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ABUNDANCE AND DISTRIBUTION OF THE CLADOCERAN ZOOPLANKTON *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia galeata mendotae* AND *Daphnia retrocurva* IN THE NEARSHORE WATERS OF LAKE MICHIGAN NEAR LUDINGTON, MICHIGAN

presented by

Joan Ellen Duffy

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By

Joan Ellen Duffy

A THESIS

Submitted to
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ABSTRACT

ABUNDANCE AND DISTRIBUTION OF THE CLADOCERAN ZOOPLANKTON *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia galeata mendotae* AND *Daphnia retrocurva* IN THE NEARSHORE WATERS OF LAKE MICHIGAN NEAR LUDINGTON, MICHIGAN

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The seasonal distribution of *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia galeata mendotae* and *Daphnia retrocurva* in Lake Michigan near Ludington, Michigan was studied in 1975-1977. The abundance of the four Cladocera was analyzed with respect to several physical and meteorological factors. *Bosmina* was the dominant Cladocera, reaching greatest densities in the summer and fall, and *Eubosmina* was most abundant in the fall. The *Daphnia* were common only in the summer and fall. Statistical tests showed that there were no significant differences between species abundances at three stations in any year. The Cladocera were bimodally distributed in 1975 and 1976, and had monocyclic patterns of distribution in 1977, when abundances were generally reduced. The environmental factors analyzed explained between 11.7 and 70.4 percent of the variation in abundance. Mean total zooplankton abundance was most frequently an important variable in explaining variance though wind direction, water temperature and air pressure were also important.

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INTRODUCTION

The Cladoceran zooplankton are an important part of the aquatic ecosystem in Lake Michigan but have received little detailed study until recently. This study was undertaken to quantify the occurrence of Cladoceran zooplankton species in a nearshore area of Lake Michigan during 1975 to 1977, and to determine to what extent the abundance of these species was affected by various physical and meteorological factors. *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia galeata mendotae* and *Daphnia retrocurva* were chosen because of their common occurrence in the Cladoceran zooplankton. Environmental factors chosen for analysis were wind speed, wind direction, water temperature, air pressure, photoperiod, water turbidity, water transparency and mean total zooplankton abundance.

Early zooplankton studies in Lake Michigan were descriptive in nature and concentrated on taxonomy (Birge 1882, Forbes 1882, Ward 1896). Eddy (1927) was the first to obtain data on seasonal distribution of zooplankton in nearshore southern Lake Michigan. Ahlstrom (1936) conducted the first offshore zooplankton study. Several early studies investigated zooplankton in the water supplies of several major cities on Lake Michigan (Damman 1945, 1960; Williams 1962, 1966). Wells (1960) was the first to conduct a quantatitive study of the seasonal distribution of zooplankton in eastern Lake Michigan. He later noted a change in the species composition in 1966 (Wells 1970) which he attributed to alewife predation.

Most large zooplankton had declined in numbers while smaller zooplankton increased in numbers. After a dramatic decline in the alewife population in 1967 the zooplankton species composition began to shift back to its earlier structure. Gannon (1972) conducted a comprehensive study of seasonal distribution and abundance of zooplankton, and showed the effects of eutrophication on the zooplankton community. Roth and Stewart (1973) studied the zooplankton in southeastern Lake Michigan near the Donald C. Cook Nuclear Plant at Bridgeman, Michigan.

The zooplankton community at the site of the present study was first studied by Duffy (1975). He reported the abundance and seasonal distribution of the zooplankton, and investigated their vertical distribution. Duffy and Liston (1978) compared the zooplankton community of the Ludington Pumped Storage Reservoir to that of Lake Michigan at the control site of the present study.

DESCRIPTION OF STUDY AREA

The study area is the site of a current environmental study conducted by the Department of Fisheries and Wildlife, Michigan State University, to determine the effects of the Ludington Pumped Storage Power Plant on the aquatic biota of Lake Michigan. The zooplankton population of the area has been monitored since 1972 as part of the overall environmental study (Duffy and Liston 1979). The area is 6.4 km (4.0 miles) south of Ludington, Michigan, adjacent to and south of the power plant (Figure 1). The impact stations are 0.8 km (0.5 miles) north of the breakwater of the power plant (station 5) and 0.8 km (0.5 miles) south of the breakwater (station 3; Figure 1). Both stations are 12 meters deep and have sand and gravel substrates. The control station is 4.8 km (3.0 miles) south of the breakwater, in an area considered unaffected by currents from the power plant. It is 12 meters deep and has a sandy substrate.

Figure 1. Map and location of permanent sampling stations in Lake Michigan adjacent to the Consumers Power Pumped Storage Plant near Ludington, Michigan.

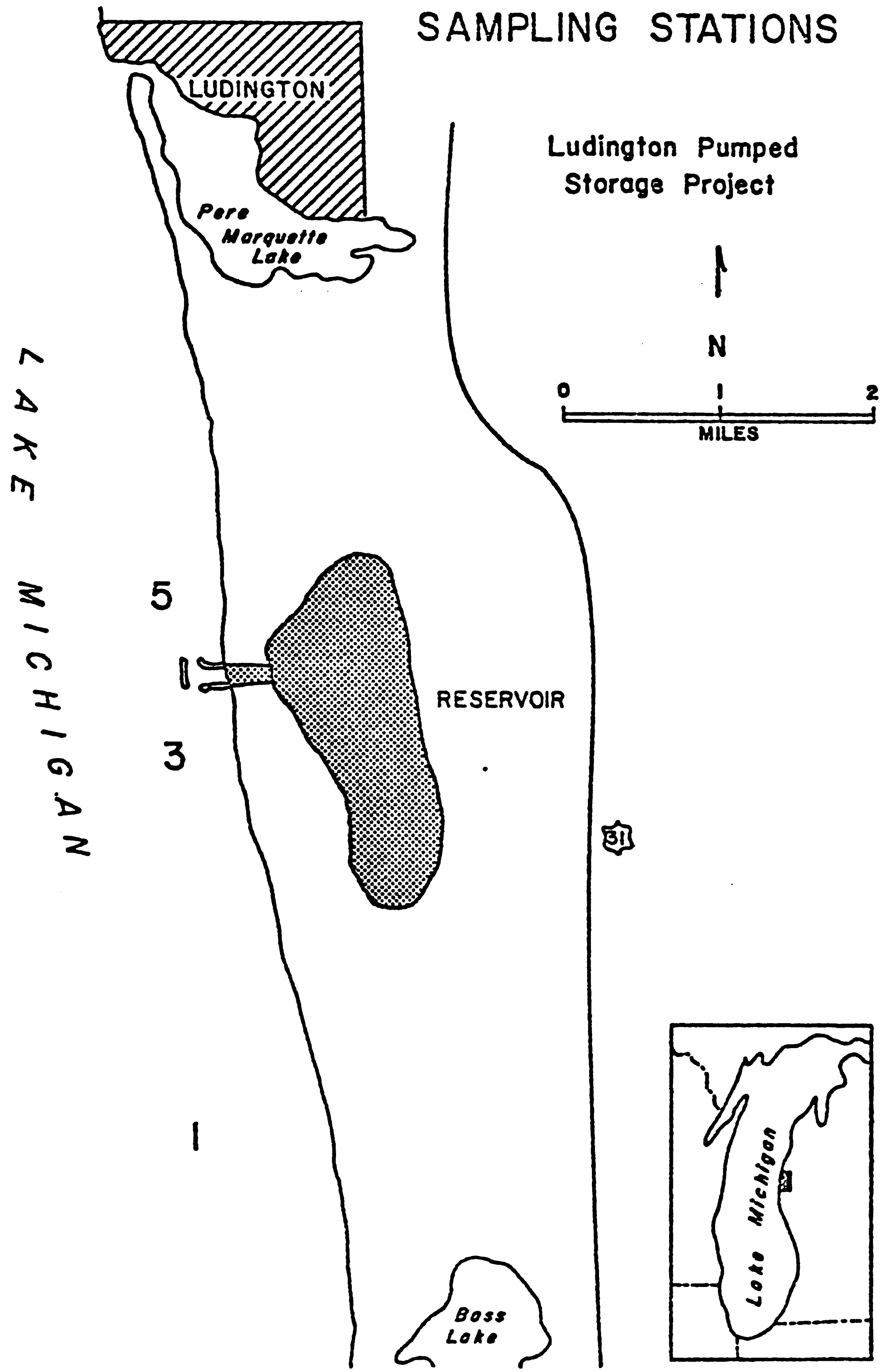
SAMPLING STATIONS
LUDINGTON
Ludington Pumped
Storage Project
Pere
Marquette
Lake
N
0
1
2
MILES
LAKE MICHIGAN
5
RESERVOIR
3
31
1
Bass
Lake
Lake Michigan

Figure 1.

METHODS AND MATERIALS

Field Methods

Zooplankton samples were collected approximately biweekly in 1975 and 1976, and monthly in 1977 (Table 1). Duplicate samples were taken between 0700 hours and 1200 hours at depths of 1 meter, 4 meters and 12 meters, resulting in 6 samples per station. For each sample, 100 liters of water were pumped through a number 20 (64 micron) nylon plankton net (Tonolli 1971). A small volume of club soda was added to relax the animals and minimize distortion of taxonomic features (Gannon and Gannon 1975) and the sample was preserved in 10 percent formalin. The samples were allowed to settle one week, and were then concentrated to a volume of approximately 50 ml. The formalin was then replaced by 70 percent alcohol and a few mililiters of glycerin added to prevent the organisms from becoming brittle.

Water temperature and water transparency were measured in the field at the time the plankton were sampled. Water temperature was measured with a YSI thermistor, and temperature was recorded to the nearest tenth degree Celsius. The water temperature value reported is the average of surface and bottom water temperatures. Water transparency was measured with a secchi disc and recorded in meters. Water samples for turbidity measurements were collected at sampling time and returned to the laboratory.

Wind direction, wind speed (knots) and air pressure (mm Hg) were obtained from daily readings made at the U.S. Coast Guard station at

Table 1. Zooplankton sampling dates in Lake Michigan in 1975-1977.

1975	1976	1977
4-22	4-14	4-18
5-2	4-28	5-17
5-13	5-12	6-13
5-29	5-25	7-21
6-17	6-7	8-18
6-30	6-21	9-13
7-14	7-6	10-22
7-28	7-21	
8-11	8-2	
8-27	8-15	
9-9	9-15	
9-24	9-26	
10-7	10-11	
11-5		

Ludington, Michigan. A mean value for these parameters was calculated for the six hour period before the sampling time on each sampling date. Photoperiod values were calculated as hours between sunrise and sunset from observations made at Muskegon, Michigan, 85 km south of the sampling area.

Laboratory Methods

The zooplankton samples were examined using a binocular microscope (magnification 7-60X), a compound microscope (magnification 100-400X) and a chambered counting cell (Gannon 1971). Each sample was mixed gently with a magnetic stirrer and a subsample of 2-10 ml was removed with a wide-mouth syringe for identification and enumeration. Subsample size was gauged so as to count 100-150 of the common organisms. The Chi-square (X^2) was used to test the randomness of the counting method, and the conditions of randomness were met (Duffy 1975). The four Cladocera were identified using keys by Brooks (1957) and Deevey and Deevey (1971). Counts were converted to numbers per cubic meter for the analyses. Total zooplankton were counted and their abundance per cubic meter calculated. The mean total zooplankton abundance per date was calculated as a measure of competition with the other zooplankton. The abundance of the species being examined was subtracted from the mean total zooplankton abundance on each date for the analyses.

Turbidity was determined with a Hach model 2100A turbidimeter (Hach Chemical Co., Ames, Iowa). Turbidity was recorded to the nearest tenth Formazin Turbidy Unit (FTU).

Statistical Methods

The data were transformed by several methods to determine which would satisfy the assumption of a normal distribution required by parametric procedures; the log (y+1) transformation proved to be the most suitable for these data.

For the hypothesis of no mean differences between densities of zooplankton at the control station (station 1) and the impact stations (stations 3 and 5) in each year, the untransformed data were tested using a Dunnett-type procedure for data with heterogeneity of variance. This t-like test is based on an experiment-wise Type I error rate because the comparisons are correlated (Gill 1978). The 95 percent minimum significant difference (MSD) for each comparison (station 1 vs. station 3; station 1 vs. station 5) for each species and year was calculated for comparison with the actual difference between the means. The MSD was calculated by $(t_{\alpha_D/2,v})(s_{\bar{D}})$, where the t value is a percentage point from the student's t distribution with v degrees of freedom using $\alpha_D = 1-(0.95)^{1/m}$, m=3 stations, and $s_{\bar{D}}$ is the standard deviation of the difference between means for the control station and an impact station.

A one-way analysis of variance was conducted to test the hypothesis that there were no differences between years for each species. Based on the results of the Dunnett-type test, untransformed data for all stations for each species were grouped together for this analysis. Contrasts between years (1975 vs. 1976; 1975 vs. 1977; 1976 vs. 1977) were tested when the F-rations for the analysis proved to be significant at the 5 percent level.

Stepwise multiple linear regression procedure was used to test for relationships between the dependent variable (abundance) and the set of independent variables measured. The general model for the multiple linear regression procedure is $\underset{\sim}{y} - \underset{\sim}{X}\underset{\sim}{b} = \underset{\sim}{e}$, where $\underset{\sim}{y}$ is a matrix of the dependent variables, $\underset{\sim}{X}$ is a matrix of independent variables, $\underset{\sim}{b}$ is a matrix of regression parameters, and $\underset{\sim}{e}$ is a matrix of error variables. It is assumed that the errors are normally and independently distributed with homogeneous variance for any set of values of the independent variables (Gill 1978). The stepwise method of multiple linear regression involves the re-examination of all variables in the model at each stage of analysis; variables already in the model may be rejected at a later stage. An F-statistic is calculated for each variable at each stage of the regression. A variable is accepted in the model if it is significant at the 10 percent level or better, and is rejected from the model if it falls below the 25 percent significance level.

The errors (residuals) of each analysis were plotted against the predicted values of the dependent variable, and the plots were examined visually to check for departures from normality (graphs not included here). All examinations indicated that the data were reasonably free of abnormalities and were distributed normally.

The dependent variable was plotted against each of the independent variables to determine if any curvilinear relationships existed that would suggest the use of quadratic terms in the model (graphs not included here). No such relationships among the variables were discernable.

Library computer programs were used for the multiple linear regression analyses and for the one-way analysis of variance (Nie _et_. _al_. 1975) on the Cyber 750 computer at Michigan State University.

RESULTS

The Cladocera are a major seasonal component of the total zooplankton of Lake Michigan, and *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia galeata mendotae* and *Daphnia retrocurva* are dominant members of the Cladocera. *Bosmina* is the most abundant Cladocera, comprising up to 80-100 percent of all Cladocerans in the spring and summer, and up to 80 percent in the fall. *Bosmina* abundance represents up to 30 percent of the total zooplankton abundance in the summer and fall. *Eubosmina* may comprise up to 70 percent of the Cladocera in the spring and up to 50 percent of the Cladocera in the fall, but is less abundant in the summer months. *Eubosmina* may comprise up to 25 percent of the total zooplankton in the fall. The *Daphnia* species are most abundant in the summer and fall, and sometimes one species can make up 50 percent or more of the total Cladocera. They never make up a large percentage of the total zooplankton. Appendix tables A2 through A37 present the basic statistics for the four Cladocera in 1975-1977.

A Dunnett-type procedure was used to test for differences in abundance of the four Cladocera between the control and impact stations for each year. The results (Table 2) show that there were no significant differences in abundance at the different stations in any one year. Therefore a mean abundance value for each species for each sampling date was calculated from the data for all three stations (N=18), and this value

Table 2. Results of Dunnett-type test of control versus treatment stations for four Cladocera in Lake Michigan, 1975-1977. MSD = minimum significant difference (No. m^{-3}); DIFF = actual difference (No. m^{-3}); $\alpha = 0.05$.

		1975		1976		1977	
		1 vs. 3	1 vs. 5	1 vs. 3	1 vs. 5	1 vs. 3	1 vs. 5
Bosmina longirostris	MSD	3144.6	6878.0	2913.1	3259.7	1473.4	1132.5
	DIFF	1060.7	983.1	1068.8	1222.7	1432.8	-63.3
Eubosmia coregoni	MSD	3242.0	2592.0	287.0	271.7	349.5	221.5
	DIFF	121.4	-1729.7	50.6	-61.1	186.4	-9.2
Daphnia galeata mendotae	MSD	181.1	241.8	307.7	263.8	118.2	144.1
	DIFF	48.0	53.1	34.0	-190.5	44.5	39.0
Daphnia retrocurva	MSD	156.5	119.1	100.0	71.1	392.5	607.3
	DIFF	25.4	-45.3	24.1	-63.4	23.4	364.4

was used to graph the species abundance. Figures 2, 3 and 4 show this mean seasonal abundance for the four Cladocera in Lake Michigan in 1975-1977.

In 1975 Bosmina, D. galeata mendotae and D. retrocurva showed two peaks in abundance, in summer and fall, and showed a general increase in abundance at the end of the sampling period (Figure 2). Bosmina reached maximum abundance on 17 June (18,472 m^{-3}) and had a second peak abundance on 24 September (14,078 m^{-3}). Bosmina were least abundant in May (2 m^{-3} on 2 May and on 13 May). Eubosmina were not identified in the samples in 1975 until August, but showed patterns of abundance similar to Bosmina from that date on. They were most abundant in the samples at the end of the sampling period (8,129 m^{-3}) on 5 November, but had an earlier peak on 24 September (3,257 m^{-3}). The lowest abundance of Eubosmina recorded in 1975 was on 9 September (22 m^{-3}). The Daphnia species were never as abundant as either Bosmina or Eubosmia in 1975. D. galeata reached peak abundance on 27 August (1,209 m^{-3}), and showed another peak in September (910 m^{-3} on 24 September). It was least abundant in the spring; on 22 April there were 3 m^{-3} but D. galeata disappeared in the samples until 29 May (4 m^{-3}). D. retrocurva was absent from the samples until 14 July, the time of their lowest abundance (7 m^{-3}). They gradually increased in abundance, but showed a sudden decrease on 9 September, which was followed by their maximum of 1,063 m^{-3} on 24 September.

All four Cladocera showed a marked decrease on 9 September (Figure 2), which was followed by an increase in abundance on the next sampling date. This is most likely due to a decrease in water temperature on 9 September, the result of an upwelling in Lake Michigan (see discussion).

Figure 2. Mean abundance of four species of Cladocera in Lake Michigan in 1975.

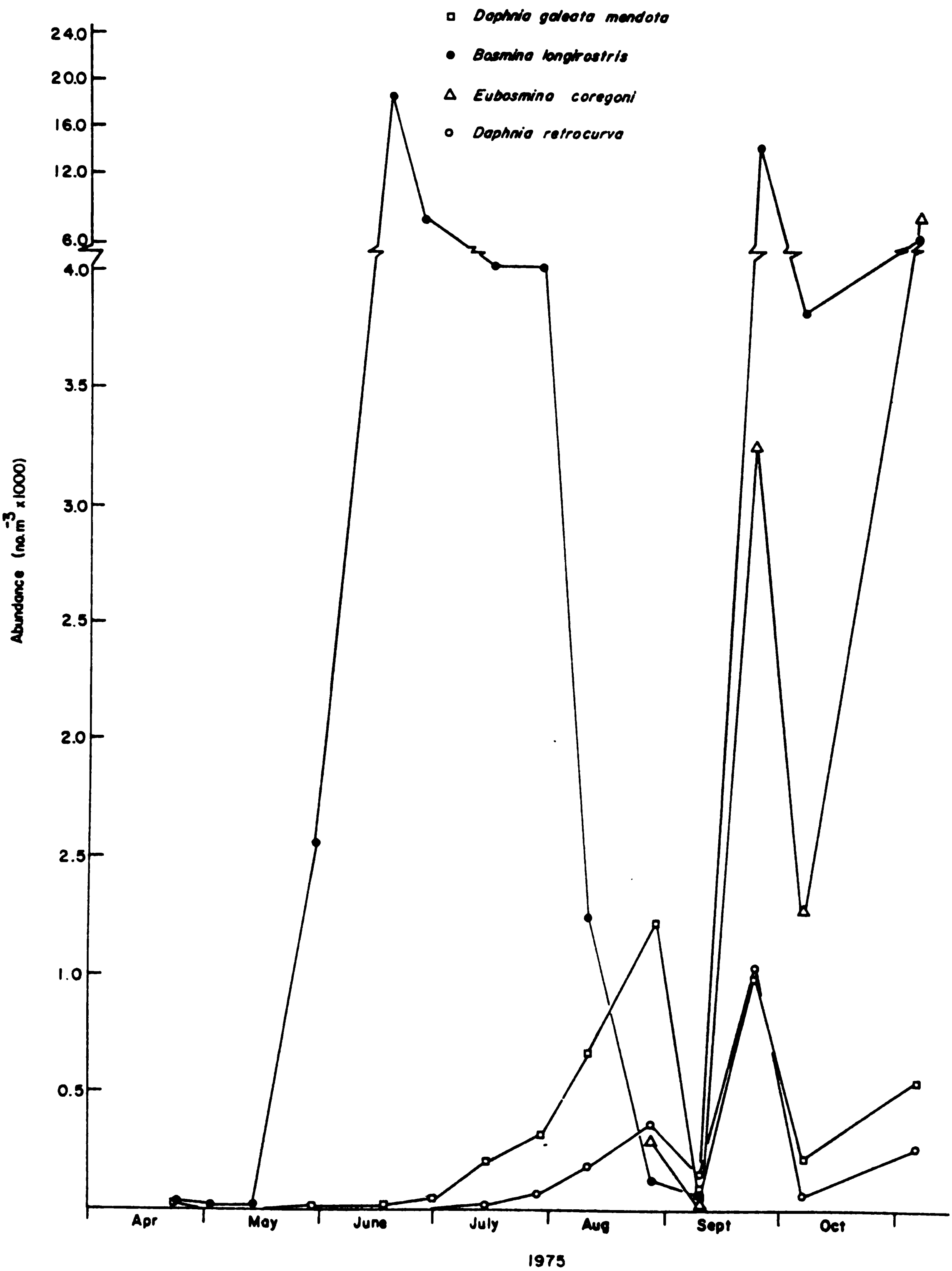
Daphnia galeata mendota
Bosmina longirostris
Eubosmina coregoni
Daphnia retrocurva
24.0
20.0
16.0
12.0
6.0
4.0
3.5
3.0
2.5
2.0
2.5
1.0
0.5
Abundance (no.m^{-3} x1000)
Apr
May
June
July
Aug
Sept
Oct
1975

Figure 2.

Figure 3. Mean abundance of four species of Cladocera in Lake Michigan in 1976.

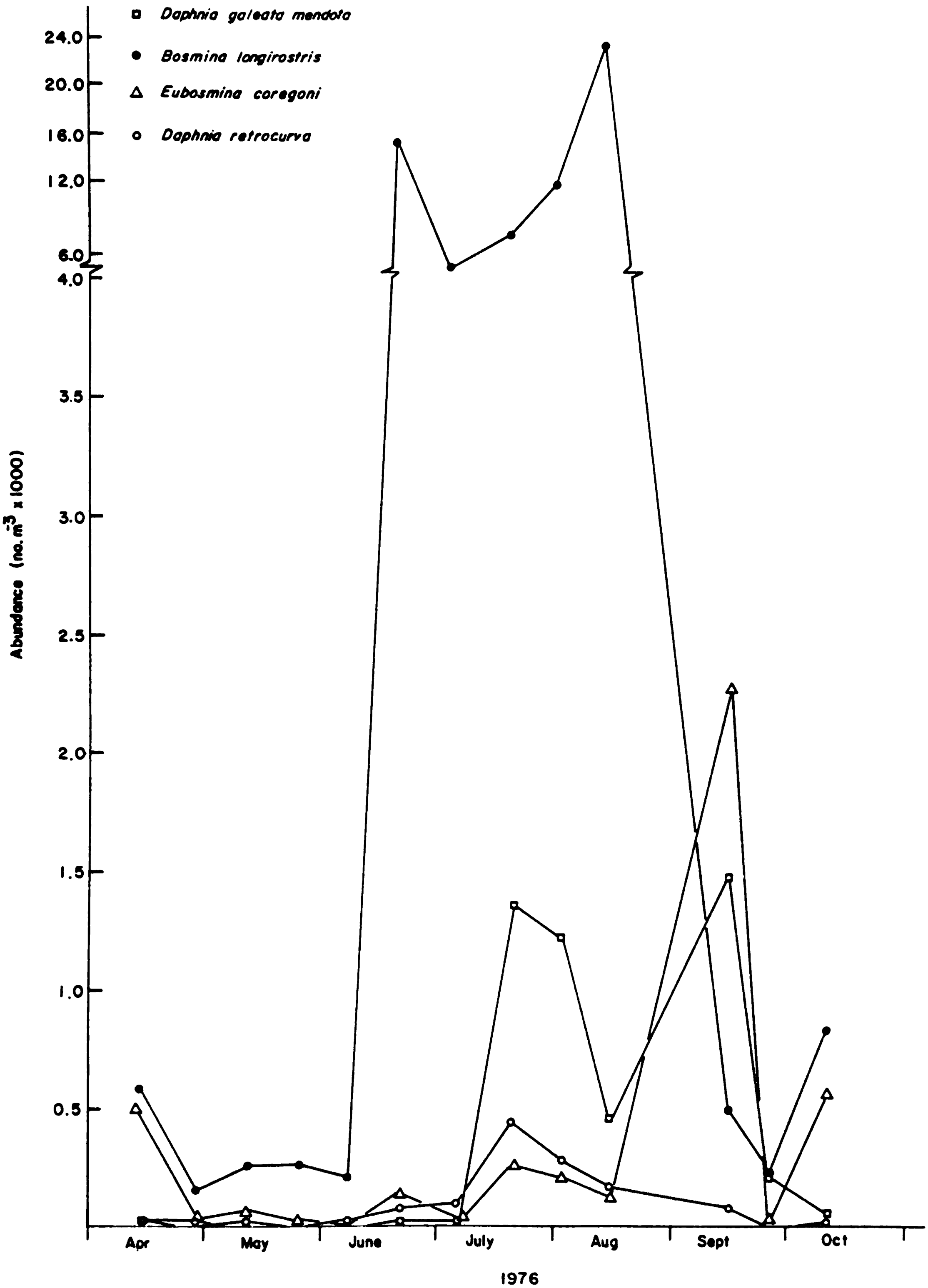
Daphnia galeata mendota
Bosmina longirostris
Eubosmina coregoni
Daphnia retrocurva
24.0
20.0
16.0
12.0
6.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Abundance (no. m^{-3} x 1000)
Apr
May
June
July
Aug
Sept
Oct
1976

Figure 3.

In 1976 a pattern of abundance similar to 1975 was seen for all species (Figure 3). Bosmina decreased after sampling was begun in the spring, and was lowest in abundance on 28 April (165 m^{-3}). A peak was seen on 21 June (15,056 m^{-3}) and again on 15 August, when the maximum was reached (22,948 m^{-3}). A slight decrease in abundance was seen at the end of the sampling period. Eubosmina also showed a decrease in abundance immediately after the start of the sampling season; the lowest numbers recorded were in April (11 m^{-3} on 25 April), but there were no Eubosmina in the samples on 7 June. Eubosmina had only one peak in abundance in 1976, on 15 September (2,261 m^{-3}). There was also a slight increase in abundance of Eubosmina at the end of the sampling season. The Daphnia were low in abundance until the end of June, and did not show an increase in abundance at the end of the sampling period. D. galeata were rare in the samples until June; the lowest numbers in the samples were on 12 May (2 m^{-3}), but no D. galeata were in the samples on 28 April, 25 May or 7 June. A peak of abundance was reached on 21 July (1,339 m^{-3}) and the maximum was seen on 15 September (1,448 m^{-3}). D. retrocurva showed their lowest abundance on 28 April (2 m^{-3}), then were absent from the samples in May. They reached a single peak in abundance on 21 July (439 m^{-3}) but remained in low numbers throughout the year.

In 1977 most of the species showed only a single peak in abundance, and were generally reduced in numbers (Figure 4). However, the frequency of sampling in 1977 was reduced to once a month, which could explain the differences seen. Bosmina were lowest in abundance in April (25 m^{-3} on 18 April). The maximum abundance was on 21 July (5,283 m^{-3}) and this was followed in August by a similar abundance (4,576 m^{-3} on 18 August).

Figure 4. Mean abundance of four species of Cladocera in Lake Michigan in 1977.

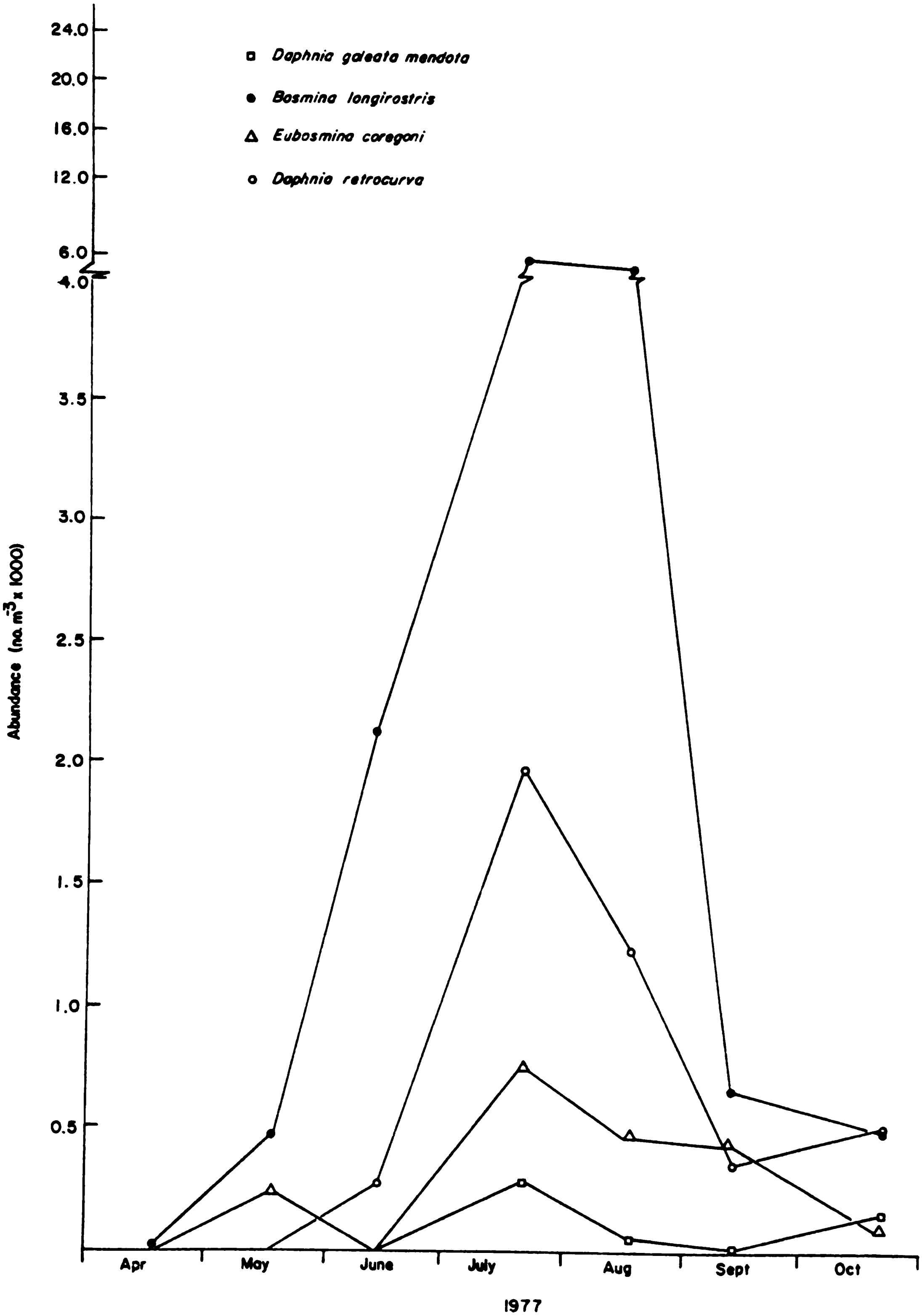
Daphnia galeata mendota
Bosmina longirostris
Eubosmina coregoni
Daphnia retrocurva
Abundance (no. m⁻³ x 1000)
24.0
20.0
16.0
12.0
6.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Apr
May
June
July
Aug
Sept
Oct
1977

Figure 4.

Eubosmina was not recorded in samples on either 18 April or 13 June, but was present in moderate numbers in May (234 m^{-3} on 17 May). The peak in Eubosmina abundance was on 21 July (760 m^{-3}) and the lowest abundance was seen on 22 October (107 m^{-3}). The Daphnia species were again rare in the spring. D. galeata was not recorded in samples until 21 July, and although it was not abundant it showed its greatest density of 1977 on this date (286 m^{-3}). The lowest abundance for D. galeata in 1977 was on 13 September (23 m^{-3}). D. retrocurva was not recorded in the samples until 13 June, and this was the lowest abundance of this species seen in 1977 (28 m^{-3}). The maximum was on 21 July (1,960 m^{-3}). Both Daphnia species showed slight increases in abundance at the end of the sampling period.

In summary, similar bimodal patterns in abundance were seen in 1975 and 1976, but most species in 1977 showed a single peak in abundance. Bosmina abundance was similar in 1975 and 1976 but decreased in 1977 by several thousand organisms per cubic meter. Eubosmina abundance appeared to have decreased over the years from a maximum of over 8,000 per cubic meter in 1975 to a maximum of less than 1,000 per cubic meter in 1977. The highest numbers of Eubosmina were recorded in the fall of 1975 and 1976, and in the summer of 1977. Daphnia galeata mendotae decreased in abundance in 1977, although it was never as abundant in 1975 or 1976 as the two bosminids. Daphnia retrocurva showed an increase in abundance in 1977; it was comparatively low in abundance in 1975 and decreased in 1976.

The analysis of abundance between years for each species (Table 3) showed that there were significant differences in abundance between years

Table 3. Results of an analysis of variance of abundance between years for four Cladocera species in Lake Michigan, 1975 - 1977.

Species	N	Analysis of Variance F-Ratio	Analysis of Variance Probability	Probabilities for Contrasts Between Years 75-76	75-77	76-77
Bosmina longirostris	567	5.98	.003	.891	.002	.001
Eubosmina coregoni	347	32.26	<.001	<.001	<.001	.892
Daphnia galeata mendotae	353	3.70	.026	.098	.121	.010
Daphnia retrocurva	316	0.52	.595	-	-	-

for Bosmina ($p=.003$), Eubosmina ($p<.001$), and Daphnia galeata mendotae ($p=.026$). Daphnia retrocurva was not significantly different in abundance between years ($p=.595$). Contrasts between years for Bosmina showed that 1977 was significantly different from both 1975 and 1976. There was no significant difference between abundance of Bosmina in 1975 and 1976. In 1975 Eubosmina was significantly different in abundance from both 1976 and 1977, but there was no difference in abundance of Eubosmina in 1976 and 1977. Abundance of Daphnia galeata was not greatly different between 1975 and 1976, or between 1975 and 1977, but was significantly different between 1976 and 1977.

A total of 12 multiple linear regression analyses were performed on the data, one analysis for each combination of species and year. The data were combined for the three stations in the analyses because the Dunnett-type test showed there were no significant differences between stations in any of the years (Table 2). This increased the size of the data set for each analysis and provided more power to the tests. The variables used in the analyses and their variable names are given in Table 4.

The mean total zooplankton variable appeared in seven of the multiple linear regression equations from the complete analyses, and in six of those from the partial analyses. All other factors appeared less frequently, but did appear in at least two of the regression equations for both the partial and complete analyses.

Tables 5 through 8 present the significant variables in the multiple linear regression analyses of abundance of Bosmina, Eubosmina, D. galeata mendotae and D. retrocurva in 1975-1977. Included in these tables are the significance levels of the variables in the order included in the equations, the R^2 values resulting from the addition of each of the variables,

Table 4. Independent variables used in the stepwise multiple linear regression analyses of Cladocera abundance in Lake Michigan, 1975-1977.

VARIABLE	VARIABLE NAME	UNITS
Wind Direction	WD	deviation from North (1-16)
Wind Speed	WS	knots
Water Temperature	WT	^{o}C
Atmospheric Pressure	PR	mm Hg
Photoperiod	PH	hours
Turbidity	TU	FTU
Water Transparency	SC	meters
Mean Total Zooplankton	TZP	No. m^{-3}

the simple correlation of each significant variable with the dependent variable, the overall significance of the equation with the addition of each variable, and the standardized regression coefficients (Betas). The Beta values are the most valuable in explaining the importance of the variables included in the equations, as they are standardized to correct for differences in the units and variability of the variables. To standardize the regression coefficients, the deviation for each variable is divided by the estimated standard deviation for that variable.

The important variables explained a total of between 34.9 percent (1976) and 44.4 percent (1977) of the observed variation in the abundance of *Bosmina* (Table 5). Air pressure was the most important variable in 1975, and accounted for 16.7 percent of the total variation explained in the analyses. Water temperature was the most important factor in the 1976 analysis, explaining 19.4 percent of the variation, and was the second most important factor in the 1975 analysis. Wind speed explained the most variation (36.7 percent) in the 1977 analysis.

The analysis of *Eubosmina* abundance produced equations that explained a total of between 11.7 percent (1977) and 70.4 percent (1975) of the observed variation (Table 6). Wind direction was the most important variable in the 1975 analysis, explaining 4.8 percent of the observed variation. In 1976 wind speed was the most important variable in the analysis, contributing 10.6 percent to the observed variation. Wind speed was also the second most important variable in the 1975 analysis. In 1975 only air pressure was significant in the analysis of *Eubosmina* abundance, explaining 11.7 percent of the variation.

Table 5. Results of the multiple linear regression analyses of the abundance of Bosmina longirostris in Lake Michigan in 1975-1977.

YEAR	VAR* NAME	VAR SIGNIF	R^2	SIMPLE r	TOTAL REGRESS. SIGNIF	BETA
1975	PR	<.001	.167	-.409	<.001	-.673
(N=204)	SC	.003	.203	.197	<.001	.178
	WT	.005	.233	.262	<.001	.419
	WD	<.001	.291	-.081	<.001	.058
	PH	<.001	.380	.106	<.001	-.353
	TZP	<.001	.409	.055	<.001	-.209
1976	WT	<.001	.194	.441	<.001	.657
(N=215)	PH	<.001	.274	.296	<.001	.475
	WS	<.001	.338	-.148	<.001	.402
	TU	.056	.349	.167	<.001	-.126
1977	WS	<.001	.367	.606	<.001	.891
(N=106)	TZP	<.001	.444	.241	<.001	-.398

*See Table 4 for explanation of variable names.

Table 6. Results of the multiple linear regression analyses of the abundance of *Eubosmina coregoni* in Lake Michigan in 1975-1977.

YEAR	VAR* NAME	VAR SIGNIF	R^2	SIMPLE r	TOTAL REGRESS. SIGNIF	BETA
1975 (N=78)	PR	<.001	.440	-.663	<.001	-.549
	WD	.010	.488	-.018	<.001	-1.713
	WS	<.001	.675	.205	<.001	1.530
	TZP	.010	.704	.016	<.001	-.244
1976 (N=167)	WS	<.001	.106	.325	<.001	.558
	WT	<.001	.198	.169	<.001	.453
	PH	<.001	.293	-.102	<.001	-.339
1977 (N=70)	PR	.004	.117	.342	.004	.342

*See Table 4 for explanation of variable names.

The regression equations for the analyses of the abundance of Daphnia galeata mendotae explained between 23.2 percent (1975) and 24.6 percent (1976) of the observed variation in abundance (Table 7). In 1975 water temperature was the most important variable in the analysis, contributing 9.5 percent to the observed variation. In 1976 wind direction was the most significant variable in the analysis, explaining 21.5 percent of the variation. There were no significant variables in the equation for the analysis in 1977. This could be attributable to the smaller sample size in this analysis (N=41) as well as to the inability of the available variables to explain the variance of this species.

In the analyses of the abundance of Daphnia retrocurva, the significant variables explained from 16.5 percent (1977) to 31.0 percent (1976) of the variance (Table 8). Air pressure was the most important variable in the analysis of 1975 abundance, explaining 11.6 percent of the variation. In 1976, wind direction was the most important variable in the analysis, explaining 9.4 percent of the variation, and photoperiod explained 7.8 percent of the variation. Both variables had nearly equal beta values, though opposite in sign. The variable mean total zooplankton was the only significant variable in the equation for the 1977 analysis, explaining 16.5 percent of the observed variation. This variable was also included in the equations for 1975 and 1976.

In summary, the important variables in the 12 analyses explained between 11.7 and 70.4 percent (mean 31.8 percent) of the variation in abundance observed in the four Cladocera. Mean total zooplankton, the most frequently significant variable in the analyses, accounted for between 1.4 and 16.5 percent (mean 6.9 percent) of the variation explained when it appeared in an equation. Wind direction and water temperature were

Table 7. Results of the multiple linear regression analyses of the abundance of <u>Daphnia galeata mendotae</u> in Lake Michigan in 1975-1977.

YEAR	VAR* NAME	VAR SIGNIF	R^2	SIMPLE r	TOTAL REGRESS. SIGNIF	BETA
1975	WT	<.001	.095	.308	<.001	.443
(N=162)		<.001	.232	-.242	<.001	-.394
1976	WD	<.001	.215	-.463	<.001	-.456
(N=126)	TU	.026	.246	.196	<.001	.177
1977 (N=41)	No variables in the equation					

*See Table 4 for explanation of variable names.

Table 8. Results of the multiple linear regression analyses of the abundance of Daphnia retrocurva in Lake Michigan in 1975-1977.

YEAR	VAR* NAME	VAR SIGNIF	R^2	SIMPLE r	TOTAL REGRESS. SIGNIF	BETA
975 (N=114)	PR	<.001	.116	.340	<.001	.363
	WS	.065	.142	.154	<.001	.147
	TZP	.045	.173	.110	<.001	.180
1976 (N=102)	WD	.002	.094	-.306	.002	-.673
	PH	.003	.171	.192	<.001	.674
	TZP	<.001	.280	-.062	<.001	-.516
	SC	.043	.310	.185	<.001	-.255
1977 (N=70)	TZP	<.001	.165	.406	<.001	.406

*See Table 4 for explanation of variable names.

most frequently the most important variable in the equations. Wind direction explained 4.8 to 21.5 percent (mean 11.8 percent) of the variation in the equations when it was significant in the analyses. Likewise, water temperature explained 1.0 to 44.0 percent (mean 14.1 percent) of the observed variation in equations it appeared in.

DISCUSSION

The four Cladocera showed a seasonal distribution that is typical of that reported in other studies. Duffy (1975) also found *Bosmina* to be the dominant Cladocera in 1974 in the same area of Lake Michigan. In 1974 *Bosmina* comprised 24 to 26 percent of the total zooplankton in July and August (up to 30 percent in the present study), although the abundance was not at its maximum then. The seasonal pattern of abundance for *Bosmina* in 1974 was essentially the same as in 1977 in the present study, but it reached greater densities in 1974 (up to 30,000 m^{-3}). Similar densities were seen in the present study in 1975 and 1976. *Eubosmina* appeared earlier in samples in 1976 and 1977 than in 1974, but were most common at the same time of year. *Eubosmina* abundance was greater in 1975 and 1976 than reported by Duffy in 1974, but was similar in 1977. *Daphnia retrocurva* was the most abundant daphnid in 1974, but its densities exceeded those of *Daphnia galeata* only in 1977 in the present study, when a similar but later maximum was reported (approximately 2,500 m^{-3}). *D. galeata* was more abundant in 1975 and 1976 than in 1974, but decreased in numbers again in 1977. *D. galeata* reached peak abundance earlier in all years of the present study than in 1974. *D. retrocurva* was most abundant on a later date in 1975 than in 1974 and on earlier dates in 1976 and 1977 than 1974.

The inshore stations sampled by Roth and Stewart (1973) in southeastern Lake Michigan are comparable to the Ludington site. Again, in 1972, Bosmina was the most common Cladocera. It had a bimodal seasonal distribution with peaks in July-August and again in October, as in 1975 of the present study. Abundance of Bosmina in August of 1972 reached 180,000 m^{-3}, compared to means of up to 22,900 m^{-3} at the Ludington study site. Eubosmina appeared earlier in samples in 1976 and 1977 than in 1972, but showed a similar seasonal distribution. Eubosmina densities reported by Roth and Stewart are similar to those in 1975 in this study. The densities they reported for the Daphnia species are greater than seen in 1975 through 1977, and the seasonal abundance showed a monocyclic distribution. The increased abundance of the four Cladocera seen in this 1973 study could be due to the trophic status of the area of Lake Michigan studied by Roth and Stewart. They characterize their inshore station as more eutrophic than the offshore stations, and Beeton (1963) discusses the advanced trophic state of that part of the lake. These Cladocera, especially Bosmina, are more common in eutrophic waters. Evans and Hawkins (1977) studied the same area of Lake Michigan as Roth and Stewart. They found greater abundances of Bosmina in July of 1974, 1975 and 1976 than in the same month in the present study. The other species were not present in significant numbers at similar depths in their study in July.

The decrease in abundance of all four Cladocera on 9 September 1975 was attributable to the upwelling in Lake Michigan evident on that date (Table A1.). It is not possible to tell the duration of the upwelling from the available data, but the water temperature averaged 7.9^{o} C colder on that date than the previous sampling date. Upwellings are caused by easternly winds pushing warmer surface waters away from shore and bringing in colder waters from deeper in the lake. The wind direction was predominantly northwesternly in direction on 8 September, shifting to east-northeast on 9 September. Upwellings in Lake Michigan have been documented by various authors (Carr *et*. *al*. 1973; Liston *et*. *al*. 1974; Duffy 1975) and zooplankton abundances have been shown to be strongly influenced by water temperature (e.g. Hutchinson 1967; Duffy 1975). Diatoms, a principle food of zooplankton, are concentrated in the area of an upwelling (Hutchinson 1967) and their growth is augmented by an increase in nutrients in the epilimnion from nutrient rich waters brought up from the hypolimnion (Liston and Anderson 1979). The Cladocera responded to warming temperatures and probable increases in diatom abundance by increasing their abundance on the next sampling date (24 September; Figure 2).

The difference in abundance of *Bosmina* in 1977 compared to the other years is due in part to the decreased sampling frequency in that year. Apparently the monthly sampling dates did not concur with periods of maximum *Bosmina* abundance; *Bosmina* densities in 1975 and 1976 were four times those of 1977. There were no major differences between the other factors measured in the study during the three years. Other factors most likely contributed to the observed decrease in abundance, but these are not readily discernable. The differences in abundance of *Eubosmina* in 1975 compared to the other years were most likely due to the lack of data on abundance in spring and early summer. The distribution of *Eubosmina* in the spring and early summer of both 1976 and 1977 was similar. The differences in abundance of *Daphnia galeata mendata* in 1977 were again likely due to decreased sampling frequency.

In the present study the sampling frequency was reduced to monthly in 1977 because of time and personnel restrictions. The significant differences in abundance of some of the Cladocera in 1977 make it evident that monthly sampling can lead to underestimated abundances of zooplankton populations. A complex array of physical and biological factors determine zooplankton abundance and species life histories. Adult Cladocera have the capacity to release a brood of young every few days to a week (Pennak 1978) and the detection of major peaks in abundance may be delayed by monthly sampling, or may be missed entirely if unfavorable environmental conditions should arise.

The mean total zooplankton variable in the multiple linear regression analyses is essentially a measure of competition from other zooplankton at the time and place of sampling. It was calculated for the four species on every date for all years. This variable was included in the regression equations most frequently, although it rarely accounted for the most explained variance (mean of 7 percent of the explained variance). Mean total zooplankton was included in equations for Daphnia retrocurva for all three years of the present study. This was the only case where one or more variables was consistently important for a species across all years. Wind speed, water temperature, photoperiod and mean total zooplankton were important in analyses in two of the three years for Bosmina longirostris, but the other species had no variables that appeared in two analyses for more than one year. It is not possible to predict which variables are the most important in explaining the variation in abundance for a given species in a given year; the relative influence of the variables in this study varies from year to year.

Wind direction is important because of its influence on water flow in the lake. Its influence on zooplankton distribution and abundance can be seen in mechanical transport of organisms in induced water currents, or more indirectly by influencing water temperature in the lake. Prevailing motions of wind and water can cause important changes in the thermal structure of the lake (e.g., upwellings), which is positively correlated with overall patterns of zooplankton abundance (Patalas 1969). Wind speed works in conjunction with wind direction, and its influence is temporal.

Water temperature influences zooplankton abundance directly by controlling growth rates and development (Hutchinson 1967), and thus production, and indirectly by stimulating the growth of phytoplankton. Duffy (1975) found that variation on water temperatures between years was most likely the major factor contributing to observed differences in abundance of zooplankton in Lake Michigan. Patalas (1969) found that temperature and its distribution in the water was a decisive factor governing zooplankton abundance in the spring and summer, although the relationship was less clear in the fall. Roth and Stewart (1973) found thermal stratification to be a major factor in determining zooplankton distribution.

Photoperiod may be a controlling stimulus in the development of some Cladocera (Stross 1971; Wetzel 1975), and interacts with temperature in many situations. Photoperiod is an important stimulus in the vertical migration of zooplankton, which has been suggested to be a mechanism for predator avoidance and for optimal feeding and growth. Vertical migration can also influence zooplankton sampling. In the present study photoperiod was frequently an important factor in explaining variation in Cladoceran abundance.

Water transparency as measured by a secchi disc is highly influenced by turbidity in the water, and is closely correlated with percentage transmission of light (Wetzel 1975). Light transmission may affect growth rates of Cladocera directly (Jacobs 1962), and it acts indirectly to determine population success by affecting phytoplankton abundance (Wetzel 1975) and possibly efficiencies of growth (Buikema 1971). It is also a controlling factor in vertical migration (McNaught and Hasler 1964). Turbidity negatively affects the productivity of aquatic environments (Murphey 1962), through both its abiogenic and biogenic components (e.g., self-shading in phytoplankton; Wetzel 1975). However, water transparency and turbidity were not frequently important variables in this study, both appearing in fewer equations than any other variables.

The effects of changes in atmospheric pressure on zooplankton has not been investigated thoroughly. Atmospheric pressure is one factor determining how much oxygen is dissolved in water, and thus indirectly influences zooplankton abundances. Air pressure was frequently an important variable in explaining the variation observed in Cladocera abundance.

SUMMARY

The seasonal distribution and abundance of four Cladocera at three stations in nearshore Lake Michigan (12 meter depth) near Ludington, Michigan were studied during 1975-1977. Samples were collected biweekly with a pump and net method. The species were analyzed using multiple linear regression techniques with wind direction, wind speed, water temperature, air pressure, photoperiod, water turbidity, water transparency and mean total zooplankton as factors in the analyses.

A Dunnett-type test of abundance between stations showed no significant differences in any year. The Cladocera were generally bimodally distributed in 1975 and 1976, and had monocyclic patterns of distribution in 1977. *Bosmina longirostris* was the dominant Cladocera, comprising 80-100 percent of the total Cladocera in some seasons. It reached abundances of 18,472 m^{-3} in 1975 and 22,948 m^{-3} in 1976, but only reached 5,283 m^{-3} in 1977. *Eubosmina coregoni* was most abundant in the fall. It appeared to have decreased in abundance over the years, from 8,129 m^{-3} in 1975 to 760 m^{-3} in 1977. *Daphina* spp. were common only in the summer and fall. *D. galeata mendotae* reached 1,448 m^{-3} in 1976 but decreased to 286 m^{-3} in 1977. *D. retrocurva* decreased from 1,063 m^{-3} in 1975 to 439 m^{-3} in 1976, but increased in abundance again to 1,960 m^{-3} in 1977. An analysis of abundance between years for each species showed that only *D. retrocurva* was not significantly different in abundance between any years.

The multiple linear regression analyses explained between 11.7 and 70.4 percent of the variation in abundance of the four Cladocera. No variables were consistently important in explaining variance in all species or in all years. Mean total zooplankton was most frequently a significant variable in explaining variance, and accounted for between 1.4 and 16.5 percent of the variation.

The variables most frequently important in the analyses were wind direction, whch explained 4.8 to 21.5 percent of the variation, and water temperature, which explained 1.0 to 44.0 percent of the variation. All variables appeared in at least two multiple regression equations.

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APPENDIX

Table A1. Values of variables used in multiple linear regression analyses. See Table 4 for description of variable names.

Date	WD	WS	PR	PH	TU			SC		
					1	3	5	1	3	5
1975										
4-22	7	8	30.27	13:42	2.8	2.1	3.2	1.5	2.0	1.3
5-2	9	14	30.08	14:08	1.4	2.3	2.4	3.5	3.0	1.6
5-13	1	8	30.40	14:33	2.9	1.2	1.7	2.5	3.0	3.0
5-29	2	5	29.88	15:03	1.0	1.0	1.1	2.7	2.5	2.6
6-17	9	16	29.69	15:19	1.3	1.3	1.1	3.0	5.0	4.5
6-30	5	6	30.26	15:17	1.2	0.8	1.0	5.5	6.0	4.3
7-14	3	8	30.06	15:03	1.1	1.0	1.1	4.0	4.0	5.0
7-28	11	6	29.96	14:38	3.5	2.6	2.6	2.5	2.0	2.0
8-11	9	11	29.89	14:06	1.9	1.7	2.0	3.8	3.8	3.8
8-27	13	16	30.30	13:24	2.3	3.0	2.9	3.2	3.5	3.5
9-9	5	5	30.37	12:48	1.8	4.3	4.6	5.0	1.9	1.8
9-24	3	8	30.31	12:05	2.4	3.8	3.5	3.5	1.8	---
10-7	5	6	30.21	11:28	---	1.8	2.5	---	6.6	3.1
11-5	10	13	30.18	10:09	2.5	1.9	2.4	3.0	3.0	4.0
1976										
4-14	9	13	29.86	13:20	2.5	---	2.5	3.4	3.2	3.5
4-28	16	7	30.28	13:58	5.0	3.0	4.0	1.4	2.1	2.4
5-12	1	8	29.98	14:31	4.6	3.0	5.1	1.4	2.0	2.4
5-25	1	8	30.04	14:56	2.5	2.2	3.3	3.8	3.4	3.2
6-7	10	5	30.11	15:13	1.0	0.7	0.8	4.2	4.5	5.2
6-21	10	5	30.01	15:20	1.2	---	2.1	3.4	3.2	2.8
7-6	10	5	29.98	15:13	2.0	2.1	2.3	3.9	4.0	2.1
7-21	3	7	30.02	24:52	---	---	---	4.1	---	4.1
8-2	1	8	30.18	14:28	1.8	4.1	1.7	3.0	3.2	3.5
8-15	2	9	30.06	13:56	1.6	2.9	1.8	3.4	3.0	2.2
9-15	3	9	30.19	12:31	1.5	3.5	---	3.3	---	2.5
9-26	5	8	29.83	12:00	1.7	5.2	2.1	3.8	2.8	2.9
10-11	5	7	30.04	11:17	1.4	0.9	1.0	5.1	---	3.0
1977										
4-18	6	6	29.91	13:31	1.5	---	1.4	5.4	4.3	---
5-17	9	9	29.95	14:41	2.8	1.7	2.1	4.0	4.5	3.5
6-13	3	8	30.07	15:18	2.1	2.0	1.4	3.7	4.3	5.6
7-21	9	11	30.03	14:52	1.8	1.9	3.3	4.5	5.2	4.9
8-18	16	10	30.04	13:49	1.9	1.6	2.1	5.5	4.5	5.5
9-13	5	8	29.78	12:37	2.9	2.7	3.6	3.0	2.5	2.2
10-22	15	8	27.79	10:46	1.4	1.6	2.5	2.8	2.9	---

Table A1. (cont'd.)

DATE	WT			ZP*		
	1	3	5	1	3	5
1975						
4-22	3.0	3.0	3.0	1,858.5	1,444.6	1,157.5
5-2	5.2	5.6	5.0	1,991.5	1,420.4	1,960.1
5-13	5.4	6.3	6.1	3,335.5	2,978.9	-----
5-29	12.0	12.7	14.6	19,915.7	26,534.7	19,087.0
6-17	13.6	13.5	13.5	30,312.3	33,382.7	38,661.2
6-30	16.0	15.3	15.6	14,444.0	9,071.3	18,019.5
7-14	12.3	11.9	10.9	8,530.5	12,858.0	8,992.2
7-28	20.4	20.4	20.1	9,191.9	7,301.7	7,760.6
8-11	19.1	19.1	18.5	4,620.2	5,621.1	3,987.6
8-27	20.1	20.1	19.6	2,486.8	3,217.1	4,469.4
9-9	12.3	11.9	12.0	2,208.0	2,976.2	3,426.1
9-24	14.7	14.1	14.1	13,465.0	16,030.1	7,155.6
10-7	----	12.0	12.0	----	5,888.6	6,210.2
11-5	11.0	11.0	11.0	6,860.1	11,374.9	4,953.4
1976						
4-14	4.0	4.4	4.2	1,467.5	1,517.6	1,046.1
4-28	6.2	6.0	5.8	2,308.4	2,113.6	2,003.5
5-12	7.0	7.1	7.0	2,259.6	2,796.3	4,820.4
5-25	6.0	5.8	5.9	1,187.6	6,463.2	1,505.7
6-7	7.8	8.0	9.0	1,583.4	18,870.4	2,989.6
6-21	16.6	17.5	18.1	26,516.4	25,466.0	14,990.0
7-6	11.7	15.0	11.6	11,584.0	6,692.8	7,813.7
7-21	14.2	14.8	16.0	7,421.2	14,366.7	7,336.0
8-2	7.5	6.8	8.5	26,563.9	39,543.0	32,785.3
8-15	12.5	12.6	11.9	23,568.3	28,414.0	35,219.0
9-15	14.8	15.5	17.0	12,652.5	12,356.0	11,277.7
9-26	10.4	8.0	8.4	17,083.9	3,780.3	4,576.1
10-11	13.0	13.4	13.8	4,415.6	5,897.5	5,146.6
1977						
4-18	3.0	3.2	2.9	1,772.7	2,034.5	848.0
5-17	11.8	12.6	---	4,507.8	5,389.3	4,438.5
6-13	5.5	6.0	6.6	5,194.7	7,276.7	4,349.5
7-21	22.5	22.5	22.4	13,672.7	13,672.7	27,592.7
8-18	14.6	14.0	15.1	16,553.6	23,553.2	14,829.9
9-13	17.9	18.0	17.8	6,787.8	4,799.6	5,211.3
10-22	9.0	9.2	9.0	5,950.0	5,955.0	2,693.3

*Abundance of the species being analysed was subtracted from this value to obtain the variable TZP for each date and year.

Table A2. Descriptive statistics of Bosmina longirostris in Lake Michigan at station 1 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	-	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	1,009.0	140-1,760	279.3	562.8
6-17	14,240.7	2,640-30,240	4,392.8	8,851.5
6-30	10,887.7	3,744-29,516	4,054.4	8,169.6
7-14	5,642.5	1,980-8,550	1,091.2	2,198.8
7-28	5,365.7	350-14,112	2,286.5	4,607.3
8-11	216.0	0-415	59.0	118.9
8-27	76.5	0-264	40.2	81.0
9-9	26.0	0-114	18.9	38.1
9-24	11,692.3	5,904-25,920	3,070.8	6,187.7
10-7	-	-	-	-
11-5	8,835.4	9,179-13,920	1,919.5	3,877.4
TOTAL				
N=60	5,651.9	0-30,240	953.1	1,593.1

[1]N=6

Table A3. Descriptive statistics of *Bosmina longirostris* in Lake Michigan at station 3 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	20.0	0-47	9.1	18.3
5-2	6.3	0-38	6.3	12.7
5-13	6.7	0-40	6.7	13.5
5-29	1,436.7	770-2,800	312.6	629.9
6-17	30,828.3	17,510-56,400	5,541.6	11,194.0
6-30	3,185.3	120-6,640	1,014.0	2,043.2
7-14	4,598.2	3,200-5,600	361.8	729.0
7-28	3,420.0	480-8,372	1,122.3	2,261.4
8-11	3,164.7	684-11,250	1,737.7	3,501.5
8-27	176.8	0-840	133.7	269.4
9-9	96.7	0-210	34.2	68.9
9-24	23,212.5	11,645-38,760	4,211.0	8,495.2
10-7	3,123.5	496-11,088	1,630.0	3,284.5
11-5	9,211.7	4,840-13,400	1,307.1	2,633.8
TOTAL				
N=84	5,897.9	0-56,400	1,116.6	1,857.4

[1] N=6

Table A4. Descriptive statistics of _Bosmina longirostris_ in Lake Michigan at Station 5 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	0	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	2,241.7	1,140-3,540	386.2	778.2
6-17	10,348.3	6,300-18,480	1,881.8	3,791.8
6-30	10,300.2	1,496-25,800	4,697.0	9,464.5
7-14	3,906.2	1,575-6,956	819.9	1,652.1
7-28	4,416.5	741-13,464	1,922.6	3,874.0
8-11	344.8	126-864	109.3	220.2
8-27	76.5	72-574	95.6	192.6
9-9	83.5	0-264	40.2	81.2
9-24	7,329.0	2,322-12,240	1,471.2	2,964.5
10-7	4,524.7	1,444-8,496	1,022.4	2,060.1
11-5	1,012.2	137-2,850	384.4	774.6
TOTAL				
N=66	4,076.0	0-25,800	661.8	1,104.5

[1]N=6

Table A5. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 1 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	-	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	-	-
6-17	0	-	-	-
6-30	0	-	-	-
7-14	0	-	-	-
7-28	0	-	-	-
8-11	0	-	-	-
8-27	101.2	0-198	35.0	70.5
9-9	40.5	0-102	15.6	31.4
9-24	4,516.3	2,520-7,015	639.0	1,287.6
10-7	- -	- -	- -	- -
11-5	9,108.2	3,456-21,600	3,461.9	6,993.0
TOTAL				
N=24	3,062.0	0-21,600	1,011.0	1,732.9

[1]N=6

Table A6. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 3 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	-	-	-	-
5-2	-	-	-	-
5-13	-	-	-	-
5-29	-	-	-	-
6-17	-	-	-	-
6-30	-	-	-	-
7-14	-	-	-	-
7-28	-	-	-	-
8-11	-	-	-	-
8-27	240.0	0-700	130.3	263.2
9-9	15.0	0-48	9.5	19.1
9-24	2,899.0	1,644-4,930	504.6	1,016.8
10-7	1,273.0	610-2,912	367.6	740.7
11-5	12,155.0	6,380-17,220	1,843.0	3,713.6
TOTAL				
N=30	3,315.2	0-17,220	916.9	1,557.8

[1]N=6

Table A7. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 5 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	0	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	-	-
6-17	0	-	-	-
6-30	0	-	-	-
7-14	0	-	-	-
7-28	0	-	-	-
8-11	0	-	-	-
8-27	546.0	72-1,750	253.3	510.4
9-9	11.2	0-67	11.2	22.6
9-24	2,354.5	1,204-3,570	429.4	865.2
10-7	1,291.3	304-2,478	291.9	588.2
11-5	3,124.3	1,029-4,950	640.5	1,290.6
TOTAL N=30	1,465.5	0-4,950	265.9	451.8

[1]N=6

Table A8. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 1 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	-	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	-	-
6-17	35.0	0-140	23.9	48.2
6-30	37.3	0-130	24.1	48.6
7-14	264.8	0-405	59.0	118.9
7-28	226.3	70-360	41.4	83.4
8-11	708.2	132-1,302	175.2	353.0
8-27	627.7	0-1,386	245.3	494.3
9-9	162.2	0-308	51.9	104.6
9-24	779.8	210-1,400	164.9	332.3
10-7	-	-	-	-
11-5	583.5	96-822	107.8	217.8
TOTAL N=54	370.4	0-1,400	54.2	90.8

[1]N=6

Table A9. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 3 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	6.00	0-36	6.0	12.1
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	- -	-
6-17	0	-	-	-
6-30	53.0	0-318	53.0	106.8
7-14	137.8	0-384	58.6	118.1
7-28	182.0	0-328	60.7	122.3
8-11	1,285.8	213-3,625	534.8	1,077.6
8-27	716.2	0-2,240	397.2	800.4
9-9	76.7	0-186	30.3	61.1
9-24	1,229.8	274-2,210	279.8	563.8
10-7	279.7	0-560	85.7	172.7
11-5	560.0	0-1,400	234.5	472.5
TOTAL				
N=60	452.7	0-3,625	92.6	154.8

[1]N=6

Table A10. Descriptive statistics of _Daphnia galeata mendotae_ in Lake Michigan at station 5 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	0	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	11.7	0-70	11.7	23.6
6-17	0	-	-	-
6-30	39.3	0-176	29.0	58.4
7-14	183.7	0-740	118.1	238.0
7-28	523.3	228-1,020	117.6	237.0
8-11	0	0	-	-
8-27	2,284.7	0-6,000	1,025.6	2,066.6
9-9	19.0	0-73	12.7	25.6
9-24	721.0	172-2,040	292.2	588.8
10-7	141.5	0-464	75.2	151.5
11-5	507.0	0-1,200	194.8	392.5
TOTAL				
N=54	492.4	0-6,000	146.2	244.8

[1]N=6

Table A11. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 1 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	-	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	-	-
6-17	0	-	-	-
6-30	0	-	-	-
7-14	0	-	-	-
7-28	0	-	-	-
8-11	161.7	0-638	109.6	220.8
8-27	173.7	0-688	112.5	226.7
9-9	265.5	0-513	73.9	148.9
9-24	1,181.3	630-1,840	212.7	428.6
10-7	-	-	-	-
11-5	280.8	0-732	142.5	287.1
TOTAL				
N=30	412.6	0-1,840	92.0	156.3

[1]N=6

Table A12. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 3 in 1975.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-22	0	-	-	-
5-2	0	-	-	-
5-13	0	-	-	-
5-29	0	-	-	-
6-17	0	-	-	-
6-30	0	-	-	-
7-14	21.3	0-128	21.4	43.1
7-28	170.0	0-846	136.3	274.6
8-11	270.5	0-656	129.0	259.9
8-27	329.0	0-910	162.9	328.2
9-9	58.3	42-100	8.7	17.5
9-24	1,493.2	450-3,570	443.5	893.7
10-7	18.7	0-112	18.7	37.7
11-5	279.2	0-600	100.2	201.9
TOTAL N=48	330.0	0-3,570	89.3	149.8

[1]N=6

Table A14. Descriptive statistics of _Bosmina longirostris_ in Lake Michigan at station 1 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	978.8	306-2,352	313.1	631.0
4-28	252.5	117-378	36.0	72.5
5-12	343.3	117-688	84.2	169.6
5-25	310.0	0-1,080	165.2	332.9
6-7[2]	218.3	56-450	68.5	138.0
6-21	8,567.7	1,819-21,460	2,893.9	5,831.2
7-6	3,006.7	1,131-4,625	535.9	1,079.9
7-21	5,082.5	3,255-6,480	501.2	1,009.9
8-2	9,210.0	2,325-13,650	1,819.3	3,665.9
8-15	24,864.2	8,640-43,700	6,338.7	12,772.4
9-15	500.8	0-2,170	353.6	712.4
9-26	252.8	45-546	69.8	140.6
10-11	723.7	300-1,284	170.9	344.4
TOTAL				
N=78	4,163.5	0-43,700	1,175.1	1,956.4

[1]N=6

[2]N=5 for this date

Table A15. Descriptive statistics of *Bosmina longirostris* in Lake Michigan at station 3 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	564.8	76-1,240	156.1	314.6
4-28	133.5	0-420	62.8	126.5
5-12	221.5	38-420	66.8	134.6
5-25	327.0	56-676	110.9	223.5
6-7[2]	176.8	106-318	40.8	82.4
6-21	16,671.7	9,860-35,640	4,098.7	8,259.0
7-6	6,112.5	1,155-10,050	1,568.7	3,160.8
7-21	12,151.7	3,500-18,445	2,347.9	4,731.1
8-2	14,903.3	7,000-32,100	3,838.3	7,734.1
8-15	15,918.3	6,460-22,570	2,718.2	5,477.3
9-15	419.2	0-700	102.5	206.5
9-26	207.2	0-642	108.8	219.3
10-11	552.7	254-1,040	113.1	227.8
TOTAL				
N=78	6,538.2	0-35,640	1,925.7	3,206.0

[1]N=6

[2]N=5 for this date

Table A16. Descriptive statistics of *Bosmina longirostris* in Lake Michigan at station 5 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	188.3	40-387	52.4	105.5
4-28	110.2	38-312	41.8	84.2
5-12	168.7	0-288	46.1	92.9
5-25	101.0	0-228	30.8	62.0
6-7	211.0	0-310	44.7	90.0
6-21	19,928.0	5,990-35,401	5,730.9	11,547.7
7-6	5,476.0	2,990-7,600	666.1	1,342.2
7-21	5,695.0	2,040-12,840	1,549.0	3,121.2
8-2	10,846.7	4,620-18,560	2,053.8	4,138.4
8-15	28,060.0	11,800-40,320	4,774.4	9,620.4
9-15	499.2	120-825	109.1	219.8
9-26	130.8	0-452	71.7	144.5
10-11	1,213.0	240-2,376	357.8	721.0
TOTAL				
N=78	5,400.5	0-40,320	1,408.9	2,345.7

[1]N=6

Table A17. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 1 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	799.5	170-2,520	367.5	740.5
4-28	26.0	0-156	26.0	52.4
5-12	19.7	0-43	8.9	17.8
5-25	52.3	0-270	44.1	88.9
6-7	0	-	-	-
6-21	200.0	0-580	105.4	212.4
7-6	0	-	-	-
7-21	360.0	0-810	123.4	248.6
8-2	247.5	0-465	81.7	164.7
8-15	0	-	-	-
9-15	2,037.5	0-5,270	884.7	1,782.7
9-26	91.3	0-220	37.3	75.2
10-11	415.7	120-912	150.8	303.8
TOTAL				
N=60	425.0	0-5,270	132.5	221.4

[1]N=6

Table A18. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 3 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	562.0	72-1,184	196.8	396.5
4-28	7.0	0-42	6.7	13.5
5-12	91.6	0-240	33.9	68.3
5-25	21.7	0-72	13.8	27.9
6-7	0	-	-	-
6-21	135.0	0-500	88.8	179.0
7-6	0	-	-	-
7-21	147.5	0-360	59.8	120.6
8-2	201.7	0-620	102.4	206.3
8-15	255.0	0-740	125.1	252.2
9-15	2,690.0	1,755-3,565	315.2	635.2
9-26	0	-	-	-
10-11	733.2	504-980	70.0	141.0
TOTAL				
N=66	441.1	0-3,565	116.1	193.9

[1]N=6

Table A20. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 1 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	35.3	0-126	20.2	40.6
4-28	0	-	-	-
5-12	6.3	0-38	6.3	12.7
5-25	0	-	-	-
6-7	0	-	-	-
6-21	35.7	0-214	35.7	71.9
7-6	0	0	0	0
7-21	2,292.5	1,320-3,375	299.2	602.9
8-2	1,082.5	0-3,120	467.2	941.5
8-15	127.5	0-380	63.6	128.1
9-15	1,709.2	380-2,900	475.5	958.1
9-26	70.5	0-153	24.9	50.3
10-11	53.7	0-186	29.8	60.1
TOTAL				
N=60	545.5	0-3,375	138.9	232.2

[1]N=6

Table A20. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 1 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	35.3	0-126	20.2	40.6
4-28	0	-	-	-
5-12	6.3	0-38	6.3	12.7
5-25	0	-	-	-
6-7	0	-	-	-
6-21	35.7	0-214	35.7	71.9
7-6	0	0	0	0
7-21	2,292.5	1,320-3,375	299.2	602.9
8-2	1,082.5	0-3,120	467.2	941.5
8-15	127.5	0-380	63.6	128.1
9-15	1,709.2	380-2,900	475.5	958.1
9-26	70.5	0-153	24.9	50.3
10-11	53.7	0-186	29.8	60.1
TOTAL				
N=60	545.5	0-3,375	138.9	232.2

[1]N=6

Table A21. Descriptive statistics of _Daphnia galeata mendotae_ in Lake Michigan at station 3 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	0	-	-	-
4-28	0	-	-	-
5-12	0	-	-	-
5-25	0	-	-	-
6-7	0	-	-	-
6-21	48.3	0-290	48.3	97.4
7-6	85.8	0-330	57.4	115.9
7-21	1,353.8	280-2,015	192.5	388.8
8-2	1,640.8	700-3,400	450.9	908.6
8-15	1,243.3	0-3,960	617.1	1,243.5
9-15	1,345.8	480-2,400	292.7	589.9
9-26	251.2	56-749	114.9	231.5
10-11	67.8	0-127	23.7	47.8
TOTAL				
N=66	726.5	0-3,960	135.7	226.7

[1]N=6

Table A22. Descriptive statistics of _Daphnia galeata mendotae_ in Lake Michigan at station 5 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	0	-	-	-
4-28	0	-	-	-
5-12	0	-	-	-
5-25	0	-	-	-
6-7	0	-	-	-
6-21	0	-	-	-
7-6	30.0	0-180	30.0	60.5
7-21	371.3	0-780	129.8	261.5
8-2	901.7	0-2,380	-	-
8-15	0	-	-	-
9-15	1,289.2	240-2,145	427.0	860.4
9-26	257.8	37-678	87.5	176.7
10-11	70.0	0-232	37.6	75.8
TOTAL				
N=36	482.4	0-2,380	100.2	169.1

[1]N=6

Table A23. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 1 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	7.0	0-42	7.0	14.1
4-28	0	-	-	-
5-12	0	-	-	-
5-25	0	-	-	-
6-7	0	-	-	-
6-21	101.8	0-290	51.3	103.5
7-6	230.8	0-870	139.8	281.8
7-21	674.2	0-1,240	178.4	359.6
8-2	294.2	0-640	-	-
8-15	0	-	-	-
9-15	30.8	0-185	30.8	62.1
9-26	0	-	-	-
10-11	0	-	-	-
TOTAL				
N=36	223.1	0-1,240	48.2	81.3

[1] N=6

Table A24. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 3 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	5.3	0-32	5.3	10.8
4-28	0	-	-	-
5-12	0	-	-	-
5-25	0	-	-	-
6-7	24.4	0-122	24.4	49.3
6-21	41.7	0-250	41.7	84.0
7-6	30.8	0-185	30.8	62.1
7-21	362.5	140-775	94.2	189.8
8-2	503.3	0-1,020	159.2	320.8
8-15	08.3	0-1,850	299.3	603.1
9-15	126.7	0-420	80.8	162.8
9-26	0	-	-	-
10-11	32.7	0-196	32.7	65.8
TOTAL				
N=54	2,033.1	0-1,850	1,960.6	3,284.1

[1]N=6

Table A25. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 5 in 1976.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-14	0	-	-	-
4-28	6.5	0-39	6.5	13.1
5-12	0	-	-	-
5-25	0	-	-	-
6-7	0	-	-	-
6-21	0	-	-	-
7-6	0	-	-	-
7-21	281.0	60-625	90.0	181.4
8-2	58.3	0-350	58.3	117.5
8-15	0	-	-	-
9-15	105.8	0-330	54.2	109.2
9-26	0	-	-	-
10-11	46.0	0-276	46.0	92.7
TOTAL				
N=30	99.5	0-625	23.6	40.0

[1]N=6

A26. Descriptive statistics of *Bosmina longirostris* in Lake Michigan at station 1 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	35.0	0-210	35.0	70.5
5-17	570.8	0-1,155	164.3	331.1
6-13	1,433.3	720-3,000	348.4	702.1
7-21	3,201.7	1,560-7,840	992.0	1,999.0
8-18	4,298.7	0-12,000	1,808.2	3,643.5
9-13[2]	398.0	0-620	106.0	226.0
10-22	478.3	0-740	104.1	209.8
TOTAL				
N=41	1,514.6	0-12,000	372.4	627.1

[1]N=6

[2]N=5 for this date

Table A27. Descriptive statistics of _Bosmina longirostris_ in Lake Michigan at station 1 in 1977.

DATE	[1] MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	18.3	0-110	18.3	36.9
5-17	535.0	200-780	112.7	227.0
6-13	3,006.7	1,200-4,900	603.0	1,215.1
7-21	7,816.7	4,900-13,000	1,248.9	2,516.5
8-18	7,100.0	5,500-8,400	462.6	932.2
9-13[2]	1,262.0	440-2,040	299.5	638.6
10-22	611.7	0-1,410	257.0	517.8
TOTAL				
N=41	2,947.3	0-13,000	522.3	879.5

[1] N=6

[2] N=5 for this date

Table A28. Descriptive statistics of *Bosmina longirostris* in Lake Michigan at station 5 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	21.7	0-100	16.4	33.1
5-17	301.7	0-600	110.1	221.9
6-13	1,956.7	0-5,910	896.1	1,810.1
7-21	4,830.0	1,100-8,400	1,045.0	2,105.6
8-18	2,328.7	0-3,752	611.9	1,233.0
9-13	300.0	0-990	160.1	322.5
10-22	420.0	0-1,680	266.3	536.5
TOTAL				
N=42	2,403.6	0-1,700	746.6	1,256.6

[1]N=6

Table A29. Descriptive statistics of _Eubosmina coregoni_ in Lake Michigan at station 1 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	412.5	0-1,155	175.5	354.5
6-13	0	0	0	0
7-21	0	0	0	0
8-18	399.3	0-1,700	271.4	547.0
9-13[2]	542.0	330-780	75.2	160.3
10-22	246.7	0-1,480	246.7	497.0
TOTAL				
N=23	320.9	0-1,700	96.7	166.0

[1]N=6

[2]N=5 for this date

Table A30. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 3 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	151.7	0-400	71.2	143.5
6-13	0	0	0	0
7-21	1,506.7	0-5,130	774.4	1,560.4
8-18	525.7	0-1,064	137.9	277.9
9-13[2]	360.0	0-1,400	238.7	481.0
10-22	75.0	0-450	75.0	151.1
TOTAL N=29	576.0	0-5,130	185.2	315.0

[1]N=6

[2]N=5 for this date

Table A31. Descriptive statistics of *Eubosmina coregoni* in Lake Michigan at station 5 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	138.3	0-420	69.8	140.6
6-13	0	0	0	0
7-21	775.0	0-1,800	355.8	717.0
8-18	503.2	0-1,020	186.4	375.0
9-13	195.0	0-840	139.8	281.7
10-22	0	0	0	0
TOTAL				
N=24	402.9	0-1,800	113.8	229.2

[1]N=6

Table A32. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 1 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	0	0	0	0
7-21	265.0	0-1,100	185.2	373.1
8-18	0	0	0	0
9-13	0	0	0	0
10-22	153.3	0-920.0	153.3	309.0
TOTAL				
N=12	209.2	0-1,100	115.8	208.1

[1]N=6

Table A33. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 3 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	0	0	0	0
7-21	225.0	0-1,350	225.0	453.3
8-18	0	0	0	0
9-13[2]	70.0	0-350	70.0	149.2
10-22	278.3	0-1,200	199.7	402.3
TOTAL				
N=17	198.2	0-1,350	103.9	181.5

[1]N=6

[2]N=5 for this date

Table A34. Descriptive statistics of *Daphnia galeata mendotae* in Lake Michigan at station 5 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	0	0	0	0
7-21	366.7	0-2,200	366.7	738.9
8-18	170.0	0-1,020	170.0	342.5
9-13	0	0	0	0
10-22	0	0	0	0
TOTAL				
N=12	268.3	0-2,200	194.9	350.1

[1]N=6

Table A35. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 1 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	83.3	0-500	83.3	167.9
7-21	1,126.7	0-2,750	528.6	1,065.1
8-18	771.3	288-1,360	167.7	337.9
9-13[2]	254.0	0-780	162.2	345.7
10-22	830.0	0-2,760	445.6	897.8
TOTAL				
N=29	625.5	0-2,760	157.9	268.7

[1]N=6

[2]N=5 for this date

Table A36. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 3 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	0	0	0	0
7-21	1,155.0	0-2,450	346.9	699.1
8-18	1,368.0	470-2,880	415.9	838.1
9-13[2]	326.0	0-700	143.7	306.4
10-22	621.7	0-2,350	376.2	758.0
TOTAL				
N=23	891.2	0-2,880	184.8	317.2

[1]N=6

[2]N=5 for this date

Table A37. Descriptive statistics of *Daphnia retrocurva* in Lake Michigan at station 5 in 1977.

DATE	[1]MEAN (No. m^{-3})	RANGE	STANDARD ERROR	90% CONFIDENCE INTERVAL
4-18	0	0	0	0
5-17	0	0	0	0
6-13	0	0	0	0
7-21	3,598.3	1,100-6,600	741.0	1,493.1
8-18	1,492.8	0-3,570	607.7	1,224.5
9-13	478.3	0-1,680	253.6	511.1
10-22	78.3	0-470	78.3	157.9
TOTAL				
N=24	1,412.0	0-6,600	366.9	628.8

[1]N=6