THE DISTRIBUTION AND ABUNDANCE OF BENTHIC MACROINVERTEBRATES NEAR THE WESTERN SHORE OF LAKE ERIE

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JACK EDWARD KELLY

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ABSTRACT

THE DISTRIBUTION AND ABUNDANCE OF
BENTHIC MACROINVERTEBRATES NEAR THE
WESTERN SHORE OF LAKE ERIE

By

Jack Edward Kelly

Benthic macroinvertebrate populations were studied from May, 1970 to June, 1975 in the vicinity of the Monroe power plant on western Lake Erie. Samples were collected with a Ponar dredge and subsequently washed free of sediments in a 0.5 mm diameter wire screen tub. One-way analysis of variance and Tukey's multiple range comparison tests were used to assess apparent differences in densities, mean sizes, and age ratios.

Although eight major taxonomic groups were collected during the study, two groups (Tubificidae and Chironomidae) comprised 99% of the total organisms. Some ramification of power plant operation depressed benthic macroinvertebrate abundances in the plant's discharge canal and an adjacent, shallow tributary, but appeared to have no effect at the lake stations. Benthic macroinvertebrate densities and diversities, otherwise, seemed to be related to sediment size and other related environmental factors.

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A THESIS

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INTRODUCTION

There has been an increasing concern about the changes that have occurred during past decades in Lake Erie. Dramatic changes in the benthic fauna probably more than any other event served to focus attention on the degree of damage already caused to the western basin. Britt (1955) associated a 90% reduction in the mayfly population, over a few weeks time, with the depletion of oxygen from the bottom waters. Since then, Carr and Hiltunen (1965) have reported on the changes in the benthic community which occurred in western Lake Erie since Wright's (1955) survey in 1928-30. The diversity of the macroinvertebrate benthic community has decreased to one dominated by a few species of Tubificidae, Chiromidae, Gastropoda and Sphaeridae.

The benthic macroinvertebrates are subject to many natural and artificial environmental factors. The effect of these factors are not independent of one another but may form complex interactions. Natural events that could have an effect on benthic abundances include water level changes, meteorological changes, changes in food availability (bacteria populations, phytoplankton populations, other benthic animals and the sediment detritus base), changes in predatory fish populations, changes in the physical and chemical environment (mainly temperature and oxygen), and changes in the sediment size composition. Artificial factors which may have an effect include municipal and industrial wastes, dredging and power plant operation (dike building, heated effluent and reduced oxygen beneath the plume).

The Monroe power plant, owned and operated by the Detroit Edison Company, has been the focal point of a comprehensive ecological sampling program through which data for this paper were gathered. The objectives of this research are: 1) to examine the distribution and abundance of the benthic macroinvertebrates that occur in the study area, 2) to analyze population changes over the duration of the study, and 3) to discuss the relative impacts of artificial and natural changes in the environment upon any observed changes in the benthic populations.

MATERIALS AND METHODS

Description of the Study Area

The study area is located in the western basin of Lake Erie near the mouth of the Raisin River at Monroe, Michigan (Figure 1). The western basin is a shallow, turbid body of water. Beeton (1961) attributes the high turbidities to wind-generated resuspension of bottom sediments, river discharge and, to a lesser extent, plankton densities. The prevailing southwesterly winds along with the interaction of the Detroit (95% of the drainage water entering Lake Erie) and Maumee (3%) Rivers generally cause the water along the western shore to circulate in a clockwise eddy (Hartley, et al., 1966). Temperatures in the lake are generally quite uniform from top to bottom because of the continuous mixing in the shallow basin. Secchi disc transparencies in the study area averaged between 1 and 2 m.

Water levels in the study area have been higher than the long term mean during the study period from 1970 to 1975 (Figure 2). Water levels increased to a peak in late spring, 1973 and then began to retreat. At least a portion of this increase was related to an extremely wet fall in 1972, but precipitation patterns in the upper Great Lakes watershed probably influenced Lake Erie levels even more. Except for fluctuations in the total precipitation, meteorological parameters remained relatively constant for the duration of the study (Table 1). There are an average of twenty-three days per year with a sustained wind velocity of 51 km/hr. or more. The western shores of Lake Erie are subject to flooding when

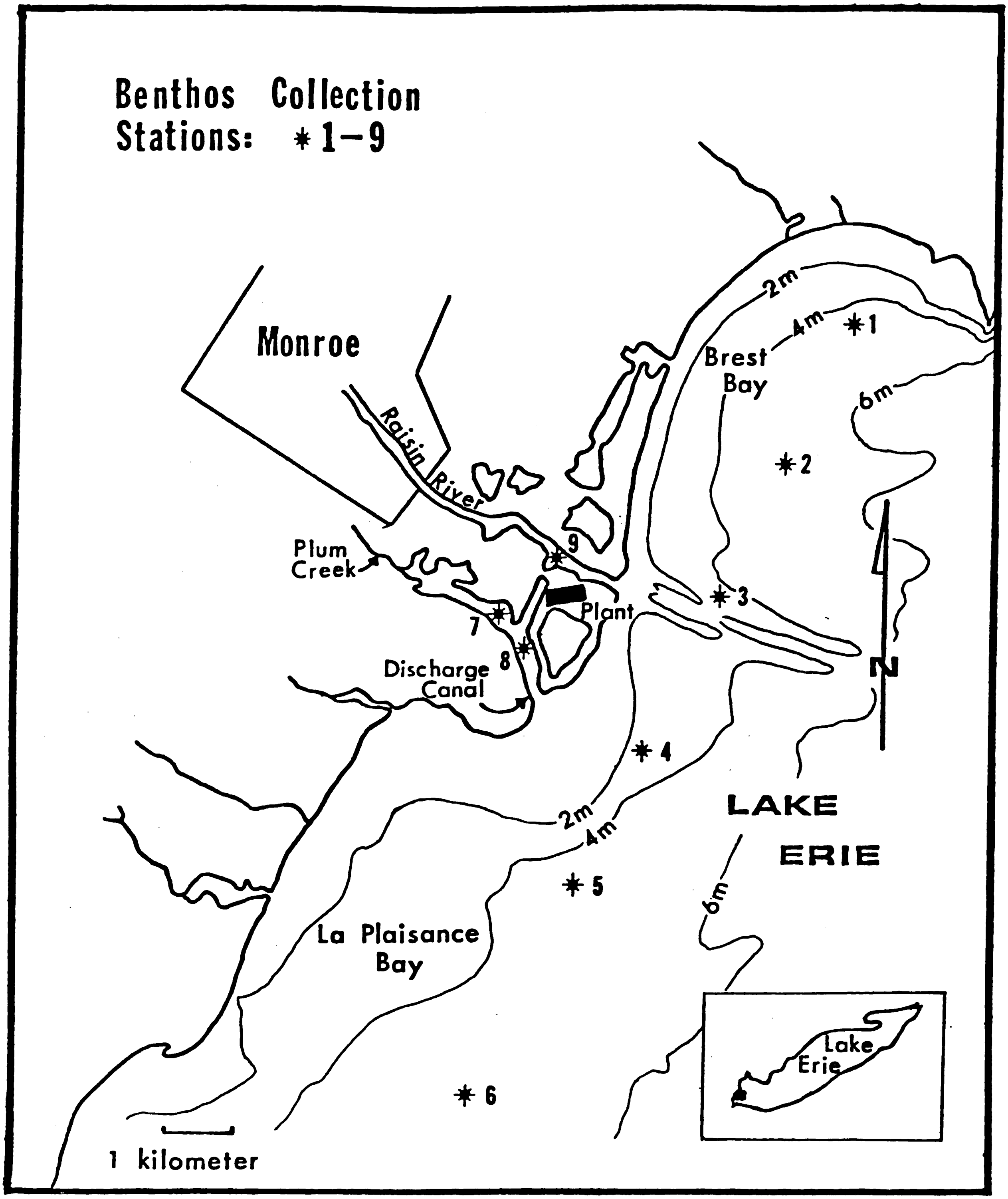


Figure 1. Map of the study area.

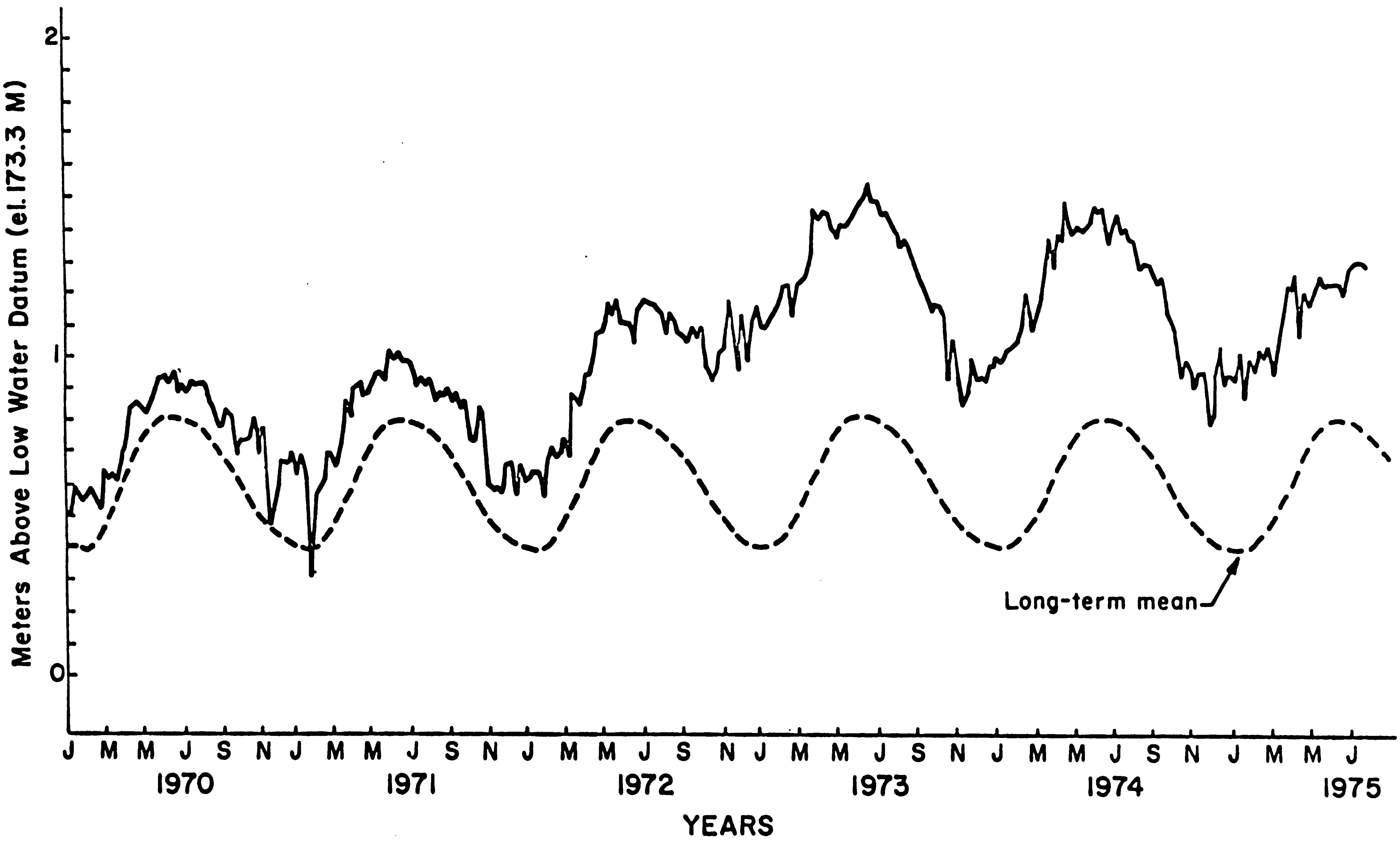


Figure 2. Recent lake levels compared to the long-term mean lake level over the past century (data from the United States Corps of Engineers and the United States Lake Survey).

Table 1. Meteorological data[1] for the study area from 1970 to 1974.

Year	Mean Temperature (°C)	Total Precipitation (mm)	Mean Wind Speed (km/h)	Resultant Wind[2] speed	Resultant Wind[2] direction[3]
1970	8.94[4]	961.14	15.45[4]	4.67[4]	25[4]
1971	9.50	588.77	15.61	5.47	25
1972	8.61	975.61	15.45	3.70	26
1973	10.22	829.82	15.45	3.86	25
1974	9.00	726.95	15.13	4.18	25
NORMAL[5]	9.61	800.35	15.29		WSW

[1] Data from the U. S. Department of Commerce, Toledo, Ohio.
[2] Resultant wind is the vector sum of wind directions and speeds divided by the number of observations.
[3] In tens of degrees from true north; i.e., 09-East, 18-South, 27-West, 36-North and 00-Calm.
[4] Figures are yearly averages.
[5] Normals are based on record for the 1941-1970 period.

the lake level is high and prolonged periods of east to northeast winds prevail.

The lake bottom of the study area is fairly uniform with relatively gentle slopes and a maximum depth of 6 m. Bottom slopes are steepest near Stoney Point (Station 1), a shoal off the mouth of the discharge canal (Stations 4 and 5) and along the dredged access channel to the Raisin River (Station 3). Stations 2 and 6 are located over the deepest water where the bottom slopes very gradually. Plum Creek (Station 7) is a relatively shallow, flat bottomed tributary to the discharge canal (Station 8) which contributes less than 1% to the volume flow through the discharge canal. The Raisin River (Station 9) and discharge canal (Station 8) are dredged to a depth of 7 m. The Detroit Edison Company dredged the discharge canal in 1969 prior to the study period. The U. S. Corps of Engineers have dredged the Raisin River each year of the study from mid-September to mid-October.

At the beginning of the study period, the Raisin River was highly polluted, particularly with oxygen demanding municipal and industrial wastes. Certain aspects of the water quality in the river improved after May, 1972 when a new activated sludge waste treatment plant for Monroe, Michigan began operating. The plant has operated continuously since 1972 except for two very brief interruptions from power failures.

Power Plant Description

The power plant is operated by the Detroit Edison Company at a full production level of 3150 megawatts, and requires cooling water at the rate of nearly 100 m^3/sec. The first of four 788 megawatt units began operating in June, 1971 and the fourth unit was completed in May, 1974. Cooling water from the Raisin River (annual average flow of 17 m^3/sec.)

and Lake Erie enters the plant through a 100 m long intake canal which is located one-half kilometer upstream from the mouth of the river. At full production, virtually all the river water flows into the plant. Inside the plant, the water passes through a condenser where water temperatures are elevated about 10 C above ambient. The heated water then flows down a concrete conduit and enters the discharge canal about twenty minutes later. Less than 10% of the heat is lost as water passes through the 150 m wide and 2000 m long discharge canal into the lake. The thermal plume from the discharge canal may extend 4 kilometers into the lake and moves with the wind over a wide arc in the discharge zone where surface water temperatures can be measured above ambient temperatures.

Field and Laboratory Procedures

Samples were collected from May, 1970 through June, 1975. Duplicate bottom samples were taken at each of the nine stations in the study area. Three collection dates per season were included in the analyses with the exception of spring, 1972, when samples were collected on only two dates (Table A1). Midwinter sampling was not conducted because of hazardous weather conditions. Water temperature and dissolved oxygen were usually recorded within a day of the benthic samples and sediment samples were usually collected once a season from 1970 through 1974.

Sampling procedures were slightly modified during spring, 1975 to assess the representativeness of data collected from Stations 1 to 6 as compared to the whole study area. These changes included triplicate sampling at Stations 3, 6, 8 and 9 and eight random samples taken from both the discharge zone and the adjacent water body segment (Figure 3). The discharge zone was defined by that area covered by a recognizable plume at one time or another. Perhaps one-fourth of the discharge zone

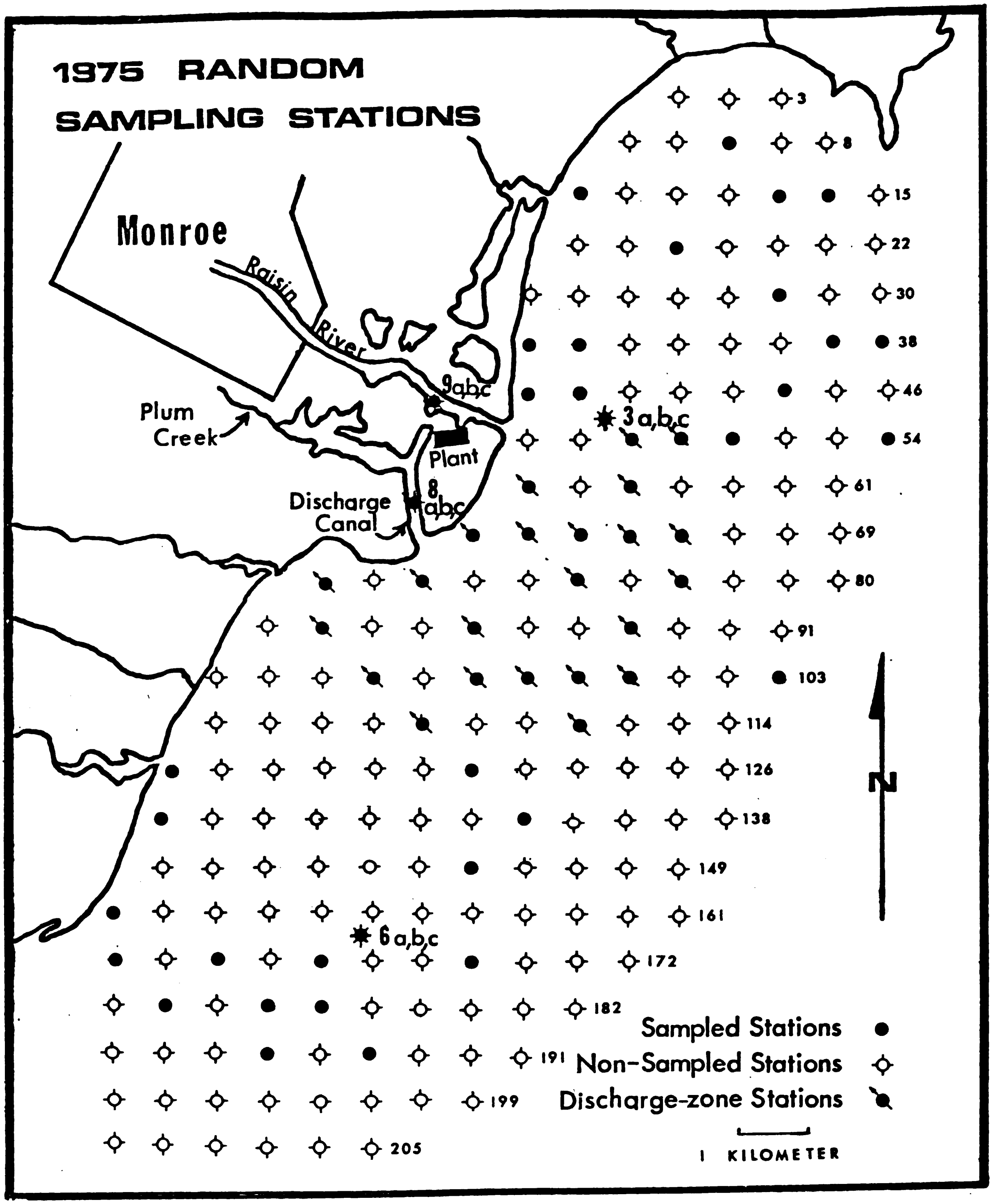


Figure 3. Map of the sampling stations during spring, 1975.

will be covered by the plume at any one time. Three different dates were examined for bottom fauna while five collection dates of bottom samples were brought back to the laboratory for detailed sediment analysis.

The Ponar dredge (520 cm^2 sampling area) was used throughout the study and performed well in most of the substrates present in the study area (Hudson, 1970). Some difficulty was encountered in taking samples on compacted bottoms of clay or sand. Samples were placed in plastic bags aboard ship and taken ashore. If a sediment sample was needed, approximately 10% of the total sample was extracted and placed in a glass bottle. The bottom material was then transferred from the plastic bags to 0.5 mm diameter wire screen tubs (Tyler sieve number 32) and washed free of sediments. The screened material, including the animals, was preserved in a 10% formalin solution and brought back to the laboratory. Organisms from all samples were subsequently hand sorted, identified and counted.

Oligochaetes were measured to the nearest 5 mm, wet weighed, cleared in Amman's lactophenol and later mounted in CMC (Turtox) mounting medium. Wet weights were not recorded in 1970 and 1971; therefore, a length-dry weight relationship was derived for these two years (Figure A1). A conversion equation for arriving at dry weight from the wet weight was developed to enable a biomass estimate for each sample (Figure A2a). Oligochaete identification under 100X or greater magnification was carried to the specific level. All of the oligochaetes examined belonged to the family Tubificidae. Nomenclature of the tubificids followed the work of Brinkhurst (1965) and Hiltunen (1967, 1973) with the exception of keeping *Limnodrilus spiralis* (Eisen) as a variant form of *Limnodrilus hoffmeisteri* Claparède.

The larvae of the dipteran family Chironomidae (midges) were measured to the nearest 2mm, wet weighed and identified at the generic level. The head capsule or entire body of smaller specimens was permanently mounted and identified using Mason's (1968) and Usinger's (1971) keys. A wet weight-dry weight conversion equation was also developed for the midges (Figure A2b). Characteristic features of the four genera of Chironomidae and the six most abundant species of Tubificidae can be seen in Figure A3.

A portion of the tubificids and chironomids sampled were broken or had distinguishing parts missing. These specimens were listed as "unidentifiables," but contributed to the total sample biomass and density. In samples where densities were extremely high, all organisms were counted, measured and weighed, but only representative portions of the samples were examined microscopically. The proportionate amount of each genus or species was then related back to the total population count.

Organisms which were infrequently encountered throughout the study area were identified only to the family level. These relatively rare organisms were not included in any statistical analysis, since they never comprised more than 1% of the density collected on any one date.

The bottom sediments were transported back to the laboratory and examined for particulate size composition and carbon and nitrogen concentrations. The size composition of each sample was determined by a combination of wet and dry sorting. Clay and silt were removed from the balance of the sediments on the basis of settling time after an aliquot is stirred vigorously in water (Cummins, 1962). Coarse materials that settled in less than 15 seconds were dried and sieved, using Tyler sieve numbers 5, 16, 28, and 60. The supernatant containing the clay and silt from the first separation was reagitated and again allowed to settle for 15 minutes. Those particles that settled during that period were defined as silt. The remaining aqueous solution was siphoned off and allowed to settle for 24 hours. These settled materials were defined as clay. The mean sediment size of each sample was calculated by multiplying the mean size of the Tyler sieve by the corresponding percent that segment made up of the total. The division of the sediments into categories was based on their mean size using Wentworth's classification of the sediments (Welch, 1948).

Chemical analyses of organic carbon and nitrogen were conducted on a Perkin-Elmer Elemental Analyzer (Model 240). Temperature and oxygen measurements were usually conducted biweekly during the ice-free season using a Y.S.I. oxygen meter which was calibrated against a mercury thermometer and Winkler determinations made at the surface.

Data Analyses

As a result of the observed differences between means, Bartlett's test (Snedecor and Cochran, 1967) was used to assess whether or not all the variance estimates being compared were estimates of the same total population variance. Results showed that significant differences occurred in a portion of the data. To reduce the heterogeneity of variance, log transformations, $\log_{10}(x + 1)$, were performed on all the density and biomass calculations (Elliot, 1971).

A one-way analysis of variance was applied after transformation to test for differences at stations and seasons across the years of the study. Parameters examined included densities, biomass estimates, species diversity, species equitability (evenness), mean macroinvertebrate sizes and the age ratio of tubificids. Tukey's multiple range comparison tests were used to sort mean values at $\alpha = 0.05$ when differences were determined to be significant ($\alpha = 0.05$) in the analysis of variance. The coefficient of variation ($C = s/\bar{x}$, where s = the standard deviation and $\bar{x}$ = the sample mean) was used to determine the relative amount of variation among the sediments and benthic population over the years of the study (Snedecor and Cochran, 1967).

The benthic species diversity was measured on densities using Shannon's formula (Pielou, 1966): $d = -\sum_{i}^{s}(Ni/N)\ [\log_{10}(Ni/N)]$ where Ni = the number observed for each species, N = total number of all species grouped together and S = the number of different species. The equitability index (the ratio of observed diversity to maximum diversity for the same number of species) was calculated from the formula: $e = \text{diversity}/\log_{10}S$, where S = the number of different species (Pielou, 1966).

RESULTS

Environmental Characteristics of the Benthic Biotope

Oxygen

Oxygen concentrations in the study area outside the discharge canal remain close to saturation at all depths during the colder months of the year, but as water temperatures increase during the warmer months, bottom oxygen concentrations may drop to half of the concentration found at the surface and less than 50% of the saturation concentration. All of the six lake stations and Plum Creek had seasonally similar oxygen concentrations (Figure 4). The Raisin River carried a high organic load from municipal and industrial wastes during the first two years of the study. Oxygen concentrations in the river decreased almost to anoxic levels in early fall, 1970. Installation of a new waste treatment plant during late spring, 1972 apparently has increased oxygen levels in the river.

The commencement of power plant operation in 1971 created immediate changes in oxygen concentration in the discharge canal. During early operation, a greater proportion of cooling water came from oxygen depleted river waters. As more lake water was drawn in later years and as the river water itself improved because of better sewage treatment, the mean seasonal oxygen concentration in the discharge canal approached saturation.

Temperature

Temperatures in the lake generally are quite uniform from top to bottom because of continuous mixing in the shallow basin. Some temporary

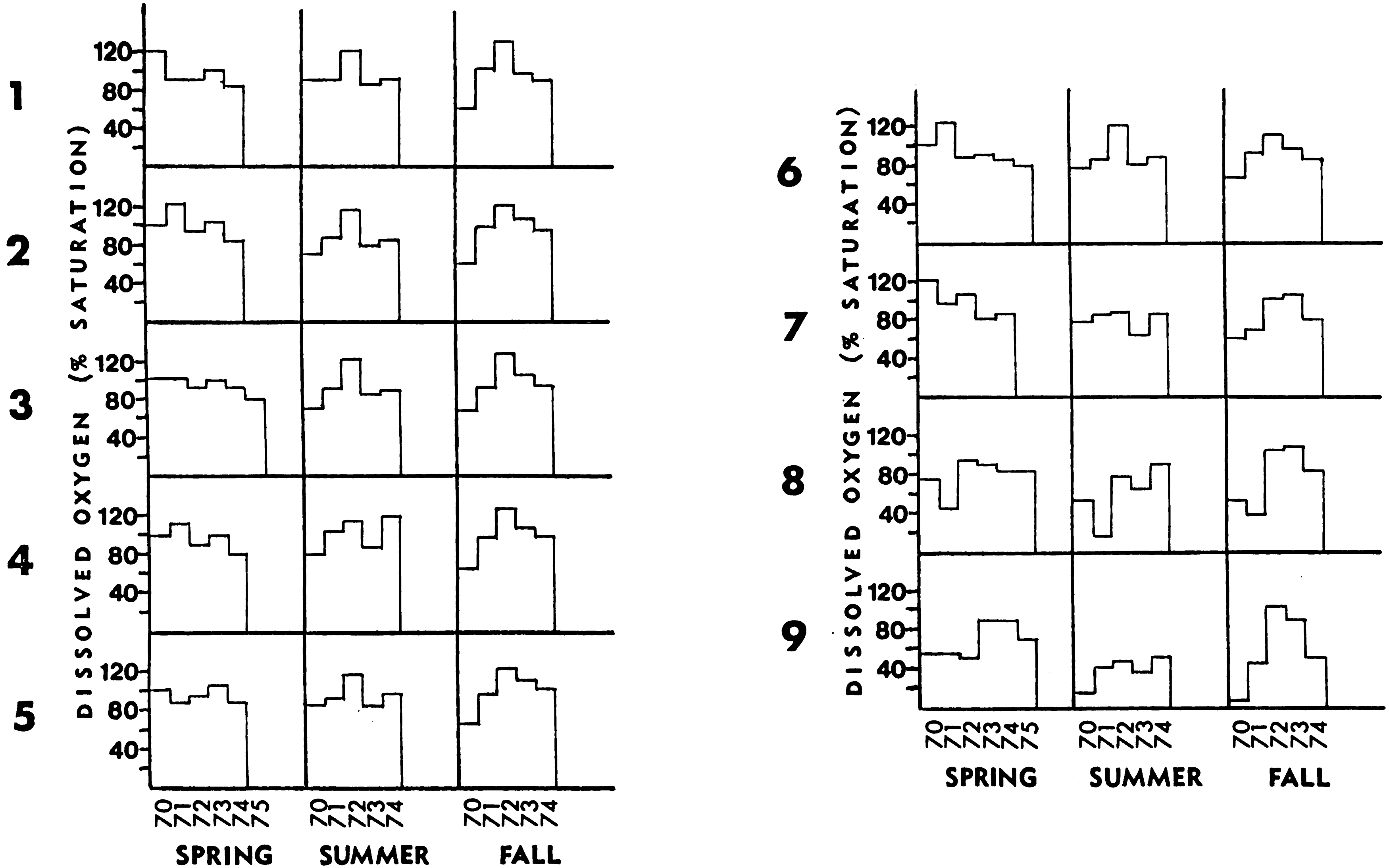


Figure 4. Mean seasonal dissolved oxygen concentrations measured just above the water-sediment interface (values shown are means from four dates per season).

stratification occurs when water temperatures rise above 20 C but this usually lasts less than a day. Seasonal bottom temperatures in the Raisin River and the lake varied by 1 or 2 C from each other (Figure 5). The bottom temperatures in the discharge canal and Plum Creek have increased over the duration of the study as a result of power plant operation. Most of the impact of the heated effluent was confined to the discharge canal and Plum Creek. Bottom temperatures in the discharge zone of the lake were undifferentiable from adjacent lake waters.

Carbon and Nitrogen

The carbon and nitrogen content of the sediments is related to the size of the sediments (Figure 6); finer sediments have higher concentrations of carbon and nitrogen. The analysis of carbon and nitrogen concentrations in the sediments reflects the combined variation in concentration per sediment size class and the distribution of sediments in the study area (Tables A2 and A3). The relatively high carbon and nitrogen values found at the inshore stations (7, 8 and 9) are caused partly by relatively large amounts of allocthonous plant remains and other organics in the sediments.

Sediment Distributions

The nearshore bottom of the study area was composed primarily of coarse, medium and fine sand (Figure 7). The relative amount of silt in the sediments increased at the deeper, offshore stations. The size of the sediments at the nine fixed sampling stations varied considerably in composition (Table A5). Stations 4 and 5 are located on the sandy shoal off the mouth of the discharge canal. Sediments at Stations 1 and 2 intergrade between silt, clay, sand and some pebbles. Station 3 is

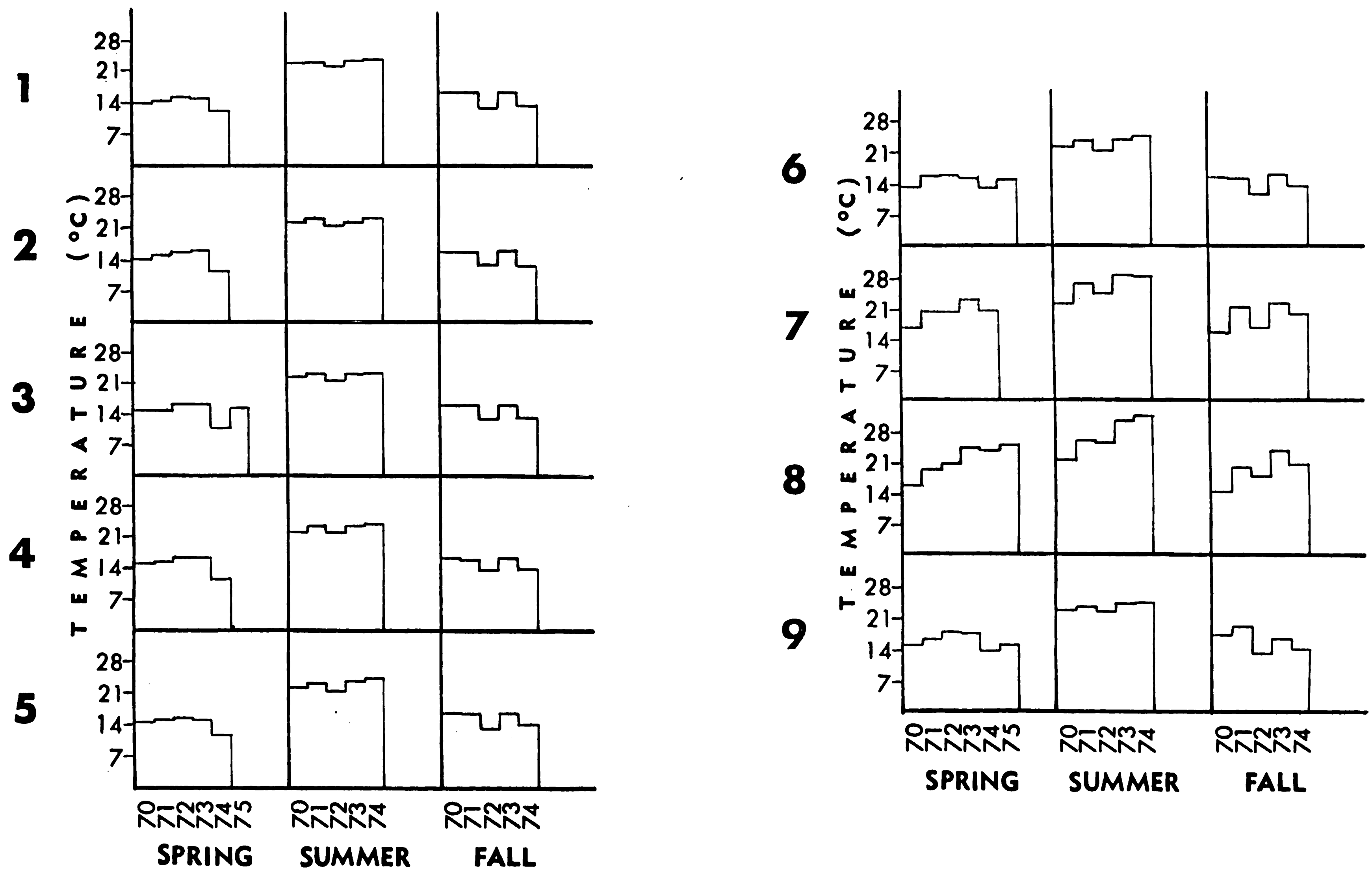
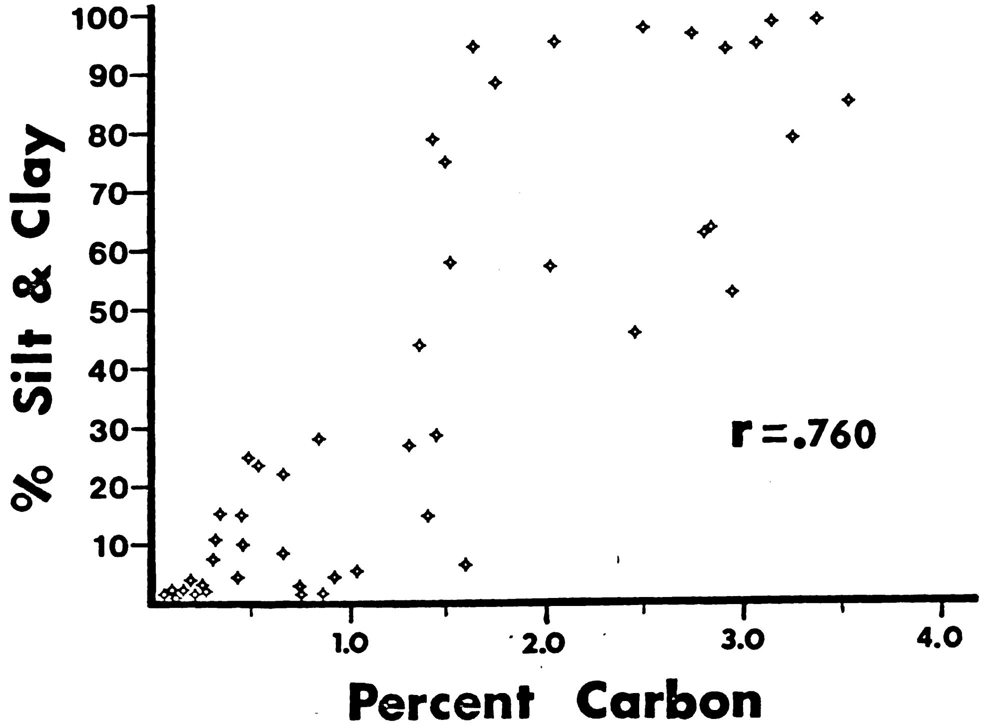


Figure 5. Mean seasonal temperatures measured just above the water-sediment interface (values shown are mean from four dates per season).



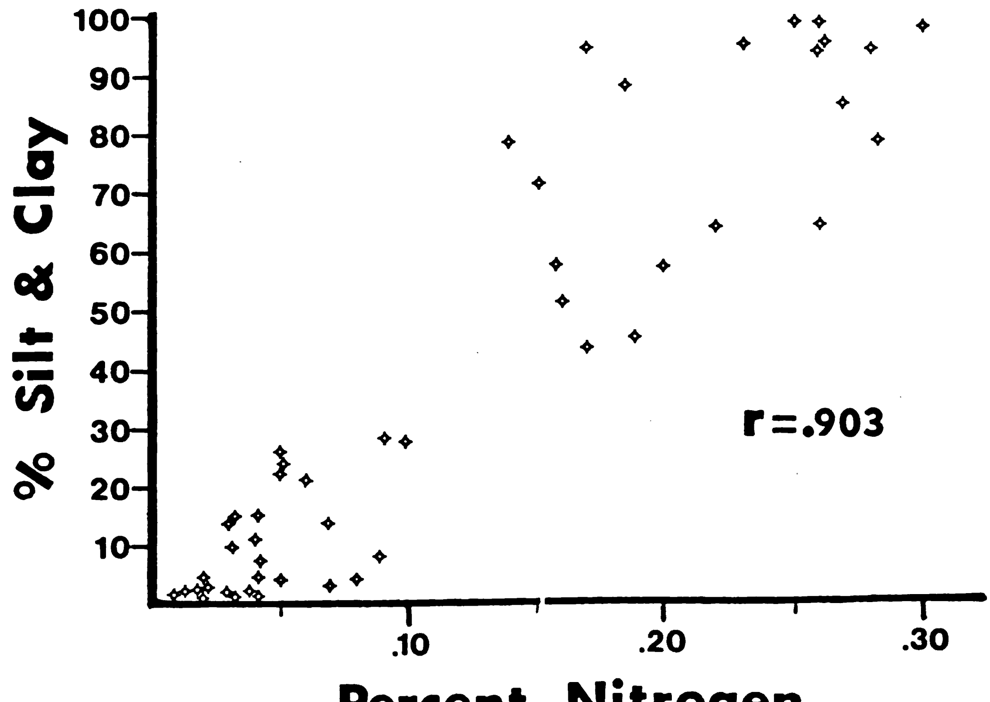


Figure 6. Relation of the organic carbon and nitrogen concentration in the sediment to the amount of silt and clay in the sediment of the lake stations (spring, 1975).

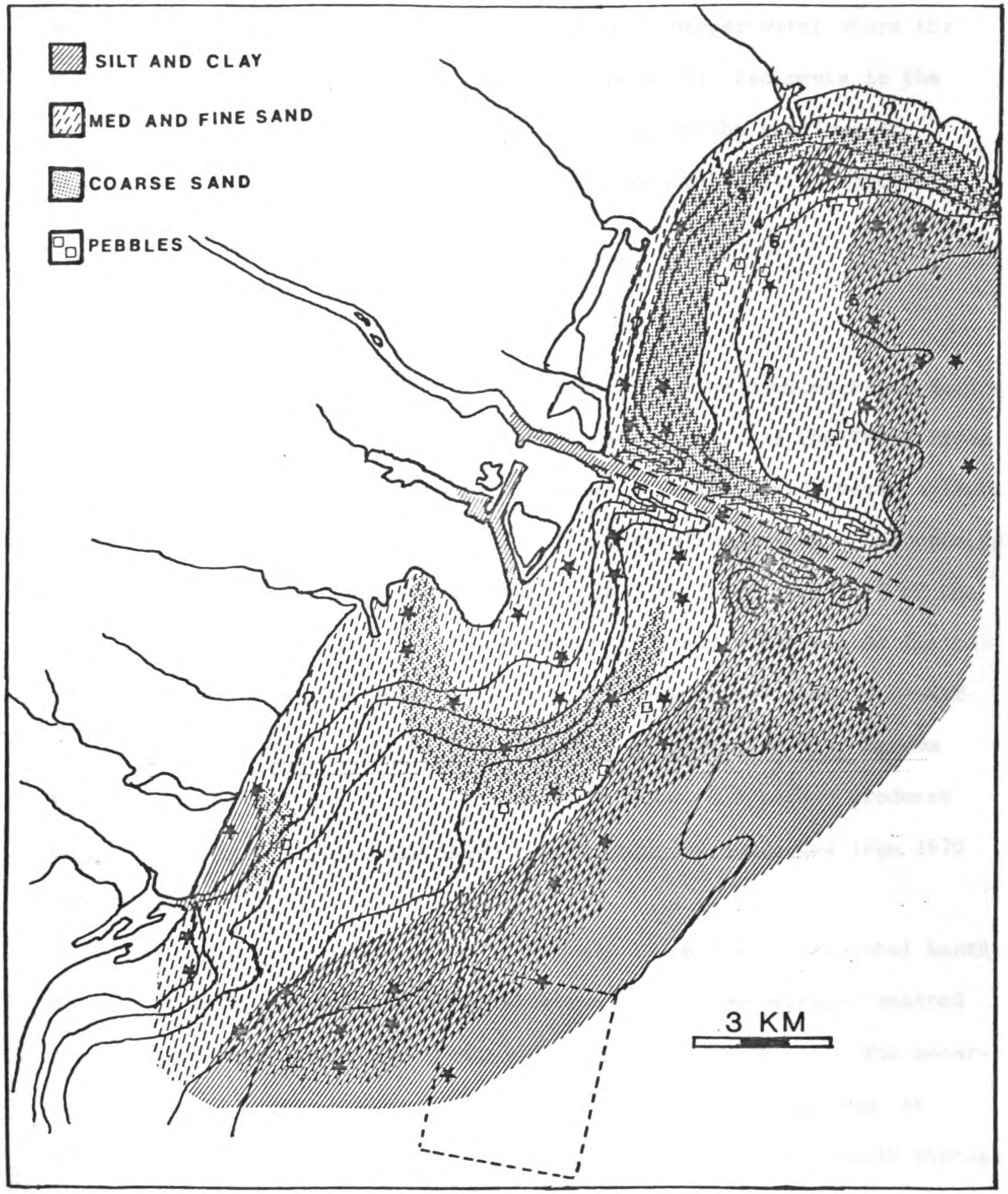


Figure 7. Generalized map of the sediments in the study area during spring, 1975 (map constructed from Table A4).

predominantly sand, but is highly variable because of nearby Raisin River dredge deposits. Station 6 is located in deeper water where the gradually sloping bottom is covered with fine silt. Sediments in the Raisin River, discharge canal and the protected marshy shallows at Station 7 were composed of silt, clay and recognizable plant debris.

Benthic Macroinvertebrates

Total Density and Biomass

Eight major taxonomic groups were present in the samples taken during the study period. Of all the organisms found, members of the Tubificidae and Chironomidae were the most common (Table 2). Tubificids were collected at all stations and contributed 83.2% of the total organisms. Chironomids were also collected at all stations but were less numerous (16.7% of the total organisms). In addition to the species of adult tubificids listed in Table 2, unidentifiable immature tubificids comprised about one-half the total tubificids collected during each year of the study. Random sampling conducted in 1975 at stations identified in Figure 3 produced no species which had not been collected in sampling conducted from 1970 through 1974.

Chironomid larvae made up approximately 10 to 20% of the total benthic density at each station. In terms of biomass, this percentage remained somewhat the same except for Stations 5, 6 and 7 (Figure 8a). The occurrence of considerable numbers of relatively large _Chironomus_ spp. at these stations accounted for this shift in percentage. The yearly average spring biomass was higher than either the summer or fall biomass (Figure 8b). Total benthic biomass reached a low in summer and then increased again in fall. A large portion of the summer decline can be attributed

Table 2. Average density (no./m^2) of benthic macroinvertebrates collected in the study area from 1970 to 1974.

Taxon	1970	1971	1972	1973	1974	MEAN
Limnodrilus hoffmeisteri	300.1	57.7	137.4	57.8	98.6	130.3
Chironomus spp.	142.8	51.3	58.7	120.5	44.3	83.5
L. cervix (variant)	91.6	45.8	71.0	44.6	44.1	59.4
L. maumeensis	159.3	29.1	36.7	25.6	32.3	56.6
Procladius spp.	80.6	25.5	36.3	16.1	7.7	33.2
L. cervix	57.9	17.2	2.7	8.3	8.1	18.8
L. claparedianus	66.6	5.4	5.0	0.2	14.2	18.3
L. udekemianus	20.9	12.4	40.7	8.4	8.3	18.1
Coelotanypus spp.	19.3	20.9	14.7	6.3	11.4	14.5
Branchiura sowerbyi	26.8	3.6	5.5	6.1	4.2	9.2
L. profundicola	3.0	1.1	15.5	8.9	3.2	6.3
Potamothrix moldaviensis	17.4	5.1	3.7	1.8	1.0	5.8
Cryptochironomus spp.	3.1	2.6	3.6	1.5	2.5	2.7
Aulodrilus pluriseta	2.9	0.5	0.4	0.0	0.0	0.8
Potamothrix vejdovskyi	1.1	0.2	0.0	0.0	0.3	0.3
Aulodrilus americanus	0.2	0.4	0.4	0.0	0.0	0.2
Aulodrilus pigueti	0.7	0.0	0.0	0.0	0.0	0.1
Glossiphoniidae	0.01	0.04	0.04	0.02	0.02	0.03
Sphaeriidae	0.01	0.01	0.05	0.02	0.04	0.02
Gammaridae	0.00	0.01	0.02	0.01	0.01	0.01
Elmidae	0.00	0.00	0.00	0.00	0.04	0.01
Asellidae	0.00	0.00	0.01	0.01	0.00	0.01
Unionidae	0.01	0.01	0.01	0.00	0.01	0.01
TOTAL	994.3	279.0	432.4	304.4	280.1	458.0

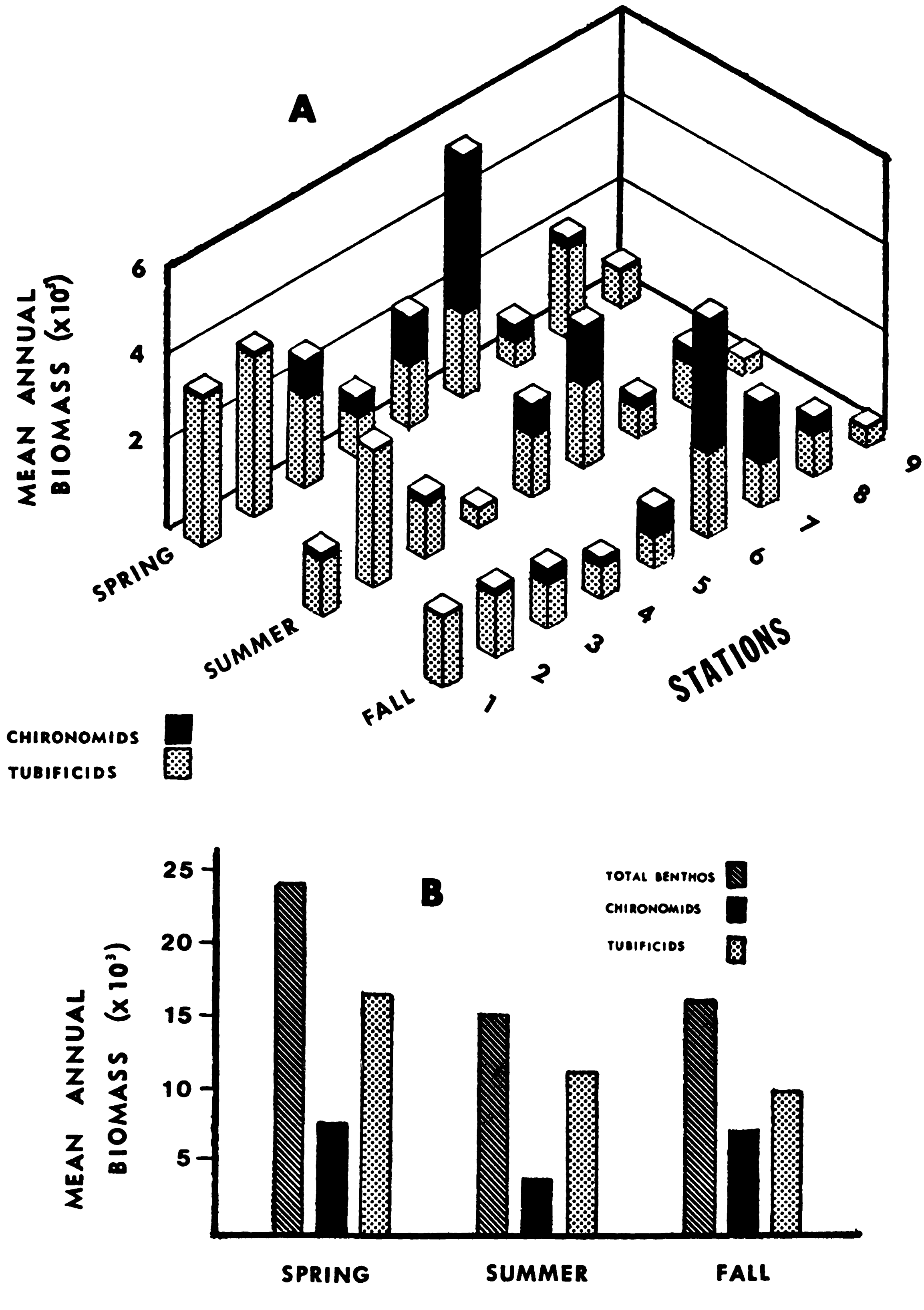


Figure 8. Mean yearly biomass (mg/m^2) in the study area, 1970 to 1974. Biomass is broken down seasonally by a) individual stations and b) combined stations.

to the absence of midge larvae in the samples. The emergence of many adult chironomids reached a peak in late spring and early summer and continued, to a lesser degree, into early fall.

Benthic macroinvertebrate densities were highest at most stations during the first year of the study (Figure 9). However, abundances at the six lake stations varied erratically from year to year with no consistent trend after 1970. The number of river animals generally appeared to increase during the study period, especially during the summer and fall seasons. Densities in Plum Creek (Station 7) and the discharge canal (Station 8) steadily decreased during the study. Some facet of power plant operation apparently reduced densities, particularly from 1972 to 1975.

Temporal variabilities of the sediments were calculated (Tables A2, A3 and A5) and compared to benthic macroinvertebrate populations from corresponding dates (Table 3). The depth and slope for each station were also recorded. Spatial and temporal variability among the sediments appeared to be related mostly to sediment size composition, depth, bottom slope and exposure to wave action. Variability (as measured by the coefficient of variation) between replicates (spatial) and years (temporal) was calculated at several representative stations (2, 3, 4, 6 and 8). Those stations with a relatively high proportion of silt and clay in the sediments (Stations 2, 6 and 8) exhibited much less temporal variability. These stations were also the deepest, had the least slope and were least affected by wave action. Replicated analysis of their sediments indicated that spatial variability was from one-half to one-eighth the temporal variability. Temporal variability was much greater among the stations composed of larger sediments (Stations 3 and 4). Both of these stations

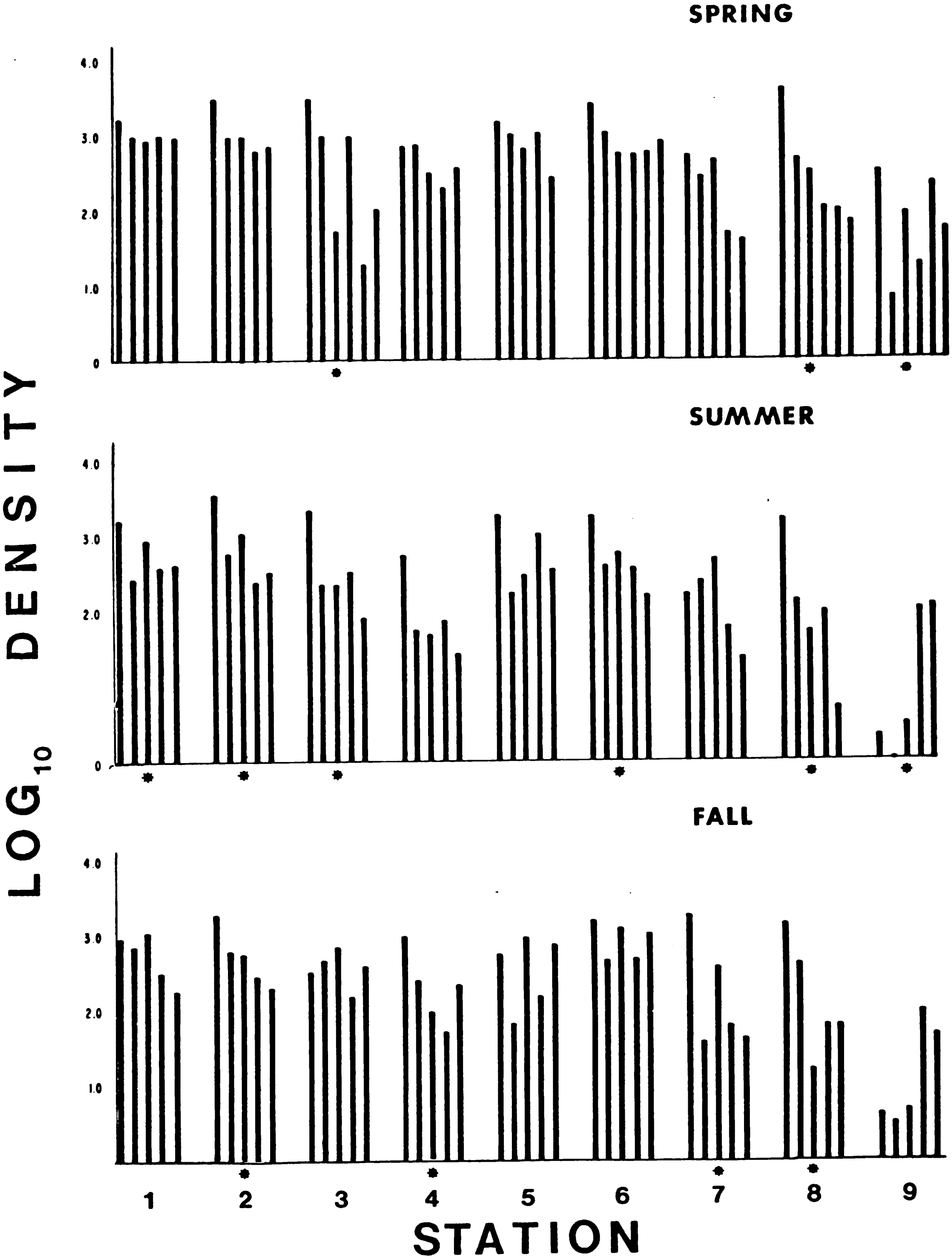


Figure 9. Density (no./m^2) of benthic macroinvertebrates in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B2. Vertical bars are mean densities for each year of the study (1970 to 1974 or 1975).

Table 3. The coefficient of variation and relative variability of the sediments and macroinvertebrate abundance, and the average depth and slope in the study area, 1970 to 1975.

	STATIONS								
Variable	1	2	3	4	5	6	7	8	9
Carbon	0.95	0.40	0.96	1.42	0.63	0.39	0.28	0.22	0.22
Nitrogen	0.73	0.48	0.97	1.34	0.95	0.38	0.73	0.29	0.25
Silt and Clay	0.91	0.60	1.36	1.13	1.29	0.31	0.56	0.29	0.24
Macroinvertebrates	0.28	0.22	0.54	0.32	0.26	0.22	0.31	0.55	0.87
Depth (m)	4.0	5.3	4.3	3.6	4.3	5.3	1.5	7.0	7.0
Slope (x 10^{-2})	0.25	0.03	0.22	0.08	0.15	0.03	0.00	0.00	0.00

	VARIABILITY AMONG LAKE STATIONS					
Variable	Least Variable				Most Variable	
Carbon	6	2	5	1	3	4
Nitrogen	6	2	1	5	3	4
Silt and Clay	6	2	1	4	5	3
Macroinvertebrates	6	2	5	1	4	3
Depth	6	2	5	1	3	4
Slope	6	2	4	5	3	1

are relatively shallow and exposed to greater wave action than other stations. Spatial variability between replicates was similar to temporal variability. In general, those lake stations with the least variable sediments, greatest depths and lowest slopes also had the highest, least variable benthic abundance.

Species Diversity and Equitability

Macroinvertebrate species diversity at all stations except the discharge canal varied erratically and revealed no recognizable trends (Figure 10). Diversities at Station 9 and, to a lesser extent, Station 4 were lower than those found at the other stations. A significant impact of the plant discharge on macroinvertebrate diversity was suggested by the decline in diversity at Stations 7 and 8 over the study period during all seasons. This response was caused mainly by a redistribution of abundances among species without a change in the number of species as borne out by the equitability indices. Diversities in Plum Creek (Station 7) decreased significantly over the study period during the spring and summer seasons and the number of species that occurred in Plum Creek also decreased over the duration of the study. Sampling conducted in 1975 showed that diversity and the number of different species found at each station is related to the mean size of the sediments (Figure 11). As the mean size of the sediment decreases the diversity and the number of species increases. This may partially explain the relatively low diversity seen at Station 4 during the previous years of study, since its sediments were among the most coarse in the study area. The diversity indices at all stations were relatively low when compared to other benthic studies. The dominance of one species, Limnodrilus hoffmeisteri, at most of the stations sampled was the cause for the low values recorded.

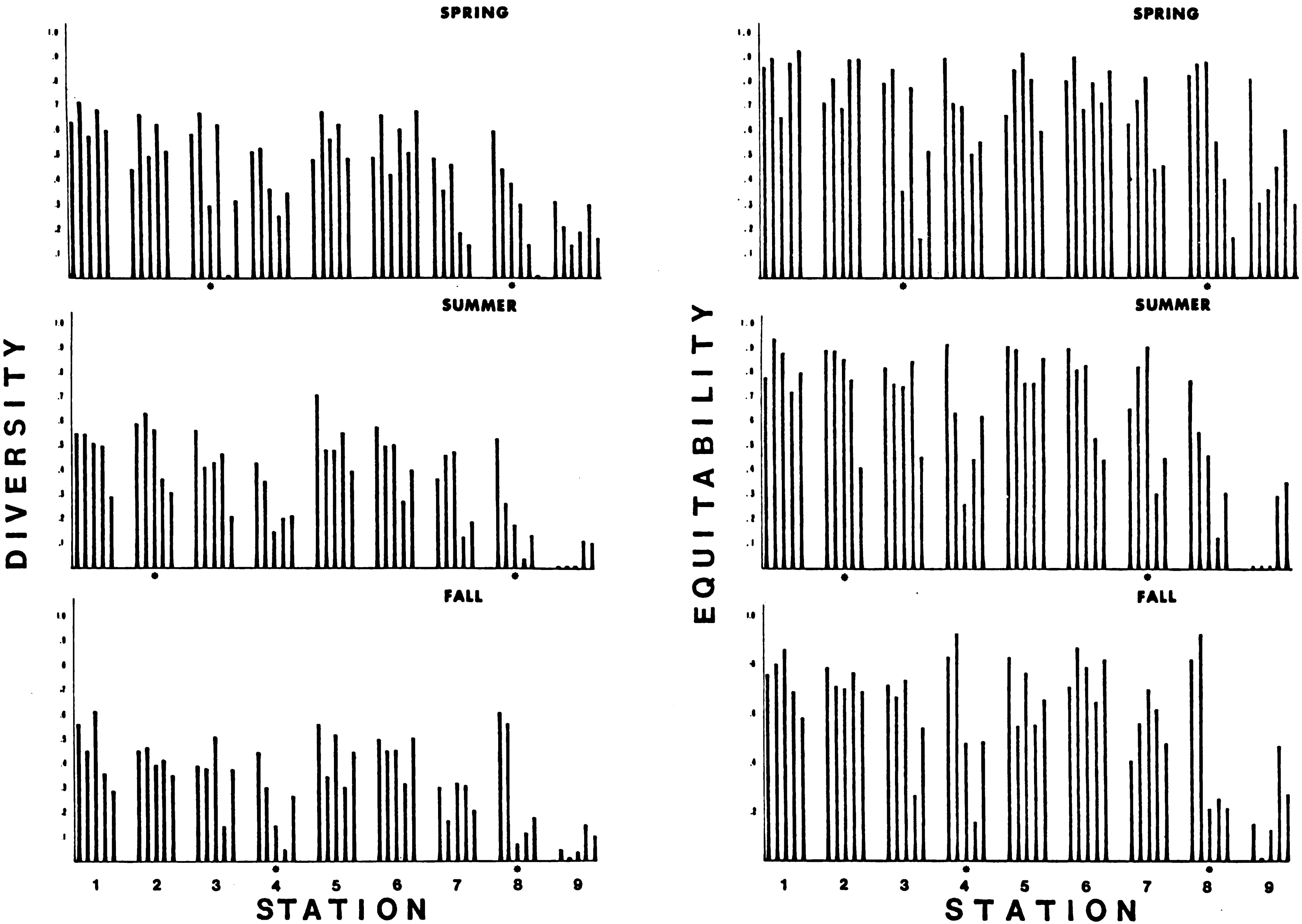


Figure 10. Species diversity and equitability for benthic macroinvertebrates in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B2.

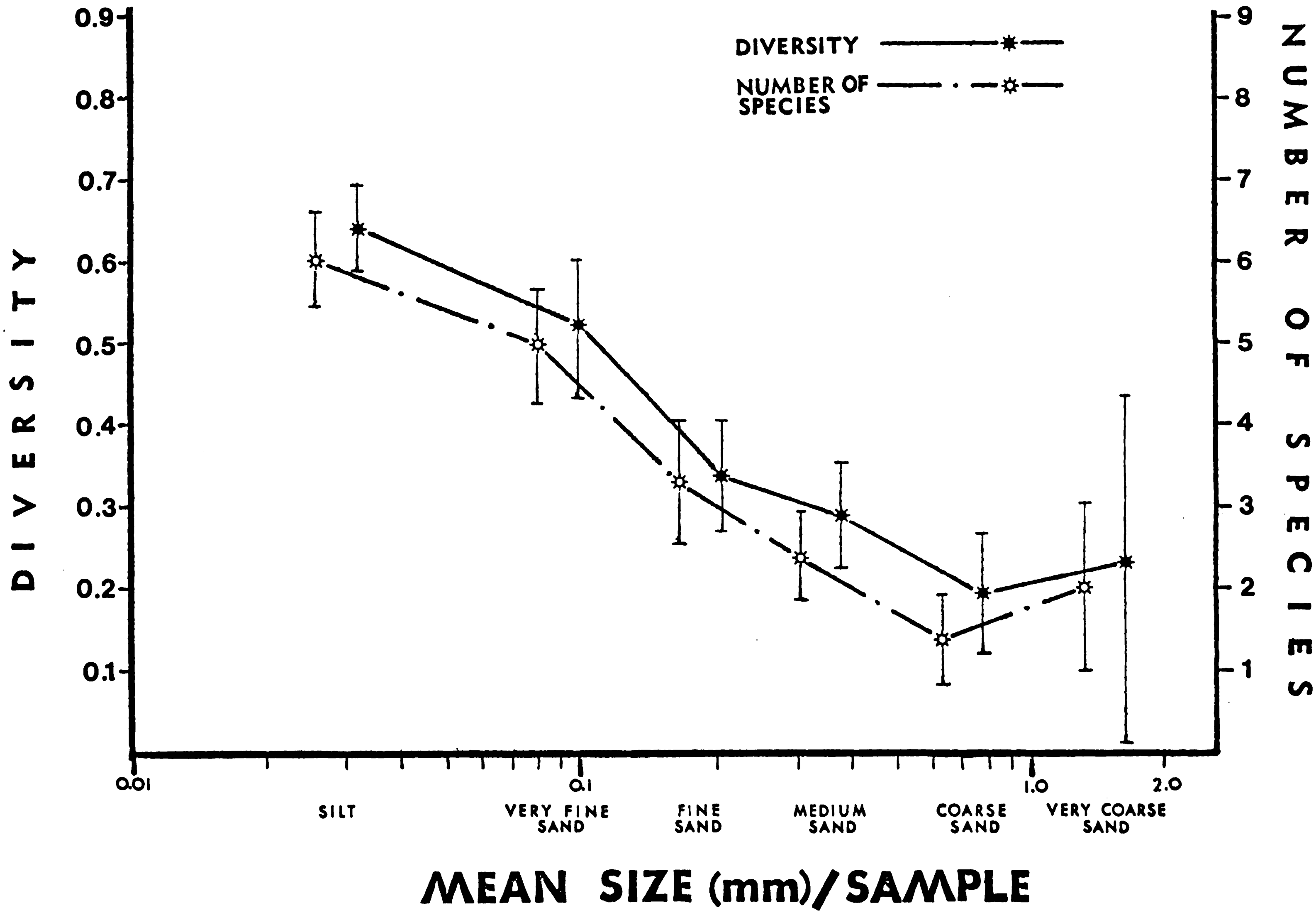


Figure 11. Relation of species diversity and number of species to mean sediment size during spring, 1975. Vertical bars represent one standard error either side of the mean.

Tubificidae

Tubificid abundances were responsible for most of the observed changes in the total benthic abundance (Figure 12). Abundances at Station 3 (dredge deposits) and Station 4 (shifting, sandy bottom) were highly variable. Power plant operation had a definite impact on the tubificids. The decline of tubificids in the discharge canal (Station 8) was caused mainly by the response of Limnodrilus maumeensis Brinkhurst and Cook (Figure 13). Limnodrilus hoffmeisteri, by far the most abundant species in the study area, appeared to be least affected by power plant production. Except for a drop off in summer, densities remained relatively constant throughout the study. An increasing trend in Limnodrilus hoffmeisteri abundance at Station 9 is the main reason for the Raisin River's increased benthic abundance.

Random sampling conducted in 1975 showed that tubificid abundance is partly influenced by the size and organic carbon content of the sediments. Aquatic oligochaetes, like their terrestrial counterparts, are believed to indiscriminately ingest all sedimentary particles below a certain size and digest some fraction of these particles. The abundance of tubificids appears to increase as the percent carbon (food content) increases and the mean sediment particle size decreases toward a silty composition (Figure 14). This may explain some of the observed changes occurring at the various lake stations during the study period.

Although tubificid sizes frequently changed significantly from year to year, the changes were generally without trend over the study period (Figure 15). The mean size appeared to significantly increase in the river during the last two years of the study. Part of the observed size fluctuations may be caused by a change in the ratio of juvenile to adult

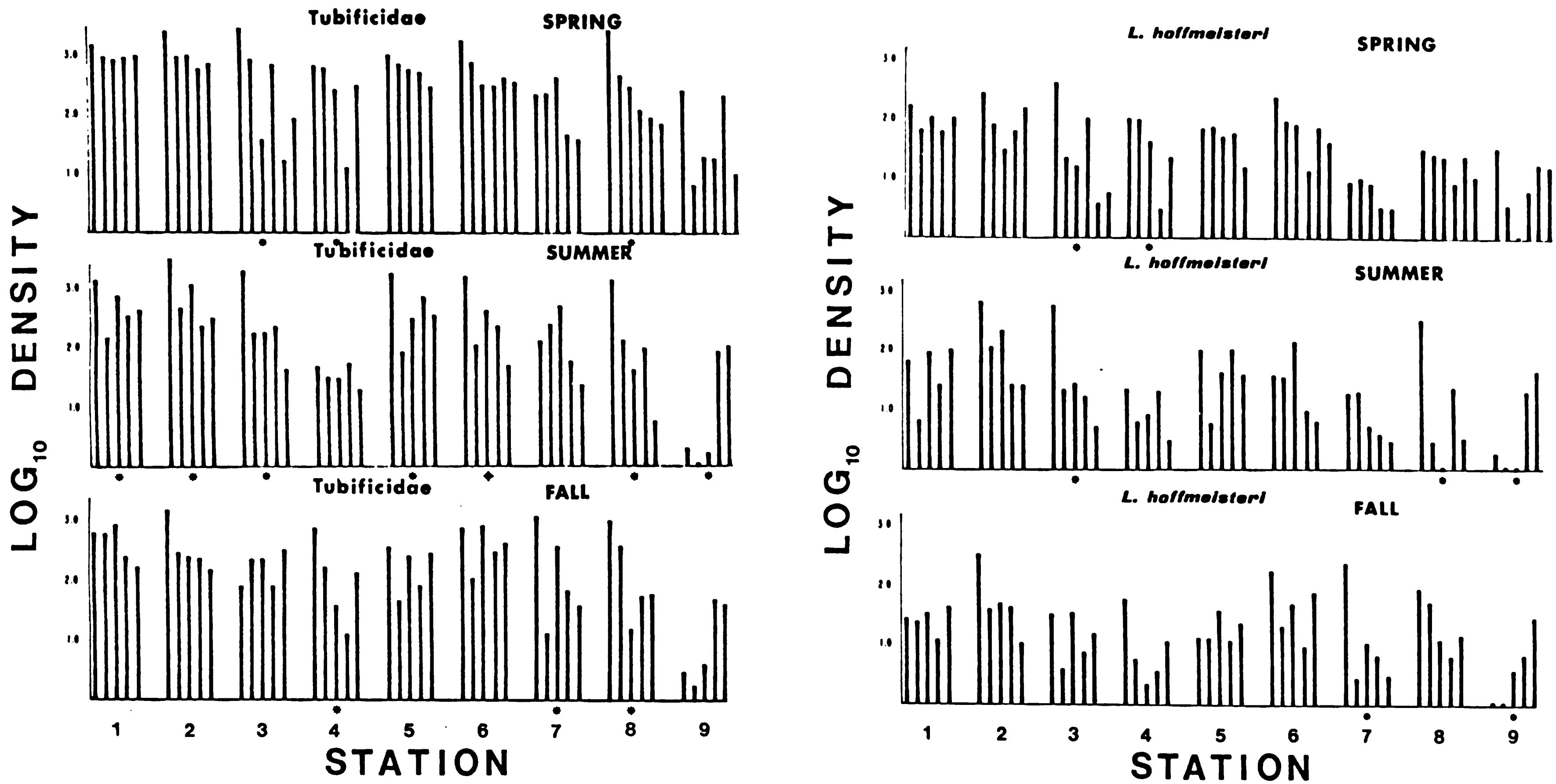


Figure 12. Density (no./m^2) of Tubificidae and Limnodrilus hoffmeisteri in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B3.

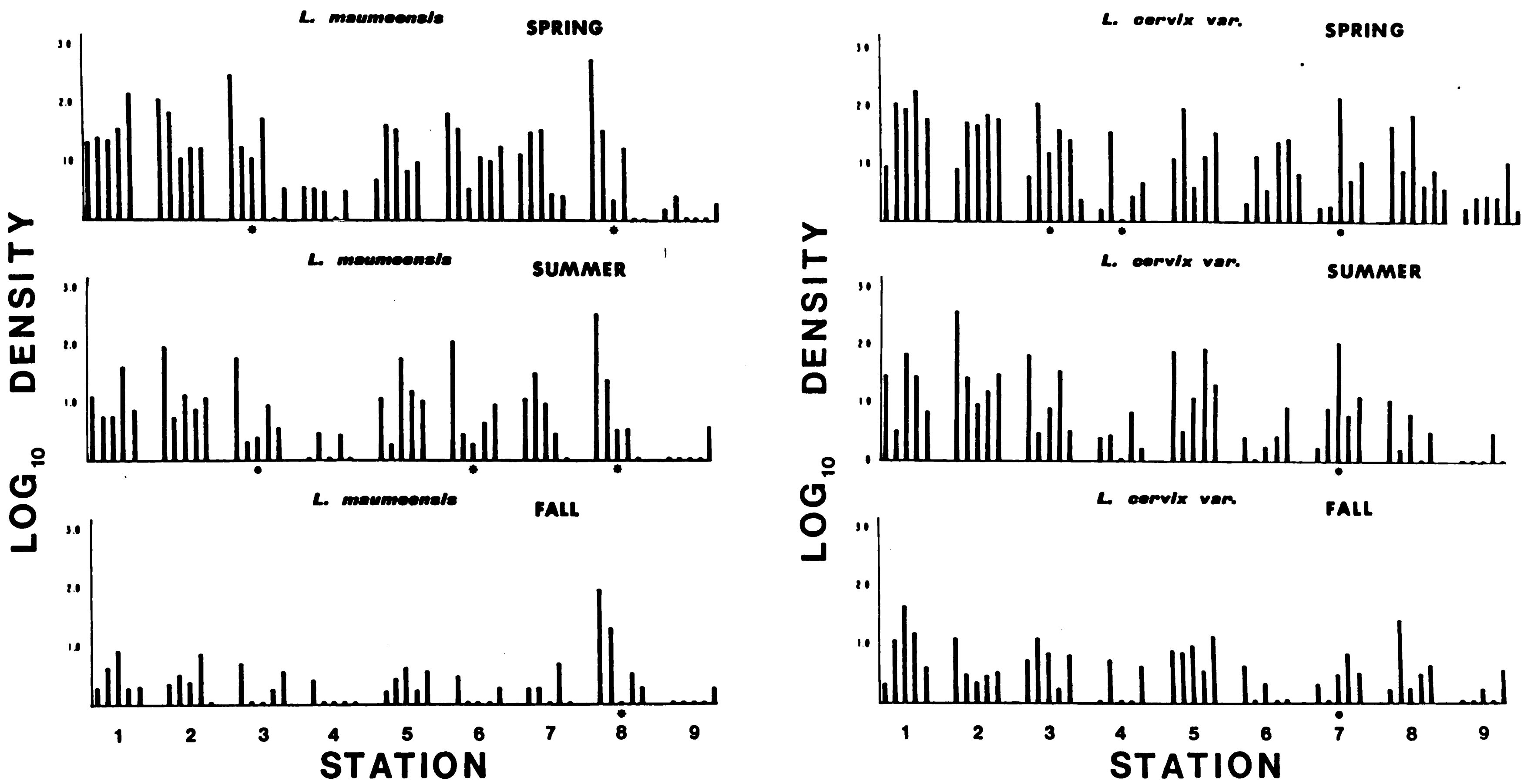


Figure 13. Density (no./m^2) of Limnodrilus maumeensis and Limnodrilus cervix variant in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B3.

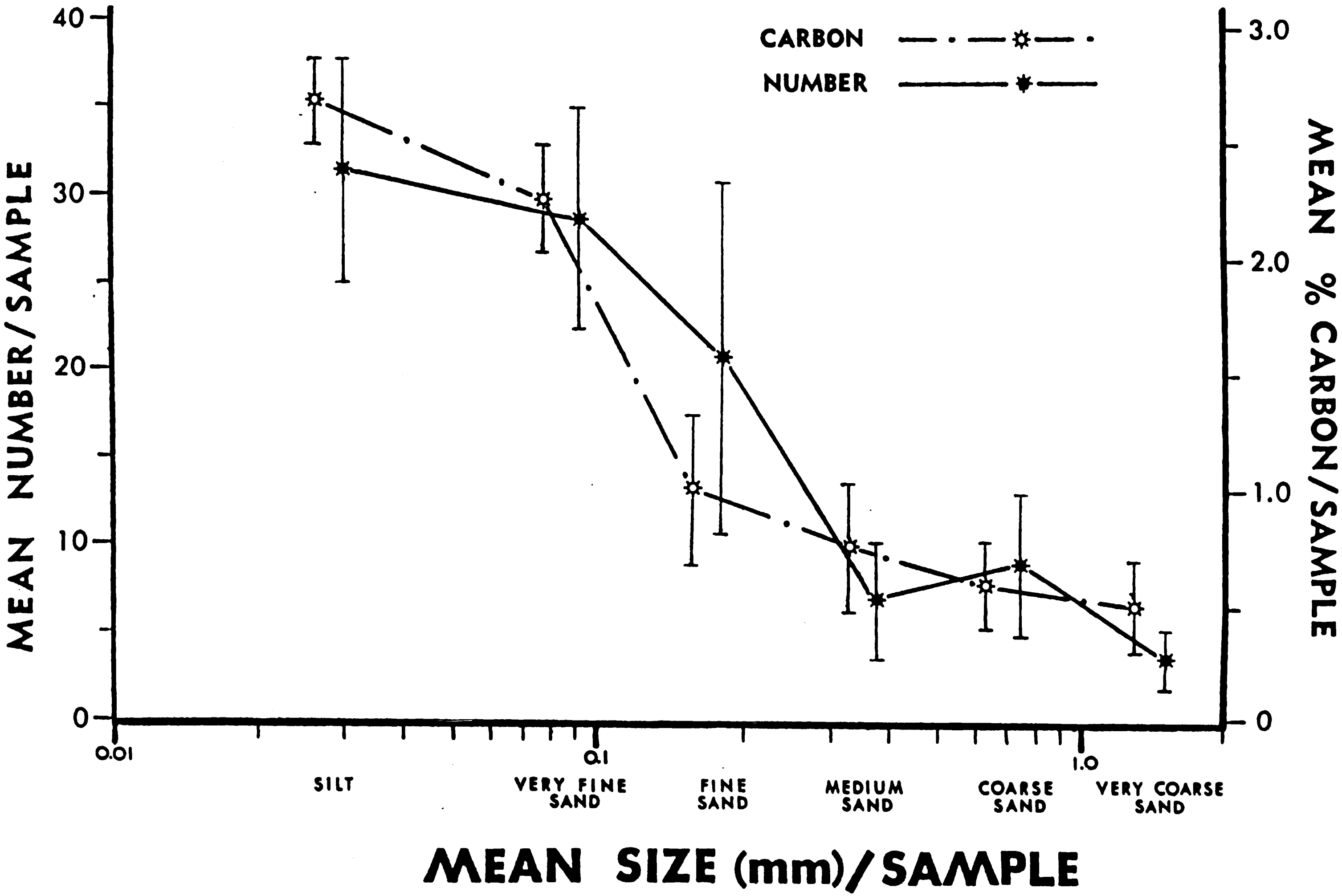


Figure 14. Relation of the mean number of tubificids to the carbon concentration and sediment size during spring, 1975. Vertical bars represent one standard error either side of the mean.

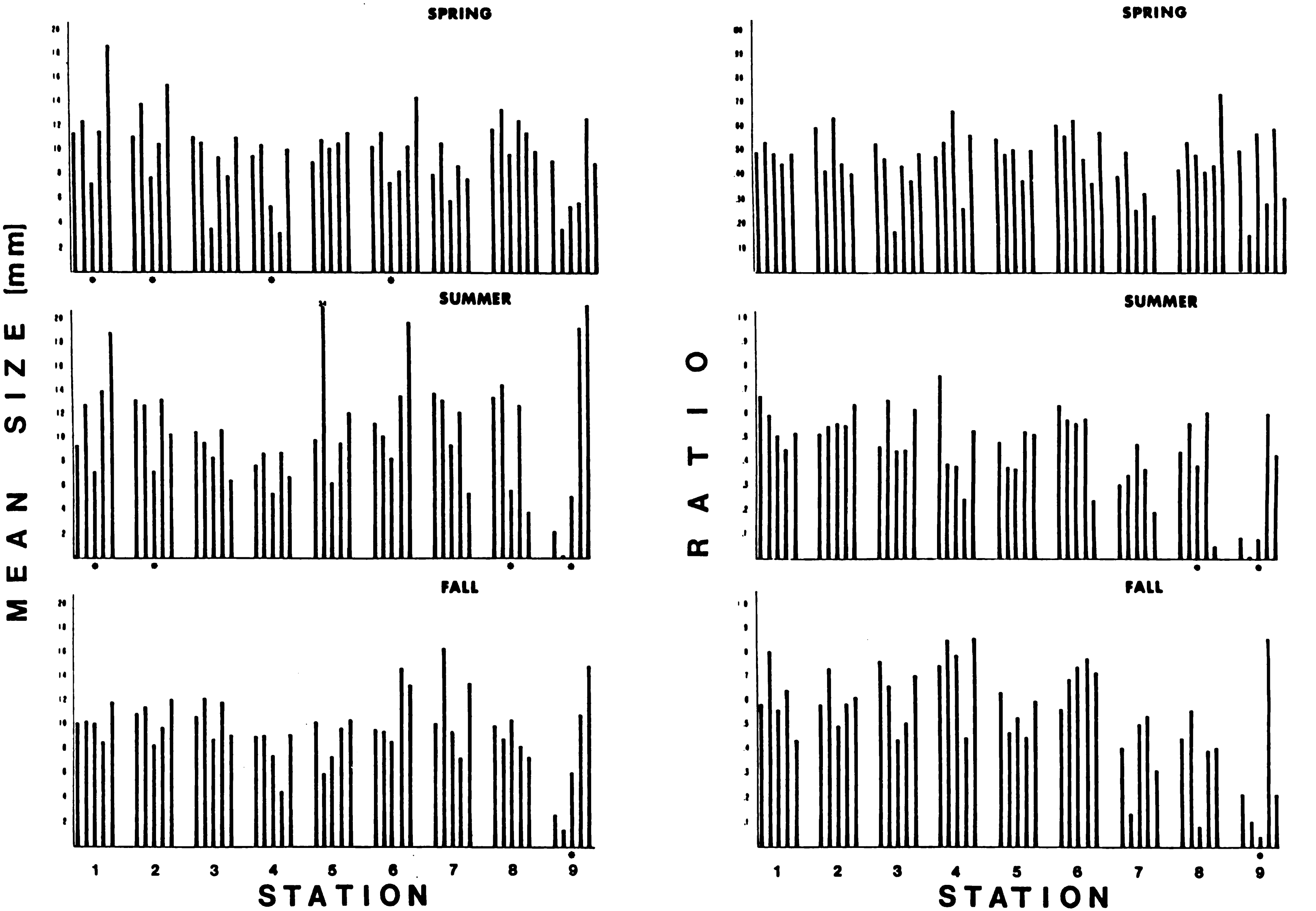


Figure 15. The mean size and ratio of immatures to adults for Tubificidae in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B3.

tubificids. Values remained relatively constant within each season. Spring and summer ratios centered around 40 to 50%. Autumn tubificid populations appeared to be comprised of a larger number of juveniles. The number of adult *Limnodrilus maumeensis* and *Limnodrilus cervix* variant Brinkhurst decreased during the fall season (see Figure 13). The number of juveniles in the discharge canal and Plum Creek is lower compared to the other stations especially during the fall seasons.

Chironomidae

Chironomidae abundances varied erratically from year to year and were particularly low at most stations during spring and summer, 1974 (Figure 16). *Chironomus* spp. was mainly responsible being entirely absent at many of the stations. The density of chironomids at most stations was lower during summer than any other season. The number of chironomids in the Raisin River was virtually nonexistent during the summer and fall seasons. The numbers of *Chironomus* spp. and *Procladius* spp. was negatively affected by power plant operation (Figure 17). Comparatively high values were recorded at Stations 7 and 8 in 1970 for these two species. *Coelotanypus* spp., found most commonly at Stations 2, 5 and 6, usually was not present in Plum Creek, the discharge canal or the Raisin River.

Unlike the Tubificidae, which showed similar sediment preferences among the species, the Chironomidae did not appear to be as dependent on the sediment composition (Figure 18). When broken down by the four species present in the study area, 1975 data revealed distinct patterns of abundance (Figure 19). The average yearly densities of these same four species were also plotted at each of the six lake stations during the previous five years of the study (Figure 20). The species with the lowest abundance,

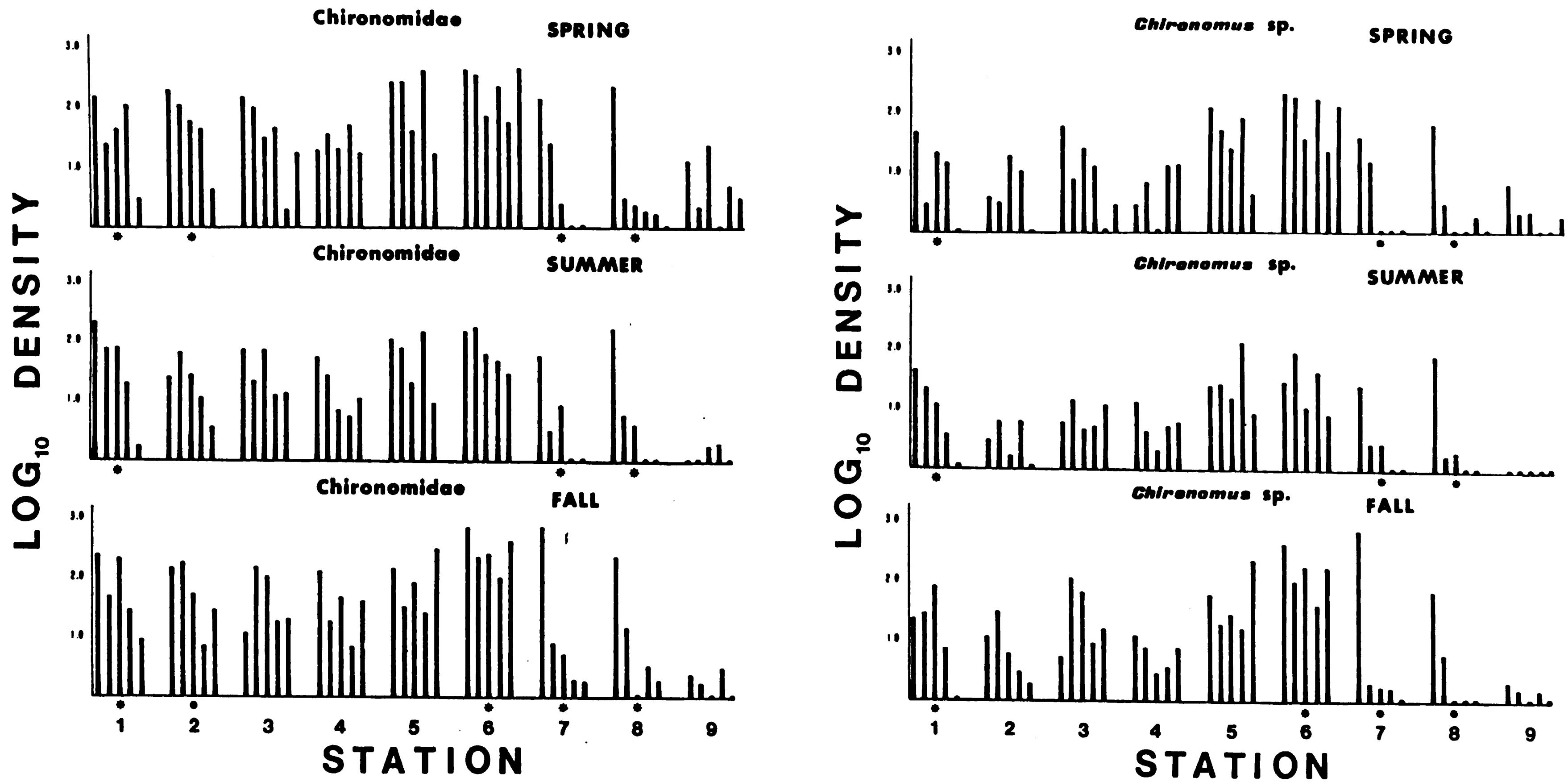


Figure 16. Density (no./m^2) of Chironomidae and <u>Chironomus</u> sp. in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B4.

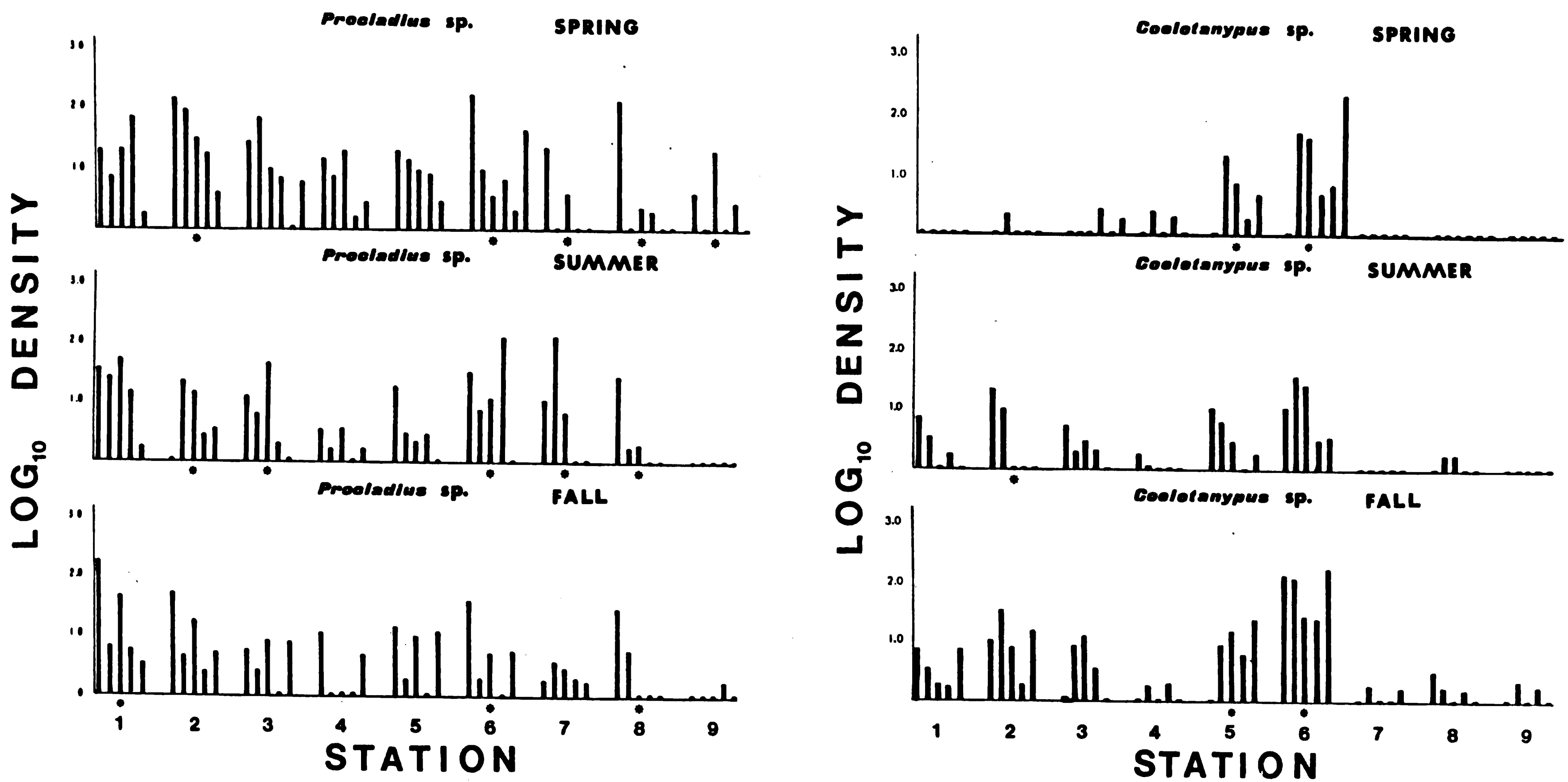


Figure 17. Density (no./m^2) of Procladius sp. and Coelotanypus sp. in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B4.

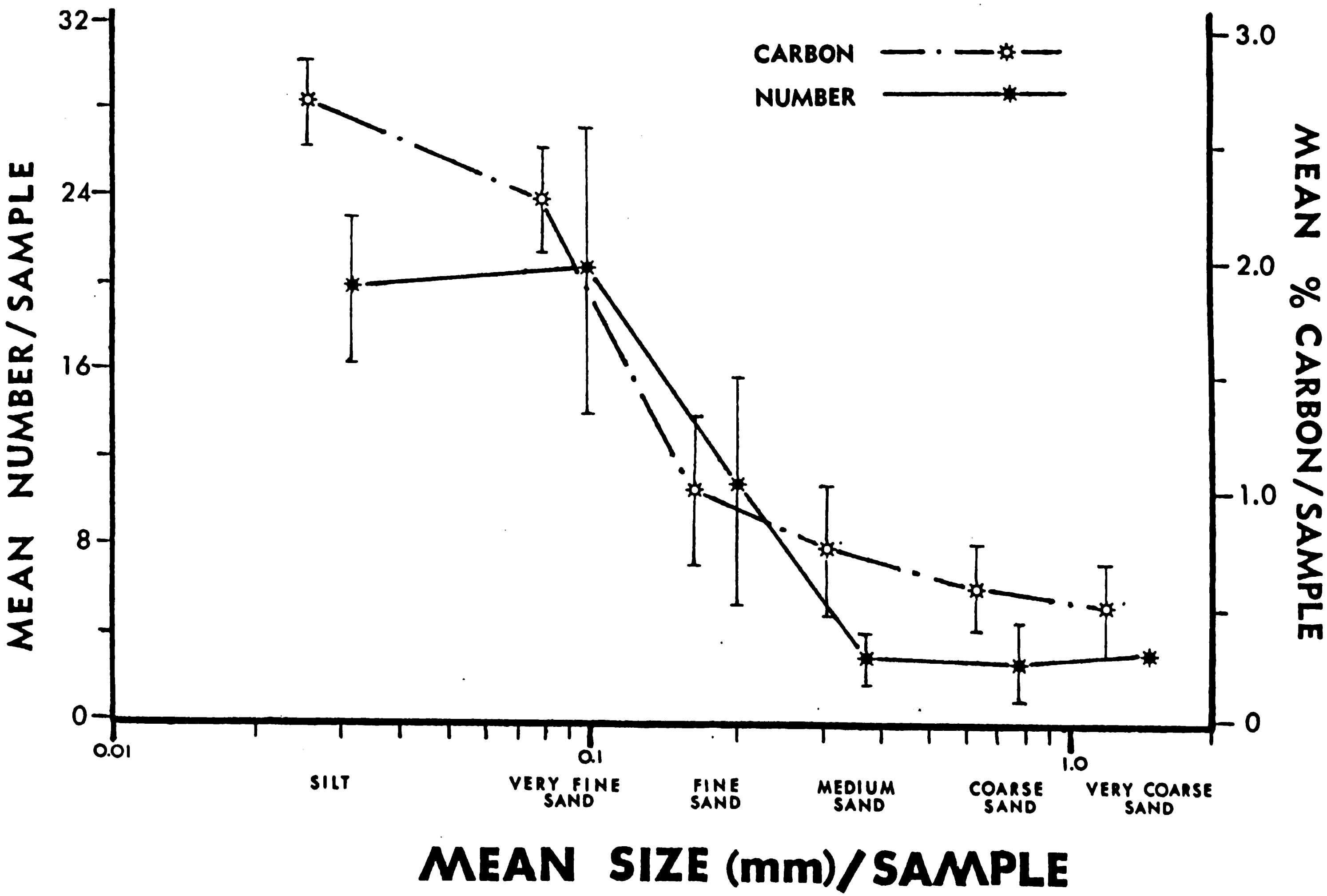


Figure 18. Relation of the mean number of chironomids to the carbon concentration and sediment size during spring, 1975. Vertical bars represent one standard error either side of the mean.

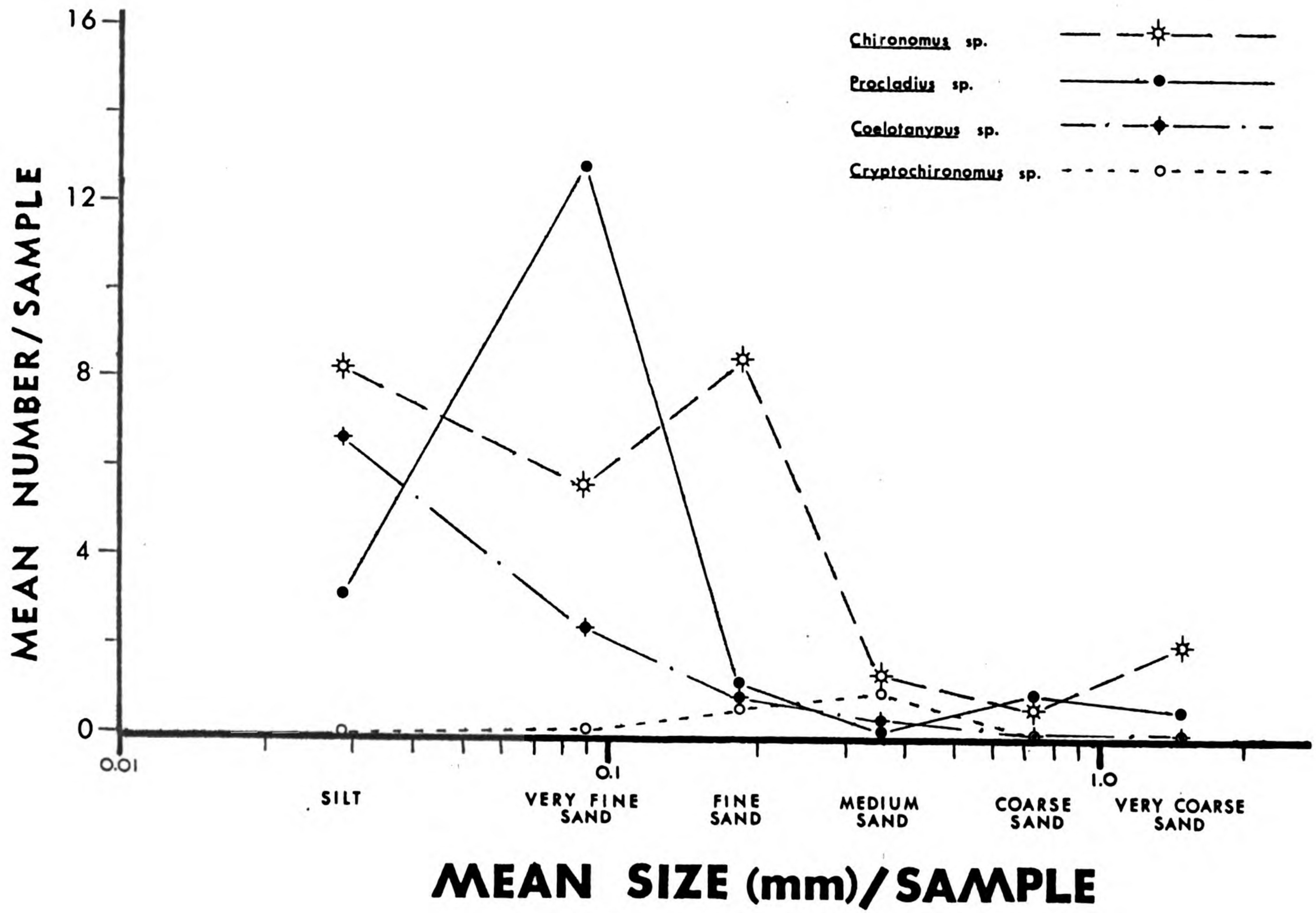


Figure 19. Relation of the mean number of individual species of Chironomidae to the sediment size during spring, 1975.

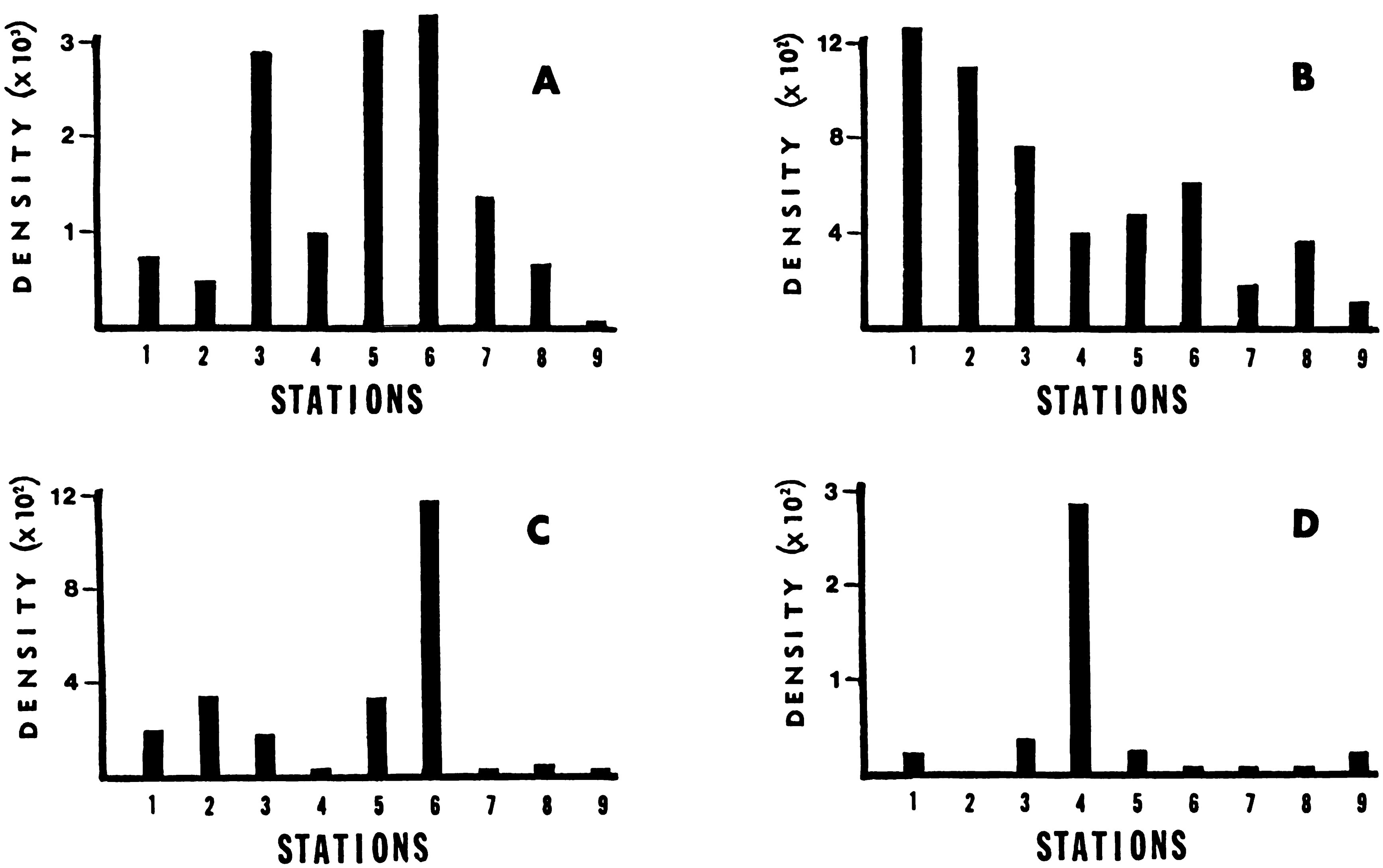


Figure 20. Mean yearly density (no./m^2) of individual species of Chironomidae at each station from 1970-1974; a) Chironomus sp., b) Procladius sp., c) Coelotanypus sp. and d) Cryptochironomus sp.

Cryptochironomus spp., was most common in fine and medium sand and was found almost entirely on the sandy bottom at Station 4. Coelotanypus spp., also relatively low in abundance, occurred most commonly in the highly silty sediments of Station 6. Chironomus spp., by far the most abundant chironomid, was mostly present in bottoms ranging from fine sand to silt. Its densities were highest at Stations 3 and 5 (both silt-sand) and Station 6 (mostly silt). Procladius spp. did not have such distinct patterns of abundance, but did have relatively high densities at the sandy-silt Stations 1 and 2.

Significant changes in the chironomid mean size rarely occurred in the lake throughout the study period (Figure 21). In contrast, the mean size of midges decreased during all seasons at Plum Creek and the discharge canal. Mean sizes in the river fluctuated without trend. The comparatively high values seen at Station 6 and somewhat at Station 5 are the result of high populations of the relatively large Chironomus spp.

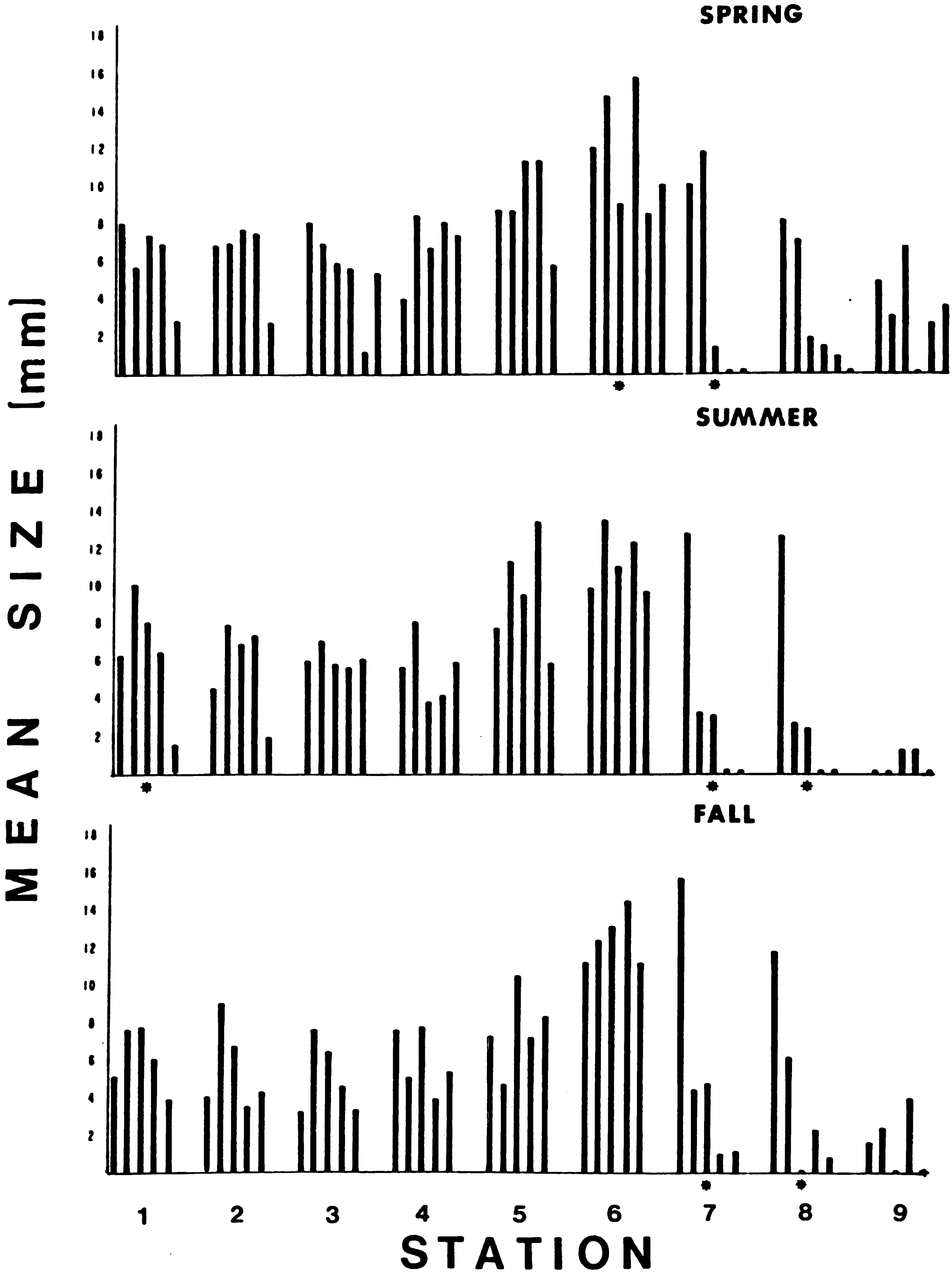


Figure 21. Mean size of chironomids in the study area. Tukey's test for significantly different stations marked with an asterisk are shown in Table B3.

DISCUSSION

Changes in the Benthic Fauna of Lake Erie

A comparison of studies undertaken by Wright (1955) in 1930 and Carr and Hiltunen (1965) in 1961 showed that significant long-term changes have taken place in the populations of bottom dwelling organisms in western Lake Erie. Five stations located in the Raisin River area made up a portion of these two studies. Their reports indicated a sixfold increase in the number of oligochaetes, a twofold increase in the number of midge larvae, a twelvefold increase in the number of fingernail clams and a tenfold increase in the number of gastropods. Burrowing mayfly nymphs (*Hexagenia* sp.) were not abundant in 1930, but were present in moderate numbers at three of the five stations. Only four specimens were collected in 1961. The only widespread genera of midges in the westernmost part of Lake Erie were *Procladius*, *Coelotanypus* and *Cryptochironomus*. *Chironomus* spp. (the most abundant midge species during our study) was neither widely distributed nor abundant. Oligochaete species of the genus *Limnodrilus* were extremely abundant in the mouth of the Raisin River. Additional studies by Beeton (1961), Wood (1963) and IJC (1969) generally confirm the changes and distribution of organisms observed in the western basin by Carr and Hiltunen (1965).

Changes in the abundance and distribution of the benthic fauna within the study area from 1960 to 1975 were not as dramatic as those shown for the period from 1930 to 1960. Although benthic densities were not quite as high as those reported by Carr and Hiltunen (1965) in 1961, comparable stations from the present study had relatively equal species composition (Table 4). By 1970 virtually 99% of all benthic macroinvertebrates were composed of four species of Chironomidae and eight species of Tubificidae. The Sphaeriidae, Gastropoda, Hirudinea and Amphipoda were rarely encountered from 1970 to 1975 although moderate abundances were reported for 1960. Therefore, it appears that subtle changes in composition have continued since 1960 to the present.

Brinkhurst (1967) suggests that the proportion of oligochaetes to other forms of life and the relative contribution of <u>Limnodrilus hoffmeisteri</u> may be a very useful guide to the degree of organic pollution. The four species of Chironomidae found in the study area were also classified by Brinkhurst <u>et al</u>. (1968) as tolerant of eutrophic conditions. The input of the Raisin and Maumee Rivers' organic wastes could have been partially responsible for the species composition found over the duration of the study. However, the impact of these two rivers on the changes observed in the benthic abundances at the various stations appears to be negligible. No obvious gradients in macroinvertebrate densities related to these two point sources materialized in the study.

Benthic abundances were particularly high during the preoperational year (1970) of the study. The drop in densities during subsequent years, other than in the discharge canal and Plum Creek, does not appear to originate from power plant operation. Remote reference Stations 1, 2 and 6, relatively unaffected by thermal discharge, also showed decreases in benthic abundances from the high values recorded in 1970. Densities increased again in 1972, but values were still only 50% of those recorded in 1970. It appears that 1970 was an exceptionally good year for the benthic organisms. Unfortunately, this kind of annual variation is one

Table 4. Density (no./m^2) of benthic macroinvertebrates in 1930, 1961 and 1970[@] in the Raisin River area.

Year and Station Number			Oligochaeta			Chironomidae			Hexagenia		
1930	1961	1970	1930	1961	1970	1930	1961	1970	1930	1961	1970
116	1R	6	0	4185	1853	540	634	513	40	0	0
116D	2R	5	0	9328	1342	68	297	235	0	4	0
210	3R	3	5800	13311	1975	135	310	157	0	0	0
---	6R	2	**	4144	3552	**	729	313	**	0	0
MEAN			1933	7742	2180	248	492	279	13	1	0
RELATIVE PERCENT			85.2	93.7	88.6	10.9	5.8	11.3	0.5	0	0

Year and Station Number			Sphaeriidae			Gastropoda		
1930	1961	1970	1930	1961	1970	1930	1961	1970
116	1R	6	14	14	0	**	4	0
116D	2R	5	0	0	0	14	23	0
210	3R	3	109	0	0	54	0	0
---	6R	2	**	50	0	**	0	0
MEAN			41	16	0	34	7	0
RELATIVE PERCENT			1.8	0.1	0	1.4	0.1	0

[@]Values listed are a yearly average over nine dates.
** No data.

of the arguments against having only one year as a preoperational reference for studying the impact of power plant operation.

Environmental Effects

Power Plant Operation

The onset of power plant operation in the summer of 1971 had a definite impact on the benthic organisms in the discharge canal and Plum Creek. The decrease in the number of tubificids at these two stations appears to be a negative response to increased temperatures. Oxygen concentrations were low in 1971, but as more lake water was drawn into the plant in later years, and as the river water itself seemed to improve because of better sewage treatment, oxygen concentrations approached saturation in the discharge canal. Concurrent studies on the same area have shown a significant increase during the study period in the number of bottom feeding fish occurring in the discharge canal (unpublished data). Studies conducted on other power plants have also shown that certain species of fish tended to concentrate in the effluent-outfall area (Mount, 1969; Gammon, 1970; Neill and Magnuson, 1974). Predation, as determined by close examination of stomach contents for undigestible parts (e.g. setae), showed negligible impact on tubificid numbers in the discharge canal and Plum Creek (Kenaga and Cole, 1975).

Predation plays a much larger role in the dynamics of the chironomids. Chironomidae (particularly *Procladius* spp. and *Chironomus* spp.) form a large percent of the food organisms occurring in the stomachs of fish captured during the study (Kenaga and Cole, 1975). The increased numbers of benthic feeding fish in the discharge canal and Plum Creek may have caused a portion of the decrease in chironomid abundance at these two stations. Size-selective predation by the fish may also have caused the reduction in the mean size of the chironomids.

Increased velocities caused by the addition of pumping units over the study period may have contributed to the decrease in densities apparent in the discharge canal. Velocities average between 0.10 to 0.15 m/sec. at full production. However, benthic abundances also decreased in the shallow, protected waters of Plum Creek where current velocity changes appeared to be negligible. It would appear that some factor or combination of factors other than increased velocity is mainly responsible for the decrease in benthic densities in the discharge canal.

Raisin River

The benthic abundances in the Raisin River are much lower compared to the other stations. In general, the tubificids are known for their ability to survive in organically polluted streams and lakes. As long as some oxygen is available from time to time, and the poisonous products of anaerobic breakdown of organic matter and metabolic wastes do not accumulate, then the rich food supply usually permits rapid growth of many tubificid species (Brinkhurst, 1971). The low abundances in the river may be caused by a complex interaction between periods of low oxygen and toxic contaminents. The diversion of the river water through the power plant and the subsequent heating may have caused an intensified effect on the benthic macroinvertebrates in the discharge canal and Plum Creek.

Sediments

The abundance of tubificid species at the lake stations appears to be related mainly to the sediments or factors associated with sediment types such as slope, depth and exposure to wave action. Other environmental factors such as oxygen and temperature remained relatively constant throughout the lake stations. The densities of tubificids and chironomids are both related to depth. The abundance of tubificids increases in the deeper, offshore areas of a lake (Mozley and Alley, 1973; Brinkhurst and Jamieson, 1971; Kinney, 1972). The number of chironomids is inversely related to depth, with the greatest number occurring at the shallowest depth (Thut, 1968). Although the Lake Erie water levels have risen during the past five years, the shallow, relatively uniform depth in the study area is not likely to vary enough for depth to directly influence the distribution of the tubificids and chironomids. However, minor variations in depth are probably related to the impact of wave action on sediment size composition.

The variability of the sediments had an impact on benthic abundances at the lake stations. The depth and slope of the bottom are related to the amount of silt at a particular station. Those lake stations with a high percentage of silt in the sediments were less variable over the duration of the study and also exhibited much less spatial variability. Benthic abundances at these stations were relatively high when compared to shallower, sandy sediments.

The percent of organic carbon and nitrogen in the sediments (food availability) appears to have an impact on benthic abundances. Wachs (1967) showed that oligochaetes would move into sediments with the highest nutritional potential in terms of organic carbon and nitrogen regardless of the texture of the sediment. In the present study, the carbon and nitrogen content of the lake sediments proved to be closely related to the sediment size. Mozley and Alley (1973), in their paper on southern Lake Michigan, also stated oligochaetes were associated more with silty than coarse sediments. However, unpredictable abundances of tubificids at "less preferable" locations frequently occurred throughout the study period. A more detailed analysis of the type of food material available for the detritus feeding tubificids may be needed. Brinkhurst and Chua (1969) found that the free organic matter and the available bacteria may prove to be more directly related to tubificid abundance than either the physical or chemical factors.

As a group, the chironomids appear to be related to sediment size, but when examined individually, the food habits and life histories of the species tend to dictate the type of sediment on which they are found. *Procladius* spp. is primarily predacious feeding upon cladocerans, copepods, ostracods, tubificids and other chironomid larvae (Thut, 1968). *Procladius* spp. is found at the surface of sediments composed of very fine sands. *Chironomus* spp. functions as a filter feeder, constucting a salivary net across the lumen of their mud-tubes and undulating their bodies to create a current through the tubes. *Coelotanypus* spp. was found mainly in the silty sediments at Station 6. *Cryptochironomus* spp. appeared to prefer sediments composed of medium sized sand particles.

In summary, power plant operation decreased benthic abundances in the discharge canal and Plum Creek (either through a negative response to the heated effluent, increased predation or the impact of diverted Raisin River water), but appeared to have negligible impact on the six lake stations. Changes in the abundance of benthic macroinvertebrates at the lake stations appear to be related mainly to the sediments (size, variability and food content). Other environmental factors remained relatively constant throughout the study period. The discharge canal empties onto a broad sandy shoal which may be one of the best places along the western shore such a thermal release could be made on the basis of macroinvertebrate abundance. This sandy area is characterized by highly variable sediments, shallow depths and increased wave action and is among the least suitable for benthic macroinvertebrates.

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LITERATURE CITED

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APPENDIX A

Table A1. Collection dates during the study period.

SPRING	SUMMER	AUTUMN
04/30/70	07/20/70	09/14/70
05/27/70	08/03/70	10/10/70
06/22/70	09/01/70	11/07/70
05/01/71	07/08/71	09/07/71
05/17/71	08/03/71	09/22/71
06/15/71	08/26/71	10/16/71
05/15/72	07/06/72	09/06/72
* * * *	08/01/72	09/28/72
06/17/72	08/16/72	10/26/72
05/07/73	06/26/73	08/10/73
05/24/73	07/22/73	08/28/73
06/22/73	08/01/73	09/28/73
05/23/74	07/01/74	09/05/74
06/05/74	07/18/74	09/18/74
06/20/74	08/01/74	10/08/74
03/18/75		
05/06/75		
06/24/75		

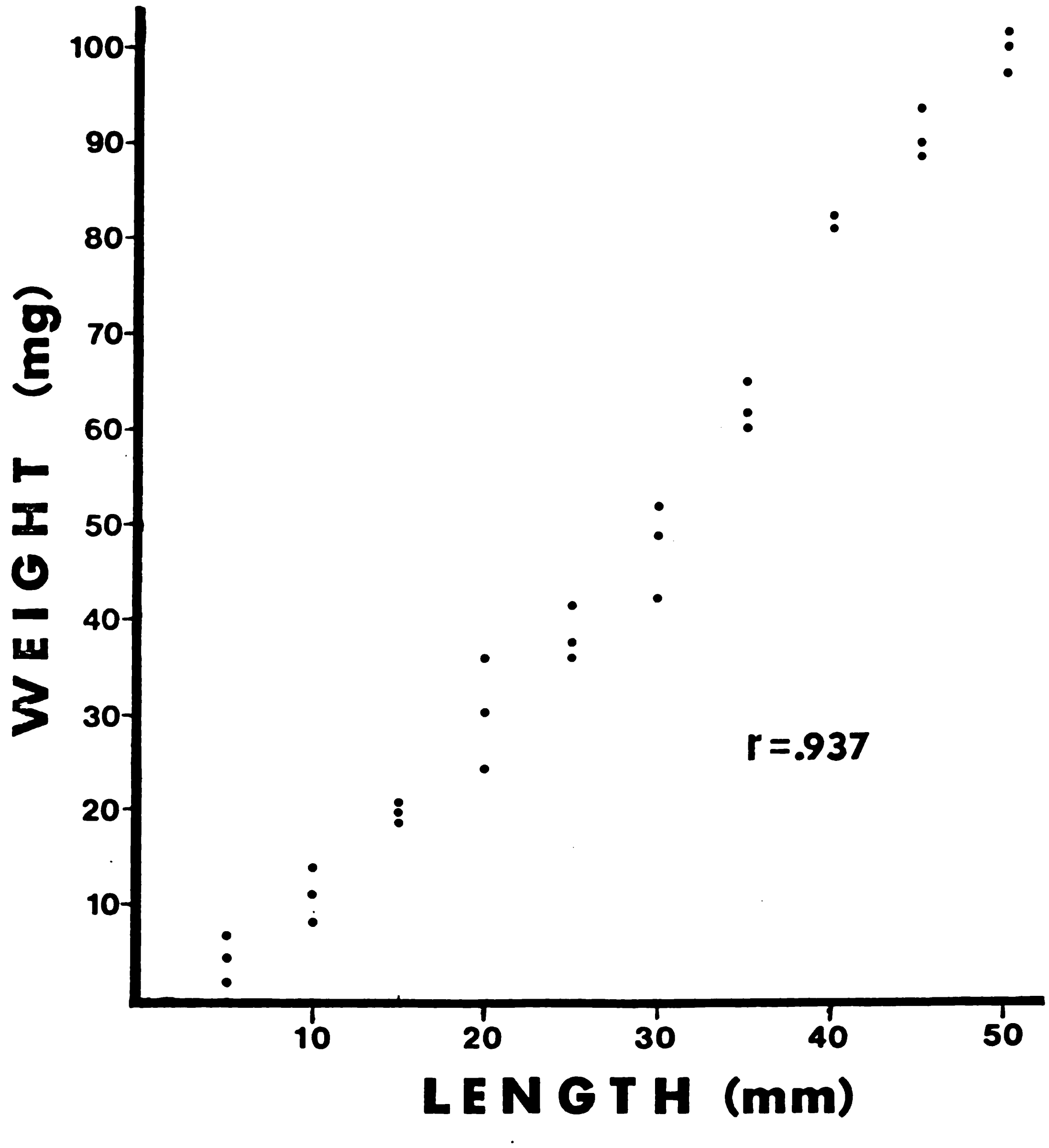


Figure A1. Relation of the length and dry weight of Tubificidae. Dry weight represents a total of 50 worms per sample.

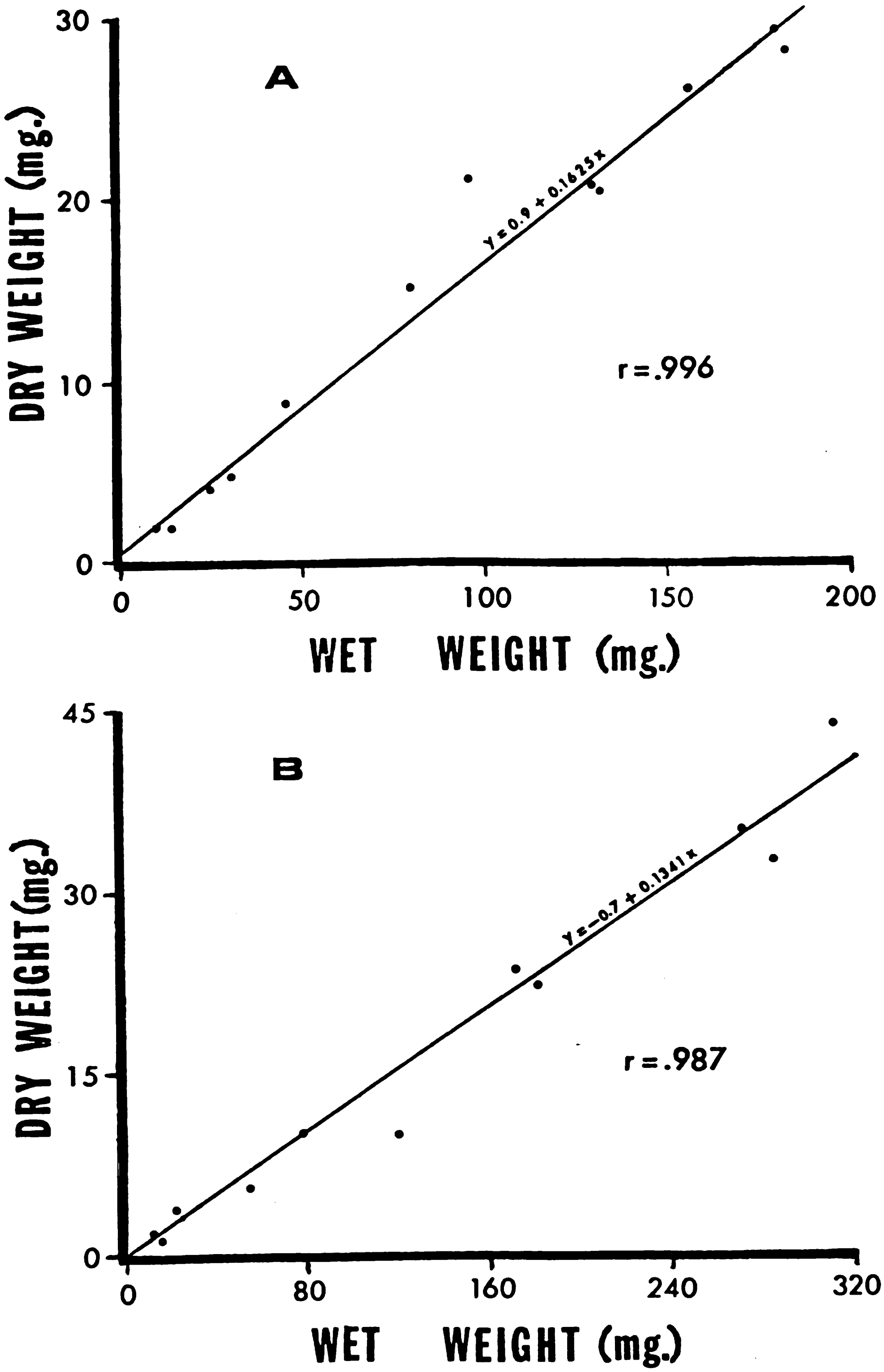


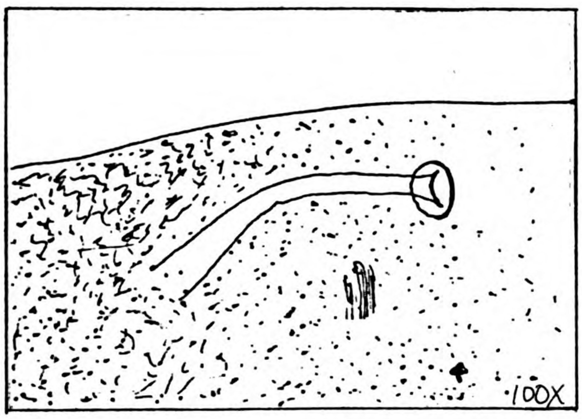
Figure A2. Relation of wet weight and dry weight of a) Tubificidae and b) Chironomidae.

Head capsule of Chironomus sp.
Station 6, 8/26/71

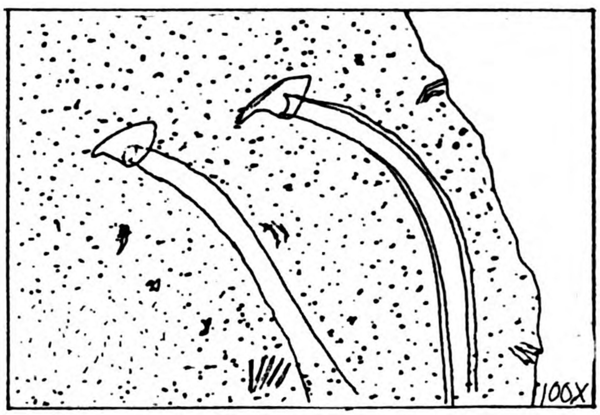
Head capsule of Procladius sp.
Station 1, 8/26/71

Head capsule of Coelotanypus sp.
Station 6, 8/26/71

Head capsule of Cryptochironomus sp.
Station 4, 7/8/71

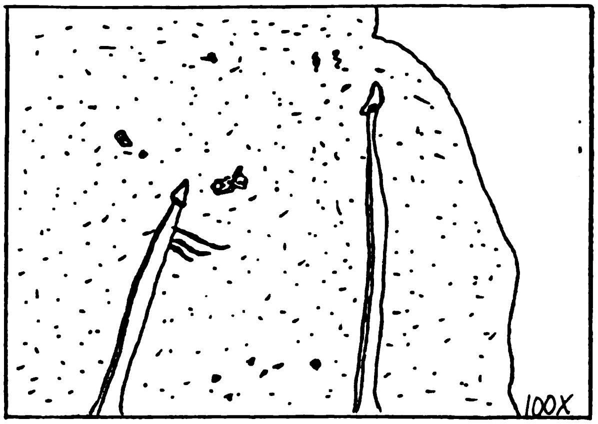


Penis tube of Limnodrilus hoffmeisteri. Station 6, 9/28/72

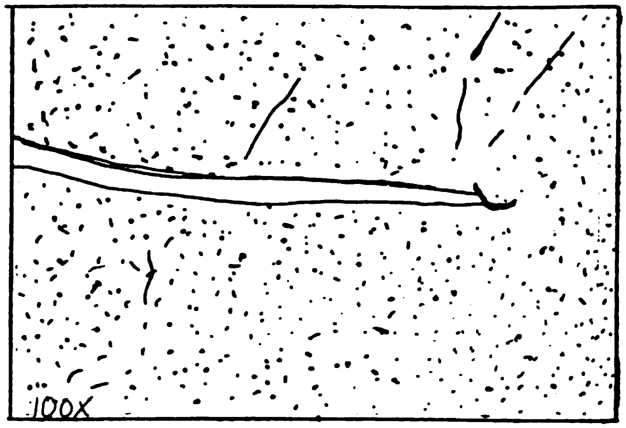


Penis tube of Limnodrilus maumeensis.
Station 1, 8/1/72

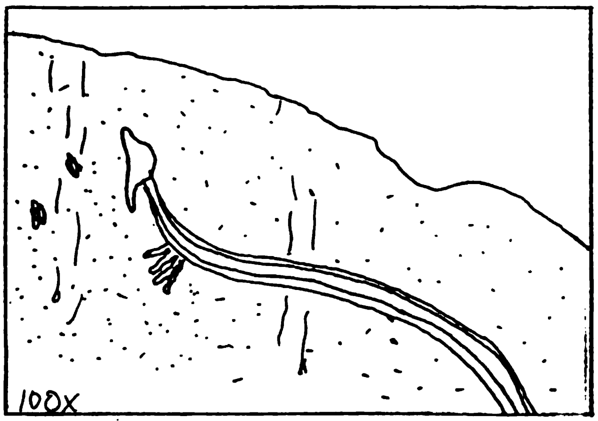
Figure A3. Characteristic features for the most abundant species collected in the study area.



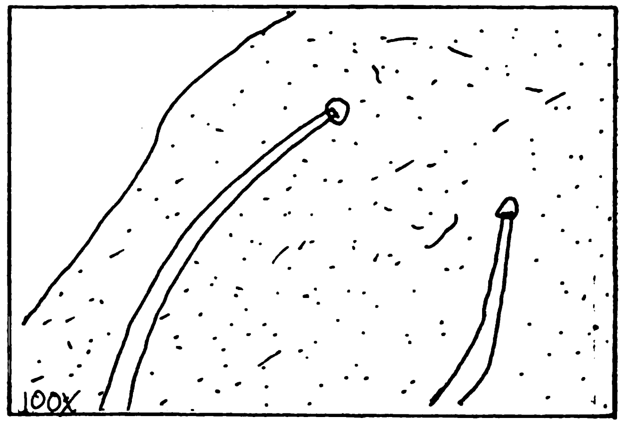
Penis tube of Limnodrilus cervix variant. Station 5, 7/6/72



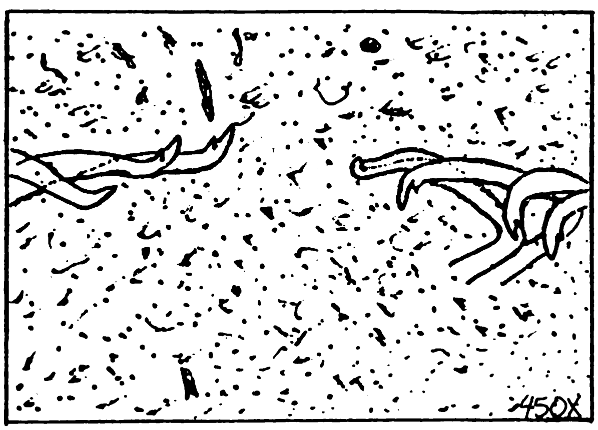
Penis tube of Limnodrilus cervix variant (side view). Station 1, 6/20/74



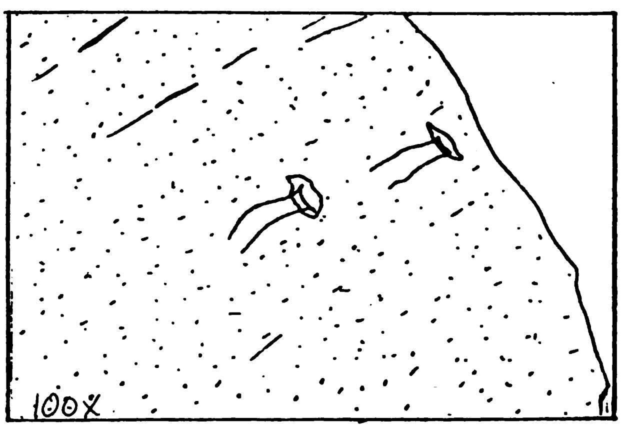
Penis tube of Limnodrilus cervix. Station 7, 8/16/72



Penis tube of Limnodrilus claparedianus. Station 5, 7/6/72



Setae of Limnodrilus udekemianus. Station 3, 7/1/74



Penis tube of Limnodrilus udekemianus. Station 3, 7/1/74

Figure A3 (cont'd.).

Table A2. Percent carbon in the sediments of the study area.

Date	STATIONS 1	2	3	4	5	6	7	8	9
04/30/70[b]	2.59	1.52	0.36	0.75	0.80	3.44	7.00	5.86	6.48
07/06/70[b]	0.56	1.85	0.13	0.61	0.61	3.69	4.00	6.85	7.89
09/29/70[b]	0.14	4.21	1.08	1.00	1.00	3.76	7.42	5.56	7.57
MEAN	1.09	2.52	0.52	0.78	0.80	3.63	6.14	6.09	7.31
05/17/71[b]	1.52	2.20	1.19	2.06	1.31	3.02	5.56	4.68	6.15
08/03/71[b]	0.57	2.06	0.77	1.09	1.67	3.28	6.11	5.37	5.63
10/16/71[b]	1.50	2.04	0.72	2.02	1.80	2.75	5.11	5.06	4.75
MEAN	1.19	2.10	0.89	1.73	1.59	3.01	5.59	5.03	5.51
06/17/72[b]	0.43	1.18	0.13	0.44	1.63	2.86	5.00	4.16	5.98
05/07/73[b]	0.84	1.27	0.33	0.17	0.91	3.66	6.48	4.61	5.96
08/01/73[b]	0.93	1.27	1.71	0.27	0.85	0.16	7.46	4.70	4.49
MEAN	0.88	1.27	1.02	0.22	0.88	1.91	6.97	4.65	5.22
07/01/74[a]	3.19	1.68	0.06	0.24	**	0.38	2.56	3.10	3.04
08/20/74[b]	3.65	2.63	0.11	0.18	2.27	2.66	4.51	3.39	4.01
11/11/74[b]	3.63	1.82	1.04	0.28	0.49	2.72	7.22	3.76	5.07
MEAN	3.49	2.04	0.40	0.23	1.38	1.92	4.76	3.38	4.04
03/18/75[b]			1.35			2.71		4.49	5.33
05/06/75[b]			0.56			3.21		5.41	4.95
06/24/75[b]			0.81			1.61		3.24	4.08
MEAN			0.90			2.51		4.38	4.78
GRAND MEAN	2.38	1.88	0.78	0.79	1.31	2.62	5.83	4.56	5.29

[a] Values listed are from one sample.
[b] Values listed are means from three replicates.

Table A3. Percent nitrogen in the sediments of the study area.

	STATIONS								
Date	1	2	3	4	5	6	7	8	9
04/30/70[b]	0.11	0.06	0.02	0.01	0.01	0.16	0.39	0.24	0.31
07/06/70[b]	0.03	0.10	0.01	0.01	0.01	0.23	0.45	0.38	0.34
09/29/70[b]	0.01	0.25	0.01	0.01	0.01	0.20	0.45	0.29	0.40
MEAN	0.05	0.13	0.01	0.01	0.01	0.19	0.43	0.30	0.35
05/17/71[b]	0.17	0.23	0.21	0.11	0.24	0.25	0.45	0.39	0.42
08/03/71[b]	0.05	0.17	0.08	0.08	0.08	0.29	0.45	0.40	0.66
10/16/71[b]	0.17	0.22	0.11	0.15	0.09	0.32	0.42	0.36	0.40
MEAN	0.13	0.20	0.13	0.11	0.13	0.28	0.44	0.38	0.49
06/17/72[b]	0.02	0.10	0.02	0.04	0.13	0.21	0.33	0.30	0.39
05/07/73[b]	0.06	0.14	0.01	0.01	0.05	0.28	0.96	0.38	0.50
08/01/73[b]	0.13	0.08	0.11	0.02	0.07	0.03	0.59	0.41	0.35
MEAN	0.09	0.11	0.06	0.01	0.06	0.15	0.77	0.39	0.42
07/01/74[a]	0.26	0.13	0.01	0.05	**	0.05	0.16	0.19	0.32
08/20/74[b]	0.28	0.24	0.02	0.02	0.17	0.27	0.38	0.18	0.37
11/11/74[b]	0.25	0.12	0.02	0.02	0.06	0.24	0.50	0.23	0.30
MEAN	0.26	0.16	0.01	0.03	0.11	0.18	0.34	0.20	0.33
03/18/75[b]			0.12			0.27		0.37	0.38
05/06/75[b]			0.03			0.27		0.38	0.37
06/24/75[b]			0.08			0.16		0.26	0.35
MEAN			0.07			0.23		0.33	0.36
GRAND MEAN	0.14	0.16	0.07	0.05	0.10	0.23	0.49	0.33	0.41

[a]Values listed are from one sample.
[b]Values listed are means from three replicates.

Table A4. 1975 Sediment particle size.

		PERCENT COMPOSITION							
Station	Date	Pebbles	Granules	Coarse Sand	Medium Sand	Fine Sand	Silt	Clay	Comments
6	6/24	13.9	1.4	0.8	5.0	22.4	55.2	1.3	
9	6/24	8.4	17.0	11.9	35.8	25.5	1.4	0.1	
14	3/18	0.0	0.0	0.3	3.1	13.6	76.1	6.9	Shell Fragments
28	5/28	0.0	1.4	1.2	12.9	22.2	61.5	0.7	
31	4/22	0.0	0.0	0.0	0.6	2.9	6.2	90.3	
32	4/22	6.9	7.3	4.8	18.2	39.1	23.0	0.6	
37	3/18	0.0	0.0	0.4	6.8	29.8	59.4	3.8	Shell Fragments
38	3/18	0.0	0.0	0.2	2.3	12.7	81.5	5.0	Shell Fragments
39	3/18	0.0	0.2	0.4	2.1	96.6	0.6	0.1	
49	3/18	0.0	0.7	2.0	16.3	52.4	26.7	1.9	
49	5/6	0.6	3.8	6.3	27.0	52.3	9.8	0.3	
49	5/28	0.5	11.8	18.8	39.2	28.3	1.4	0.1	
50	5/6	13.9	6.3	9.3	20.8	27.1	21.3	1.3	
51	6/24	0.3	2.4	6.3	53.8	35.1	1.9	0.1	Shell Fragments
54	4/22	0.0	0.3	0.8	2.9	6.4	88.5	1.1	Shell Fragments
55	6/24	0.0	0.7	2.0	19.5	43.9	32.6	1.2	Shell Fragments
57	3/18	0.0	0.0	0.7	2.4	44.7	49.7	2.5	Detritus, shells
62	4/22	0.0	0.1	0.5	52.8	46.4	0.2	0.1	
62	6/24	0.0	0.2	0.3	1.1	19.2	77.0	2.2	
63	5/28	0.0	0.1	2.2	2.8	93.0	1.6	0.2	

Table A4 (cont'd.).

Station	Date	PERCENT COMPOSITION Pebbles	Granules	Coarse Sand	Medium Sand	Fine Sand	Silt	Clay	Comments
63	4/22	0.0	0.0	1.1	2.2	89.6	6.6	0.5	Detritus
64	3/18	0.0	0.0	0.5	4.3	68.6	25.4	1.2	Detritus
64	4/22	0.5	3.2	1.8	16.5	66.9	11.0	0.1	Shell Fragments
64	5/28	0.0	0.3	1.3	16.7	63.5	17.6	0.5	
65	5/6	0.6	4.5	11.9	35.9	44.7	2.1	0.1	Shell Fragments
66	4/22	0.0	0.5	4.8	22.8	26.6	44.6	0.8	
70	3/18	3.6	12.2	9.0	26.7	47.3	0.8	0.3	Shell Fragments
70	6/24	0.0	0.0	0.2	0.5	98.8	0.5	0.0	
75	3/18	0.0	1.3	2.4	26.3	68.8	1.0	0.2	Shell Fragments
75	6/24	0.0	0.5	1.6	14.6	58.8	23.5	0.8	
77	5/6	0.0	1.9	2.7	11.7	68.8	14.6	0.5	
82	5/28	0.0	0.1	0.4	1.5	96.1	1.6	0.2	
85	4/22	0.1	0.1	0.4	8.9	90.3	0.1	0.0	Shell Fragments
85	6/24	0.0	1.9	4.8	39.9	52.7	0.7	0.1	
88	5/6	0.0	1.5	4.9	33.0	59.5	1.1	0.1	
88	5/28	1.8	2.5	3.8	20.0	70.9	0.9	0.1	
95	3/18	0.0	1.6	2.9	20.2	67.9	6.2	1.2	
95	4/22	0.2	8.3	7.4	28.3	55.2	0.7	0.1	Detritus
97	5/6	0.0	0.0	0.2	1.0	98.5	0.3	0.1	
98	5/6	0.0	0.7	4.0	64.0	29.5	1.4	0.5	Shell Fragments

Table A4 (cont'd.).

Station	Date	PERCENT COMPOSITION Pebbles	Granules	Coarse Sand	Medium Sand	Fine Sand	Silt	Clay	Comments
98	6/24	8.8	5.0	47.1	26.0	10.6	2.2	0.2	
99	5/6	0.0	1.1	55.5	64.2	28.1	1.0	0.1	Shell Fragments
100	4/22	1.0	2.2	4.1	43.8	47.2	0.8	1.0	Shell Fragments
100	6/24	3.5	0.9	1.7	15.4	51.4	25.8	1.4	
103	4/22	1.2	2.4	2.2	11.8	72.2	10.9	0.1	
108	3/18	21.8	9.9	8.5	26.3	30.6	2.2	0.4	
108	4/22	19.6	9.3	4.1	31.6	34.6	0.8	0.1	
108	6/24	0.1	0.4	0.5	9.8	86.9	1.1	0.1	
108	5/28	1.4	4.3	3.8	13.8	42.3	33.4	1.0	
111	3/18	0.0	2.1	3.3	11.4	40.1	38.9	4.1	Shell Fragments
111	5/28	11.4	5.0	5.5	33.8	40.1	4.1	0.2	
115	4/22	68.8	23.1	3.8	1.9	2.1	0.3	0.1	
115	5/6	0.4	7.3	4.4	6.2	15.5	64.1	2.0	Shell Fragments
121	3/18	18.5	3.8	4.9	15.6	43.9	11.9	1.4	
134	6/24	0.0	0.1	1.4	19.3	65.4	13.2	0.6	
145	6/24	0.4	2.0	2.0	31.0	53.6	10.2	0.6	
150	3/18	0.0	0.4	0.2	16.2	83.0	0.1	0.1	
162	6/24	0.0	0.1	0.1	1.1	98.2	0.5	0.1	
164	5/28	0.2	0.2	0.1	0.7	10.8	87.6	0.5	
166	3/18	0.0	0.0	0.0	0.5	3.6	86.4	9.5	

Table A4 (cont'd.).

Station	Date	PERCENT COMPOSITION Pebbles	Granules	Coarse Sand	Medium Sand	Fine Sand	Silt	Clay	Comments
166	4/22	0.0	0.5	0.5	9.3	73.5	15.5	0.6	Shell Fragments
166	5/6	0.2	4.0	5.6	41.0	48.6	1.6	0.1	
169	4/22	0.9	7.3	5.2	13.5	32.4	39.8	0.9	Detritus
174	5/28	0.0	0.1	0.1	1.8	29.8	66.6	1.6	
176	5/6	0.0	0.1	0.3	3.8	38.9	54.6	2.4	
177	5/28	0.0	1.4	1.5	5.2	33.6	56.6	1.7	
186	5/6	16.2	31.5	8.2	13.6	25.5	4.8	0.2	
188	6/24	0.0	0.0	0.0	0.1	4.2	92.9	2.8	
6	5/28		N O	S A M P L E					Large Pebbles
13	5/28		N O	S A M P L E					Large Pebbles
18	5/28		N O	S A M P L E					Large Pebbles
40	5/6		N O	S A M P L E					Large Pebbles
44	3/18		N O	S A M P L E					Large Pebbles
72	5/28		N O	S A M P L E					Compacted Clay
127	3/18		N O	S A M P L E					Compacted Clay

Table A5. Percent silt and clay in the sediments of the study area.

	STATIONS								
Date	1	2	3	4	5	6	7	8	9
04/30/70[c]	57.9	38.5	11.8	6.6	3.9	97.3	71.3	82.7	98.0
07/06/70[c]	4.4	36.3	1.0	2.0	4.1	97.6	78.0	92.7	96.6
09/29/70[c]	12.0	61.2	4.2	0.4	11.1	95.5	59.1	94.3	98.6
MEAN	24.8	45.3	5.6	3.0	6.4	96.8	69.5	89.9	97.7
05/17/71[b]	18.6	14.6	19.3	13.6	20.1	95.1	70.2	83.7	83.8
08/03/71[b]	7.8	37.2	12.2	7.1	18.0	96.3	77.9	94.1	92.2
10/16/71[b]	36.9	44.5	22.3	2.0	2.5	93.7	97.6	71.5	93.7
MEAN	20.8	32.1	17.9	7.6	13.5	94.7	81.9	83.1	89.6
06/17/72[a]	0.6	12.5	0.8	5.2	**	42.2	11.6	15.1	44.2
05/07/73[a]	3.6	40.6	1.8	0.3	5.0	99.9	99.9	99.9	35.3
08/01/73[a]	22.8	16.0	31.6	0.8	2.4	3.0	29.5	67.6	96.2
MEAN	13.2	28.3	16.7	0.6	3.7	51.5	64.7	83.8	65.8
07/01/74[a]	88.8	11.1	0.4	7.7	**	7.5	15.3	20.6	99.4
08/20/74[b]	89.0	90.6	1.0	0.5	61.5	98.2	87.1	71.5	99.8
11/11/74[b]	68.1	47.3	1.8	0.8	6.8	97.9	75.7	71.1	94.3
MEAN	81.9	49.8	1.0	3.0	34.2	67.9	59.4	54.4	97.8
03/18/75[c]			19.3			96.9		69.1	59.6
05/06/75[c]			3.7			97.8		95.8	90.8
06/24/75[c]			37.8			87.4		90.1	98.6
MEAN			20.3			94.0		85.0	83.0
GRAND MEAN	37.0	40.2	13.3	4.1	16.3	86.8	61.4	77.7	86.2

[a]Values listed are from one sample.
[b]Values listed are means from two replicates.
[c]Values listed are means from three replicates.

APPENDIX B

Table B1. Explanation of abbreviations used in Appendix B.

Abbreviation	Meaning
TOTAL	Total macroinvertebrate density
SHANN	Shannon's species diversity index
EQUIT	Equitability index
TUBIF	Tubificidae density
LHOFF	*Limnodrilus hoffmeisteri* density
LMAUM	*Limnodrilus maumeensis* density
LCERV	*Limnodrilus cervix* variant density
OSIZE	Tubificidae mean size
RATIO	Ratio of immature to adult Tubificidae
CHIRO	Chironomidae density
CHRSP	*Chironomus* sp. density
PROCL	*Procladius* sp. density
COELO	*Coelotanypus* sp. density
CSIZE	Chironomidae mean size
a,b,c	Years having the same small letter are *not* significantly different from each other

Table B2. Tukey's multiple range comparison test for benthic macro-invertebrates.

Variable	Station	Season	1970	1971	1972	1973	1974	1975
TOTAL	3	Spring	a	a	a b	a	b	a b
TOTAL	8	Spring	a	a b	a b	b	b	b
TOTAL	9	Spring	a	b	a b	a b	a b	a b
TOTAL	1	Summer	a	b	a	a b	a	
TOTAL	2	Summer	a	a	a	b	a b	
TOTAL	3	Summer	a	a	a b	a	b	
TOTAL	6	Summer	a	a	a	a b	b	
TOTAL	8	Summer	a	a	b c	a b	c	
TOTAL	9	Summer	a	a	a	b	b	
TOTAL	2	Fall	a	a	a b	b	b	
TOTAL	4	Fall	a	a	a b	b	a	

Table B2 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
TOTAL	7	Fall	a	b	a b	b	b	
TOTAL	8	Fall	a	a	b	a	a b	
SHANN	3	Spring	a	a	a b	a	b	a b
SHANN	8	Spring	a	a b	a b c	b c d	c d	d
SHANN	2	Summer	a b	a	a b	a b	b	
SHANN	8	Summer	a	a	a b	b	b	
SHANN	4	Fall	a	a	b	b	a b	
SHANN	8	Fall	a	a	b	b	b	
EQUIT	3	Spring	a	a	a b	a	b	a
EQUIT	8	Spring	a	a	a	a b	a b	b
EQUIT	2	Summer	a	a b	a b	a b	b	

Table B2 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
EQUIT	7	Summer	a	a	a		a	
			b	b		b	b	
EQUIT	4	Fall	a	a	a		a	
					b	b		
EQUIT	8	Fall	a	a				
					b	b	b	

Table B3. Tukey's multiple range comparison test for Tubificidae.

Variable	Station	Season	1970	1971	1972	1973	1974	1975
TUBIF	3	Spring	a	a		a		a
				b	b	b		b
					c	c	c	c
TUBIF	4	Spring	a	a	a		a	
					b	b		
TUBIF	8	Spring	a	a	a			
				b	b	b	b	b
TUBIF	1	Summer	a		a	a	a	
				b	b	b	b	
TUBIF	2	Summer	a	a	a			
				b	b	b	b	
TUBIF	3	Summer	a	a	a	a		
				b	b	b	b	
TUBIF	5	Summer	a		a	a	a	
				b	b	b	b	
TUBIF	6	Summer	a	a	a	a		
				b	b	b	b	
TUBIF	8	Summer	a	a		a		
				b	b	b		
					c		c	
TUBIF	9	Summer	a	a	a			
						b	b	
TUBIF	4	Fall	a	a	a		a	
				b	b	b	b	

Table B3 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
TUBIF	7	Fall	a	c	a b	b c	b c	
TUBIF	8	Fall	a	a b	b	a b	a b	
LHOFF	3	Spring	a	a	a b	a	b	b
LHOFF	4	Spring	a	a	a b	b	a b	
LHOFF	3	Summer	a	a	a	a b	b	
LHOFF	8	Summer	a	b	c	a b	b c	
LHOFF	9	Summer	a	a	a	b	b	
LHOFF	7	Fall	a	b	a b	b	b	
LHOFF	9	Fall	a	a	a b	b	b	
LMAUM	3	Spring	a	b	b c	a b	c	b c
LMAUM	8	Spring	a	b	c d	c	d	d

Table B3 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
LMAUM	3	Summer	a	b	b	a b	a b	
LMAUM	6	Summer	a	b	b	a b	a b	
LMAUM	8	Summer	a	b	b c	b c	c	
LMAUM	8	Fall	a	a b	b	b	b	
LCERV	3	Spring	a b	a	a	a	b	b
LCERV	4	Spring	a b	a	b	a b	a b	
LCERV	7	Spring	a	a	b	a	b	
LCERV	7	Summer	a	b	b	a b	b	
LCERV	7	Fall	a b	b	a	a	a b	
OSIZE	1	Spring	a b	a	b	a b	c	
OSIZE	2	Spring	a b c	a b	c	b c	a	

Table B3 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
OSIZE	4	Spring	a	a			a	
			b		b			
					c	c		
OSIZE	6	Spring	a	a			a	a
			b	b	b	b	b	
OSIZE	1	Summer	a	a	a	a		
				b		b	b	
OSIZE	2	Summer	a	a		a	a	
			b	b	b		b	
OSIZE	8	Summer	a	a		a		
					b		b	
OSIZE	9	Summer	a	a	a			
					b	b		
						c	c	
OSIZE	9	Fall	a	a	a			
					b	b	b	
RATIO	8	Summer	a	a	a	a		
					b		b	
RATIO	9	Summer	a		a		a	
				b	b			
						c	c	
RATIO	9	Fall	a	a	a		a	
						b		

Table B4. Tukey's multiple range comparison test for Chironomidae.

Variable	Station	Season	1970	1971	1972	1973	1974	1975
CHIRO	1	Spring	a	a	a	a		
				b	b	b	b	b
CHIRO	2	Spring	a	a	a	a		
				b	b	b	b	
CHIRO	7	Spring	a	a				
					b	b	b	
CHIRO	8	Spring	a					
				b	b	b	b	b
CHIRO	1	Summer	a	a	a	a		
						b	b	
CHIRO	7	Summer	a		a			
				b	b	b	b	
CHIRO	8	Summer	a					
				b	b	b	b	
CHIRO	1	Fall	a	a	a	a		
						b	b	
CHIRO	2	Fall	a	a	a		a	
			b		b	b	b	
CHIRO	6	Fall	a	a	a		a	
				b		b		
CHIRO	7	Fall	a					
				b	b	b	b	

Table B4 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
CHIRO	8	Fall	a	b	c	b	b c	
CHRSP	1	Spring	a	a b	a b	a b	b	
CHRSP	7	Spring	a	a b	b	b	b	
CHRSP	8	Spring	a	b	b	b	b	b
CHRSP	1	Summer	a	a	a b	a b	b	
CHRSP	7	Summer	a	a	a b	b	b	
CHRSP	8	Summer	a	b	b	b	b	
CHRSP	1	Fall	a	a	a	a b	b	
CHRSP	6	Fall	a	a b	a	b	a	
CHRSP	7	Fall	a	b	b	b	b	
CHRSP	8	Fall	a	b	b	b	b	

Table B4 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
PROCL	2	Spring	a	a b	a b	a b	b	
PROCL	6	Spring	a	a b	b	b	b	a b
PROCL	7	Spring	a	b	a b	b	b	
PROCL	8	Spring	a	b	b	b	b	b
PROCL	9	Spring	a b	b	a	b	a b	b
PROCL	2	Summer	a	b	b	a b	b	
PROCL	3	Summer	a	a	a	a b	b	
PROCL	6	Summer	a	a b	a	b	b	
PROCL	7	Summer	a	a b	a b	a b	b	
PROCL	8	Summer	a	b	b	b	b	
PROCL	1	Fall	a	b	a b	b	b	

Table B4 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
PROCL	6	Fall	a	b	a b	b	a	
PROCL	8	Fall	a	a b	b	b	b	
COELO	5	Spring	a	b	a b	a b	a b	
COELO	6	Spring	a	b c	b c	a b	a b	c
COELO	2	Summer	a	a b	a b	a b	b	
COELO	5	Fall	a	a b	a b	a b	b	
CSIZE	6	Spring	a b	a b	a b	a	b	a b
CSIZE	7	Spring	a	a	b	b	b	
CSIZE	1	Summer	a b	a	a	a b	b	
CSIZE	7	Summer	a	b	b	b	b	
CSIZE	8	Summer	a	b	b	b	b	
CSIZE	7	Fall	a	b	b	b	b	

Table B4 (cont'd.).

Variable	Station	Season	1970	1971	1972	1973	1974	1975
CSIZE	8	Fall	a	a				
				b	b	b	b	