 8). The sand did show somewhat more seasonal variation at the lower site (Appendix 7).

There was little change in diversity between the two Au Sable sites. Part of this was due to the similarity in physical and chemical characteristics. Also, the lower section had been enriched for a long time prior to this study, at least in comparison to the Jordan River, and thus had had time to develop a rich and stable community under such conditions

(Hynes, 1970). Nutrient inputs were less localized and farther upstream from the lower section than in the Jordan River (Figures 1 and 2). The removal of the nutrient input from the sewage treatment facilities at Grayling also reduced the difference between the two sites.

It can be shown that some changes in the composition of the community did occur. The increased production was directly related to enrichment. Differences in the productivity of fish populations in the Jordan and Au Sable Rivers have also been attributed to enrichment by Quick (1971), and Smith (1972); although other factors also were thought to have effected the brown trout and sculpin populations studied. Such increased production in both macroinvertebrate and fish populations has been shown experimentally in Berry Creek, Oregon, by enriching sections of the stream with sucrose (Warren, 1971).

Red Cedar River

Direct measurement of nutrient levels and other water chemistry parameters clearly demarked the Red Cedar study sites from those on the Au Sable and Jordan, but did not differentiate between the two sections (Table 1). The lower study area was slightly deeper than the upper, and exhibited even greater variability in discharge (Table 3). This, in conjunction withthe unstable and substrate conditions, produced a marked scouring effect. During periods of low flow, silt and detrital deposits accumulated and heavy macrophyte growth occurred at the lower site. Periphytic production was highly variable and showed no difference between the two sections. Oxygen levels were somewhat low at the upper site and quite low at the lower site (Table 2). On August 11, 1971, oxygen depletion caused a major fish kill at the lower section and immediate vicinity. Following this the number of taxa of macroinvertebrates found was less, diversity decreased, and the standing crop of the taxa remaining was increased for the duration of the study. Pesticide and heavy metal residues occurred in moderately high levels in sediment and fish, particularly at the lower study area (Haines, 1971).

The upper site had a large number of taxa, especially of Trichoptera, Chironomidae, and Gastrapoda; the lower showed a distinct paucity of taxa (Table 4; Appendices 5, 6, and 10). The upper station showed an increase in number of taxa, especially more pollution intolerant forms, and numbers of individuals of such groups, during the winter (Appendix 5). Subsequent to the fish kill in August the lower station displayed an even greater lack of macroinvertebrate variety (Appendix 6). The upper site had large numbers of amphipods, hydropsychids (*Cheumatopsyche sp.*), elmids, pelycepods, and chironomids of the tribe Chironomini. The lower was predominated by naidid and tubificid oligocheates, planarians (*Dugesia spp.*), and a moderate number of chironomids of the tribe Chironomini (Appendices 5 and 6).

The lower section showed higher productivity, particularly in terms of numbers of individuals (Tables 5 and 6). This was the result of the large numbers of relatively small oligocheates at the lower site. When comparing the sand substrate (in effect the only substrate at the lower site), especially the more stable areas with macrophytes, the difference in production is more marked, both as numbers of individuals and biomass (Appendix 9).

Diversity was considerably less at the lower site, particularly when using numbers of individuals. The upper section had fairly high values calculated from numbers of individuals but is low when biomass is used. The lower site had low values in both respects. Equitability was noticeably lower for biomass indices at the upper, and both numbers of individuals and biomass at the lower Red Cedar than either index at any other site (Tables 7 and 8). The difference between stations was shown more markedly when the diversity of the sand substrata are compared - as was the case with productivity - and for much the same reasons; the lower site having much lower values and exhibiting greater seasonal fluctuation (Appendix 7). The gravel added a great deal of substrate variety and stability to the upper section, thus increasing both the number of taxa and the diversity values.

Many parameters showed both the Red Cedar sites to be more enriched than sites on the other rivers, particularly the lower Red Cedar. The oxygen depletion which caused the fish kill in the lower section undoubtedly effected the macroinvertebrate community as well. The unstable substrate and fluctuation in discharge were the result of runoff from agricultural and urban developments. This runoff, particularly from the combined storm and sanitary sewers, was also responsible to a large degree for differences in water chemistry from the other streams. The fact that coarse gravel supports a more varied and stable community (Hynes, 1970) kept the diversity at the upper site at a moderate level. In fact the sand at the upper study area also had quite low diversity values (Appendix 7). Sand has often been shown to be a relatively poor substrate and to be more susceptible to reduction in numbers and diversity of macroinvertebrates than other substrates (Hynes, 1970; Wilhm and Dorris, 1966). The lack of stable substrate together with an abundant supply of particulate organic material lead to the large production of the few species, such as tubificids, that do well under such conditions, and the subsequent reduction in diversity, particularly in the lower Red Cedar. Similar results have been reported by Jensen (1966) and Talsma (1972).

DISCUSSION

Macroinvertebrate diversity indices were found to be more sensitive than other indicators of human perturbation when comparing stations on any given stream. Sites were located close enough together so decreased diversity and increased production were largely the result of the known human activity between the sites and not of natural changes encountered moving downstream in the watershed.

The increased production and decrease in mean annual diversity, using numbers of individuals, from 4.04 to 3.08, show the effect of the Jordan River National Fish Hatchery on the river. These results agree with those of Gislason (1971), who showed a decrease from 4.33 to 2.98 when using artificial substrates, and with those of the Michigan Water Resources Commission (1969). A small amount of enrichment from the hatchery had a marked effect on this pristine stream where nutrients were the limiting factor to productivity. The irregular pattern of nutrient addition was an unpredictable event to the stream organisms, and thus resulted in an unstable condition.

The mean annual diversity values, using numbers of individuals, of 4.38 and 3.93 for the Au Sable sites are not considered different. The 3.93 value for the lower site is considerably higher than the 2.76 reported by Gislason (1971). While some of the difference may have been due to his selection of artificial substrate, the major reason was the reduced level of enrichment subsequent to Grayling's land disposal system becoming operational. It is significant that this reduction in enrichment was detected by macroinvertebrate diversity although undetectable when using other parameters such as water chemistry.

The mean annual diversity values, using numbers of individuals, of 3.66 and 0.80, clearly show the degradation between the two sites on the Red Cedar River. Talsma (1972) attributes much of this degradation directly to the input from the large number of drains entering between the sites. The diversity values agree with Talsma's (1972) 4.13 and 1.35 values as well as Gislason's (1971) value of 1.70 for a site further downstream. The Red Cedar was not responding to nutrient enrichment, but was limited by other factors. These factors included the introduction of toxic substances and oxygen depletion, as well as the lack of stable substrate and large fluctuations in discharge.

These diversity index values show the changes in the macroinvertebrate communities caused by human activity. They also follow closely the suggestion of Wilhm and Dorris (1968) and Wilhm (1970) that values greater than 3.0 are generally indicative of clean waters, 3.0 to 1.0 of moderately disturbed conditions, and of less than 1.0 of grossly polluted conditions.

The ability to compare levels of perturbation between streams by use of diversity indices is less sensitive than the comparison of sites on the same stream, as other variables may also effect diversity values. As mentioned previously, substrate conditions and discharge have significant effects on the macroinvertebrate community and may or may not be related to human usage of the watershed. Current velocity has been shown by Szluha (1972) to be correlated with periphytic production, and Popma (1971) concluded that macrophytic growth was more closely related to discharge and substrate conditions than to nutrient levels in the streams studied. These in turn effect the macroinvertebrate community. Many organisms and communities are closely related to substrate (Thorup, 1964; Hynes, 1970). The variety of substrate types, including the types of macrophytes, also has a large effect on the community (Cole, 1973; Hynes, 1970).

The correlation reported by Gislason (1971) between magnitude of seasonal variation in diversity indices and level of perturbation is believed to have been partially the result of seasonal variation in discharge, but largely of the artificial substrates designed to simulate macrophyte beds. Such growths are seasonal in nature in temperature climates and thus would be expected to be used in a seasonal manner by macroinvertebrates evolved under such conditions, probably as a substrate during the summer and as a food source by those utilizing detritus in the fall. This was the case in the Pine River studied by Barber (1970). Samples containing macrophytes in the present study showed less seasonal variation than the unstable sand substrate, but more variation than the more stable gravel or log substrates (Appendix 7).

Diversity of numbers of individuals would appear to be more sensitive than of biomass when describing differences between two sites on a given stream, thus supporting the current usage of such indices. Diversity in terms of biomass might be considered to be a better way of classifying the areas of the three streams according to the apparent level of human perturbation, at least with respect to where the upper Red Cedar fits in the classification system suggested by Wilhm and Dorris (1968).

Enrichment would appear to have caused an increase in production before effecting a lowering of the diversity indices, particularly when using numbers of individuals. This can best be seen in the log samples from the Jordan River and the gravel samples from the Au Sable River (Appendix 9). It has been suggested (Waters, 1961, 1966; Dimond, 1967) that drift of macroinvertebrates might be a function of production in excess of carrying capacity. If this is the case, standing crop estimates alone would not accurately estimate production. Eyman (1969) found that while standing crops of macroinvertebrates were not well correlated with the apparent enrichment in the three streams studied, total drift was. He therefore concluded that drift analysis could give indications of changes taking place at an early stage of enrichment.

Diversity indices are a useful tool to show the amount of human perturbation of streams, but they are only a manifestation - they provide no framework for causal explanation. As has been pointed out, many factors which may or may not be man caused can effect changes in diversity indices. Other methods of analysis, such as the tolerance of certain groups of organisms to various substances, the food habits of the community, or methods of obtaining oxygen, may show a closer relation to the cause of the alteration of the community. At times, standing crops or drift might better show enrichment. All methods of analysis available should be used, as any method of data reduction does only that, reduce data; hopefully in a concise manner and to a form that is more easily used by workers in other fields.

In this study the diversity of macroinvertebrate communities, calculated using numbers of individuals, was found to be the most sensitive indicator of human perturbation of streams, particularly enrichment. The effect of the hatchery on the Jordan River and the removal of sewage effluents from the Au Sable River demonstrate the sensitivity of Shannon's diversity index to enrichment. Results were most clear when other differences were minimal; this limits the use of such an index in comparing different types of streams.

As Hynes (1960) has warned, it is a mistake to rely on any one formal method of data analysis, as doing so tends to lead to rigidity of thought and approach. The investigator should use all means feasible under the prevailing conditions. Warren (1971) concurs when he states that such indices "should not replace the use of other knowledge about the biology and environmental requirements of the species contributing to diversity." Both agree that the presentation of tables of species and numbers permit the use of many methods of analysis and interpretation. As Warren (1971) has so succinctly put it - "There is no single path to understanding."

SUMMARY

Benthic macroinvertebrate communities in three Michigan streams were studied through an annual cycle. Natural substrates were sampled both above and below known areas of human activity on each stream. Taxonomic composition, standing crop, and diversity indices were used in an attempt to find a sensitive indicator that would show the varying levels of perturbation of the streams.

The Jordan River exhibited the effects of the National Fish Hatchery's enrichment of the stream. Standing crop was increased, number of taxa found decreased, and diversity values were lower below the hatchery. The slight enrichment of this pristine stream had a measurable effect on the macroinvertebrate community.

The Au Sable River had a higher standing crop below the city of Grayling and the state fish hatchery, but showed little difference in number of taxa collected and diversity from the section above these inputs. The important disclosure here was the marked increase in diversity from an earlier study conducted by Gislason (1971). This was a result of the Grayling sewage treatment plant's completion of conversion to a land disposal system. The diversity index responded to this change that water chemistry data failed to show.

The Red Cedar River exhibited a dramatic change in taxonomic composition and a marked reduction in diversity at the lower site. Here substrate stability, variable discharge, periodic oxygen depletion, and occasional introduction of toxic substances were the cause of the reduced macroinvertebrate communit stability. An oxygen depletion caused fish and

invertebrate kill in the lower section early in the study led to a decreased number of taxa and decreased diversity, but an increased production of the remaining taxa for the remainder of the study.

Diversity indices were found to be the most responsive to changes in stream conditions of the indicators examined. As macroinvertebrate communities integrate all the conditions they are exposed to, they are useful for detecting subtle changes in the lotic environment. They have been shown useful in detecting the effects of enrichment in an above and below situation on the Jordan River, a before and after situation on the Au Sable River, and to respond to other conditions in the Red Cedar River. However, as these communities act as integrators, care must be used when attempting to attribute changes in diversity to a specific cause. This makes comparison among streams difficult, especially if the streams are physically or chemically disimilar. Whenever possible other parameters should be studied and other indicators used in conjunction with diversity indices.

LITERATURE CITED

Ball, R. C. 1973a. Personal communication.

Ball, R. C. 1973b. Unpublished manuscript.

Barber, W. E. 1970. Ecological factors influencing macroinvertebrates in the Pine River. Ph.E. thesis. Michigan State University, 77 p.

Coffman, W. P., K. W. Cummins, and J. C. Wuycheck. 1971. Energy flow in a woodland stream ecosystem I. Tissue support trophic structure of the autumnal community. Arch. Hydrobiol. 68(2): 232-276.

Cole, R. A. 1973. Variations in stream community response to nutrient enrichment. J. Water Poll. Contr. Fed. In press.

Dickman, M. 1968. Some indices of diversity. Ecology, 49(6): 1191-1193.

Dimond, J. B. 1967. Evidence that drift of stream benthos is density related. Ecology, 48: 855-857.

Eyman, L. D. 1969. A comparison of invertebrate drift in three Michigan streams. M.S. thesis, Michigan State University, 44 p.

Gauffin, A. R. 1958. The effects of pollution on a mid-western stream. The Ohio Journal of Science, 58(4): 197-208.

Gaufin, A. R. and C. M. Tarzwell. 1956. Aquatic macroinvertebrate communities as indicators of organic pollution in Lyttle Creek. Sewage and Ind. Wastes, 28(7): 906-924.

Gislason, J. C. 1971. Species Diversity of Benthic Macroinvertebrates in Three Michigan Streams. M.S. thesis, Michigan State University, 53 p.

Haines, T. A. 1971. An ecological evaluation of stream eutrophication. Interim completion report, Office of Water Resources Research, project C-2205.

Harrel, R. C. and T. C. Dorris. 1968. Stream order, physico-chemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. Am. Mid. Nat. 80: 220-251.

Hooper, F. F. 1969. Eutrophication indices and their relation to other indices of ecosystem change. pp. 225-235 In: Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences. Washington, D. C.

Howmiller, R. P. 1972. Effects of preservatives on weights of some common macroinvertebrates. Trans. Amer. Fish Soc. 101(4): 743-746.

Hynes, H. B. N. 1960. The Biology of Polluted Waters. Liverpool University Press, Liverpool, England.

Hynes, H. B. N. 1970. The Ecology of Running Water. University of Toronto Press, Toronto, Ontario, Canada.

Jensen, A. L. 1966. Stream water quality as related to urbanization of its watershed. M.S. thesis, Michigan State University, 128 p.

MacArthur, R. H. 1965. Patterns of species diversity. Biological Reviews, 40: 510-533.

Mathis, B. J. 1968. Species diversity of benthic macroinvertebrates in three mountain streams. Transactions of the Illinois State Academy of Science, 61: 171-176.

Mathis, B. J. and T. C. Dorris. 1968. Community structure of benthic macroinvertebrates in an intermittent stream receiving oil field brines. Am. Mid. Nat. 80: 428-439.

Mawson, J. C. and P. J. Godfrey. 1971. DIVERSE: A fortran IV program to calculate diversity indices of stream bottom organisms. Water Resources Research Center. Univ. of Mass., Amherst.

Michigan Water Resources Commission. 1969. Biological monitoring of the Jordan River, vicinity of the Jordan River National Fish Hatchery, Elmira, Michigan. Dept. of Natural Resources, Lansing, Michigan.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 137-144.

Popma, T. J. 1971. A comparative study of standing crops and of phosphorus and nitrogen contents of four macrophyte stream communities. M.S. thesis, Michigan State University, 45 p.

Quick, Robert F. 1971. The age and growth of brown trout (Salmo trutta) and sculpin (Cottus spp.) as it relates to eutrophication in the Jordan and Au Sable Rivers. M.S. thesis, Michigan State University, 86 p.

Shannon, C. E. and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana.

Smith, Wayne L. 1972. The dynamics of brown trout (Salmo trutta) and sculpin (Cottus spp.) populations as indicators of eutrophication. Ph.D. thesis, Michigan State University, 43 p.

Szluha, Adam T. 1972. Potomological effects of fish hatchery discharge on the Jordan River, northern lower Michigan. Ph.D. thesis, Michigan State University, 54 p.

Talsma, A. R. 1972. The characterization and influence of domestic drains on the Red Cedar River. M.S. thesis, Michigan State University, 127 p.

Thorup, Jens. 1964. Substrate type and its value as a basis for delineation of bottom fauna communities in running water. In: K. W. Cummins, et al. (ed) Organismic-Substrate relationships in streams. Pymatuning Symposia in Ecology Special publication #4.

Warren, C. E. 1971. Biology and Water Pollution Control. W. B. Saunders and Co., Philadelphia, Pennsylvania.

Waters, T. F. 1961. Standing crop and drift of stream bottom organisms. Ecology, 42: 532-537.

Waters, T. F. 1966. Production rate, population density, and drift of a stream invertebrate. Ecology, 47: 595-604.

Waters, T. F. 1969. The turnover ratio in production ecology of freshwater invertebrates. The American Naturalist, Vol. 103, No. 930, pp. 173-185.

Waters, T. F. 1973. Personal communication.

Wilhm, J. L. 1968. Use of biomass units in Shannon's formula. Ecology, 49(1): 153-155.

Wilhm, J. L. 1968. Range of diversity index in benthic macroinvertebrate populations. J. Water Poll. Contr. Fed. 42: R221-R224.

Wilhm, J. L. and T. C. Dorris. 1966. Species diversity of macroinvertebrates in a stream receiving domestic and oil refinery effluents. Am. Mid. Nat. 76: 427-449.

Wilhm, J. L. and T. C. Dorris. 1968. Biological parameters for water quality control. Bioscience. 18(6): 477-481.

Winberg, G. G. (ed.). 1971. Methods for the Estimation of Production of Aquatic Animals. Academic Press, New York. 175 p.

APPENDICES

Table A1. Species collected at the upper Jordan site.

Species	Number Collected 8/12/71	10/09/71	1/30/72	5/20/72
HYDRACARINA			10	
ISOPODA				
Asellus milltaris	57	4	12	30
AMPHIPODA				
Gammarus fasciatus	24	7	15	
Hyallela azteca	117	37	36	38
ODANATA				
**Enallagma sp.*				
Cordulegaster sp.		1		
**Gomphus sp.*				
PLECOPTERA				
Pteronarcys sp.		1		1
Nemoura sp.	1			
Isoperla spp.	2	12	80	23
**Acroneuria sp.*				
Paragnetina sp.	1	8	1	1
TRICHOPTERA				
Lype sp.	1			
unknown psychomyiid		1	3	
Psychomia sp.	1	4		1
Polycentropus sp.		5		
Cheumatopsyche sp.		11	25	1
Hydropsyche sp.	8	236	260	40
H. slossonae				1
Rhyacophila sp.			1	
Glossosoma sp.	1			
Agraylea multipunctata		1	127	4
Neotrichia sp.				1
Phryageniadae	1			1
Brachycentrus americanus		3	13	45
Micrasema sp.			22	19
Lepidostoma sp.	5	7	10	9
Pycnopsyche sp.		1		
Mollana sp.	4	1		2
Mystacides sp.			1	1
Oecetis sp.		2	4	12
EPHEMEROPTERA				
Ephemera simulans	2	5	27	11
**Hexagenia limbata*				
Caenis sp.		2	4	6
Tricorythodes sp.	33			

Table A1 (con't.)

EPHEMEROPTERA (con't.)				
Stenonema sp.		2	14	
Epeorus sp.	1	1	27	46
Ephemerella sp.	4	160	824	258
Baetisca sp.		1	1	
Baetis sp.	134	8	79	72
Pseudocloeon sp.	18			
Paraleptophlebia sp.			35	1
P. debillis		2		
P. mollis			21	4
HEMIPTERA				
Corixidae	2			
DIPTERA				
Tipula sp.		1	1	
Antocha sp.	41	186	196	61
#Hexatoma sp.		3	2	1
Pedicia sp.		1	8	
Liriope sp.	4			
Simulium sp.	6	3		
Prosimulium sp.		1	12	
Odontomyia sp.		1	1	
Tabaninae	8		4	
Chrysops sp.		4	3	2
Atherix variegata	2	2	20	
Epididae	9	2	118	15
Unknown Diptera 'A'	33	24	135	
Prodiamesia sp.	2	2	10	6
Orthocladiinae	85	55	184	318
Cardiocladius sp.	28	13	22	95
Cricotopus sp.				10
Tanypodinae	37	34	206	102
Polypedilum sp.	7	1	50	320
Microtendipes sp.		42	131	84
Cryptochironomus sp.	1			
Tantytarsini	283	11	95	221
Ceratapogonidae	6	6	26	29
COLEOPTERA				
Unknown Coleoptera	1			
Optioservus sp.	17	35	40	47
Haliplus sp.		1		1
MEGALOPTERA				
Sialus sp.	1	6		1
Nigronia sp.	2		2	

Table A1 (con't.)

GASTROPODA				
Aplexa hypnorum			2	
Amnicola sp.				1
Promentus exacuous				1
PELECYPODA				
Sphaerium sp.	93	8		6
Pisidium sp.	276	77	45	63
HIRUDINEA				
unknown Hirudenea		1		
Hellobdella stagnalis	11	2	1	3
H. fusca	1			
TRICLADIA				
Dugesia tigrina	1	1		2
unknown Turbellaria	1			
OLIGOCHEATA				
Lumbriculidae	18	3	2	11
Tubificidae	9	8	8	32
Naididae	2	1		

*Species found in the study site that was not present in the samples analyzed quantitatively.

#Includes *Eriocera*.

Table A2. Species collected at the lower Jordan site.

Species	8/12/71	10/09/71	1/30/72	5/20/72
	Number Collected			
AMPHIPODA				
Gammarus fasciatus	84	100	257	9
Hyallela azteca				4
PLECOPTERA				
Pteronarcys sp.			2	4
Nemoura sp.			1	1
N. venosa	4		6	
Brachyptera sp.			1	
Isoperia spp.	5	60	189	32
**Acroneuria sp.*				
Paragnetina sp.	1			
TRICHOPTERA				
unknown Trichoptera				3
Psychomia sp.	1	1	8	
psychomyiid genus 'A'	1	12	56	2
Polycentropus sp.		4	2	4
Cheumatopsyche sp.	7	9	762	25
Hydropsyche sp.		20	40	2
H. recurvata		1		
Rhyacophila sp.	1			
Agapetus illini		1	2	
Glossosoma sp.		1		
Brachycentrus americanus	7	69	503	201
Micrasema sp.		4	82	57
Lepidostoma sp.			2	
EPHEMEROPTERA				
Tricorythodes sp.	17			
Stenonema sp.			6	
Epeorus sp.	1		6	
Ephemerella spp.	31	256	1876	514
Baetis sp.	298	80	738	139
Pseudocloeon sp.	182			
Paraleptophlebia sp.		5	116	
HEMIPTERA				
Merragata sp.	1	1		
DIPTERA				
Antocha sp.	83	60	140	19
#*Hexatoma sp.*			3	
Dicranota sp.			4	
Simulium sp.	178	8	8	107
Prosimulium sp.			46	11
Odontomyia sp.			8	5

Table A2 (con't.)

DIPTERA (con't.)				
Tabanus sp.			2	
Atherix variegata			1	
Limnophora aquifrons	1	1		
Epididae	1	2	54	3
Diamesia sp.			194	25
Prodiamesia sp.	136	26	175	29
Orthocladiinae	144	29	11	272
Cardiocladius sp.	43	3	384	26
Metrocnemius sp.	106		268	
Cricotopus sp.			1483	
Tanypodinae	31	34	486	41
Polypedilum sp.	5		8	16
Microtendipes sp.		2	101	9
Tantytarsini	295	4	153	94
Ceratapogonidae	1		8	
COLEOPTERA				
unknown Dytiscid			2	
Acilius sp.			1	
Optioservus sp.	42	10	211	35
GASTROPODA				
Physa sp.			4	
Aplexa hypnorum			4	
PELECYPODA				
Sphaerium sp.	1			3
Pisidium sp.	1	3	4	9
TRICLADIA				
Dugesia tigrina			8	
OLIGOCHEATA				
Lumbricuidae			4	
Lumbriculidae	6	6	57	3
Tubificidae	483	681	1820	3793

*Species found in the study site that was not present in the samples analyzed quantitatively.

#Includes Eriocera.

Table A3. Species collected at the upper Au Sable site.

Species	Number Collected 8/11/71	10/02/71	1/29/72	5/19/72
HYDRACARINA	1			
AMPHIPODA				
Gammarus fasciatus	146	14	29	8
ODANATA				
Agrion sp.	8	1		
Ishnura sp.	11			
Boyeria sp.	5		1	
Gomphus sp.		1		1
Ophiogomphus sp.		1	1	
PLECOPTERA				
Nemoura sp.			84	
Taeniopteryx sp.		8	5	
Isoperla sp.	8		1	
TRICHOPTERA				
Chimarra sp.	2			
psychomyiid genus 'A'		1	1	
Polycentropus sp.		1	3	
P. glacialus	1			
**P. flavus*				
Cheumatopsyche sp.	229	94	133	41
unknown hydropsychid		1		
Hydropsyche sp.	222	15	60	10
H. recurvata	120	58	27	18
H. slossonae		1		
H. bifida group	61	12	6	7
H. betteni			3	
Arctopsyche sp.				1
Rhyacophila sp.	5	3	4	6
Agapetus illini	1			
Glossosoma sp.			1	2
Protoptila sp.	1			
Agraylea multipunctata	3			
phyraganeid genus 'A'		1		
Brachycentrus americanus		6	2	
B. numerosus	3			
B. lateralis	30	1	10	
Lepidostoma sp.		3		7
Goera sp.			1	
Limnephilus sp.				6
Pycnopsyche sp.	1	2		
Neophylax sp.	1			1
**Ganonema sp.*				
Leptocella sp.	3			

Table A3 (con't.)

EPHEMEROPTERA				
Ephemera simulans	17	140	6	2
Hexagenia limbata	21	12		12
Caenis sp.	48	104	3	33
Tricorythodes sp.	77	13		
Stenonema sp.	5	15	2	
Ephemerella sp.	3	6	57	76
Baetisca sp.	2	13	3	
Baetis sp.	9		1	13
Pseudocloeon sp.	257	4	1	
Siphlonurus sp.			1	1
Isonychia sp.	98	1		
Leptophlebia sp.			5	1
Paraleptophlebia praepidita	1	39		
HEMIPTERA				
Trichocorixa sp.	5	2		2
DIPTERA				
Tipula sp.				1
Antocha sp.	7	23	7	9
#Hexatoma sp.	9	11	5	1
Simulium sp.	315	8	29	8
Prosimulium sp.			117	
Tabaninae		4		2
Chrysops sp.	13	25	17	12
Atherix variegata	4	4	2	7
Epididae	4		6	3
Diamesia sp.	3	1		5
Prodiamesia sp.	5		64	2
Orthocladiinae	109	66	109	106
Cardiocladius sp.	4		24	
Tanypodinae	224	31	33	61
Conchepelopia sp.	2			
Chironomini	14		2	33
Polypedilum sp.	255	147	161	106
Microtendipes sp.	261	19	58	8
Cryptochironomus sp.	10			
Tantytarsini	671	41	15	261
Ceratopogonidae	14	8	7	11
COLEOPTERA				
Optioservus sp.	53	37	62	9
Dubaraphia sp.	7	2	2	8
Stenelemis sp.	2	4		
Donacia sp.				1
MEGALOPTERA				
Sialus sp.	6	7	1	
Nigronia sp.	5	2	4	

Table A3 (con't.)

DECAPODA				
Orconectes virilis	4	2	2	
GASTROPODA				
Physa sp.	20			
Amnicola sp.	259			2
Somatogyrus sp.	29			
Promentous sp.	36			
Gyraulus sp.	22			
Lioplax sp.	9			
Ferrisia sp.	5			
PELECYPODA				
Sphaerium sp.	17	32	8	11
Pisidium sp.	33	15	22	11
Lampsilis sp.		1		
HIRUDENIA				
Hellobdella fusca		1		
TRICLADIA				
Dugesia tigrina	1	1		
unknown Turbellaria	1			
OLIGOCHEATA				
Lumbricuidae	1		1	1
Lumbriculidae	1	1	3	5
Tubificidae	71	26	24	85
Naididae	2			2

*Species found in the study site that was not present in the samples analyzed quantitatively.

#Includes *Eriocera*.

Table A4. Species collected at the lower Au Sable site.

Species	Number Collected 8/10/71	10/02/71	1/29/72	5/19/72
HYDRACARINA		1	1	
ISOPODA				
Asellus militaris	91	193	125	7
AMPHIPODA				
Gammarus fasciatus	251	627	70	5
LEPIDOPTERA				
Paragyractus sp.		1		
PLECOPTERA				
Nemoura sp.			3	
Isoperla sp.			4	
Paragnetina sp.	1			
TRICHOPTERA				
Chimarra sp.	1		2	
C. feria	1			
C. alterrima				1
C. obscura	1			1
unknown psychomyiid		1		
Psychomyia sp.	8	14	10	
psychomyiid genus 'A'		29	29	1
Polycentropus sp.		4	3	
P. centralis	1	2	1	
Phylocentropus sp.	2			
Neuriclipsis sp.	1			
Cheumatopsyche sp.	831	502	275	19
Hydropsyche sp.	272	129	245	32
H. recurvata	504	180	289	68
H. slossonae	87	45	51	11
H. bifida group	403	381	301	62
Arctopsyche sp.	1			
Rhyacophila sp.	1	13		
Agapetus illini	106	482	270	908
Glossosoma sp.		6	40	12
Protoptila sp.	78	1	28	
Hydroptila sp.	3			2
Agraylea multipunctata	44			
Brachycentrus sp.	2			
B. americanus	16	26	21	26
B. numerosus	1		2	
B. lateralis	20	3	8	
Micrasema sp.		1		
Lepidostoma sp.		7		1
Neophylax sp.			1	

Table A4 (con't.)

TRICHOPTERA (con't.)				
Ganonema sp.			7	
Heliocopsyche borealis		1		
Leptocella sp.	3			
EPHEMEROPTERA				
Ephemera simulans	1		1	1
Tricorythodes sp.	4			
Stenonema sp.	17	15	34	1
Ephemerella sp.	5	20	219	26
Baetisca sp.		2		1
Baetis sp.	439	82	7	4
Pseudocloeon sp.	79	30	2	
Siphlonurus sp.			1	
Paraleptophlebia mollis			1	
HEMIPTERA				
Corixidae				1
DIPTERA				
Tipula sp.	1	5	1	1
Antocha sp.	4	61	87	17
Simulium sp.	988	924	867	133
Prosimulium sp.		1	1	1
Chrysops sp.	7	1	2	3
Epididae	2	5	5	6
Diamesia sp.	332	165	214	210
Prodiamesia sp.	50	7	138	6
Orthocladiinae	143	32	103	94
Cardiocladius sp.	12	40	340	11
Conchepelopia sp.	15	1		1
Chironomini			8	24
Polypedilum sp.	228	114	69	400
Microtendipes sp.	9	47	243	24
Tantytarsini	216	125	192	119
COLEOPTERA				
Optioservus sp.	112	317	160	69
Dubaraphia sp.	1	2		
Haliplus sp.				1
MEGALOPTERA				
**Sialus sp.*				
Nigronia sp.			1	
DECAPODA				
Orconectes virilis	1	1		

Table A4 (con't.)

GASTROPODA				
Physa sp.	9			
Amnicola sp.	75	37	1	1
Somatogyrus sp.		4		
Planorbula sp.	1	1		
Gyraulus sp.	3	1		
Helisoma antrosa	1			
Lioplax sp.		1		
Ferrisia sp.	1			
PELYCEPODA				
Sphaerium sp.	7	51		1
Pisidium sp.	10	96	2	15
HIRUDINEA				
Erpobdella punctata		1		
**Nephelopsis obscura*				
**Hellobdela nepheloidea*				
TRICLADIA				
Dugesia tigrina	99	166		
D. microbursalis		2		
OLIGOCHEATA				
Lumbriculidae	10	82	16	3
Tubificidae	602	1209	19	542
Naididae	1	2		

*Species found in the study site that was not present in the samples analyzed quantitatively.

Table A5. Species collected at the upper Red Cedar site.

Species	Number Collected 8/18/71	10/19/71	1/18/72	5/10/72
HYDRACARINA			1	
AMPHIPODA				
Gammarus fasciatus		6	1	
Hyallela azteca	353	514	83	21
LEPIDOPTERA				
Paragyractus sp.		1		
ODANATA				
Agrion sp.	1			
Hetaerina sp.	2		1	
unknown Coenagrionid		1		
Ishnura sp.	5	13		
Enallagma sp.		4	3	
Gomphus sp.	2		1	
PLECOPTERA				
Taeniopteryx sp.		1	14	
Perlinella drymo			1	
Acroneuria sp.	1	1	11	
Phasgonophora sp.	1		3	
Paragnetina sp.	6		1	
Classenia sp.		1	12	
TRICHOPTERA				
unknown Trichoptera	1			
Psychomyia sp.		1	2	
psychomyiid genus 'A'	1	1	2	
Polycentropus sp.		3		
P. remotus	3	6	6	
P. cineirius	1			
Neuriclipsis sp.		4		
Cheumatopsyche sp.	36	28	455	
Hydropsyche sp.	50	2	98	
H. recurvata	4			
H. bifida group	1	3	43	
H. aerata			1	
Rhyacophila sp.			2	
Glossosoma sp.			1	
Orthotrichia sp.		1		
Agraylea sp.		1		
Brachycentrus sp.		1	66	
B. americanus			5	
Sericostoma sp.	1			
Helicopsyche borealis			2	
Athripsodes ancylus			1	
A. dilutus			1	
Oecetis eddlestoni		1	2	

Table A5 (con't.)

EPHEMEROPTERA				
Hexagenia limbata	3	18	1	
Caenis sp.	94	8	1	2
Tricorythodes sp.	8	1		
Stenonema sp.	20	26	26	
Baetis sp.	21	4	41	1
Siphlonurus sp.			1	
Isonychia sp.			2	
Leptophlebia sp.		5	13	
Paraleptophlebia sp.		8	1	
HEMIPTERA				
Corixidae			2	
DIPTERA				
Tipula sp.			1	
Antocha sp.		1	48	
#Hexatoma sp.	23	1	15	
Psychoda sp.			1	
Simulium sp.			9	
Chrysops sp.		7		
Atherix variegata			1	
Epididae			5	
Prodiamesia sp.			9	
Orthocladiinae		50	445	
Cricotopus sp.			838	
Tanypodinae	35	34	46	3
Chironomini	40	192	242	160
Chironomus sp.	7	232	466	21
Polypedilum sp.	23	3		
Microtendipes sp.	1	69	44	
Cryotochironomus sp.	1			26
Endochironomus sp.			1	
Tantytarsini	50	56	335	36
Ceratopogonidae				7
COLEOPTERA				
Optioservus sp.		1	3	
Dubaraphia sp.	25	47	32	8
Stenelemis sp.	127	62	270	
Macronychus sp.		1	3	
Psphenus herriki	2	3	2	
MEGALOPTERA				
Sialus sp.	12	16	2	
Corydalus cornutus			1	
Nigronia sp.	2			
DECAPODA				
Orconectes propinquis	10	5	4	

Table A5 (con't.)

GASTROPODA				
Physa sp.	4			
Aplexa hypnorum	1		1	
Amnicola sp.	24	4	45	3
Somatogyrus sp.			4	2
Promentus exacuous			2	
Gyraulus sp.			4	1
Helisoma antrosa	1			
Lioplax sp.	3	3	1	1
Stagnicola sp.		2		
S. emarginata	1	1		
Viviparous sp.			1	
Campeloma sp.	1			
Ferrisia sp.			2	
Pleurocera acuta	4	1		
PELYCEPODA				
Sphaerium sp.	77	30	64	11
Pisidium sp.	17	31	56	32
**Antodontoides* sp.				
HIRUDENIA				
unknown Hirudenia			2	
Hellobdela sp.			5	
TRICLADIA				
*unknown Turbellaria				
Dugesia tigrina	14	2	28	
D. microbursalis		1		
OLIGOCHEATA				
Tubificidae	20	143	39	58
Naididae	2	17	2	13

*Species found in the study site that was not present in the samples analyzed quantitatively.

#Includes *Eriocera*.

Table A6. Species collected at the lower Red Cedar site.

Species	Number Collected 8/19/71	10/29/71	1/19/72	5/10/72
ISOPODA				
Asellus militaris	1			
ODANATA				
Enallagma sp.		5		
Ishnura sp.	2			
TRICHOPTERA				
Cheumatopsyche sp.	2		1	
Hydropsyche slossonae	1			
DIPTERA				
unknown Diptera	2			
Psychoda sp.			1	
Simulium sp.	6	5	4	
Muscidae	2	2		
Orthocladiinae	191	25	5	9
Tanypodinae	58	43	15	
Chironomini	158			22
Chironomus sp.	202	16	2	17
Polypedilum sp.	124		1	
Cryptochironomus sp.		1		
Tantytarsini	61			1
COLEOPTERA				
Dubaraphia sp.	5	9	3	
Stenelemis sp.	1			
DECOPODA				
Orconectes propinquis	1			
GASTROPODA				
Physa sp.	2	2		
Aplexa hypnorum		1		
Amnicola sp.	20			
Planorbula sp.	1			
Promentus exacuous	1			
Gyraulus sp.	4			
Helisoma antrosa	1	1		
PELYCOPODA				
Sphaerium sp.	5	1		4
Pisidium sp.	92	103	15	191
Lampsilis sp.	1			

Table A6 (con't.)

HIRUDENIA				
unknown Hirudenia				1
Hellobdella stagnalis		1		
H. fusca		1		
Glossiphonia complanta			1	
TRICLADIA				
Dugesia tigrina	86	199		
D. microbursalis	5			
OLIGOCHEATA				
Lumbriculidae		6		
Tubificidae	3942	12708	3078	6547
Branchiura sowerbyi	11			
Naididae	466	667	268	492

Table A7. Shannon diversity indices.

	Numbers of Individuals					Biomass				
	Summer	Fall	Winter	Spring	Annual Mean (± 1 S.E.)	Summer	Fall	Winter	Spring	Annual Mean (± 1 S.E.)
UPPER JORDAN										
log	3.22	2.80	3.53	3.51	3.27±0.17	3.87	2.32	3.41	2.33	3.21±0.33
sand w/o pl	2.52	0.97	1.24	2.22	1.74±0.48	1.99	0.47	1.72	1.45	1.41±0.33
sand-b	3.37	3.33	3.37	3.15	3.31±0.05	1.08	3.02	3.56	2.81	2.62±0.54
any w/pl	3.34	3.89	3.61	3.88	3.68±0.13	2.51	3.36	3.71	3.77	3.34±0.29
silt-b	3.03	3.82	3.51	3.57	3.48±0.17	3.36	3.48	3.35	3.10	3.32±0.08
All samples	3.98	4.01	4.09	4.09	4.04±0.03	3.55	3.58	4.00	3.89	3.76±0.11
LOWER JORDAN										
log	3.76	3.46	3.71	3.28	3.55±0.11	3.77	3.05	3.37	2.84	3.26±0.20
sand w/o pl	1.01	0.14	1.98	0.85	1.00±0.38	1.16	0.56	2.28	0.93	1.23±0.37
sand-b	2.09	0.74	2.27	0.86	1.49±0.56	2.49	1.91	2.90	1.56	2.22±0.30
All samples	3.63	2.88	3.79	2.01	3.08±0.41	3.70	3.24	3.65	2.86	3.36±0.20
UPPER AU SABLE										
gravel	3.68	4.26	3.75	3.55	3.81±0.16	4.15	3.18	3.95	3.28	3.64±0.24
sand w/o pl	2.63	3.19	3.21	3.22	3.06±0.14	1.69	3.33	2.92	1.80	2.44±0.41
sand-b	4.24	3.19	3.21	3.22	3.47±0.26	3.15	3.33	2.92	1.80	2.80±0.34
any w/pl	4.40	3.40	4.19	3.46	3.86±0.25	3.92	2.82	2.92	2.16	2.96±0.36
silt-b	3.43	3.57	4.19	3.47	3.67±0.18	3.21	2.13	2.92	2.20	2.59±0.25
All samples	4.48	4.52	4.49	4.02	4.38±0.12	4.10	3.48	3.84	3.45	3.72±0.16
LOWER AU SABLE										
gravel	4.07	4.13	4.14	2.80	3.79±0.33	3.67	3.65	3.95	3.48	3.69±0.10
sand w/o pl	1.65	0.27	3.16	2.52	1.90±0.86	0.86	0.77	2.76	2.59	1.75±0.54
sand-b	3.61	2.68	3.76	2.41	3.12±0.34	3.23	2.87	3.61	2.72	3.11±0.20
any w/pl	3.54	3.93	3.48	1.84	3.20±0.46	3.65	3.61	3.35	2.21	3.21±0.34
All samples	4.16	4.03	4.25	3.28	3.93±0.22	3.96	3.87	4.15	3.95	3.98±0.06

Table A7 (con't.)

UPPER RED CEDAR										
gravel	3.99	4.31	3.66		3.99±0.19	0.71	0.74	2.17		1.81±0.48
sand w/o pl	2.54	2.41			2.47±0.07	1.24	1.48			1.36±0.12
sand-b	2.55	2.91	2.82	3.01	2.82±0.10	2.44	2.38	1.93	1.78	1.54±0.16
any w/pl	1.52	2.37			1.95±0.42	2.42	2.59			2.51±0.09
All samples	3.96	3.72	3.95	3.01	3.66±0.22	1.05	1.50	2.64	1.78	1.74±0.46
LOWER RED CEDAR										
sand w/o pl	1.90	0.43			1.17±0.31	0.81	0.32			0.57±0.46
sand-b	1.72	0.50	0.38	0.61	0.80±0.73	2.33	0.50	0.53	0.43	0.95±0.25
any w/pl	1.60	0.50			1.05±0.94	2.34	0.51			1.43±0.92
silt-b	1.00	0.82			0.91±0.09	1.07	1.41			1.24±0.59
All samples	1.67	0.54	0.38	0.61	0.80±0.29	2.31	0.66	0.53	0.43	0.98±0.45

Table 8. Equitability values for diversity indices appearing in Table A-7.

	Numbers of Individuals					Biomass				
	Summer	Fall	Winter	Spring	Mean	Summer	Fall	Winter	Spring	Mean
UPPER JORDAN										
log	0.36	0.26	0.29	0.41	0.33	0.56	0.10	0.27	0.33	0.34
sand w/o pl	0.52	0.49	0.30	0.52	0.46	0.36	0.35	0.41	0.30	0.36
sand-b	0.65	0.59	0.47	0.34	0.51	0.13	0.48	0.54	0.27	0.36
any w/pl	0.30	0.48	0.42	0.37	0.39	0.17	0.33	0.45	0.34	0.32
silt-b	0.26	0.40	0.35	0.37	0.35	0.33	0.32	0.31	0.27	0.31
All samples	0.31	0.29	0.32	0.32	0.31	0.23	0.21	0.30	0.27	0.25
LOWER JORDAN										
log	0.45	0.39	0.30	0.35	0.37	0.45	0.30	0.24	0.26	0.31
sand w/o pl	0.67	0.55	0.25	0.18	0.41	0.74	0.74	0.30	0.19	0.49
sand-b	0.30	0.12	0.19	0.09	0.18	0.40	0.27	0.29	0.14	0.28
All samples	0.38	0.25	0.28	0.11	0.26	0.39	0.32	0.25	0.20	0.29
UPPER AU SABLE										
gravel	0.29	0.39	0.38	0.38	0.36	0.40	0.18	0.44	0.31	0.33
sand w/o pl	0.69	0.43	0.34	0.44	0.48	0.36	0.48	0.28	0.17	0.32
sand-b	0.39	0.43	0.34	0.44	0.40	0.18	0.48	0.28	0.17	0.28
any w/pl	0.32	0.24	0.49	0.39	0.36	0.23	0.16	0.20	0.16	0.19
silt-b	0.36	0.42	0.35	0.38	0.38	0.29	0.16	0.20	0.16	0.20
All samples	0.30	0.41	0.40	0.34	0.36	0.23	0.20	0.26	0.23	0.23
LOWER AU SABLE										
gravel	0.31	0.36	0.41	0.20	0.32	0.24	0.26	0.36	0.33	0.30
sand w/o pl	0.29	0.13	0.41	0.29	0.28	0.17	0.19	0.31	0.30	0.24
sand-b	0.32	0.18	0.45	0.23	0.30	0.25	0.20	0.41	0.29	0.29
any w/pl	0.31	0.30	0.46	0.26	0.33	0.33	0.24	0.42	0.33	0.33
All samples	0.28	0.29	0.39	0.23	0.30	0.25	0.26	0.36	0.36	0.31

Table A8 (con't.)

UPPER RED CEDAR										
gravel	0.38	0.48	0.22		0.36	0.04	0.04	0.08		0.05
sand w/o pl	0.48	0.38			0.43	0.20	0.20			0.20
sand-b	0.27	0.26	0.20	0.45	0.30	0.25	0.18	0.11	0.19	0.18
any w/pl	0.16	0.20			0.18	0.30	0.23			0.27
All samples	0.31	0.24	0.21	0.45	0.30	0.04	0.05	0.09	0.19	0.09
LOWER RED CEDAR										
sand w/o pl	0.27	0.34			0.31	0.13	0.31			0.22
sand-b	0.11	0.08	0.10	0.15	0.11	0.17	0.08	0.11	0.13	0.12
any w/pl	0.13	0.08			0.11	0.22	0.08			0.15
silt-b	0.25	0.22			0.24	0.26	0.33			0.30
All samples	0.10	0.07	0.10	0.15	0.11	0.16	0.08	0.11	0.13	0.12

Table A9. Density as standing crops.

	Number of Individuals/m^2				
	Summer	Fall	Winter	Spring	Mean (± 1 S.E.)
UPPER JORDAN					
log	2,458	2,771	13,075	3,593	5,474 ± 2,545
sand w/o pl	1,783	652	2,565	11,543	4,136 ± 2,500
sand-b	2,507	1,275	4,754	10,986	4,881 ± 2,159
any w/pl	1,174	3,130	7,870	13,478	6,413 ± 2,743
silt-b	12,551	3,884	7,420	10,348	8,551 ± 2,873
All samples	4,846	2,996	9,849	6,909	6,150 ± 1,469
LOWER JORDAN					
log	6,249	8,145	46,841	19,117	20,088 ± 14,902
sand w/o pl	4,000	1,109	49,239	4,084	14,608 ± 11,564
sand-b	12,493	10,652	42,870	62,101	32,029 ± 12,452
All samples	7,701	9,793	40,225	40,598	24,579 ± 9,151
UPPER AU SABLE					
gravel	4,233	2,353	1,750	1,510	2,462 ± 617
sand w/o pl	1,435	5,783	3,087	4,783	3,772 ± 957
sand-b	30,725	1,928	3,087	3,188	9,732 ± 7,069
any w/pl	21,720	3,722	6,333	6,913	9,672 ± 4,076
silt-b	7,478	3,667	6,333	7,087	6,141 ± 858
All samples	8,918	2,493	2,683	2,991	4,272 ± 1,552
LOWER AU SABLE					
gravel	14,967	11,050	12,687	8,740	11,861 ± 1,314
sand w/o pl	5,607	45,217	7,826	8,239	16,722 ± 9,516
sand-b	18,185	42,870	10,435	16,580	22,018 ± 7,149
any w/pl	20,521	22,753	15,652	33,261	23,047 ± 3,713
All samples	15,722	17,000	12,266	10,751	13,935 ± 1,458
UPPER RED CEDAR					
gravel	1,757	1,377	9,357		4,164 ± 2,599
sand w/o pl	3,870	9,935			6,903 ± 3,033
sand-b	8,928	,362	16,913	6,029	12,558 ± 3,006
any w/pl	19,043	35,217			27,130 ± 8,087
All samples	3,098	4,553	10,770	6,029	6,113 ± 1,664
LOWER RED CEDAR					
sand w/o pl	10,522	39,522			25,022 ± 26,862
sand-b	67,565	186,942	79,696	105,580	109,946 ± 14,500
any w/pl	96,087	260,652			178,370 ± 82,283
silt-b	10,188	12,870			11,529 ± 1,341
All samples	38,877	99,906	76,696	105,580	81,015 ± 15,104

Table A9 (con't.)

	Biomass (mg)/m^2				
	Summer	Fall	Winter	Spring	Mean (± 1 S.E.)
UPPER JORDAN					
log	1,942	9,266	16,351	6,579	8,535 ± 3,013
sand w/o pl	1,413	522	3,000	8,500	3,359 ± 1,789
sand-b	9,029	4,290	10,855	17,000	10,294 ± 2,629
any w/pl	22,203	11,116	15,942	25,043	18,576 ± 5,557
silt-b	17,348	10,261	10,884	22,725	15,304 ± 2,947
All samples	7,239	8,489	13,808	12,802	10,585 ± 1,604
LOWER JORDAN					
log	5,585	25,189	138,689	46,451	53,979 ± 29,444
sand w/o pl	1,891	870	54,630	28,348	21,435 ± 12,763
sand-b	10,493	14,913	50,014	50,493	31,478 ± 19,896
All samples	14,298	22,228	98,186	47,482	45,549 ± 18,918
UPPER AU SABLE					
gravel	4,370	12,487	2,577	4,895	6,082 ± 2,192
sand w/o pl	435	3,500	8,478	21,130	8,386 ± 4,560
sand-b	105,536	2,333	8,478	14,807	32,609 ± 24,347
any w/pl	59,183	29,089	61,319	47,826	49,354 ± 7,912
silt-b	38,464	32,203	61,319	49,145	45,283 ± 6,388
All samples	25,687	13,993	12,760	15,805	17,059 ± 2,942
LOWER AU SABLE					
gravel	39,390	43,323	49,280	8,740	35,183 ± 9,046
sand w/o pl	25,848	35,609	21,304	8,239	22,750 ± 5,683
sand-b	40,011	101,217	32,696	16,580	47,626 ± 18,522
any w/pl	35,021	73,733	15,652	33,261	39,417 ± 12,246
All samples	39,536	54,168	46,179	21,409	40,323 ± 6,978
UPPER RED CEDAR					
gravel	57,870	48,927	81,643		62,813 ± 9,763
sand w/o pl	8,870	30,587			± 10,859
sand-b	16,928	34,783	62,507	7,275	30,373 ± 12,132
any w/pl	33,043	43,174			38,109 ± 5,066
All samples	50,214	46,285	78,065	7,275	45,460 ± 14,562
LOWER RED CEDAR					
sand w/o pl	4,261	23,739			14,000 ± 16,630
sand-b	68,261	131,275	57,087	72,942	82,391 ± 9,739
any w/pl	100,261	185,043			142,652 ± 42,391
silt-b	5,217	13,536			9,377 ± 4,160
All samples	36,739	72,399	57,087	72,942	59,792 ± 8,518

Table A10. Cm^2 substrate sampled and number of taxa found.

	Cm^2 Substrate Sampled				Number of Taxa Found				
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Total
UPPER JORDAN									
log	1550	2140	1595	1564	26	27	40	28	
sand w/o pl	460	460	460	460	11	4	8	9	
sand-b	690	690	690	690	16	17	22	26	
any w/pl	690	690	690	690	34	31	29	40	
silt-b	690	690	690	690	31	35	33	32	
All samples	2930	3520	2975	2944	51	56	54	54	87
LOWER JORDAN									
log	2170	954	1548	634	30	28	43	28	
sand w/o pl	460	460	460	460	3	2	16	10	
sand-b	690	690	690	690	14	14	26	21	
All samples	2880	1544	2538	1354	33	30	50	36	63
UPPER AU SABLE									
gravel	3000	3000	3000	2000	44	49	35	31	
sand w/o pl	230	460	690	460	9	21	27	21	
sand-b	690	690	690	690	48	21	27	21	
any w/pl	1690	1690	690	690	67	44	37	28	
silt-b	690	690	690	690	30	28	37	29	
All samples	4380	4380	4380	3380	75	56	56	48	99
LOWER AU SABLE									
gravel	3000	3000	3000	2000	54	49	43	34	
sand w/o pl	460	230	460	460	11	9	22	20	
sand-b	920	690	690	690	38	36	30	23	
any w/pl	1460	1460	230	230	38	50	24	14	90
All samples	3920	3690	3690	2690					

Table A10 (con't.)

UPPER RED CEDAR									
gravel	3000	3000	3000		42	41	58		
sand w/o pl	460	460			12	14			
sand-b	690	690	690	690	22	29	36	18	
any w/pl	230	230			18	26			
All samples	3690	3690	3690	690	51	56	73	18	102
LOWER RED CEDAR									
sand w/o pl	230	230			14	4			
sand-b	690	690	690	690	30	18	13	10	
any w/pl	460	460			23	17			
silt-b	690	690			8	8			
All samples	1380	1380	690	690	31	20	13	10	39