

SPECIES DIVERSITY OF  
BENTHIC MACROINVERTEBRATES  
IN THREE MICHIGAN STREAMS

Thesis for the Degree of M. S.  
MICHIGAN STATE UNIVERSITY  
JEFFREY C. GISLASON  
1971

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## ABSTRACT

### SPECIES DIVERSITY OF BENTHIC MACROINVERTEBRATES IN THREE MICHIGAN STREAMS

By

Jeffrey C. Gislason

Four benthic macroinvertebrate communities, each subject to a different level of human perturbation, in three Michigan streams were studied during an annual cycle to determine the effects of human perturbation on community composition and species diversity. Species diversity indices derived from information theory were used.

Species diversity of benthic macroinvertebrates was inversely related to the level of perturbation, and the degree of variability of the diversity index of a community during an annual cycle generally increased as the level of perturbation increased. The abundance of species decreased and the abundance of individuals generally increased as the level of perturbation increased. Indices of species diversity appear to be highly sensitive indicators of the degree of human perturbation.

SPECIES DIVERSITY OF BENTHIC MACROINVERTEBRATES  
IN THREE MICHIGAN STREAMS

By

Jeffrey C. Gislason

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## INTRODUCTION

Community structure of benthic macroinvertebrates has been widely used as an indicator of conditions in polluted streams. Many investigators have attempted to classify benthic organisms according to pollutional tolerance and use associations of organisms as criteria of pollution (Richardson, 1928; Patrick, 1950; Wurtz, 1955; Gaufin and Tarzwell, 1956; Gaufin, 1958). Recently a number of investigators have utilized indices derived from information theory that express species diversity to summarize community structure of benthic macroinvertebrates in streams.

Information theory indices of species diversity are considered among the best and most sensitive indicators of ecological change (Wilhm and Dorris, 1968; Hooper, 1969). Wilhm and Dorris (1966) first used species diversity methods 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) studied three unpolluted mountain streams, and Mathis and Dorris (1968) investigated the effects of

oil field brine in a stream. Hooper (1969) has pointed out the need for further studies to identify more precisely the relation of diversity indices to changes in nutrient level.

One of the objectives of this study was to compare the effects of different levels of human perturbation on species diversity of benthic macroinvertebrates. Human perturbation is defined as any disturbance to the stream ecosystem caused by man, primarily artificial enrichment. Benthic macroinvertebrate communities subject to four levels of human perturbation, ranging from no perturbation to heavy agricultural and industrial pollution, in three Michigan streams, were examined periodically during an annual cycle. Another objective was to determine if the degree of variability of a diversity index of a community during an annual cycle was related to the degree of perturbation.

## DESCRIPTION OF STUDY AREAS

The Jordan River originates in northeastern Antrim County and flows 53 km to the South Arm of Lake Charlevoix. The watershed is heavily forested, and the upper reaches are unpopulated and undisturbed by man. A fish hatchery is situated about one-third of the way down the watercourse, and a few farms and cabins are located along the lower reaches. Two study sites were selected on the Jordan River, one in the undisturbed upper reaches, and another 24 km farther downstream.

The upper Jordan study site was located in the N $\frac{1}{2}$ , N $\frac{1}{4}$ , section 31, T31N, R5W, Michigan Principle Meridian. The average depth near the two sampling areas was 0.6 m, the average width was 14 m, and the discharge in June, 1970 was 0.6 m<sup>3</sup>/second. The bottom consisted mainly of sand along with marl concretions and numerous submerged logs. Beds of Chara vulgaris were present along the edges of the stream. This site represents a system subject to no human perturbation.

The lower Jordan study site was located in the NW $\frac{1}{4}$ , NW $\frac{1}{4}$ , section 7, T31N, R6W, Michigan P. M. Average depth near the sampling areas was 0.8 m, average width

was 14 m, and the discharge in June, 1970 was  $4.1 \text{ m}^3/\text{second}$ . The bottom was similar to that of the upper site, except for a few areas of exposed rubble at the lower site, and submerged logs were less numerous. Beds of submerged vegetation composed of Elodea canadensis and Potamogeton filiformis were present along the stream edges.

This site represents a system subject to slight human perturbation. The site is located approximately 22 km downstream from the Jordan River National Fish Hatchery which contributes an effluent containing unconsumed fish food and fish fecal material into the river. About 9.2 metric tons of ammonia nitrogen, 30 metric tons of nitrate nitrogen, and 3 metric tons of phosphorus are added to the river during a year.

The AuSable River originates near the town of Frederic in Crawford County and empties into Lake Huron. The total length is about 322 km. The watershed is largely forested and is subjected to little agricultural or industrial use.

The AuSable study site was located on the E boundary, section 10, T26N, R3W, Michigan P. M., about 46 km below the source. The average depth near the sampling areas was 0.8 m, the average width was 23 m, and the discharge during June, 1970 was  $4.0 \text{ m}^3/\text{second}$ . The bottom was composed primarily of gravel, with scattered

sandy and silty areas along the edges. Macrophyte beds containing Potamogeton filiformis, Potamogeton crispus, and Elodea canadensis were present along the stream edges throughout the year. During the macrophyte growing season, the gravel in the center portion of the stream became covered by a dense growth of Potamogeton filiformis.

This site represents a system subject to a moderate level of perturbation. It is located approximately 7 km below the town of Grayling and a state fish hatchery which discharge effluents containing a combined total of about 36 metric tons of nitrogen and 7.3 metric tons of phosphorus into the river annually. Numerous cottages along the river bank probably contribute nutrients from their septic tank systems to the river. This section of the river is subjected to heavy recreational use by canoeists, fishermen, and campers.

The Red Cedar originates in Livingston County at Cedar Lake and flows 79 km to the city of Lansing where it joins the Grand River. There is considerable agricultural development and urbanization within the watershed. Several industrial plants are also located along the river.

The Red Cedar study site was located in the NE $\frac{1}{4}$ , SE $\frac{1}{4}$ , section 22, T4N, R2W, Michigan P. M., in the city of Lansing. The average depth near the sampling areas was 1.2 m, and the average width was 17 m. The discharge is usually around 1.5 m<sup>3</sup>/second during June. It may be as

high as  $25 \text{ m}^3/\text{second}$  during the spring and is generally below  $0.3 \text{ m}^3/\text{second}$  during the summer months (Ball et al., 1968). The bottom consisted of clay covered with large amounts of silt and organic sediment. Scattered patches of Potamogeton crispus and Elodea nuttalli were present only during the summer.

This site represents a system subject to severe human perturbation. The Red Cedar receives the effluent from the municipal waste treatment plants of five communities and wastes from a metal plating plant, all located above the study site. The Red Cedar is also subject to heavy pesticide pollution resulting from agricultural and urban runoff. Flooding usually occurs in the spring and may occur at other times of the year (Ball et al., 1968).

## METHODS AND MATERIALS

To compare differences in macroinvertebrate community structure due to perturbation among sites, it was necessary to sample in areas that were physically similar except for conditions produced by perturbation. Submerged aquatic macrophyte beds were selected as specific sampling areas because they were the only stable microhabitat common to all four sites. Because of the frequent sampling required, artificial substrates were employed in the sampling procedure instead of using other sampling methods that would reduce the density of the macrophytes.

The artificial substrates were designed to simulate natural aquatic vegetation. Each substrate consisted of a clay flower pot with a top opening 15 cm in diameter filled with concrete to within 4 cm of the top. Fifty 1 by 30 cm strips of fiberglass window screen were attached to the surface of the concrete by embedding one end of each strip in the concrete before it hardened. The strips were evenly spaced over the concrete surface. When the substrates were placed in macrophyte beds with the rim flush with the surface of the sediment, the space



at the top became filled with sediment. The fiberglass strips then protruded 25 cm above the surface of the sediment which had an area of  $0.02 \text{ m}^2$ .

Two plots of nine substrates each were placed in plant beds at all four sites. These two plots were located about 75 m apart in 30 to 45 cm of water and 1 to 3 m from the stream edge. The nine substrates in each plot were arranged in a square of three columns and three rows. The axis of each column was parallel to the current direction.

On each sampling date, the three substrates in one of the columns in each plot (a total of six substrates from each site) were removed, sampled, and placed back into the stream bed. The column sampled was the one that had been undisturbed for the longest period of time. Substrates were removed beginning with the downstream substrate and moving upstream. To remove a substrate, a tube 90 cm long and 15 cm in diameter with a foam rubber seal on one end was inserted into the top of the substrate enclosing the sediment in the substrate, the fiberglass strips, and the water column above the substrate. The tube and the substrate were then lifted out together and placed in a container. Aufwuchs, benethic organisms, and sediment were washed from the substrate, sorted with a sieve having 0.25 mm openings (U.S. Standard Sieve Series #60), and preserved in 10% formalin. Benthic

macroinvertebrates were later separated by sugar solution flotation (Anderson, 1959), transferred to 75% alcohol, and hand sorted under a binocular microscope. Organisms were identified to the species level when possible and counted.

The substrates were placed in the macrophyte beds at the study sites in April, 1970 and sampled five weeks later in May. Sampling took place at four-week intervals from May through October, the season in which aquatic insects were emerging and reproducing. During the winter, samples were collected at all sites in December, 1970, and at the upper and lower Jordan and AuSable sites in February, 1971. The Red Cedar was sampled in March, 1971, because flooding made sampling impossible in February.

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

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

where  $N$  is the total number of individuals in a community,  $s$  is the total number of species, and  $n_i$  is the number of individuals of species  $i$ . Diversity per individual is expressed in binary digits, or bits, per individual. One bit is the amount of information required to make a choice

between two equally probable alternatives. Assuming reasonably large samples, Brillouin's equation is approximated by Shannon's formula for information as described by Patten (1962):

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

Diversity, which is considered synonymous with information, is equated with the degree of uncertainty involved in predicting correctly the species of the next individual collected from a community. The greater the number of species in a community, and the greater the evenness of distribution of individuals among species, the greater the uncertainty involved. Diversity of a community would be minimal if all individuals belonged to the same species. The probability that an individual belonged to the single species would be one, and  $\bar{d}$  would be zero. Diversity would be maximal if each individual belonged to a separate species (cf., Wihlm and Dorris, 1968).

Information theory indices of diversity have several advantages over other types of indices of community structure. They take into account the number of species as well as the relative importance of each species. Rare species that are often overlooked in sampling contribute little information to the index. They are relatively

independent of sample size, therefore only a few samples are needed (Wihlm and Dorris, 1968). They also make possible objective comparisons of fauna between streams in widely separated geographic areas (Mathis, 1968).

An index of the evenness of the distribution of individuals among species, or equitability, was obtained by using MacArthur's (1965) method. If all species in a sample are equally abundant,  $\bar{d} = \log_2 s$ , and  $s = 2^{\bar{d}}$ . If a particular sample has  $s$  number of species and a diversity of  $\bar{d}$ , then  $2^{\bar{d}}$  equally common species would have the same diversity as the  $s$  unequally common species in the sample. The ratio,  $\frac{2^{\bar{d}}}{s}$ , is the equitability of the sample.

Water samples were taken every month at the four sites from March, 1970 through October, 1970. Alkalinity, pH, hardness, suspended and dissolved solids, nitrate nitrogen, ammonia nitrogen, total phosphorus, and chloride were determined by the Institute of Water Research Water Quality Laboratory at Michigan State University. Twenty-four hour continuous monitoring of dissolved oxygen and temperature was carried out every month at most of the study sites during the summer and fall. Fish collected at the four study sites were analyzed for pesticide residues (DDT, DDD, DDE, and dieldrin) by the Pesticide Research Center, Michigan State University.

## RESULTS

Nutrient levels in the water did not reflect the degree of perturbation at the three least perturbed study sites. Nitrate nitrogen and ammonia nitrogen were slightly higher at the upper Jordan site (Table 1) than at the lower Jordan site (Table 2), and nitrate nitrogen was higher at both the Jordan River sites than at the AuSable River site (Table 3). Total phosphorus was similar at all three of these sites. Values for nutrients and other water parameters were typical of natural waters. The high levels of nitrate nitrogen, ammonia nitrogen, and phosphorus in the Red Cedar River indicate a high degree of enrichment (Table 4).

Diurnal variation in dissolved oxygen at the four study sites is shown in Table 5. Dissolved oxygen never fell below 8.3 mg/L (80% saturation) in the upper and lower Jordan and showed relatively little diurnal fluctuation. Dissolved oxygen levels were generally lower and fluctuations greater in the AuSable. During the summer months fluctuations of 4 to 6 mg/L occurred, and a low reading of 5.8 mg/L (60% saturation) was recorded. The wide fluctuations were probably due to the large standing

TABLE 1.--Water quality parameters at the upper Jordan study site from March to October, 1970, in mg/L where applicable.

| Date     | pH  | Total Alkalinity | Hardness | Solids |       | NO <sub>3</sub> -N | NH <sub>4</sub> -N | Total Phosphorus | Cl <sup>-</sup> |
|----------|-----|------------------|----------|--------|-------|--------------------|--------------------|------------------|-----------------|
|          |     |                  |          | Susp.  | Diss. |                    |                    |                  |                 |
| March 25 | 8.1 | 159              | 173      | 2      | 185   | 0.79               | 0.15               | 0.01             | 1               |
| April 12 | 8.5 | 157              | 169      | 1      | 186   | 0.79               | 0.16               | 0.05             | 2               |
| May 3    | 8.5 | 160              | 191      | 1      | 194   | 0.73               | 0.19               | 0.01             | 1               |
| May 31   | 8.2 | 165              | 172      | 1      | 204   | 0.84               | 1.21               | 0.05             | 3               |
| June 26  | 8.3 | 161              | 185      | 3      | 202   | 0.65               | 0.18               | 0.04             | 1               |
| July 19  | 8.5 | 160              | 193      | 1      | 187   | 0.69               | 0.01               | 0.02             | 2               |
| Aug. 11  | 8.4 | 216              | 195      | 2      | 208   | 0.59               | 0.04               | 0.03             | 2               |
| Sept. 4  | 8.0 | 140              | 164      | 2      | 191   | 0.81               | 0.11               | 0.04             | 2               |
| Sept. 25 | 8.4 | 163              | 186      | 1      | 201   | 0.69               | 0.36               | 0.01             | 1               |
| Oct. 18  | 8.5 | 161              | 181      | 1      | 202   | 0.75               | 0.22               | 0.01             | 1               |
| MEAN     | 8.3 | 164              | 180      | 1.5    | 196   | 0.73               | 0.26               | 0.03             | 1.6             |

TABLE 2.--Water quality parameters at the lower Jordan study site from March to October, 1970, in mg/L where applicable.

| Date     | pH  | Total Alkalinity | Hardness | Solids |       | NO <sub>3</sub> -N | NH <sub>4</sub> -N | Total Phosphorus | Cl- |
|----------|-----|------------------|----------|--------|-------|--------------------|--------------------|------------------|-----|
|          |     |                  |          | Susp.  | Diss. |                    |                    |                  |     |
| March 25 | 8.1 | 155              | 166      | 4      | 196   | 0.43               | 0.53               | 0.01             | 1   |
| April 12 | 8.5 | 157              | 171      | 2      | 196   | 0.64               | 0.14               | 0.09             | 2   |
| May 3    | 8.4 | 183              | 174      | 4      | 201   | 0.29               | 0.15               | 0.03             | 3   |
| May 31   | 8.3 | 172              | 178      | 10     | 210   | 0.55               | 0.10               | 0.09             | 4   |
| June 26  | 8.4 | 165              | 174      | 6      | 207   | 0.55               | 0.03               | 0.04             | 2   |
| July 19  | 8.6 | 164              | 192      | 6      | 208   | 0.57               | 0.02               | 0.01             | 1   |
| Aug. 11  | 8.5 | 204              | 201      | 2      | 201   | 0.56               | 0.04               | 0.03             | 2   |
| Sept. 4  | 7.9 | 143              | 176      | 11     | 203   | 0.62               | 0.06               | 0.02             | 3   |
| Sept. 25 | 8.5 | 167              | 190      | 2      | 212   | 0.64               | 0.16               | 0.01             | 2   |
| Oct. 18  | 8.4 | 165              | 186      | 3      | 208   | 0.60               | 0.01               | 0.01             | 3   |
| MEAN     | 8.4 | 168              | 181      | 5      | 204   | 0.54               | 0.12               | 0.03             | 2.3 |

TABLE 3.--Water quality parameters at the AuSable study site from March to October, 1970, in mg/L where applicable.

| Date     | pH  | Total Alkalinity | Hardness | Solids |       | NO <sub>3</sub> -N | NH <sub>4</sub> -N | Total Phosphorus | Cl <sup>-</sup> |
|----------|-----|------------------|----------|--------|-------|--------------------|--------------------|------------------|-----------------|
|          |     |                  |          | Susp.  | Diss. |                    |                    |                  |                 |
| March 25 | 7.9 | 143              | 151      | 1      | 171   | 0.14               | 0.09               | 0.03             | 4               |
| April 12 | 8.5 | 128              | 132      | 1      | 154   | 0.08               | 0.02               | 0.08             | 4               |
| May 3    | 8.2 | 128              | 136      | 2      | 170   | 0.08               | 0.22               | 0.04             | 5               |
| May 31   | 8.2 | 131              | 137      | 6      | 173   | 0.09               | 0.02               | 0.07             | 5               |
| June 26  | 8.2 | 141              | 160      | 2      | 237   | 0.06               | 0.02               | 0.02             | 4               |
| July 19  | 8.4 | 138              | 165      | 5      | 218   | 0.07               | 0.04               | 0.05             | 5               |
| Aug. 11  | 8.6 | 130              | 166      | 4      | 175   | 0.07               | 0.07               | 0.06             | 6               |
| Sept. 4  | 8.2 | 122              | 144      | 3      | 167   | 0.23               | 0.14               | 0.04             | 5               |
| Sept. 25 | 8.3 | 134              | 154      | 3      | 174   | 0.10               | 0.26               | 0.03             | 5               |
| Oct. 18  | 8.6 | 137              | 154      | 2      | 179   | 0.12               | 0.29               | 0.02             | 5               |
| MEAN     | 8.3 | 133              | 150      | 3      | 182   | 0.10               | 0.12               | 0.04             | 4.3             |



TABLE 4.--Water quality parameters at the Red Cedar study site from March to October, 1970, in mg/L where applicable.

| Date     | pH  | Total Alkalinity | Hardness | Solids |       | NO <sub>3</sub> -N | NH <sub>4</sub> -N | Total Phosphorus | Cl <sup>-</sup> |
|----------|-----|------------------|----------|--------|-------|--------------------|--------------------|------------------|-----------------|
|          |     |                  |          | Susp.  | Diss. |                    |                    |                  |                 |
| March 25 | 7.8 | 229              | 347      | 2      | 497   | 1.52               | 0.42               | 0.37             | 37              |
| April 12 | 8.4 | 202              | 306      | 13     | 477   | 1.67               | 0.22               | 0.39             | 26              |
| May 3    | 8.1 | 228              | 330      | 14     | 475   | 1.84               | 0.55               | 0.18             | 30              |
| May 31   | 8.0 | 279              | 364      | 12     | 577   | 0.86               | 1.21               | 0.35             | 49              |
| June 26  | 8.0 | 175              | 263      | 15     | 484   | 0.93               | 0.63               | 0.27             | 40              |
| July 19  | 8.1 | 200              | 284      | 9      | 447   | 1.32               | 0.37               | 0.47             | 42              |
| Aug. 11  | 8.3 | 266              | 399      | 15     | 631   | 0.46               | 1.28               | 0.86             | 88              |
| Sept. 14 | 7.8 | 279              | 369      | 7      | 631   | 0.20               | 2.50               | 1.14             | 108             |
| Sept. 25 | 8.1 | 261              | 360      | 25     | 579   | 2.21               | 0.21               | 0.15             | 89              |
| Oct. 19  | 8.0 | 257              | 379      | 18     | 582   | 0.80               | 1.27               | 1.02             | 46              |
| MEAN     | 8.1 | 238              | 340      | 13     | 538   | 1.18               | 0.87               | 0.52             | 55.6            |

TABLE 5.--Diurnal variation in dissolved oxygen at the four study sites.

| Study Site   | Date        | Dissolved Oxygen (mg/L) |         |             |
|--------------|-------------|-------------------------|---------|-------------|
|              |             | Minimum                 | Maximum | Fluctuation |
| Upper Jordan | June 26-27  | 8.6                     | 11.2    | 2.6         |
|              | Aug. 24-26  | 9.1                     | 10.4    | 1.3         |
|              | Sept. 21-22 | 8.3                     | 9.6     | 1.3         |
|              | Oct. 17-18  | 10.5                    | 11.7    | 1.2         |
|              | Nov. 14-15  | 12.6                    | 13.3    | 0.7         |
| Lower Jordan | June 24-26  | 9.6                     | 10.5    | 0.9         |
|              | July 22-23  | 8.8                     | 9.8     | 1.0         |
|              | Aug. 22-24  | 9.0                     | 11.1    | 2.1         |
|              | Sept. 20-21 | 8.5                     | 11.1    | 2.6         |
|              | Oct. 15-16  | 10.5                    | 11.7    | 1.2         |
| AuSable      | Nov. 14-15  | 13.1                    | 13.9    | 0.7         |
|              | June 22-24  | 6.8                     | 11.5    | 4.7         |
|              | July 20-22  | 7.1                     | 11.0    | 3.9         |
|              | Aug. 18-20  | 5.8                     | 11.5    | 5.7         |
|              | Sept. 19-20 | 7.5                     | 10.7    | 3.2         |
| Red Cedar    | Oct. 14-15  | 8.0                     | 10.5    | 2.5         |
|              | Nov. 12-13  | 11.1                    | 11.7    | 0.6         |
|              | Aug. 5-6    | 3.1                     | 4.7     | 1.6         |
|              | Aug. 10-11  | 1.1                     | 1.8     | 0.7         |
|              | Aug. 27-29  | 1.0                     | 2.3     | 1.3         |
|              | Sept. 22-23 | 3.7                     | 4.2     | 0.5         |
|              | Oct. 19-20  | 5.0                     | 7.2     | 2.2         |
|              | Nov. 17-18  | 10.1                    | 10.8    | 0.7         |

crop of aquatic macrophytes present in the summer. In the Red Cedar, dissolved oxygen was low and fluctuated only slightly. Values as low as 1.0 mg/L (11% saturation) were observed during the summer, probably caused by the high B.O.D. of organic effluents entering the stream.

Levels of pesticide residues in fish from the Jordan and AuSable river study sites were considerably less than 1 ppm. Levels of pesticide residues were much higher in fish from the Red Cedar study site. Levels of DDD and DDE as high as 17 ppm were found in adult carp from the Red Cedar site.

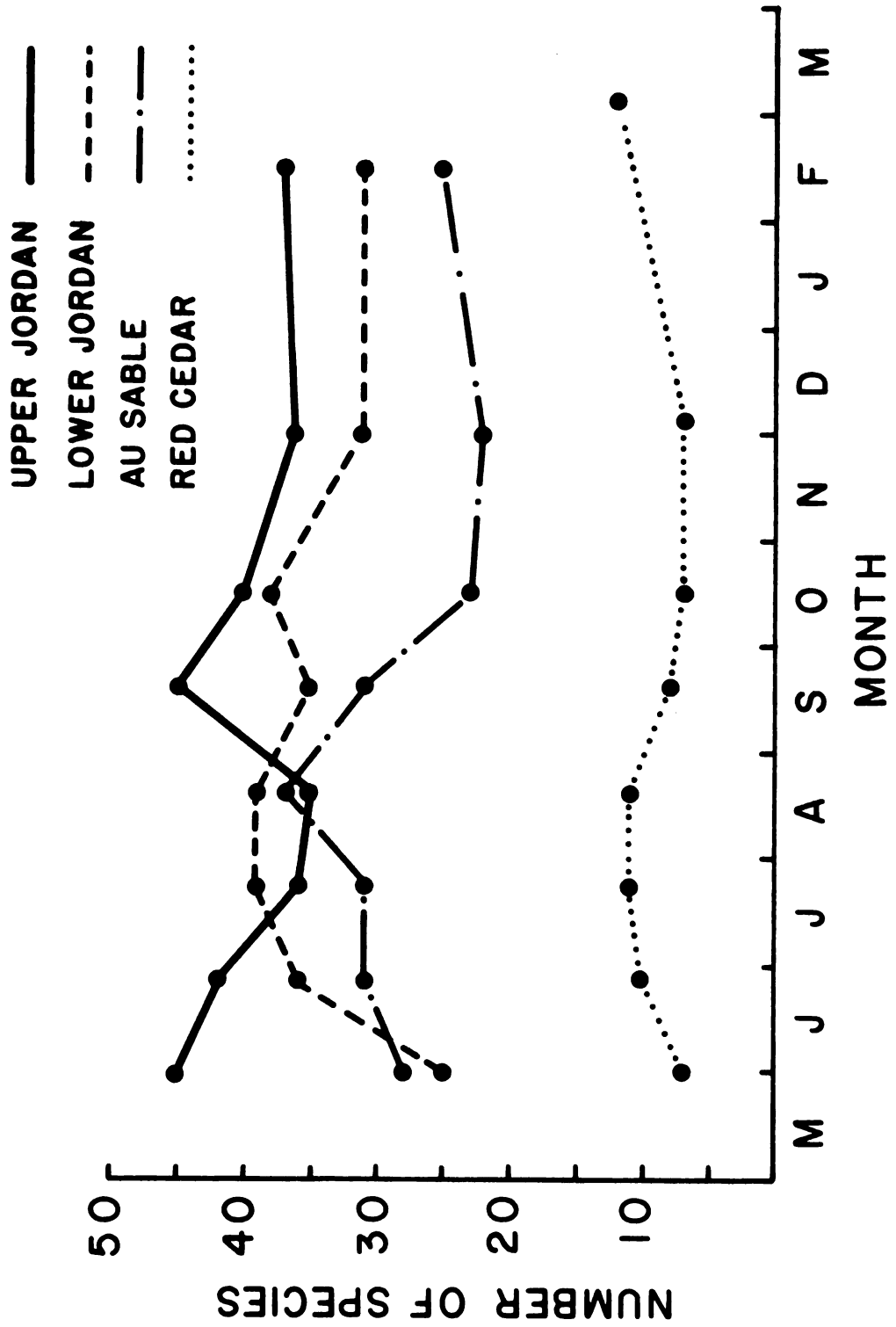
The number of species and number of individuals collected from each substrate plot on the sampling dates, as well as species diversity, were compared using a paired t-test to determine if there were any differences between the two plots at each study site. More species were present in the upstream plot than in the one farther downstream at the upper Jordan site ( $P < .05$ ), but similar numbers were present in both plots at the other sites ( $P > .05$ ). Generally, the same species were found in both plots at all the sites. There was a difference in the number of individuals collected from the two plots at the upper and lower Jordan sites ( $P < .05$ ), but numbers of individuals were similar ( $P > .05$ ) at the two other sites. Species diversity, however, was the same in both

plots at all the sites ( $P > .2$ ), and data from both plots were pooled to calculate the monthly diversity indices.

The number of species collected varied among study sites (Figure 1). The number of species collected was generally high at the upper Jordan site, intermediate at the lower Jordan and AuSable sites, and very low at the Red Cedar site.

The upper Jordan site was characterized by an abundance of species of the taxa Ephemeroptera, Trichoptera, and Chironomidae. No single species was abundant enough during all seasons to be considered dominant. The dominant species at the lower Jordan site were Tricorythodes sp., which accounted for 66% of the individuals collected in July, Ephemerella rotunda, Ephemerella subvaria (Ephemeroptera), and Simulium sp. (Diptera). The AuSable site was characterized by an abundance of Gammarus fasciatus (Amphipoda) and Asellus militaris (Isopoda). These two species formed between 40 and 80% of the total number of individuals collected. Two pollution tolerant species, Tubifex tubifex (Oligochaeta), and Chironomus tentans (Diptera), together comprised from 40% to 92% of the individuals collected at the Red Cedar site. A complete listing of numbers of individuals and species collected on the sampling dates at each study site is provided by Tables A1, A2, A3, and A4 of the Appendix.

Figure 1. Number of species collected at the four study sites from May, 1970, to March, 1971.



Species collected at the four study sites were categorized according to pollutional tolerance by using the classifications of Gaufin (1958) and the Michigan Water Resources Commission (1969). The results are presented in Figures 2 and 3. The benthic fauna of the upper and lower sites on the Jordan River is composed almost entirely of equal numbers of intolerant and facultative species, and this situation changes only slightly during the year. At the AuSable site, however, the number of facultative species is greater than the number of intolerant species during all seasons and up to three times greater in summer, indicating degradation of water quality. The fauna at the Red Cedar site consists of equally low numbers of tolerant and facultative species throughout the year with only one individual representing the intolerant species present in May.

The number of individuals collected varied among study sites as well as seasonally (see Figures 4 and 5). The AuSable River site had the greatest mean annual density of individuals, and the lower Jordan site had the lowest density. The density of individuals was relatively stable at the upper Jordan and Red Cedar sites throughout the year, but highly variable at the lower Jordan and AuSable sites. Density was highest in the spring and lowest during the fall. The exceptionally high density in July at the lower Jordan site was due to the large

Figure 2. Number of intolerant, facultative, and tolerant species collected at the four study sites during spring and summer, 1970.



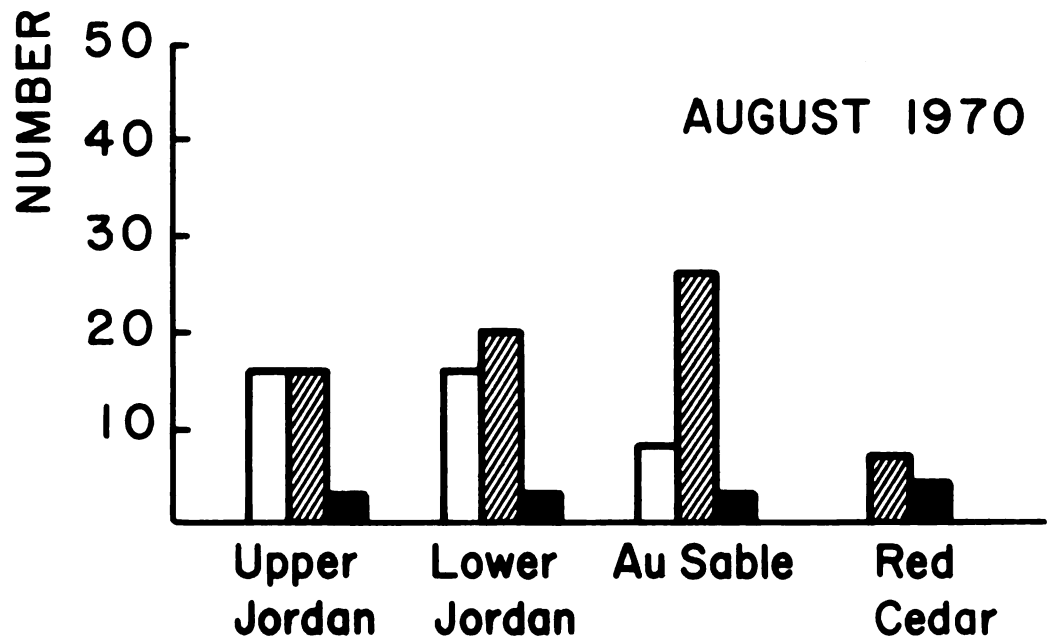
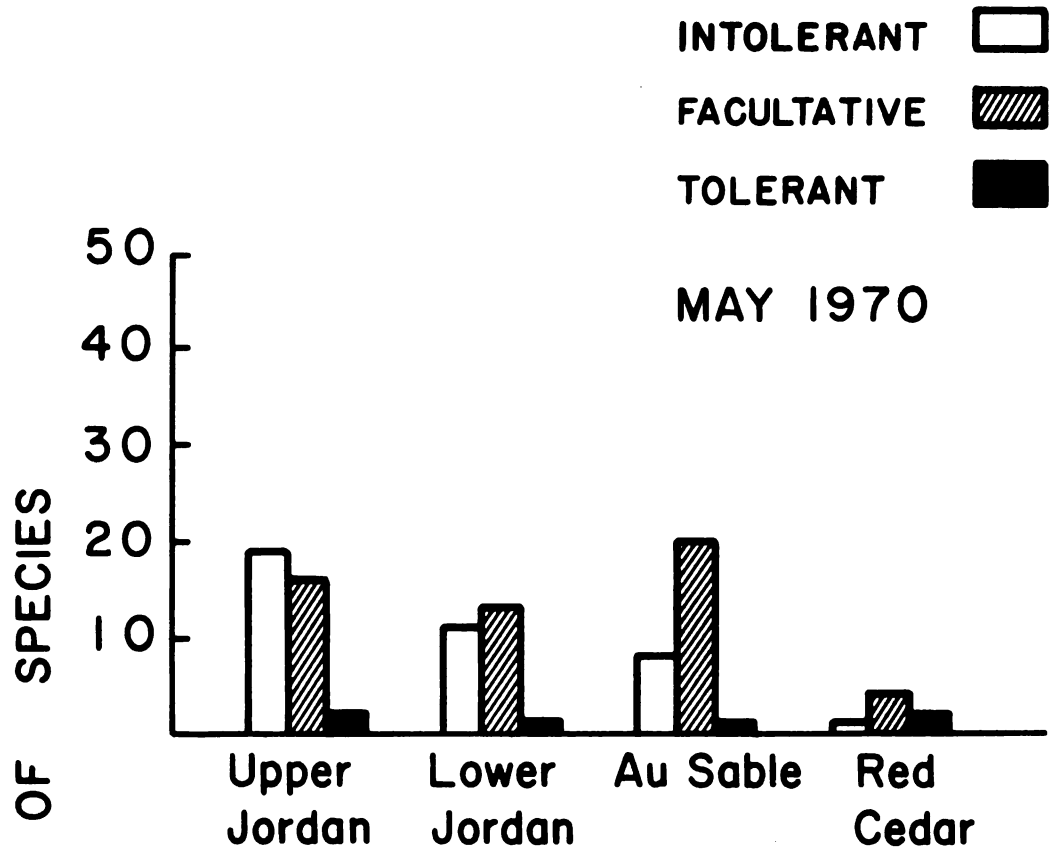


Figure 3. Number of intolerant, facultative, and tolerant species collected at the four study sites during fall and winter, 1970.

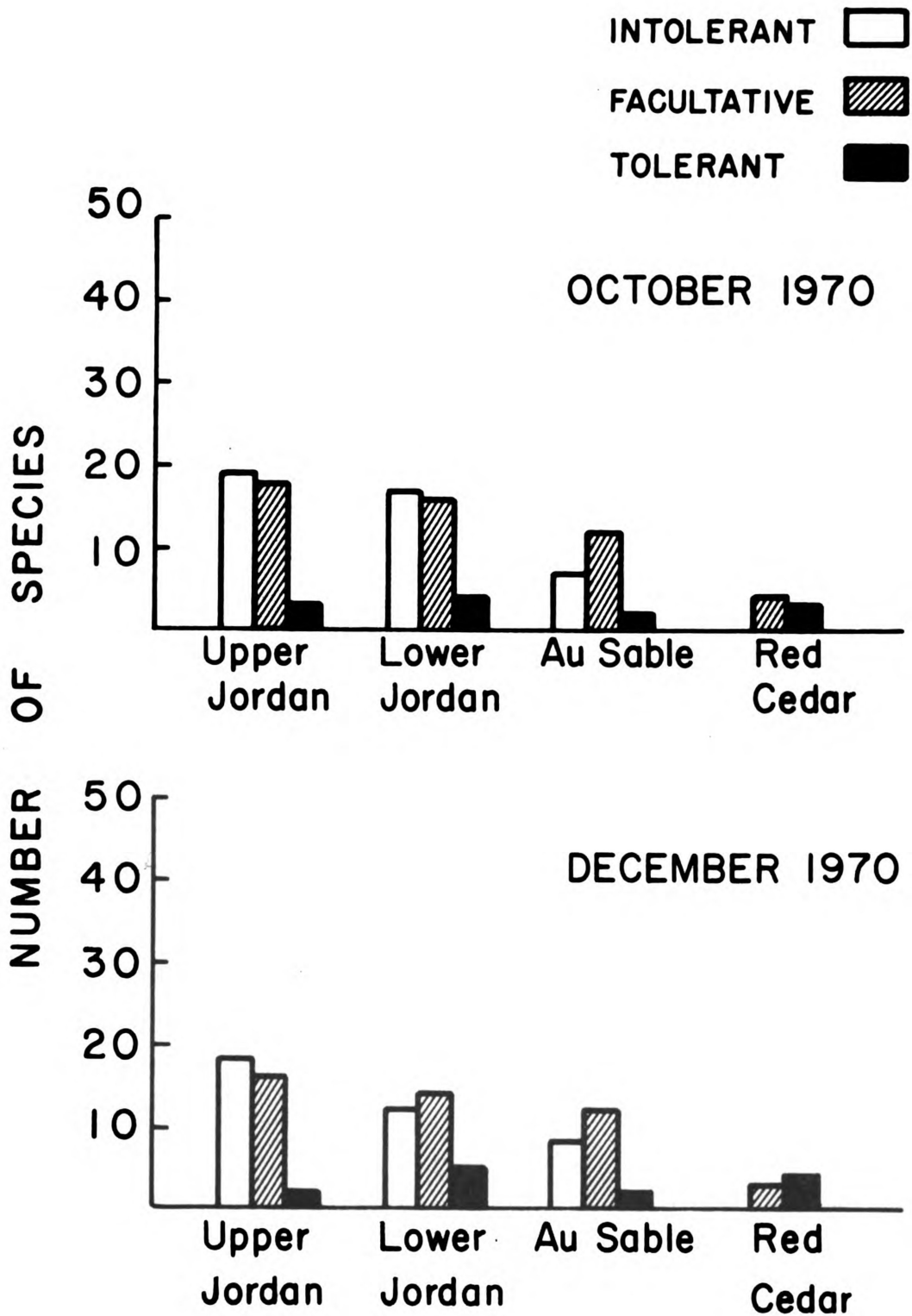


Figure 4. Density of benthic macroinvertebrates in aquatic macrophyte beds at the upper and lower Jordan study sites from May, 1970, to February, 1971. ( $\bar{x} \pm 1 \text{ SE}$ )

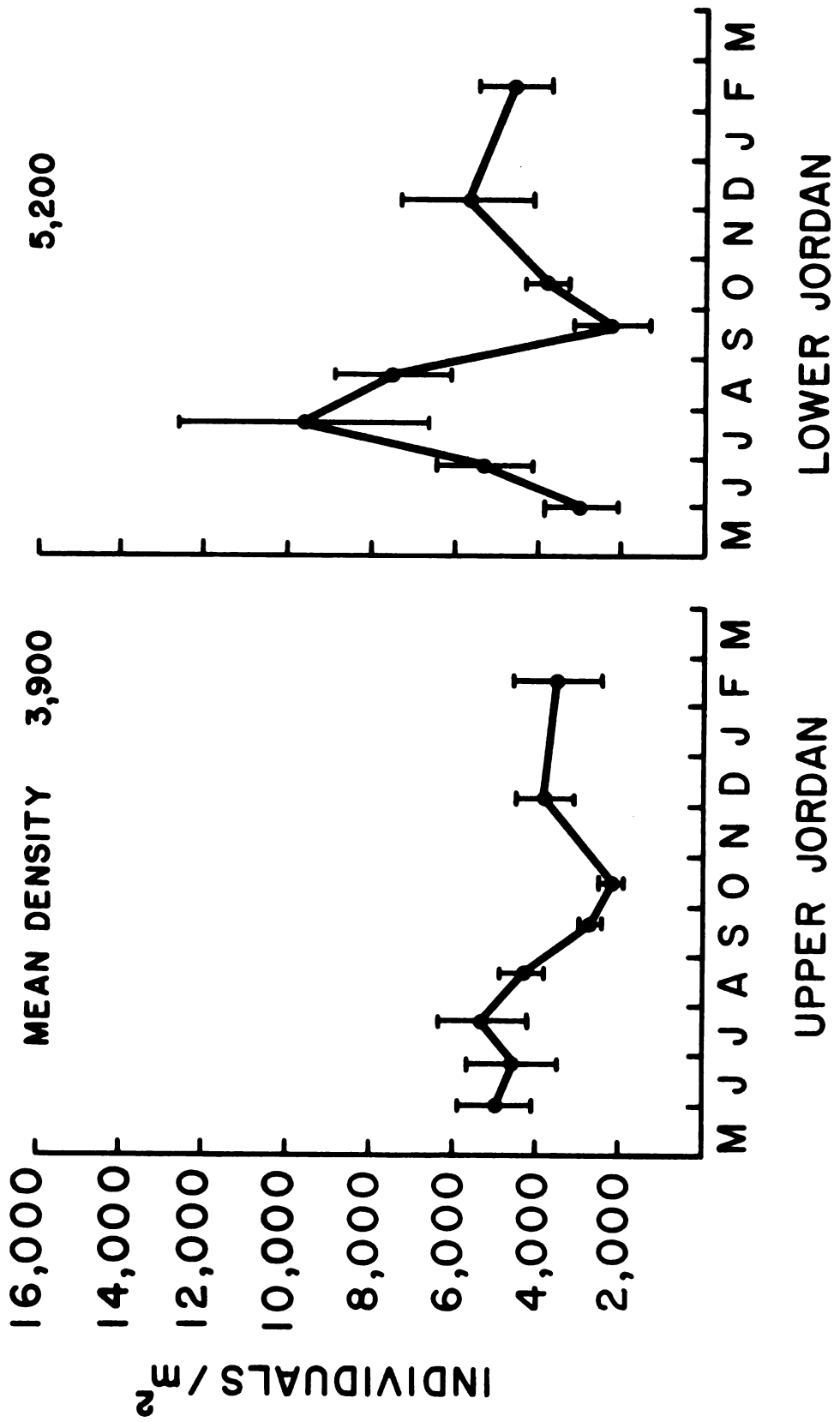
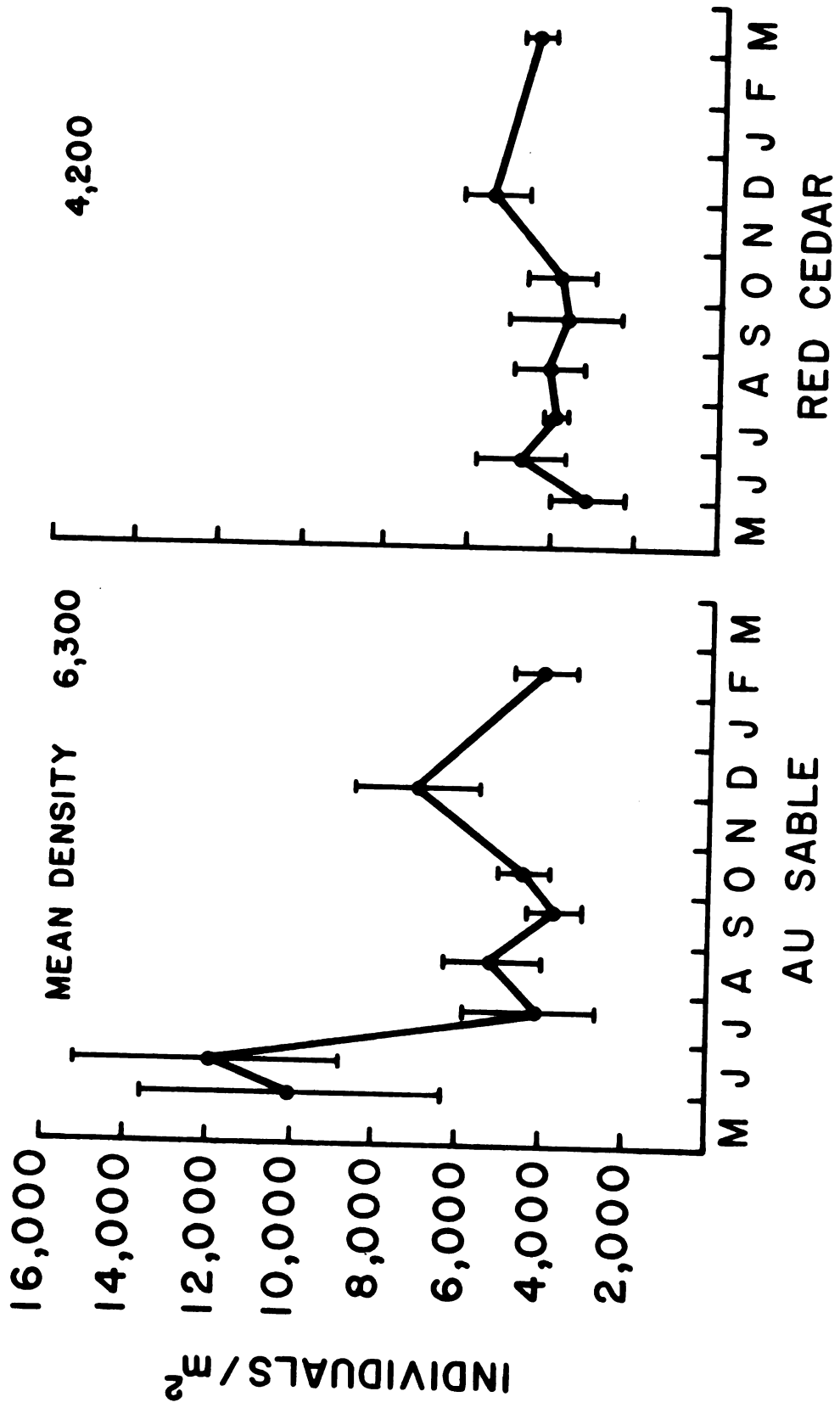


Figure 5. Density of benthic macroinvertebrates in aquatic macrophyte beds at the AuSable and Red Cedar study sites from May, 1970, to March, 1971. ( $\bar{x} \pm 1 \text{ SE}$ )



population of Tricorythodes sp. present at that time. The large populations of Gammarus fasciatus and Asellus militaris present during spring and winter at the AuSable site account for the high densities observed in May, June, and December.

Species diversity varied among sites as well as seasonally. The Shannon (Figure 6) and Brillouin (Figure 7) formulas produced almost identical results. Mean annual diversity (Table 6) was highest at the upper Jordan study site, considerably lower at the lower Jordan study site, lower still at the AuSable study site, and lowest at the Red Cedar site. Diversity was generally highest during late summer and lowest during mid-winter.

Diversity was high and stable during the year at the upper Jordan study site, ranging between 4.08 in August to 4.84 in September, and equitability was always high. Values of diversity in this range are typical of unpolluted streams (Mathis, 1968).

Diversity was always lower at the lower Jordan site than at the upper site and more variable, ranging from 2.27 in June to 4.03 in September. In general, the same species of organisms were present at both the Jordan River sites, but a slightly reduced number of species and lowered equitability resulted in lower species diversity. The extremely low diversity in June was due primarily to the large numbers of Tricorythodes sp. collected at that time.



Figure 6. Species diversity, as calculated by Shannon's formula, at the four study sites from May, 1970, to March, 1971.

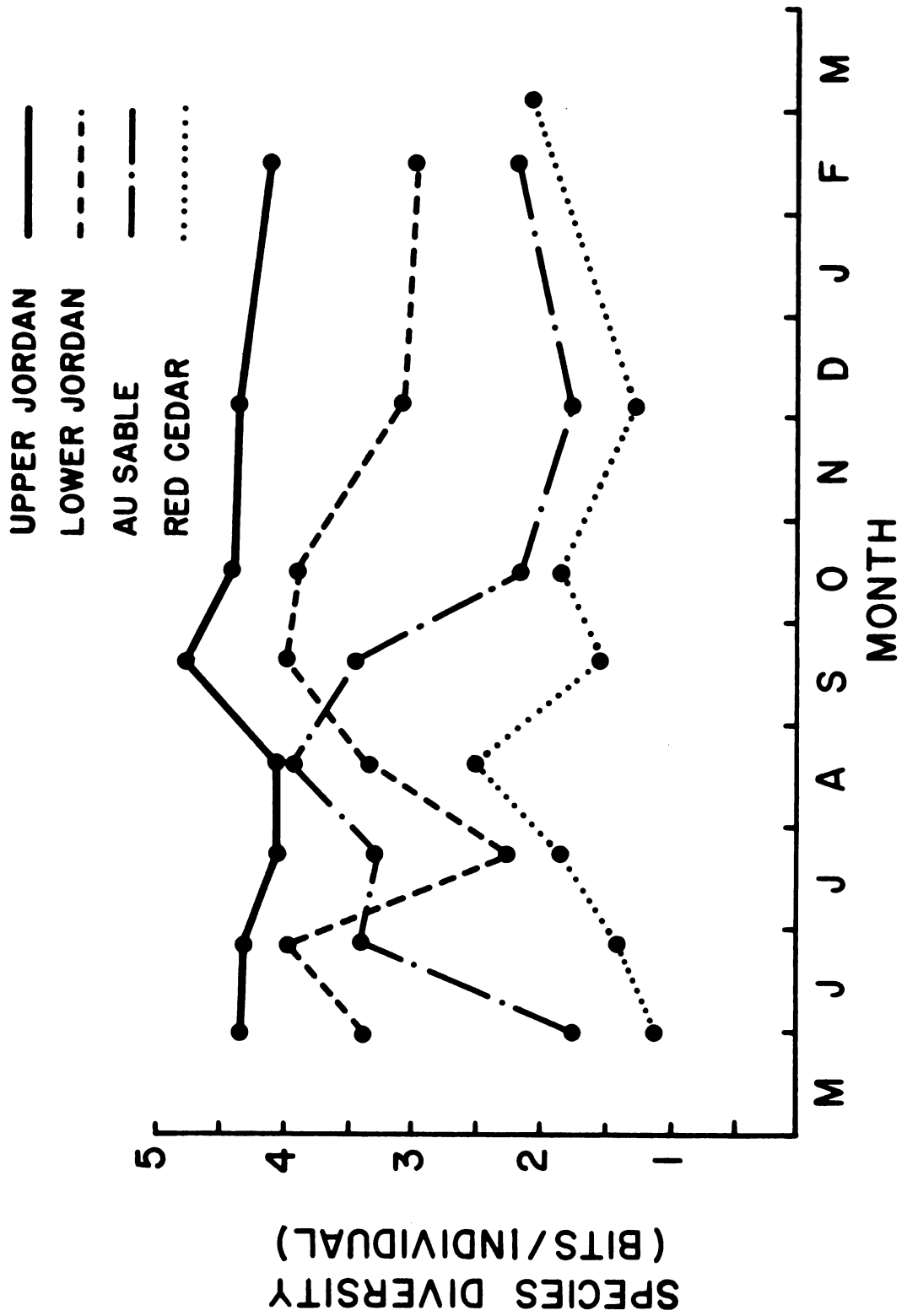


Figure 7. Species diversity, as calculated by Brillouin's formula, at the four study sites from May, 1970, to March, 1971.

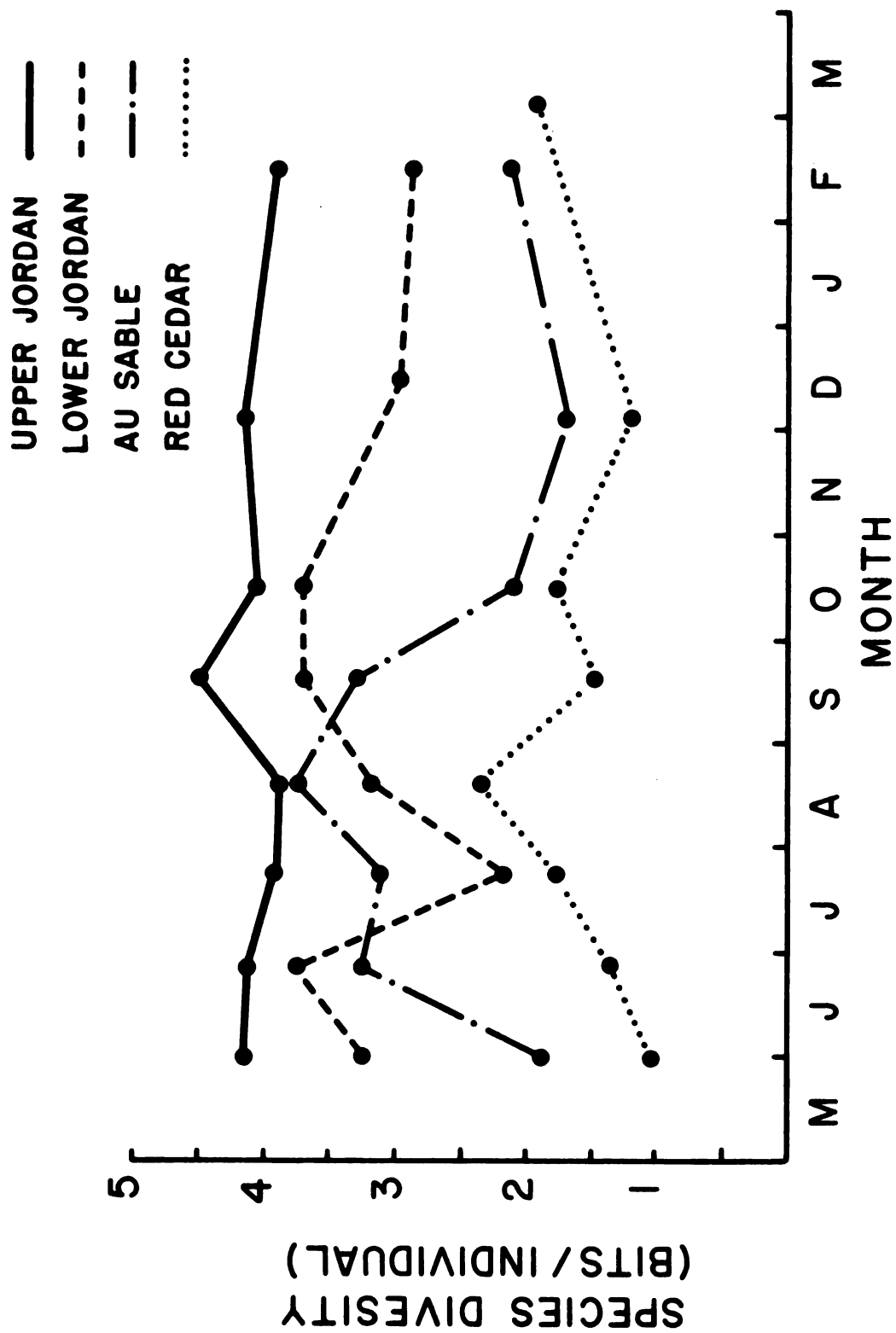


TABLE 6.--Species diversity ( $\bar{d}$ ), as calculated by Shannon's method, and equitability (E) at the four study sites from May, 1970, to March, 1971.

| Date      | Study Site   |       |              |       |           |       |
|-----------|--------------|-------|--------------|-------|-----------|-------|
|           | Upper Jordan |       | Lower Jordan |       | AuSable   |       |
|           | $\bar{d}$    | E     | $\bar{d}$    | E     | $\bar{d}$ | E     |
| May       | 4.37         | (.46) | 3.44         | (.44) | 1.76      | (.09) |
| June      | 4.34         | (.48) | 3.88         | (.39) | 3.41      | (.35) |
| July      | 4.10         | (.47) | 2.27         | (.13) | 3.28      | (.16) |
| August    | 4.08         | (.49) | 3.34         | (.26) | 3.97      | (.41) |
| September | 4.84         | (.64) | 4.03         | (.47) | 3.46      | (.35) |
| October   | 4.43         | (.55) | 3.92         | (.39) | 2.19      | (.20) |
| December  | 4.36         | (.57) | 3.10         | (.29) | 1.75      | (.15) |
| February  | 4.12         | (.47) | 2.98         | (.26) | 2.23      | (.18) |
| March     |              |       |              |       | 2.10      | (.38) |
| MEAN      |              |       |              |       |           |       |
| ANNUAL    |              |       |              |       |           |       |
| DIVERSITY | 4.33         |       | 3.37         |       | 2.76      |       |
|           |              |       |              |       | 1.70      |       |

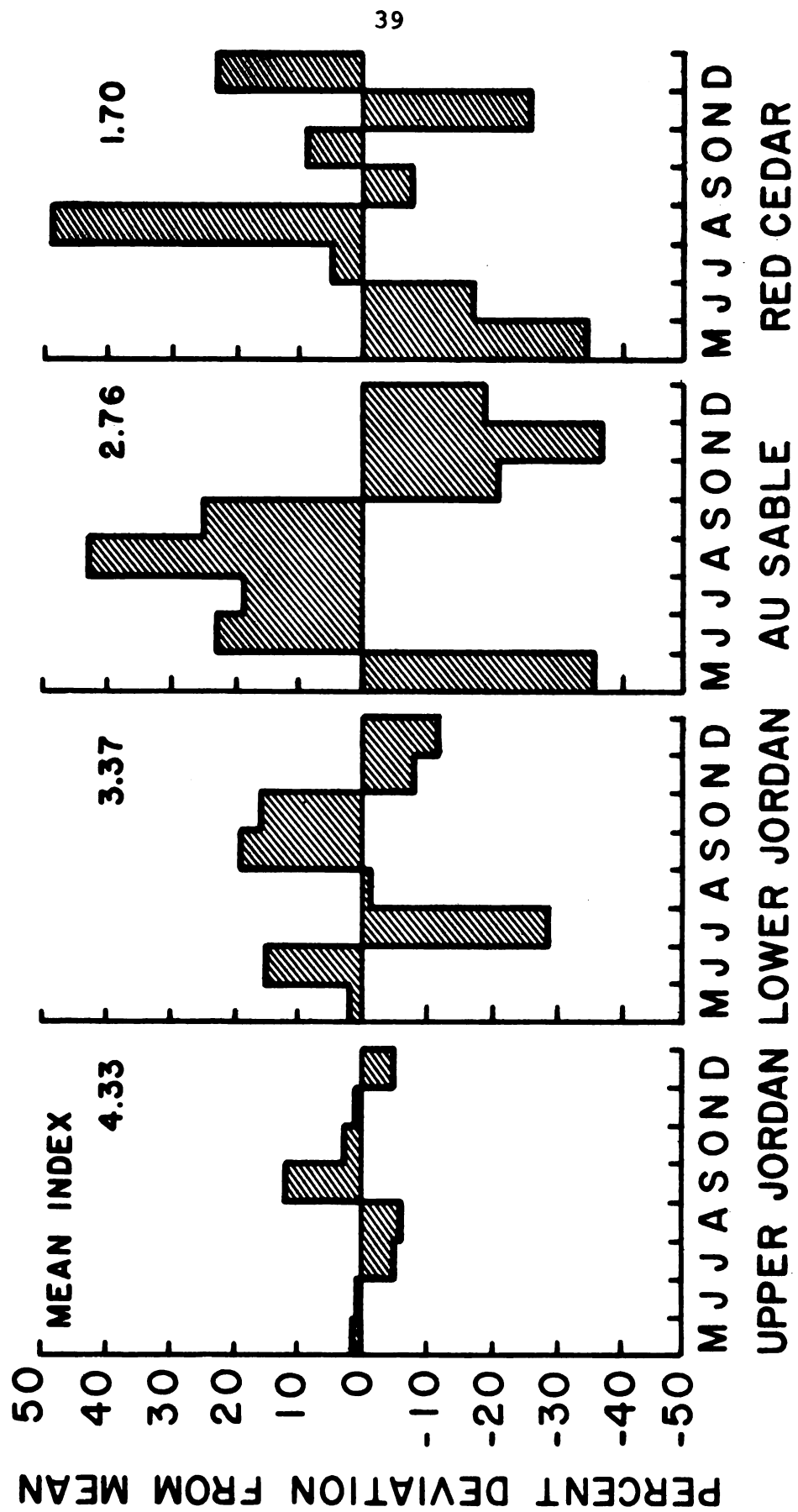
At the AuSable site, species diversity was usually lower than at the lower Jordan site. Diversity and equitability were very low in the fall, winter, and spring as a result of the large populations of amphipods and isopods present during those seasons. Diversity was also highly variable, ranging from 1.76 in May to 3.97 in August. Values of less than 3 are usually indicative of moderate pollution (Wilhm and Dorris, 1968).

Diversity was low and variable at the Red Cedar site, ranging between 1.11 in May to 2.53 in August. The extremely low number of species and low equitability, although not quite as low as the equitability of the AuSable site, resulted in the low diversity. Values in this range also indicate moderate pollution.

Percent deviation of monthly diversity indices from the mean annual index is shown in Figure 8. The index at the upper Jordan site, which showed the least variability of the four sites, fluctuated only slightly during an annual cycle. Fluctuations in the index were greater at the lower Jordan site. The Red Cedar and AuSable sites were the most variable sites, but the fluctuation of the Red Cedar index was slightly less than the fluctuation of the AuSable index.

Another measure of variability, the coefficient of variation of the mean annual index, substantiates these results. The coefficient of variation of the index of the

Figure 8. Percent deviation of monthly diversity indices from the mean annual index at the four study sites.





upper Jordan site was only 6%, while the coefficient of the lower Jordan index was 18%. The coefficient of the AuSable index was 31%, but the coefficient of the Red Cedar index was 27%.

## DISCUSSION

The abundance of species and individuals in the aquatic macrophyte beds at the four study sites was related to the degree of perturbation at the sites. Numbers of species were highest under the lower levels of perturbation and lowest under the higher levels of perturbation. Abundance of individuals increased as the level of perturbation increased until the level of perturbation reached an extremely severe level at the Red Cedar site. Increased levels of nutrients at the other sites probably resulted in increased productivity of benthic organisms, but the severe conditions at the Red Cedar site may have limited the abundance of organisms.

The theoretical major regulators of species diversity are stability, predictability, and rigor of the environment (Poulson and Culver, 1969). High species diversity environments are characterized by high environmental predictability and low variability (Slobodkin and Sanders, 1969). Slobodkin and Sanders have categorized low diversity environments as "(1) 'new' environments, in which the number of species is in the process of increasing, (2)

'severe' environments, which may become completely abiotic with relatively slight environmental change, and (3) 'unpredictable' environments, in which the variances of environmental properties around their mean values are relatively high and unpredictable both spatially and temporally." They believe that the severity and unpredictability of certain environments limits the species of organisms that can live in these environments, resulting in low species diversity. If two regions have identical geometric and geological properties, the less severe and more predictable will have greater species diversity.

There are several other important factors that influence species diversity. Environments with high spatial heterogeneity tend to have greater species diversity than less geometrically complex environments (Poulson and Culver, 1969). Margalef (1968) has proposed that a sudden increase in primary productivity lowers species diversity because not every species responds equally to the increase, resulting in greater unevenness of species abundances. Paine (1966) has shown that a decrease in the number of predator species in a food web results in decreased diversity. Diversity of animals can also be related to the diversity of plants (Slobodkin and Sanders, 1969). The major regulators combined with these factors control the species diversity of ecological communities.

Species diversity indices have been proposed as sensitive indicators of ecological change (Wilhm and Dorris, 1968; Hooper, 1969). Changes in the environment caused by man reduce the predictability and stability and may increase the rigor of the environment, resulting in lowered species diversity. This study showed that species diversity of benthic macroinvertebrates was inversely related to the degree of human perturbation.

Species diversity of benthic macroinvertebrates was high throughout the year at the upper Jordan study site. Similar ranges of values have been reported for other natural stream communities (Mathis, 1968). The environment at the upper Jordan was probably as predictable, as stable, and as least rigorous as possible in a stream in the Temperate Zone and has remained unchanged by human perturbation. Diversity was high under these conditions as expected.

Species diversity at the lower Jordan study site was lower than at the upper Jordan site, indicating an environmental change, probably caused by the fish hatchery effluent entering the stream. The Michigan Water Resources Commission (1969) reported that the fish hatchery effluent had caused a degradation of community composition of benthic organisms in the three miles of stream below the hatchery outfall. This study indicates that the effects of the hatchery effluent extend as far as 22 km below

the hatchery. To the organisms in a pristine trout stream, artificially accelerated enrichment is a very unpredictable event and would decrease diversity according to Slobodkin and Sanders' (1969) theory. The increased nutrients probably increased primary productivity and may have produced lowered equitability and diversity as Margalef (1968) suggests.

Species diversity was usually lower at the AuSable study site than at the lower Jordan site. The level of enrichment was greater than at the lower Jordan site, and lower oxygen concentrations and greater diurnal fluctuation created a more rigorous and unpredictable environment. Popma (1971), in a study of aquatic macrophytes done concurrently and at the same study sites as were used in this study, reported that seasonal fluctuations in the standing crop of aquatic macrophytes were also very great at the AuSable site. Cole (1971) studied a macroinvertebrate community below a source of gross organic enrichment and found that species diversity was not significantly reduced in a section of stream dominated by aquatic macrophytes. He concluded that the macrophytes increased spatial heterogeneity by creating patches of plants and sediments in the exposed rubble bottom of the stream, thereby maintaining diversity. The dense growth of Potamogeton filiformis that dominated the gravel bottom in the center of the stream at the AuSable site during

the summer months probably increased spatial heterogeneity and may account for the relatively high diversity values observed during the summer.

Species diversity was very low at the Red Cedar study site, the site with the least stable and predictable and most rigorous environment. The very low concentrations of oxygen, severe flooding, and presence of pesticides, metal plating wastes, and large amounts of silt contributed to the severity of the environment. The predictability and stability of the environment were reduced by the highly variable water level. The spatial heterogeneity of the bottom was reduced by the covering of silt and organic sediment. Only organisms with broad tolerance limits could exist in this environment, and the lack of competitors and predators enabled a few tolerant species to become very abundant.

Stability of ecological communities increases as the number of links in the food web increase (MacArthur, 1955). Human perturbation may eliminate intolerant organisms and reduce the complexity of the food web, resulting in increased fluctuations in numbers and abundances of species. These fluctuations should be reflected in the variability of the diversity index of a community over a period of time, and species diversity of benthic macro-invertebrates has been reported to be variable during the year and to be more variable in communities in polluted

waters (Wilhm and Dorris, 1966). This study indicated that the variability of the diversity index of a community during an annual cycle generally increased as the level of perturbation increased.

Information theory indices of species diversity appear to be sensitive to even slight changes in community structure caused by human perturbation. They were sensitive enough to detect a difference in community structure between the communities at the upper and lower Jordan study sites that was not found by other methods. They also indicated a degradation of water quality at the AuSable study site, although this section of the stream is still considered a good trout fishing area.

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## APPENDIX

TABLE A1. Species collected at the upper Jordan study site on the sampling dates.

| Species                      | Number Collected* |      |      |      |      |       |      |         |  |  |
|------------------------------|-------------------|------|------|------|------|-------|------|---------|--|--|
|                              | 5/30/70           | 6/25 | 7/24 | 8/19 | 9/21 | 10/17 | 12/3 | 2/14/71 |  |  |
| OLIGOCHAETA                  |                   |      |      |      |      |       |      |         |  |  |
| <u>Limnodrilus</u> sp.       | 3                 | 3    |      | 9    | 18   | 5     | 1    | 1       |  |  |
| <u>Lumbriculus</u> sp.       |                   | 4    | 1    | 3    | 3    | 2     |      |         |  |  |
| <u>Tubifex tubifex</u>       |                   |      |      |      |      |       |      |         |  |  |
| ISOPODA                      |                   |      |      |      |      |       |      |         |  |  |
| <u>Asellus militaris</u>     | 4                 | 12   | 5    | 9    | 11   | 2     | 7    | 13      |  |  |
| AMPHIPODA                    |                   |      |      |      |      |       |      |         |  |  |
| <u>Gammarus fasciatus</u>    | 29                | 36   | 42   | 24   | 20   | 20    | 22   | 3       |  |  |
| <u>Hyalella azteca</u>       | 8                 | 2    | 3    | 2    | 7    | 2     | 3    | 5       |  |  |
| PLECOPTERA                   |                   |      |      |      |      |       |      |         |  |  |
| <u>Isoperla bilineata</u>    | 12                |      | 1    | 2    | 7    | 9     | 11   | 13      |  |  |
| <u>Isoperla confusa</u>      |                   | 9    | 16   | 1    | 1    |       |      |         |  |  |
| <u>Isoperla richardsoni</u>  | 10                | 1    |      |      |      |       |      |         |  |  |
| <u>Nemoura venosa</u>        | 7                 |      | 6    |      |      |       |      |         |  |  |
| <u>Pteronarcys dorsata</u>   |                   |      |      |      |      |       | 6    |         |  |  |
| EPHEMEROPTERA                |                   |      |      |      |      |       |      |         |  |  |
| <u>Baetis cingulatus</u>     | 16                | 2    | 2    |      | 1    | 1     |      |         |  |  |
| <u>Baetis pygmaeus</u>       | 5                 | 17   | 27   | 61   | 20   | 6     | 32   | 5       |  |  |
| <u>Baetis vagans</u>         |                   | 3    |      |      | 8    | 2     | 10   | 23      |  |  |
| <u>Baetis</u> sp.            |                   |      | 5    | 5    |      |       |      |         |  |  |
| <u>Baetisca obesa</u>        | 1                 |      |      | 1    | 7    | 10    | 1    | 6       |  |  |
| <u>Caenis</u> sp.            | 7                 | 4    |      |      | 16   | 4     |      |         |  |  |
| <u>Epeorus vitreus</u>       |                   | 2    |      |      |      |       |      |         |  |  |
| <u>Ephemera simulans</u>     | 2                 | 1    |      |      | 2    | 1     |      | 1       |  |  |
| <u>Ephemerella deficiens</u> |                   |      |      |      |      |       |      |         |  |  |
| <u>Ephemerella rotunda</u>   | 34                |      | 1    |      | 3    | 2     | 16   | 31      |  |  |
| <u>Ephemerella simplex</u>   |                   | 6    |      |      |      |       |      |         |  |  |
| <u>Emphemerella subvaria</u> |                   |      |      |      | 1    | 8     | 65   | 47      |  |  |

TABLE A1. Continued.

| Species                         | Number Collected |      |      |      |      |       |      |         |  |   |
|---------------------------------|------------------|------|------|------|------|-------|------|---------|--|---|
|                                 | 5/30/70          | 6/25 | 7/24 | 8/19 | 9/21 | 10/17 | 12/3 | 2/14/71 |  |   |
| <u>Ephemerella temporalis</u>   | 2                | 6    |      |      | 1    | 1     |      |         |  |   |
| <u>Hexagenia limbata</u>        |                  | 1    | 2    | 1    |      | 1     |      |         |  | 1 |
| <u>Leptophlebia nebulosa</u>    |                  |      |      |      |      | 7     |      |         |  |   |
| <u>Paraleptophlebia debilis</u> |                  | 4    | 12   | 36   | 5    | 4     |      |         |  |   |
| <u>Paraleptophlebia mollis</u>  | 16               | 2    |      |      |      | 1     | 1    | 2       |  |   |
| <u>Pseudocloeon anoka</u>       |                  | 25   | 33   | 33   | 3    | 3     | 6    | 17      |  |   |
| <u>Stenonema fuscum</u>         |                  | 2    | 1    | 2    | 8    | 6     | 11   | 11      |  |   |
| <u>Tricorythodes sp.</u>        |                  | 52   | 89   | 18   |      |       |      |         |  |   |
| TRICHOPTERA                     |                  |      |      |      |      |       |      |         |  |   |
| <u>Brachycentrus americanus</u> | 3                | 1    |      |      |      |       | 2    | 2       |  |   |
| <u>Brachycentrus numerosus</u>  |                  |      |      |      |      |       | 1    |         |  |   |
| <u>Cheumatopsyche sp.</u>       | 2                | 1    | 5    |      | 1    |       |      | 6       |  |   |
| <u>Goera sp.</u>                |                  |      |      |      | 1    |       |      |         |  |   |
| <u>Hydropsyche bifida</u>       | 7                | 5    | 4    | 6    | 5    |       |      | 52      |  |   |
| <u>Lepidostoma sp.</u>          | 37               | 43   | 17   | 13   | 12   | 12    | 11   | 3       |  |   |
| <u>Limnephilus consocius</u>    |                  |      |      |      | 3    | 21    | 23   |         |  |   |
| <u>Molanna sp.</u>              | 4                | 1    |      | 4    | 12   | 10    | 5    | 1       |  |   |
| <u>Nemotaulius sp.</u>          |                  |      |      |      |      | 6     | 6    | 1       |  |   |
| <u>Neureclipsis sp.</u>         |                  |      |      | 2    |      | 2     |      | 1       |  |   |
| <u>Oligostomis ocelligera</u>   |                  |      | 1    |      | 2    |       |      |         |  |   |
| <u>Oxyethira sp.</u>            |                  |      |      |      | 2    |       | 1    | 1       |  |   |
| <u>Polycentropus cinereus</u>   |                  |      | 1    |      | 5    |       | 1    |         |  |   |
| <u>Pycnopsyche guttifer</u>     |                  |      |      |      |      |       | 9    |         |  |   |
| <u>Trentonius sp.</u>           | 46               | 3    | 2    |      |      | 1     |      | 7       |  |   |
| ODONATA                         |                  |      |      |      |      |       |      |         |  |   |
| <u>Agrion sp.</u>               |                  |      |      |      | 3    |       |      |         |  |   |
| <u>Cordulegaster sp.</u>        | 1                |      |      |      |      | 1     |      |         |  |   |
| MEGALOPTERA                     |                  |      |      |      |      |       |      |         |  |   |
| <u>Chauliodes sp.</u>           | 2                |      | 1    | 1    |      | 1     |      |         |  |   |

TABLE A1. Continued.

| Species                     | Number Collected |      |      |      |      |       |      |         |  |  |
|-----------------------------|------------------|------|------|------|------|-------|------|---------|--|--|
|                             | 5/30/70          | 6/25 | 7/24 | 8/19 | 9/21 | 10/17 | 12/3 | 2/14/71 |  |  |
| <u>Sialis</u> sp.           | 5                | 8    | 6    | 6    | 6    | 7     |      | 2       |  |  |
| LEPIDOPTERA                 |                  |      |      |      |      |       |      |         |  |  |
| <u>Nymphula</u> sp.         |                  |      | 1    |      |      |       |      |         |  |  |
| COLEOPTERA                  |                  |      |      |      |      |       |      |         |  |  |
| Dytiscidae                  |                  | 1    |      |      |      |       |      |         |  |  |
| <u>Limnius</u> sp.          | 1                | 1    |      | 2    | 1    |       |      | 2       |  |  |
| DIPTERA                     |                  |      |      |      |      |       |      |         |  |  |
| Ceratopogonidae             | 5                |      | 4    | 6    | 5    | 1     | 1    | 3       |  |  |
| <u>Chrysops</u> celer       |                  |      |      |      | 1    | 1     | 1    |         |  |  |
| <u>Corynoneura</u> sp.      | 4                | 14   | 11   | 7    | 2    | 2     |      | 1       |  |  |
| <u>Cricotopus</u> sp.       |                  |      |      |      |      |       |      | 11      |  |  |
| <u>Cryptochironomus</u> sp. |                  |      | 5    | 1    |      |       |      |         |  |  |
| <u>Diamesa</u> sp.          | 4                | 16   |      |      |      |       |      |         |  |  |
| <u>Limnophila</u> sp.       | 6                | 3    | 3    | 1    | 2    |       | 2    | 1       |  |  |
| <u>Metriocnemus</u> sp.     |                  |      |      | 36   | 2    | 3     |      |         |  |  |
| <u>Microprosectra</u> sp.   | 17               | 27   | 69   | 98   |      | 1     | 31   | 42      |  |  |
| <u>Microtendipes</u> sp.    |                  |      |      | 1    | 1    | 3     |      |         |  |  |
| <u>Nanocladius</u> sp.      |                  |      |      |      | 4    |       | 12   | 4       |  |  |
| <u>Pentaneura</u> sp.       | 86               | 74   | 66   | 41   | 28   | 10    | 14   | 3       |  |  |
| <u>Polypedilum</u> sp. a    | 28               | 10   | 16   | 12   | 7    | 3     | 1    |         |  |  |
| <u>Polypedilum</u> sp. b    | 11               | 7    |      |      | 1    |       |      |         |  |  |
| <u>Procladius</u> sp.       |                  |      |      | 9    | 5    | 4     | 7    | 1       |  |  |
| <u>Prodiamesa</u> sp.       |                  |      | 36   |      |      |       |      |         |  |  |
| <u>Psectrocladius</u> sp.   |                  |      |      |      |      |       | 16   |         |  |  |
| <u>Ptychoptera</u> sp.      | 1                |      |      |      | 2    |       |      |         |  |  |
| <u>Simulium</u> sp.         |                  | 4    | 7    | 1    |      |       | 21   | 7       |  |  |
| GASTROPODA                  |                  |      |      |      |      |       |      |         |  |  |
| <u>Amnicola</u> sp.         | 1                |      |      |      |      |       |      |         |  |  |
| <u>Gyraulus</u> sp.         | 2                | 1    |      |      |      |       |      |         |  |  |

TABLE A1. Continued.

| Species           | Number Collected |      |      |      |      |       |      |         |
|-------------------|------------------|------|------|------|------|-------|------|---------|
|                   | 5/30-70          | 6/25 | 7/24 | 8/19 | 9/21 | 10/17 | 12/3 | 2/14/71 |
| <u>Physa</u> sp.  | 25               | 41   | 19   | 6    | 21   | 51    | 51   | 9       |
| <u>PELECYPODA</u> |                  |      |      |      |      |       |      |         |
| Sphaerium sp.     | 74               | 44   | 61   | 23   | 22   | 10    | 3    | 7       |

\*To convert to number per m<sup>2</sup>, multiply by 8.33.



TABLE A2. Species collected at the lower Jordan study site on the sampling dates.

| Species                        | Number Collected* |      |      |      |      |       |      |         |
|--------------------------------|-------------------|------|------|------|------|-------|------|---------|
|                                | 5/30/70           | 6/24 | 7/23 | 8/19 | 9/20 | 10/16 | 12/3 | 2/14/71 |
| TRICLADIA                      |                   |      |      |      |      |       |      |         |
| <u>Dugesia tigrina</u>         |                   |      | 1    | 5    | 5    | 3     | 6    | 4       |
| OLIGOCHAETA                    |                   |      |      |      |      |       |      |         |
| <u>Limnodrilus sp.</u>         |                   | 19   | 5    | 3    | 8    |       | 1    |         |
| <u>Lumbriculus sp.</u>         | 52                | 71   | 17   | 34   | 25   | 25    | 16   | 7       |
| <u>Tubifex tubifex</u>         |                   |      | 4    |      | 1    |       | 1    | 1       |
| HIRUDINEA                      |                   |      |      |      |      |       |      |         |
| <u>Glossiphonia complanata</u> |                   |      | 1    |      |      |       |      |         |
| <u>Helobdella stagnalis</u>    |                   |      | 2    |      |      |       |      |         |
| AMPHIPODA                      |                   |      |      |      |      |       |      |         |
| <u>Gammarus fasciatus</u>      | 3                 | 5    | 6    | 4    | 3    | 5     | 9    | 2       |
| <u>Hyalella azteca</u>         |                   | 1    | 1    | 1    | 1    | 1     |      | 1       |
| DECAPODA                       |                   |      |      |      |      |       |      |         |
| <u>Orconectes virilis</u>      |                   |      | 1    |      | 1    |       |      |         |
| PLECOPTERA                     |                   |      |      |      |      |       |      |         |
| <u>Brachyptera gracialis</u>   |                   |      |      |      |      |       |      | 6       |
| <u>Isoperla bilineata</u>      | 4                 | 1    | 2    | 7    | 4    | 39    | 51   | 19      |
| <u>Isoperla confusa</u>        |                   |      |      |      |      |       | 6    | 6       |
| <u>Isoperla richardsoni</u>    | 9                 | 11   |      |      |      |       |      |         |
| <u>Peltoperla sp.</u>          |                   | 1    |      |      |      |       |      |         |
| <u>Pteronarcys dorsata</u>     |                   | 3    |      |      |      | 1     | 6    | 1       |
| EPHEMEROPTERA                  |                   |      |      |      |      |       |      |         |
| <u>Baetis brunneicolor</u>     |                   | 1    |      | 4    |      |       |      |         |
| <u>Baetis cingulatus</u>       |                   |      |      |      |      | 1     |      |         |
| <u>Baetis pygmaeus</u>         |                   |      |      |      | 2    |       |      |         |
| <u>Baetis vagans</u>           |                   | 15   | 11   | 6    | 5    | 1     |      | 5       |
| <u>Baetis sp.</u>              | 5                 | 9    |      |      |      |       | 1    |         |
| <u>Baetisca obesa</u>          |                   |      |      |      | 2    | 6     |      |         |

TABLE A2. Continued.

| Species                         | Number Collected |      |      |      |      |       |      |         |  |    |
|---------------------------------|------------------|------|------|------|------|-------|------|---------|--|----|
|                                 | 5/30/70          | 6/24 | 7/23 | 8/19 | 9/20 | 10/16 | 12/3 | 2/14/71 |  |    |
| <u>Caenis</u> sp.               |                  |      | 1    |      |      |       |      |         |  |    |
| <u>Epeorus vitreus</u>          |                  | 1    |      |      |      |       |      |         |  |    |
| <u>Ephemerella deficiens</u>    |                  | 8    |      |      |      |       |      |         |  |    |
| <u>Ephemerella needhami</u>     | 62               | 50   |      |      |      |       |      |         |  |    |
| <u>Ephemerella rotunda</u>      | 89               |      |      | 22   |      | 98    | 205  | 246     |  |    |
| <u>Ephemerella simplex</u>      |                  | 31   | 5    |      |      |       |      |         |  |    |
| <u>Ephemerella subvaria</u>     |                  |      |      |      | 19   | 75    | 199  | 66      |  |    |
| <u>Ephemerella walkeri</u>      |                  | 1    |      |      |      |       |      |         |  |    |
| <u>Hexagenia limbata</u>        |                  | 1    | 1    | 1    |      |       |      |         |  |    |
| <u>Paraleptophlebia debilis</u> |                  |      |      | 3    |      |       |      |         |  |    |
| <u>Paraleptophlebia mollis</u>  | 3                | 7    | 21   | 37   | 3    | 31    | 18   | 8       |  |    |
| <u>Pseudocloeon anoka</u>       |                  | 56   |      | 3    | 2    | 3     | 4    | 1       |  |    |
| <u>Stenonema fuscum</u>         |                  | 125  | 695  | 166  | 7    |       |      |         |  |    |
| <u>Tricorythodes</u> sp.        |                  |      |      |      |      |       |      |         |  | 55 |
| TRICHOPTERA                     |                  |      |      |      |      |       |      |         |  |    |
| <u>Athripsodes</u> sp.          |                  | 1    |      |      |      |       |      |         |  |    |
| <u>Brachycentrus americanus</u> | 3                | 8    | 1    | 3    |      | 9     | 10   | 44      |  |    |
| <u>Brachycentrus numerosus</u>  |                  |      | 3    | 16   |      | 10    |      | 1       |  |    |
| <u>Hydropsyche bifida</u>       |                  |      | 2    | 18   |      | 11    |      | 2       |  |    |
| <u>Hydropsyche</u> sp.          | 1                |      |      |      |      |       |      |         |  |    |
| <u>Lepidostoma</u> sp.          | 12               | 21   | 1    | 1    | 8    | 7     | 7    | 14      |  |    |
| <u>Micrasema</u> sp.            |                  | 32   |      |      |      |       |      |         |  |    |
| <u>Molanna</u> sp.              |                  |      |      |      |      |       | 1    |         |  |    |
| <u>Nemotaulius</u> sp.          |                  |      |      |      |      | 2     |      |         |  |    |
| <u>Neophylax oligius</u>        |                  |      |      |      |      |       |      |         |  |    |
| <u>Neureclipsis</u> sp.         |                  |      |      | 3    | 5    | 1     |      | 3       |  |    |
| <u>Oligostomis ocelligera</u>   |                  |      | 2    |      |      |       |      |         |  |    |
| <u>Polycentropus cinereus</u>   |                  |      |      |      | 4    | 1     |      |         |  |    |
| <u>Pycnopsyche guttifer</u>     | 1                |      |      |      | 1    |       | 20   | 5       |  |    |

TABLE A2. Continued.

| Species                       | Number Collected |      |      |      |      |       |      |         |  |    |
|-------------------------------|------------------|------|------|------|------|-------|------|---------|--|----|
|                               | 5/30/70          | 6/24 | 7/23 | 8/19 | 9/20 | 10/16 | 12/3 | 2/14/71 |  |    |
| MEGALOPTERA                   |                  |      |      |      |      |       |      |         |  |    |
| <u>Chauliodes sp.</u>         |                  |      |      | 1    |      |       |      |         |  |    |
| <u>Sialis sp.</u>             |                  |      | 1    | 2    |      |       |      |         |  |    |
| LEPIDOPTERA                   |                  |      |      |      |      |       |      |         |  |    |
| <u>Nymphula sp.</u>           |                  |      |      |      | 1    | 1     |      |         |  |    |
| COLEOPTERA                    |                  |      |      |      |      |       |      |         |  |    |
| <u>Gyrinus sp.</u>            |                  |      |      | 1    |      |       |      |         |  |    |
| <u>Halplidae</u>              |                  |      |      |      | 13   | 10    |      |         |  | 18 |
| <u>Limnius sp.</u>            |                  |      | 2    | 7    |      |       | 3    |         |  |    |
| DIPTERA                       |                  |      |      |      |      |       |      |         |  |    |
| <u>Atherix variegata</u>      |                  | 10   |      | 2    | 2    | 1     | 4    |         |  | 5  |
| <u>Brilla sp.</u>             | 1                |      |      |      |      |       |      |         |  | 56 |
| <u>Cardiocladius sp.</u>      |                  |      | 7    |      |      |       |      |         |  |    |
| <u>Ceratopogonidae</u>        |                  |      |      | 3    | 3    | 2     | 2    |         |  | 1  |
| <u>Chrysops celer</u>         | 7                | 22   | 14   | 18   | 12   | 10    | 3    |         |  | 3  |
| <u>Clinotanypus sp.</u>       | 2                |      |      |      |      |       |      |         |  |    |
| <u>Corynoneura sp.</u>        |                  | 3    | 10   | 17   | 8    | 1     |      |         |  |    |
| <u>Cricotopus sp.</u>         |                  |      |      |      |      | 17    | 13   |         |  | 5  |
| <u>Cryptochironomus sp.</u>   |                  | 7    |      |      |      |       |      |         |  |    |
| <u>Damesa sp.</u>             |                  |      |      | 2    | 2    |       |      |         |  |    |
| <u>Limnophila sp.</u>         | 1                | 1    |      | 7    |      | 3     |      |         |  |    |
| <u>Metriocnemus sp.</u>       |                  |      |      |      |      |       |      |         |  |    |
| <u>Micropectra sp.</u>        |                  | 3    | 1    | 23   |      | 1     | 6    |         |  | 4  |
| <u>Microtendipes sp.</u>      | 1                |      | 52   |      |      |       | 6    |         |  |    |
| <u>Nanocladius sp.</u>        | 4                | 10   | 30   |      | 5    |       |      |         |  |    |
| <u>Paralauterbornella sp.</u> |                  | 1    | 6    | 13   |      |       |      |         |  |    |
| <u>Pentaneura sp.</u>         | 5                | 31   | 26   | 17   | 2    | 2     | 1    |         |  | 1  |
| <u>Polypedilum sp.</u>        | 26               | 9    | 1    | 3    | 6    | 3     |      |         |  |    |
| <u>Procladius sp.</u>         | 6                |      | 6    | 6    | 3    |       |      |         |  |    |

TABLE A2. Continued.

| Species                    | Number Collected |      |      |      |      |       |      |         |
|----------------------------|------------------|------|------|------|------|-------|------|---------|
|                            | 5/30/70          | 6/24 | 7/23 | 8/19 | 9/20 | 10/16 | 12/3 | 2/14/71 |
| <u>Prodiamesa sp.</u>      |                  |      |      |      |      |       | 11   | 5       |
| <u>Psectrocladius sp.</u>  |                  |      | 2    | 40   |      |       |      |         |
| <u>Simulium sp.</u>        |                  | 9    | 81   | 315  | 71   | 28    |      | 1       |
| <u>Stenochironomus sp.</u> |                  |      |      |      | 2    |       |      |         |
| <u>Tanytarsus sp.</u>      |                  | 2    |      |      |      |       |      |         |
| <u>Tanytarsus sp.</u>      |                  | 2    |      |      |      |       |      |         |
| <u>Tipula sp.</u>          | 1                |      |      | 1    |      |       |      |         |
| GASTROPODA                 |                  |      |      |      |      |       |      |         |
| <u>Physa sp.</u>           |                  |      | 1    | 1    | 1    | 2     | 2    |         |
| PELECYPODA                 |                  |      |      |      |      |       |      |         |
| <u>Sphaerium sp.</u>       | 14               | 12   | 12   | 1    | 2    | 3     | 2    | 1       |

\*To convert to number per m<sup>2</sup>, multiply by 8.33.

TABLE A3. Species collected at the Ausable study site on the sampling dates.

| Species                        | Number Collected* |      |      |      |      |       |      |         |
|--------------------------------|-------------------|------|------|------|------|-------|------|---------|
|                                | 5/31/70           | 6/26 | 7/20 | 8/20 | 9/19 | 10/15 | 12/4 | 2/15/71 |
| <u>TRICLADIA</u>               |                   |      |      |      |      |       |      |         |
| <u>Dugesia tigrina</u>         |                   |      | 7    | 62   | 15   | 12    | 9    | 1       |
| <u>OLIGOCHAETA</u>             |                   |      |      |      |      |       |      |         |
| <u>Limnodrilus sp.</u>         |                   |      |      | 15   | 23   | 16    | 4    | 1       |
| <u>Lumbriculus sp.</u>         |                   |      |      | 12   | 13   | 5     |      |         |
| <u>Pristina sp.</u>            |                   |      |      | 6    |      |       |      |         |
| <u>Tubifex tubifex</u>         | 2                 | 14   | 3    |      |      |       |      |         |
| <u>HIRUDINEA</u>               |                   |      |      |      |      |       |      |         |
| <u>Glossiphonia complanata</u> |                   |      |      | 1    | 1    |       |      |         |
| <u>Nepheleopsis obscura</u>    | 1                 | 4    | 4    | 5    | 2    |       |      |         |
| <u>ISOPODA</u>                 |                   |      |      |      |      |       |      |         |
| <u>Asellus militaris</u>       | 93                | 219  | 40   | 90   | 85   | 117   | 160  | 134     |
| <u>AMPHIPODA</u>               |                   |      |      |      |      |       |      | 58      |
| <u>Gammarus fasciatus</u>      | 796               | 396  | 175  | 138  | 135  | 269   | 492  | 216     |
| <u>DECAPODA</u>                |                   |      |      |      |      |       |      |         |
| <u>Orconectes virilis</u>      | 1                 | 7    | 3    | 4    | 2    | 3     | 1    |         |
| <u>PLECOPTERA</u>              |                   |      |      |      |      |       |      |         |
| <u>Taeniopteryx sp.</u>        |                   |      |      |      |      |       |      | 1       |
| <u>EPHEMEROPTERA</u>           |                   |      |      |      |      |       |      |         |
| <u>Baetis brunneicolor</u>     |                   | 2    |      |      |      |       |      |         |
| <u>Baetis pygmaeus</u>         |                   | 2    |      | 2    | 1    |       |      |         |
| <u>Baetis vagans</u>           |                   | 24   |      |      |      |       |      |         |
| <u>Baetis sp.</u>              | 5                 | 44   |      | 19   |      |       |      |         |
| <u>Baetisca obesa</u>          | 1                 |      |      |      |      | 1     |      |         |
| <u>Caenis sp.</u>              |                   |      | 1    |      |      |       |      |         |
| <u>Ephemera simulans</u>       | 2                 |      |      |      |      |       |      |         |
| <u>Ephemerella deficiens</u>   |                   |      | 1    |      |      |       |      |         |
| <u>Ephemerella rotunda</u>     | 3                 |      |      |      |      |       |      |         |
| <u>Ephemerella subvaria</u>    |                   |      |      |      | 1    |       |      | 5       |

TABLE A3. Continued.

| Species                         | Number Collected |      |      |      |      |       |      |         |  |    |
|---------------------------------|------------------|------|------|------|------|-------|------|---------|--|----|
|                                 | 5/31/70          | 6/26 | 7/20 | 8/20 | 9/19 | 10/15 | 12/4 | 2/15/71 |  |    |
| <u>Hexagenia limbata</u>        |                  | 163  | 3    | 10   |      | 1     |      |         |  |    |
| <u>Pseudocloeon anoka</u>       |                  |      |      | 4    | 6    | 4     | 2    |         |  |    |
| <u>Stenonema fuscum</u>         |                  | 36   | 57   | 10   | 1    |       |      |         |  |    |
| <u>Tricorythodes sp.</u>        |                  |      |      |      |      |       |      |         |  |    |
| TRICHOPTERA                     |                  |      |      |      |      |       |      |         |  |    |
| <u>Brachycentrus americanus</u> |                  |      |      | 1    |      |       |      |         |  |    |
| <u>Brachycentrus lateralis</u>  |                  |      | 4    |      |      |       |      |         |  |    |
| <u>Cheumatopsyche sp.</u>       | 5                | 1    | 17   | 15   | 12   | 1     | 3    | 10      |  |    |
| <u>Hydropsyche bifida</u>       | 3                | 34   | 57   | 26   | 17   | 2     | 2    | 5       |  |    |
| <u>Hydropsyche slossonae</u>    |                  |      | 1    |      |      |       | 1    | 2       |  |    |
| <u>Hydropsyche sp.</u>          |                  |      |      |      |      |       | 1    | 5       |  |    |
| <u>Lepidostoma sp.</u>          | 3                | 1    |      |      | 3    | 4     | 1    | 1       |  | 59 |
| <u>Limnephilus consocius</u>    | 1                |      |      |      | 1    |       |      |         |  |    |
| <u>Molanna sp.</u>              |                  |      |      |      |      |       |      |         |  |    |
| <u>Mystacides sp.</u>           |                  |      |      |      |      |       |      | 1       |  |    |
| <u>Neureclipsis sp.</u>         |                  |      |      |      |      |       | 1    |         |  |    |
| <u>Ochrotrichia sp.</u>         |                  |      | 1    |      |      |       |      |         |  |    |
| <u>Oligostomis ocelligera</u>   |                  |      |      | 2    |      |       |      |         |  |    |
| <u>Polycentropus sp.</u>        |                  |      |      |      | 1    |       | 2    |         |  |    |
| <u>Pycnopsyche guttifer</u>     | 39               | 23   | 4    |      |      | 3     | 3    | 12      |  |    |
| <u>Trienodes marginata</u>      |                  |      | 14   |      |      |       |      |         |  |    |
| ODONATA                         |                  |      |      |      |      |       |      |         |  |    |
| <u>Agrion sp.</u>               | 1                | 1    |      |      |      |       |      |         |  |    |
| HEMIPTERA                       |                  |      |      |      |      |       |      |         |  |    |
| <u>Belostoma sp.</u>            |                  |      |      |      |      |       |      |         |  | 1  |
| MEGALOPTERA                     |                  |      |      |      |      |       |      |         |  |    |
| <u>Sialis sp.</u>               |                  |      | 2    |      |      | 1     |      |         |  |    |
| LEPIDOPTERA                     |                  |      |      |      |      |       |      |         |  |    |
| <u>Nymphula sp.</u>             |                  |      |      | 1    | 1    |       |      |         |  |    |

TABLE A3. Continued.

| Species                      | Number Collected |      |      |      |      |       |      |         |   |  |
|------------------------------|------------------|------|------|------|------|-------|------|---------|---|--|
|                              | 5/31/70          | 6/26 | 7/20 | 8/20 | 9/19 | 10/15 | 12/4 | 2/15/71 |   |  |
| <b>COLEOPTERA</b>            |                  |      |      |      |      |       |      |         |   |  |
| Dytiscidae                   |                  | 3    |      |      | 2    |       |      |         | 1 |  |
| Halipilidae                  |                  |      |      |      |      |       |      |         | 1 |  |
| Hydrophilus sp.              |                  |      |      |      |      |       |      |         |   |  |
| <b>DIPTERA</b>               |                  |      |      |      |      |       |      |         |   |  |
| Antocha sp.                  |                  |      |      | 1    |      |       |      |         |   |  |
| Chironomus (Kiefferulus) sp. |                  | 3    |      |      |      |       |      |         |   |  |
| Chrysops celer               | 1                |      |      | 1    | 1    | 1     | 3    |         |   |  |
| Corynoneura sp.              | 4                | 2    | 1    | 9    | 8    |       |      |         |   |  |
| Cricotopus sp. a             | 2                | 96   |      | 36   | 14   | 3     | 11   |         | 9 |  |
| Cricotopus sp. b             |                  | 44   |      |      |      |       |      |         |   |  |
| Cryptochironomus sp.         | 2                | 10   | 3    | 3    | 3    |       |      |         |   |  |
| Diamesa sp.                  | 9                |      |      | 1    | 5    |       |      |         |   |  |
| Microsectra sp.              | 66               | 46   | 3    | 20   | 9    | 9     | 50   |         | 1 |  |
| Microtendipes sp.            |                  |      | 3    | 6    |      |       |      |         |   |  |
| Nanocladius sp.              |                  | 29   | 6    | 7    | 14   |       |      |         |   |  |
| Pentaneura sp.               | 12               | 2    | 6    | 9    |      |       |      |         |   |  |
| Polypedilum sp. a            | 13               | 70   | 11   | 24   | 4    |       | 2    |         |   |  |
| Polypedilum sp. b            |                  |      |      | 1    |      |       |      |         |   |  |
| Procladius sp.               |                  |      | 4    | 23   | 15   | 6     | 2    |         |   |  |
| Simulium sp.                 |                  |      |      | 5    |      |       |      |         |   |  |
| Tipula sp.                   | 3                |      | 1    | 1    |      | 1     |      |         |   |  |
| <b>GASTROPODA</b>            |                  |      |      |      |      |       |      |         |   |  |
| Amnicola sp.                 | 1                | 1    | 5    | 1    |      |       |      |         |   |  |
| Physa sp.                    |                  | 3    | 2    | 1    | 3    | 3     | 6    |         | 1 |  |
| <b>PELECYPODA</b>            |                  |      |      |      |      |       |      |         |   |  |
| Pisidium sp.                 | 33               | 23   | 14   | 11   | 8    | 16    | 6    |         | 5 |  |
| Sphaerium sp.                | 4                | 4    | 2    |      |      |       |      |         |   |  |

\*To convert to number per m<sup>2</sup>, multiply by 8.33.

TABLE A4. Species collected at the Red Cedar study site on the sampling dates.

| Species                           | Number Collected* |      |      |      |      |       |       |        |
|-----------------------------------|-------------------|------|------|------|------|-------|-------|--------|
|                                   | 5/28/70           | 6/29 | 7/29 | 8/25 | 9/30 | 10/28 | 12/10 | 3/3/71 |
| TRICLADIA                         |                   |      |      |      |      |       |       |        |
| <u>Dugesia tigrina</u>            |                   |      |      | 1    |      |       |       |        |
| OLIGOCHAETA                       |                   |      |      |      |      |       |       |        |
| <u>Tubifex tubifex</u>            | 223               | 185  | 209  | 60   | 94   | 71    | 151   | 29     |
| HIRUDINEA                         |                   |      |      |      |      |       |       |        |
| <u>Helobdella stagnalis</u>       |                   | 1    | 6    | 9    | 2    | 4     | 2     | 1      |
| ISOPODA                           |                   |      |      |      |      |       |       |        |
| <u>Asellus militaris</u>          |                   |      | 1    |      | 1    |       |       | 1      |
| PLECOPTERA                        |                   |      |      |      |      |       |       |        |
| <u>Taeniopteryx maura</u>         |                   |      |      |      |      |       |       | 1      |
| EPHEMEROPTERA                     |                   |      |      |      |      |       |       |        |
| <u>Caenis sp.</u>                 |                   | 1    | 1    |      |      |       |       |        |
| <u>Hexagenia limbata</u>          | 1                 |      |      |      |      |       |       |        |
| <u>Tricorythodes sp.</u>          |                   | 1    |      |      |      |       |       |        |
| COLEOPTERA                        |                   |      |      |      |      |       |       |        |
| <u>Hydrochus sp.</u>              |                   |      |      |      |      |       |       | 1      |
| DIPTERA                           |                   |      |      |      |      |       |       |        |
| Ceratopogonidae                   |                   |      |      |      |      | 3     |       |        |
| <u>Chironomus tentans</u>         | 33                | 223  | 144  | 30   | 6    | 38    | 27    | 37     |
| <u>Cryptochironomus abortivus</u> | 2                 |      |      |      |      |       |       |        |
| <u>Cryptochironomus sp.</u>       | 1                 | 1    |      |      |      |       |       |        |
| <u>Diamesa sp.</u>                | 21                | 15   | 2    | 1    | 7    |       | 5     |        |
| <u>Orthocladius sp.</u>           |                   |      |      |      |      |       |       | 76     |
| <u>Pentaneura sp.</u>             |                   |      | 1    | 2    |      | 1     | 1     | 1      |
| <u>Phaenopsectra sp.</u>          |                   |      |      | 9    | 1    |       |       |        |
| <u>Polypedilum sp.</u>            |                   | 4    | 4    | 27   |      |       |       |        |
| <u>Procladius sp.</u>             |                   | 5    | 36   | 18   | 20   | 16    | 13    | 11     |
| <u>Psychoda sp.</u>               |                   |      |      |      |      |       |       | 2      |



TABLE A4. Continued.

| Species              | Number Collected |      |      |      |      |       |              |
|----------------------|------------------|------|------|------|------|-------|--------------|
|                      | 5/28/70          | 6/29 | 7/29 | 8/25 | 9/30 | 10/28 | 12/10 3/3/71 |
| GASTROPODA           |                  |      |      |      |      |       |              |
| Amnicola <u>sp.</u>  |                  |      | 1    | 13   |      |       | 1            |
| Physa <u>sp.</u>     |                  |      |      |      |      |       | 2            |
| PELECYPODA           |                  |      |      |      |      |       |              |
| Sphaerium <u>sp.</u> |                  | 1    | 3    | 4    | 6    | 5     |              |

\*To convert to number per m<sup>2</sup>, multiply by 8.33.

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