THE CRUSTACEAN ZOOPLANKTON OF THE SOUTHERN NEARSHORE ZONE OF THE CENTRAL BASIN OF LAKE ERIE IN 1978 AND 1979: INDICATIONS OF TROPHIC STATUS

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THE CRUSTACEAN ZOOPLANKTON OF THE SOUTHERN NEARSHORE ZONE OF THE CENTRAL BASIN OF LAKE ERIE IN 1978 AND 1979: INDICATIONS OF TROPHIC STATUS

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ABSTRACT

The crustacean zooplankton community of the southern nearshore zone of the Central Basin was investigated as part of a two-year intensive limnological surveillance of Lake Erie conducted by the United States and Canada. Thirty stations were sampled in 1978 in an area approximately 155 km long and up to 5 km from shore between Vermilion and Ashtabula, Ohio. Six stations were sampled in 1979. Four sampling cruises were conducted each year from April or May through October.

Sampling methods differed between 1978 and 1979 in terms of depth of tows, net mesh widths (243 and 64 microns), number of stations sampled, number of samples per station, and sampling dates. The samples collected in 1979 from one meter above the bottom with a 64 micron mesh net provided greater abundance estimates than those collected in 1978 from two meters above the bottom with a 243 micron mesh net. Zooplankton abundance was highly variable between stations and at individual stations during each cruise, indicating a patchy zooplankton distribution; however, definite seasonal patterns in the abundance of the individual species and the total zooplankton were observable.

Thirty-two crustacean taxa were identified in 1978, including 17 species of Cladocera, six Cyclopoida, seven Calanoida, one Harpacticoida, and the order Ostracoda. In 1979, 22 species were encountered, including 11 cladocerans, four cyclopoids, six calanoids, and one ostracod. The smaller number of taxa seen in 1979 probably resulted from sampling at only six stations, only one of which was close to shore, thereby eliminating semiplanktonic or tychoplanktonic species. Highest crustacean abundances were encountered during the June, July, and October cruises, and the lowest abundances were found in April, May, and August. In 1979 the nauplii usually constituted the most abundant group and the majority of the crustaceans. The Cladocera were more numerous in July, however, at four of the six stations. In descending order of abundance, the major species during the four 1979 cruises were *Daphnia galeata mendotae*, *D. retrocurva*, *Eubosmina coregoni*, *Chydorus sphaericus*, *Eubosmina* with pseudomucro, *Cyclops bicuspidatus thomasi*, *Bosmina* sp., *Tropocyclops prasinus mexicanus*, *Mesocyclops edax*, *Diaptomus ashlandi*, and *D. oregonensis*. All of the species reported as occurring in the middle of the Central Basin in 1967 and 1968 were encountered in the nearshore zone in 1978 and 1979.

In order to evaluate whether or not major changes have taken place in the crustacean zooplankton composition of the Central Basin over the past 30 years, the present results were compared with previous Central Basin studies. Comparison of these studies was complicated by the different sampling areas; different sampling methods, apparatus, and mesh sizes; varying sampling dates; and taxonomic uncertainties. No one species has consistently been the predominant species in all studies, probably due largely to these variables, although several cladocerans and copepods have remained numerically important in the lake since at least 1928. Some species appear to have disappeared or to have increased or decreased in relative abundance, and this may be related to an increase in the eutrophication of the lake.

A trophic index based on the ratio of the abundance of calanoid copepods to the abundance of cyclopoid copepods plus cladocerans was applied to this

and several earlier studies of Lake Erie. No difference in this ratio between the present and previous studies was detectable. Compared to values obtained in parts of the upper Great Lakes, however, the ratio indicates a relatively eutrophic status for all three basins of Lake Erie. Further investigation of the effectiveness of this ratio in measuring the trophic status of lakes is necessary, especially with regard to the effects of the inclusion or exclusion of naupliar stages of copepods and the dates of sample collection.

CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

INTRODUCTION

The crustacean zooplankton community of the St. Lawrence Great Lakes forms an essential component of the food base for fishes (Wilson 1960), and its species structure provides an indication of the trophic status of the lakes (Gannon and Stemberger 1978). More fundamentally, knowledge of this community is important to understanding the inter-relations between the biotic and abiotic components of these large lake ecosystems.

Although detailed studies of the crustacean zooplankton community of Lake Erie date back at least to 1928 (Fish 1929), the composition and dynamics of the community are not well documented. All of the studies have been conducted on limited areas of one or more of the three basins, have employed a variety of sampling devices and methods, have been conducted during varying months of the year for varying durations, and have often been beset with a lack of taxonomic certainty. Yet probably the main factor precluding a detailed history of zooplankton composition and abundance in Lake Erie has been the lack of continuing studies in specific areas of the lake over the years.

The few investigations of the southern nearshore zone (defined for this report as less than 5 km offshore) of the Central Basin have been conducted during the past 30 years by Davis (1954, 1962) and Czaika (1978). A few other Central Basin studies, primarily by Davis (1968, 1969) and Patalas (1972), characterized the crustacean zooplankton of the open lake and included few if any nearshore stations. In this study, estimates of total crustacean zooplankton abundance and individual species contributions are presented and are related to the past and present trophic status of Lake Erie.

This study formed part of a two-year intensive surveillance program conducted by the United States and Canada in which the major physical, chemical, and biological components of the water column and sediments of Lake Erie were measured. The program conformed to a planning study performed by the Center for Lake Erie Area Research (CLEAR) (Herdendorf 1978), which reflected the general objectives of the Surveillance Subcommittee, Great Lakes Water Quality Board, International Joint Commission. The objectives of the surveillance plan, as stated by Herdendorf (1978), were (1) to search for, monitor, and quantify violations of the existing Agreement objectives, the IJC recommended objectives, and jurisdictional standards, criteria and objectives; (2) to monitor local and whole lake response to abatement measures and to identify emerging problems; (3) to determine the cause-effect relationship between water quality and inputs in order to develop the appropriate remedial-preventative actions and predictions of the rate and extent of local and whole lake responses to alternative abatement proposals. With consideration of key issues specific to Lake Erie, the surveillance plan additionally focussed on (1) determining the long-term trophic state of Lake Erie and determining to what degree remedial measures have effected improvements; and (2) assessing the presence, distribution, and impact of toxic substances.

In addition to this report, other reports on the southern nearshore zone of the Central Basin assess the physical and chemical components (Richards 1981), the bacteriology (E. [Stanford] McMahon, in preparation), the phytoplankton (P. A. Kline, in preparation), and the zoobenthos (Krieger 1981). Additional reports are being produced for the nearshore zones of the Eastern and Western Basins and the open lake of all three basins.

STUDY AREA

The sampling stations were located in an area approximately 155 km long from northwest of Vermilion, Ohio, to east of Ashtabula, Ohio, at distances as much as 5 km from shore (Figure 1). The exact location and the rationale for the selection of each station are provided by Herdendorf (1978). Stations were generally clustered around river mouths and harbors. Station depths at the time of sampling ranged from about 5 to 15 m.

During the four cruises in 1978, 30 stations were sampled throughout the study area, representing areas both within and outside of harbors. During the four 1979 cruises, six stations were sampled, and none of these was within harbors (Figure 1).

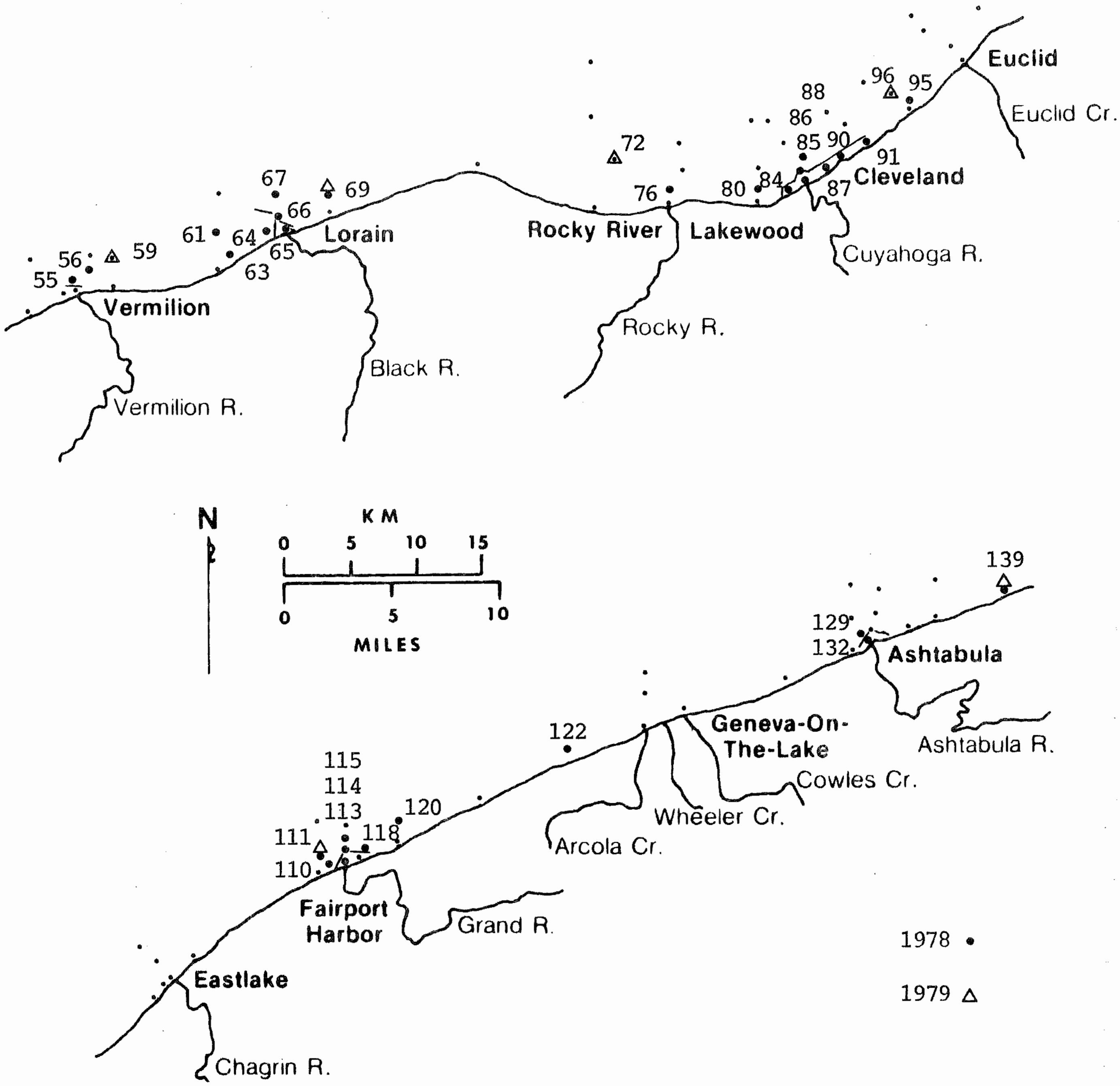

Figure 1. Map of the study area, showing stations sampled in 1978 and 1979.

METHODS

Sampling methods differed between 1978 and 1979 in ways which directly affected the data. Both years the zooplankton was sampled with a 0.5 m diameter cone net with a detachable straining bucket. In 1978, vertical tows at a constant rate were made beginning at two meters from the bottom. In 1979, vertical tows were made from one meter off the bottom. In July, August, and October 1979, at stations with a depth of over 11 m, an additional tow was made beginning at 10 m. The samples were obtained between 0700 and 1630 hours local time during four cruises each year. The sampling dates are shown in Table 1.

In 1978, a net with mesh openings of 243 microns was used, thereby retaining only the larger immature and adult crustacean zooplankters. In 1979, the 243 micron mesh net was employed except in October to obtain samples for comparison with the 1978 samples. Most samples in 1979 were obtained with a net having 64 micron mesh openings in order to ensure collection of all of the life stages of the crustacean zooplankters.

In 1978, a single sample was taken at most of the 30 stations each cruise, although duplicate samples were obtained at a few of the stations. The duplicated stations varied from cruise to cruise. In 1979, only six stations were sampled for zooplankton (Figure 1). During the April, July, and August 1979 cruises, one 64 micron sample was collected with the 243 micron net, and a second sample was collected with the 64 micron net. Duplicate samples were collected with each net at two of the stations each cruise. During the July, August, and October 1979 cruises, one 64 micron sample (or duplicates) was obtained at each station on each of three consecutive days.

The volume of water strained during each tow was measured with a calibrated General Oceanics digital flowmeter attached to the net bridle. After each tow the net was thoroughly backwashed with a stream of water to rinse all zooplankters into the straining bucket. Each sample was poured into a 500 ml bottle, and about 15 ml of carbonated water were added to anesthetize the zooplankters. After several minutes the sample was preserved with 25 ml of 37% formalin, yielding approximately 2% formalin in the sample.

In the laboratory, samples with few zooplankters were concentrated to a workable volume. A 1.13 ml or 2.32 ml aliquot was withdrawn from the thoroughly mixed sample with a calibrated Hensen-Stempel pipet and was placed in a Ward's zooplankton counting wheel for identification and enumeration of the specimens. A minimum of 200 non-naupliar crustaceans was enumerated, with additional aliquots taken as necessary. Duplicate aliquots were enumerated from 5.2% of the 1978 samples, and 7.5% of the 1978 samples were obtained in duplicate. Duplicate aliquots were omitted from the 1979 sample analysis, but approximately 33% of the 1979 samples were obtained in duplicate.

Cladocerans and adult copepod crustaceans were identified to species and sexed when possible. The systematics of the cladoceran family Bosminidae is unsettled, and variant forms occur in the Great Lakes (Watson 1974, Gannon and Stemberger 1978). Thus, bosminid specimens were identified as *Bosmina* sp. (with mucrones, probably *B. longirostris*), *Eubosmina coregoni* (without mucrones or pseudomucrones), and *Eubosmina* with pseudomucrones. There was often a gradation in the form and extent of development of the pseudomucrones

Table 1. Dates encompassed by the sampling cruises in 1978 and 1979.

	1978		1979
Cruise 1	18 - 31 May	Cruise 1	11 - 25 April
Cruise 2	15 - 27 June	Cruise 2	11 - 25 July
Cruise 3	28 August - 9 September	Cruise 3	18 August - 1 September
Cruise 4	8 - 20 October	Cruise 4	2 - 18 October

in the specimens of a given sample. Sources for identification included Brooks (1957), Czaika and Robertson (1968), Deevey and Deevey (1971), Edmondson (1959), Pennak (1978), and Torke (1974). The samples are on deposit at Heidelberg College.

Zooplankton densities were calculated as:

$$\text{Number per m}^3 = \frac{N[V(d)/V(a)]}{Q}$$

where

N = total zooplankters in aliquot

$V(d)$ = total sample volume (ml)

$V(a)$ = combined volume of aliquots (ml)

Q = quantity of water strained (m^3).

A detailed analysis of the 1978 samples was reported previously (Krieger 1980). Because the 243 micron mesh size employed in obtaining those samples allowed a large proportion of the crustaceans to pass through the net (see below), the data should be considered to be qualitative; estimates of zooplankton numbers made from these samples are too low, particularly for samples obtained when a large proportion of the crustaceans consisted of small immature forms.

Analyses of variance, t-tests, regressions, and correlations were performed using the package Minitab (Ryan et al. 1980).

RESULTS AND DISCUSSION

Detailed data on the species enumerated from each sample collected in 1978 and 1979 are provided in several appendices available under separate cover.

Environmental and Analytical Influences on the Data

The data obtained from duplicate samples and duplicate aliquots from the 1978 cruises were compared to determine the amount of field (environmental and equipment) and analytical (subsampling) variation. Selected data are presented in Table 2. A t-test revealed a highly significant difference [$t(9,6) = 27.42$, $p < .01$] in the agreement between duplicate sample densities and duplicate aliquot densities. Estimates of total crustacean zooplankton density were less variable between aliquots (mean similarity of estimates = 0.92) than between samples (mean similarity = 0.74). The high similarity of the aliquots indicates that the samples were thoroughly mixed prior to subsampling. The lower similarity between replicate samples is expected from the general patchiness of zooplankton distributions in lakes (Wetzel 1975).

In contrast to total density (Table 2), there was essentially no difference in the extent of variation between replicate aliquots and replicate samples for total taxa, taxa shared, and percent Cladocera. In these instances, the variation of both aliquots and samples would have been reduced by counting more than 200 non-nauplii, although this would have represented a compromise in terms of increased time for analysis.

Similarly, the 1979 data from 243 micron mesh tows were analyzed to determine the amount of variation between replicate samples (Table 3). The range of similarities between duplicate samples for total abundance was very similar to the 1978 range, with a mean similarity of 0.77.

Duplicate samples obtained with the 64 micron mesh net for three consecutive days were analyzed to determine whether total zooplankton abundance differed between days. F ratios obtained by one-way analyses of variance (Table 4) indicated that there was a significant difference in total abundance between days in only one of six sample sets, and in the abundance of cladocerans (water fleas) in two of the six sets. Thus, it appears that, in general, temporal changes in crustacean zooplankton dynamics cannot be detected within a three-day time interval, at least not without increasing the number of samples obtained each day (i.e., increasing precision). Nevertheless, as the 1978 data showed (Figure 2), zooplankton dynamics can be observed over a 15 day period even by sampling only once at many widely spaced stations.

Paired tows from the 10 m depth and from one meter above the bottom were accomplished on eight occasions in 1979 at three stations (Table 5). For six of the eight sample pairs, the "bottom" tow yielded a greater estimate of total zooplankton abundance, as would be expected if the zooplankters are distributed throughout the water column. The two pairs in which the 10 m tow yielded a greater estimate were at two stations where "bottom" tows produced greater estimates on other dates. Samples were collected at about the same

Table 2. Similarities (s) between duplicate samples (R) and duplicate aliquots (A) of the crustacean zooplankton in 1978. Ratios are the smaller number divided by the larger number.

Station/ Date	No./m^3 and Similarity		Number of Taxa and Similarity		Total Taxa	Taxa Shared		Percent Cladocera and Similarity	
55 780518	3402 3894 (R)	s = 0.87	8 9	s = 0.89	11	6	55%	59.5 49.0	s = 0.82
55 781008	14915 13872 (R)	s = 0.93	13 13	s = 1.00	14	12	86%	39.8 42.4	s = 0.94
56 780615	5076 5759 (A)	s = 0.88	13 14	s = 0.93	16	11	69%	65.1 58.2	s = 0.89
61 780518	8351 8802 (R)	s = 0.95	10 11	s = 0.91	11	10	91%	59.9 59.8	s = 1.00
61 781008	10304 11536 (A)	s = 0.89	13 13	s = 1.00	13	13	100%	43.2 45.7	s = 0.95
63 780615	37106 41117 (R) 22081 (A)	 s = 0.90 s = 0.60	13 10 10	 s = 0.77 s = 0.77	 15 14	 8 9	 53% 64%	33.2 35.2 33.8	 s = 0.94 s = 0.98
63 780828	44057 56612 (A)	s = 0.78	10 13	s = 0.77	14	9	64%	75.2 74.3	s = 0.99
69 780518	6155 6069	s = 0.99	13 11	s = 0.85	14	10	71%	39.4 37.4	s = 0.95
69 781008	11592 12105 (R)	s = 0.96	12 13	s = 0.92	13	12	92%	52.5 51.3	s = 0.98
76 780618	48279 90095 (A)	s = 0.54	14 11	s = 0.79	15	10	67%	53.2 65.8	s = 0.81
76 780831	15785 14481 (R)	s = 0.92	10 8	s = 0.80	12	6	50%	79.9 81.5	s = 0.98
84 780621	87233 99587 (R)	s = 0.88	9 8	s = 0.89	12	5	42%	82.9 83.2	s = 1.00
90 780525	5258 4004 (A)	s = 0.76	11 11	s = 1.00	14	8	57%	37.5 32.7	s = 0.87
113 780624	95517 75-85 (A)	s = 0.79	11 9	s = 0.82	13	7	54%	73.6 75.9	s = 0.97
118 78-528	9348 12459 (A)	s = 0.75	12 11	s = 0.92	13	10	77%	25.2 20.3	s = 0.81
122 780906	8366 19828 (A)	s = 0.42	12 10	s = 0.83	13	9	69%	83.5 85.9	s = 0.97
Mean Sample similarity	= 0.74 ± 0.17 (S.D.)		0.87 ± 0.09			69 ± 13%		0.97 ± 0.07	
Mean subsample similarity	= 0.92 ± 0.03 (S.D.)		0.88 ± 0.08			67 ± 22%		0.95 ± 0.06	

time of day each day. From these results, it appears that considerable variation in the abundance estimates can arise from the sampling process itself, perhaps being affected by such factors as the amount of drift of the sampling craft during the tow, causing an oblique tow which is taken at a

Table 3. Comparison of total crustacean zooplankton estimates ($No./m^3$) from duplicate samples collected in 1979 with a 243 micron mesh net.

Station	Date	Sample 1	Sample 2	Similarity
59	790830	1813	3260	.56
69	790723	25479	32260	.79
72	790827	1481	1145	.77
96	790417	4219	5325	.79
111	790714	18399	15126	.82
139	790411	4663	5212	.89

Table 4. Estimates of total crustacean zooplankton and total cladoceran abundance (No./cu.m.) from duplicate samples obtained on three consecutive dates in 1979 with a 64 micron mesh net. F ratios derived by one-way analyses of variance were either highly significant ($p < .01$,**), significant ($p < .05$,*) or not significant.

	Total Zooplankton				Total Cladocera			
Station	Dates			F Ratio	Dates			F Ratio
59	790830	798031	790901		790830	790831	790901	
	30629	26780	52671	8.89	5328	5091	8086	7.33
	24196	35920	45349		4535	6318	7112	
69	790723	790724	790725		790723	790724	790725	
	66325	52872	52755	0.89	37372	32044	22867	12.52*
	94722	68677	74584		41814	27109	26313	
69	791016	791017	791018		791016	791017	791018	
	54007	67941	53643	0.51	14266	20551	20007	0.04
	65098	52986	53137		19959	15646	15775	
72	790827	790828	790829		790827	790828	790829	
	14175	22094	24608	3.62	2011	3417	1098	66.90**
	14209	24823	16430		2091	3875	753	
111	790714	790715	790716		790714	790715	790716	
	193013	96690	97621	49.45**	16355	22784	33086	5.54
	174596	110798	90519		15142	36208	33120	
139	791002	791003	791004		791002	791003	791004	
	151766	124200	138563	0.17	51503	29239	29396	0.39
	84458	72934	96712		21239	20710	30911	

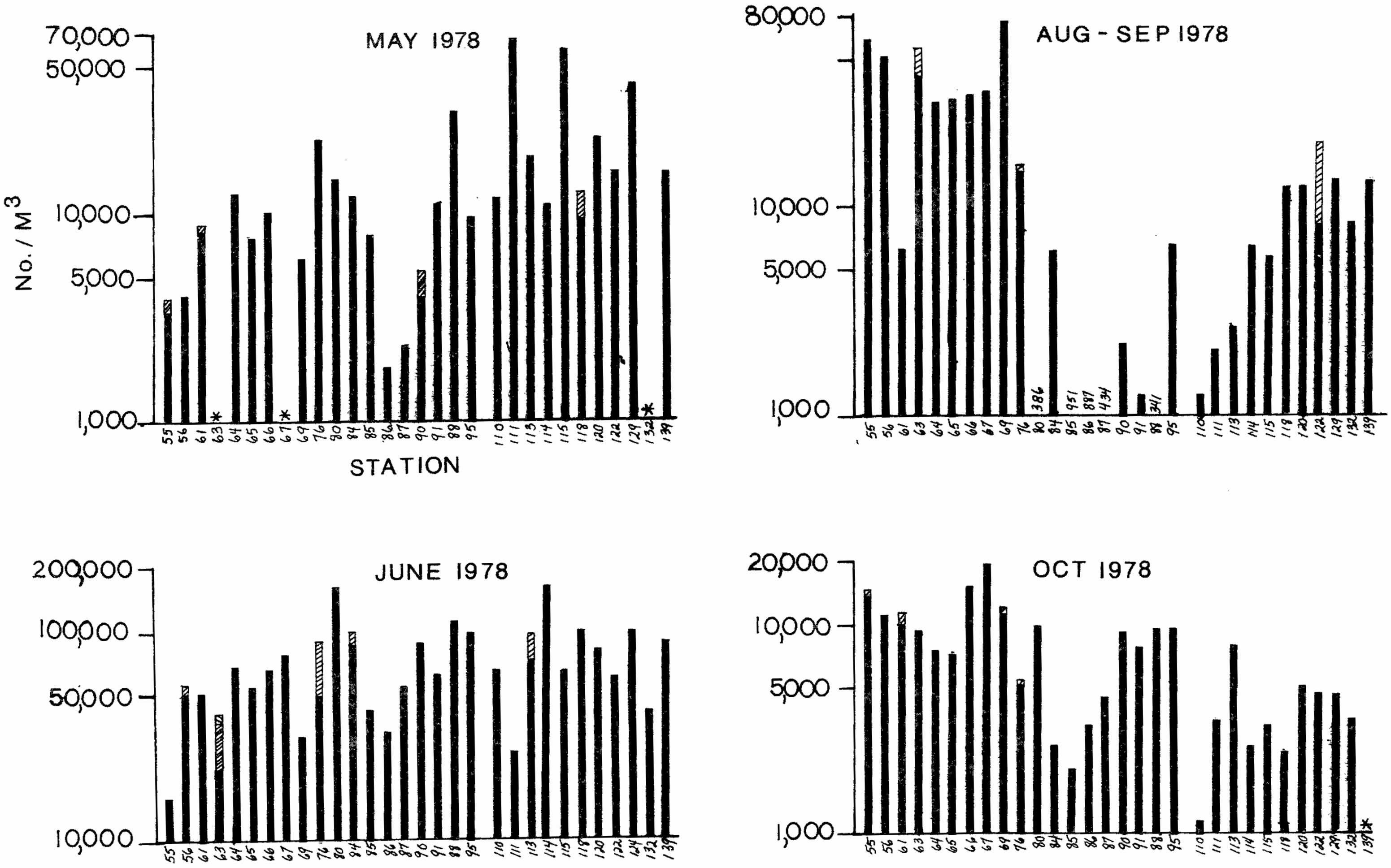

Figure 2. Total zooplankton density (No./m^3) at each stations during each cruise in 1978, estimated with a 243 micron mesh net. Densities include all crustaceans and the large rotifers of the genus Asplanchna. Hashed bars indicate the higher density of two duplicate samples, and the solid bars beneath indicate the lower density. Asterisk indicates no sample was obtained.

shallower depth than the apparent sampling depth; the extent of rolling of the sampling craft during the tow, again influencing the effective depth of sampling; whether or not the plankton net opens immediately upon beginning the tow; and the natural horizontal patchiness of zooplankton distribution, as two successive hauls are never at exactly the same location in the water column due to drifting of the craft and lake currents.

In April, July, and August 1979, paired tows were accomplished once at each of the six stations, one tow employing a 243 micron mesh net, and the other a 64 micron mesh net. Total zooplankton, cladoceran, and cyclopoid copepod abundance (number per m^3) as estimated by each net is shown in Table 6. Except for the samples obtained at station 96 in July, every pair of samples showed much larger abundance estimates in all three categories for the 64 micron mesh than for the 243 micron mesh. Mesh width (pore size) has been shown to directly affect filtration efficiency (Tranter and Smith 1968): A mesh width of 0.27 mm (270 microns) and a porosity of 0.44 demonstrated a 97% filtration efficiency, whereas a mesh width of 0.06 mm and 0.26 porosity demonstrated an 88% efficiency. It is also known, and was often very apparent during our study, that nets with smaller mesh widths clog more readily than those with larger mesh widths, and in this way filtration efficiency is further reduced in nets with smaller mesh widths.

Despite the reduced efficiency of the 64 micron mesh net, the data in Table 6 indicate that a much larger number of crustaceans was retained in that net than in the 243 micron net. Nauplii present in the 64 micron samples but absent in the 243 micron samples account for much of the difference in total zooplankton estimates. Similarly, the much less numerous young copepodid stages of the copepods were retained in the 64 micron net but usually escaped through the 243 micron net. However, the cladocerans were generally larger, and most should have been retained by both mesh sizes. As Table 6 shows, the 243 micron mesh estimates for cladocerans were also much lower than the 64 micron mesh estimates, even in July, when many of the cladocerans were large daphnias measuring well over 0.5 mm in height and over 1.0 mm in length. The greater filtration efficiency of the 243 micron net was expected to increase the estimates of those samples relative to the 64 micron samples. Thus, it seems possible that many of the larger crustaceans also were forced through the larger openings of the 243 micron net. Other factors which could have influenced the sample estimates, such as tow speed, filtering area, and depth of tow, were constant between the two mesh sizes. Different flowmeters were used on the two nets, and each was factory calibrated; therefore, erroneous readings should not have occurred. Because the 64 micron mesh net was known to retain all life stages of the crustacean zooplankters, despite its greater tendency to clog, and assuming that both flowmeters were accurate, the 64 micron mesh estimates are probably more correct than are the 243 micron mesh estimates. This smaller mesh size should be used in all future studies of the crustacean zooplankton of the Great Lakes. Few, if any, published studies of Lake Erie crustaceans have employed a mesh size greater than 119 microns (see Table 16).

Table 5. Comparison of total crustacean zooplankton abundance estimates (No./m^3) from samples obtained with a 64 micron mesh net at depths of 10 m and 1 m from the bottom.

Station	Date	Actual Depth (m)	10 m Tow	"bottom" Tow	Similarity
59	791016	12	49406	77655	.64
59	791018	13.5	75385	64117	.85
72	791012	13.5	75472	91126	.83
72	791014	14	114631	124199	.92
72	791015	14	91468	98186	.93
96	791008	12.5	255432	184518	.72
96	791010	12	84299	163468	.52
96	791011	12	91610	102377	.89

Paired t = -0.315, N.S. at alpha = 0.05 with 12 degrees of freedom.

Abundance Patterns at 30 Stations in 1978 (243 Micron Mesh Samples)

Thirty-two crustacean taxa were identified from the Central Basin nearshore zone in 1978 and included 17 species of Cladocera, 14 species of Copepoda (six Cyclopoida, seven Calanoida, one Harpacticoida), and the order Ostracoda (not identified further) (Tables 7 - 10).

Zooplankton densities, as estimated by the 243 micron mesh net, varied greatly from station to station during each sampling period, but even more so at each station between sampling periods (Figure 2). In June 1978 some zooplankton densities were more than ten times higher than those recorded in May and October. The highest densities encountered (164,000/m^3) were in June at stations 80 and 114. However, the stations with the highest zooplankton densities were different for each sampling period.

The lowest densities were found during the August-September cruise. At that time densities were severely depressed in and around Cleveland Harbor, with as few as 341 crustaceans/m^3 (Figure 2). A slight depression in total density in this vicinity was also apparent in May and October 1978.

The total densities obtained during each sampling period were strongly affected by the seasonal dynamics of the zooplankton community. During May a general increase in total abundance was apparent from west to east (Figure 2), and a gradual decline in numbers was reflected in August-September and October, again from west to east, which was the progressive direction of the cruises. Indeed, each set of histograms in Figure 2 continues at the approximate density at which the preceding set ends. Thus, differences in the crustacean densities between longitudinal areas of the basin probably are expressions more of temporal changes than instantaneous spatial differences.

Table 6. Comparison of the abundance (No./m^3) estimates of total crustacean zooplankton, total cladocerans, and total cyclopoid copepods (excluding nauplii) provided by paired samples, one employing a cone net with 243 micron mesh openings, the other a cone net with 64 micron mesh openings.

Station	Date	Total Zooplankton		Total Cladocera		Total Cyclopoida	
		64	243	64	243	64	243
59	790423	52020	3425	2871	633	2134	406
	790723	61947	29311	45645	28122	5356	1020
	790830	30626	1813	5327	1256	2683	137
69	790423	32057	1600	1083	565	1118	208
	790723	66325	25479	37372	22727	11293	2674
	790830	18549	4563	2915	3192	1255	67
72	790421	21648	2111	1162	229	1419	734
	790720	77472	20292	50100	15586	10264	4156
	790827	14174	1481	2010	578	2060	219
96	790417	33405	4219	1524	518	6741	1800
	790717	45140	49347	37495	41057	5734	6316
	790824	21835	504	1329	276	4506	5
111	790414	27686	4477	897	230	4783	1987
	790714	193015	18399	16355	7964	32063	10002
	790821	49983	7576	9302	4074	7060	471
139	790411	39426	4663	225	119	6038	2855
	790711	163078	21313	44249	17510	27477	3602
	790818	18454	731	1915	576	1711	50

The number of taxa encountered was similar for the western, central, and eastern areas of the Central Basin nearshore zone during each sampling period. The harbors revealed a possible reduction in species richness when compared to open stations except in August-September, when both areas possessed the same number of taxa. The inshore stations consistently revealed more taxa than the offshore stations, due largely to the presence shoreward of several semiplanktonic or tychoplanktonic species which do not occur in the open lake.

Seasonal changes in the abundance of each crustacean group (Cladocera, Calanoida, Cyclopoida) followed a similar pattern in most parts of the study area, with lowest densities in May and October, and peak densities in June. The changes correspond very well with the historical density fluctuations demonstrated by Watson (1974). Likewise, Davis (1968, 1969), who sampled the open lake in July and October 1967 and January 1968, noted much greater densities of all groups in July. Britt et al. (1973) sampled the Western

Table 7. Mean densities (No./m^3) of crustacean zooplankton taxa during May 1978. Means were computed using all replicates and subsamples. Station areas are Lorain-Vermilion (L-V), Cleveland (CLEV), Fairport Harbor-Ashtabula (FH-A); harbor, open; inshore (IN), offshore (OFF).

	L-V	CLEV	FH-A	HARBOR	OPEN	IN	OFF
OSTRACODA	0	0	0	0	0	0	0
CLADOCERA							
Alona guttata Sars	5	0	0	0	2	0	5
Alona quadrangularis O.F. Müller	0	0	0	0	0	0	0
Ceriodaphnia lacustris Birge	0	1	0	1	0	0	0
Ceriodaphnia reticulata (Jurine)	0	0	0	0	0	0	0
Chydorus sphaericus (O.F. Müller)	10	38	210	18	125	46	180
Daphnia ambigua Scourfield	2	47	6	46	4	27	0
Daphnia galeata mendotae Birge	22	27	5	24	9	19	15
Daphnia parvula Fordyce	73	15	0	36	24	19	49
Daphnia retrocurva Forbes	1,115	918	836	478	1,199	901	1,061
Diaphanosoma leuchtenbergiana Fischer	0	18	5	0	12	11	0
Bosminidae	1,665	3,437	5,586	1,976	4,483	2,704	5,642
Holopedium gibberum Zaddach	0	0	0	0	0	0	0
Ilyocryptus spinifer Herrick	0	0	0	0	0	0	0
Leptodora kindtii (Focke)	13	23	5	2	20	10	21
Leydigia quadrangularis (Leydig)	0	0	0	0	0	0	0
COPEPODA							
HARPACTICOIDA							
Canthocamptus sp.	25	5	0	5	12	13	2
CYCLOPOIDA							
immature Cyclopoida	790	4,086	7,526	2,229	5,291	3,312	6,275
Cyclops bicuspidatus thomasi S.A. Forbes	548	469	2,177	820	1,217	815	1,666
Cyclops scutifer Sars	0	0	3	0	2	2	0
Cyclops vernalis Fischer	111	86	181	154	112	96	193
Eucyclops speratus (Lilljeborg)	3	0	6	9	0	4	0
Mesocyclops edax (S.A. Forbes)	12	73	114	82	60	52	103
Tropocyclops prasinus mexicanus Kiefer	0	0	0	0	0	0	0
CALANOIDA							
immature Calanoida	2,134	1,196	820	1,093	1,500	1,172	1,773
Diaptomus ashlandi Marsh	160	29	157	81	131	81	188
Diaptomus minutus Lilljeborg	37	19	89	13	67	32	87
Diaptomus oregonensis Lilljeborg	16	1	0	1	8	3	10
Diaptomus sicilis S. A. Forbes	0	0	3	0	2	2	0
Diaptomus siciloides Lilljeborg	5	6	0	6	2	1	10
Epischura lacustris S. A. Forbes	0	0	0	0	0	0	0
Eurytemora affinis (Poppe)	350	372	9	563	72	76	162
Mean Total Individuals Per m^3	7,118	11,065	25,699	8,325	18,284	11,464	22,337

Basin twice monthly from mid-June to mid-September 1961 and obtained contrasting results. They found a small peak in the Copepoda in early July and a slightly higher peak in September, whereas the Cladocera demonstrated a single, large increase in density in late August and September. Studies in the Bass Islands region in 1939, 1949, and 1959 (Bradshaw 1964) demonstrated two periods of maximum density of Cladocera, in June and September, although the actual densities and the dates of their occurrence varied considerably from year to year.

Table 8. Mean densities (No./m^3) of crustacean zooplankton taxa during June 1978. Means were computed using all replicates and subsamples. Station areas are Lorain-Vermilion (L-V), Cleveland (CLEV), Fairport Harbor-Ashtabula (FH-A); harbor, open; inshore (IN), offshore (OFF).

	L-V	CLEV	FH-A	HARBOR	OPEN	IN	OFF
OSTRACODA	0	0	0	0	0	0	0
CLADOCERA							
Alona guttata Sars	0	0	0	0	0	0	0
Alona quadrangularis O.F. Müller	0	0	0	0	0	0	0
Ceriodaphnia lacustris Birge	26	29	28	33	24	28	26
Ceriodaphnia recticulata (Jurine)	0	0	55	0	29	13	33
Chydorus sphaericus (O.F. Müller)	67	0	10	29	24	16	52
Daphnia ambigua Scourfield	0	0	29	0	15	0	35
Daphnia galeata mendotae Birge	60	274	492	247	292	347	90
Daphnia parvula Fordyce	57	0	0	52	0	26	0
Daphnia retrocurva Forbes	24,126	53,738	54,011	50,867	40,054	47,859	33,816
Diaphanosoma leuchtenbergiana Fischer	332	517	1,303	713	720	745	647
Bosminidae	4,113	6,416	3,558	5,077	4,479	4,242	5,873
Holopedium gibberum Zaddach	0	21	31	9	22	14	26
Ilyocryptus spinifer Herrick	0	0	0	0	0	0	0
Leptodora kindtii (Focke)	192	124	209	213	154	210	85
Leydigia quadrangularis (Leydig)	0	0	0	0	0	0	0
COPEPODA							
HARPACTICOIDA							
Canthocamptus sp.	0	0	0	0	0	0	0
CYCLOPOIDA							
immature Cyclopoida	9,256	13,862	10,032	11,089	11,028	11,811	9,071
Cyclops bicuspidatus thomasi S.A. Forbes	3,630	3,047	2,279	2,363	3,338	2,993	2,966
Cyclops scutifer Sars	0	0	0	0	0	0	0
Cyclops vernalis Fischer	1,556	123	77	182	813	412	1,036
Eucyclops speratus (Lilluebørg)	0	0	0	0	0	0	0
Mesocyclops edax (S.A. Forbes)	282	617	1,034	512	719	756	353
Tropocyclops prasinus mexicanus Kiefer	0	0	0	0	0	0	0
CALANOIDA							
immature Calanoida	2,721	1,017	1,897	786	2,496	1,087	3,936
Diaptomus ashlandi Marsh	268	136	161	101	238	129	344
Diaptomus minutus Lilljeborg	203	198	1,853	378	962	722	827
Diaptomus oregonensis Lilljeborg	364	254	1,975	612	1,007	817	988
Diaptomus sicilis S.A. Forbes	19	15	19	0	28	19	15
Diaptomus siciloides Lilljeborg	330	617	1,746	635	1,046	837	1,055
Epischura lacustris S.A. Forbes	38	0	147	9	91	68	45
Eurytemora affinis (Poppe)	453	128	545	194	478	252	695
Mean Total Individuals per m^3	48,093	81,324	81,501	74,136	68,142	73,496	62,014

In 1978, the high June densities of Cladocera were maintained in the August samples in the western area of the basin, but not in the other areas, whereas the Cyclopoida gradually declined between June and October in all areas. The Calanoida demonstrated minimum densities in May and August, with a slight recovery in some areas in October. Britt et al. (1973) found minimum densities of Calanoida in June 1961 followed by a gradual increase in density throughout the sampling season.

Table 9. Mean densities (No./m^3) of crustacean zooplankton taxa during August-September 1978. Means were computed using all replicates and subsamples. Station areas are Lorain-Vermilion (L-V), Cleveland (CLEV), Fairport Harbor-Ashtabula (FH-A); harbor, open; inshore (IN), offshore (OFF).

	L-V	CLEV	FH-A	HARBOR	OPEN	IN	OFF
OSTRACODA	0	0	3	0	2	1	0
CLADOCERA							
Alona guttata Sars	0	0	0	0	0	0	0
Alona quadrangularis O.F. Muller	0	0	0	0	0	0	0
Ceriodaphnia lacustris Birge	0	0	0	0	0	0	0
Ceriodaphnia reticulata (Jurine)	0	0	0	0	0	0	0
Chydorus sphaericus (O.F. Muller)	122	10	6	26	51	52	17
Daphnia ambigua Scourfield	0	0	0	0	0	0	0
Daphnia galeata mendotae Birge	9,191	215	1,599	1,551	4,382	2,259	6,583
Daphnia parvula Fordyce	12	0	0	11	0	5	0
Daphnia retrocurva Forbes	9,744	814	379	1,322	4,382	2,325	6,127
Diaphanosoma leuchtenbergiana Fischer	5,927	195	673	1,086	2,571	2,214	1,706
Bosminidae	8,173	2,311	3,843	2,131	5,901	4,298	5,566
Holopedium gibberum Zaddach	275	80	31	16	174	58	289
Ilyocryptus spinifer Herrick	0	1	0	1	0	1	0
Leptodora kindtii (Focke)	200	10	94	114	90	107	76
Leydigia quadrangularis (Leydig)	0	0	3	3	0	2	0
COPEPODA							
HARPACTICOIDA							
Canthocamptus sp.	0	0	0	0	0	0	0
CYCLOPOIDA							
immature Cyclopoida	2,872	248	996	908	1,518	1,200	1,622
Cyclops bicuspidatus thomasi S.A. Forbes	116	5	83	18	92	76	44
Cyclops scutifer Sars	0	0	0	0	0	0	0
Cyclops vernalis Fischer	103	15	9	30	44	20	90
Eucyclops speratus (Lilljeborg)	0	0	0	0	0	0	0
Mesocyclops edax (S.A. Forbes)	2,574	28	328	489	1,118	785	1,238
Tropocyclops prasinus mexicanus Kiefer	0	0	7	0	4	3	0
CALANOIDA							
immature Calanoida	2,055	132	295	375	973	732	885
Diaptomus ashlandi Marsh	0	0	0	0	0	0	0
Diaptomus minutus Lilljeborg	0	0	0	0	0	0	0
Diaptomus oregonensis Lilljeborg	1,290	21	363	402	594	588	374
Diaptomus sicilis S. A. Forbes	23	0	0	0	11	10	0
Diaptomus siciloides Lilljeborg	104	10	45	4	75	60	28
Epischura lacustris S. A. Forbes	0	0	3	3	0	2	0
Eurytemora affinis (Poppe)	0	0	0	0	0	0	0
Mean Total Individuals per m^3	42,855	4,474	8,891	8,534	22,299	15,074	24,739

The relative contribution of each crustacean group in the large mesh 1978 samples varied with the sampling period (Figure 3). These samples undoubtedly would have revealed somewhat different group ratios had the nauplii and smaller immature stages been retained. In May the Cladocera were present in relatively low numbers, but in June, August-September, and October they comprised the predominant group in all areas, becoming most important in June and August. The cyclopoid copepods were relatively most abundant in May in

Table 10. Mean densities (No./m^3) of crustacean zooplankton taxa during October 1978. Means were computed using all replicates and subsamples. Station areas are Lorain-Vermilion (L-V), Cleveland (CLEV), Fairport Harbor-Ashtabula (FH-A); harbor, open; inshore (IN), offshore (OFF).

	L-V	CLEV	FH-A	HARBOR	OPEN	IN	OFF
OSTRACODA	0	0	0	0	0	0	0
CLADOCERA							
Alona guttata Sars	0	0	0	0	0	0	0
Alona quadrangularis O.F. Muller	3	1	0	1	2	2	0
Ceriodaphnia lacustris Birge	0	8	21	10	9	12	3
Ceriodaphnia reticulata (Jurine)	0	0	15	0	7	5	4
Chydorus sphaericus (O.F. Muller)	574	380	48	178	439	314	416
Daphnia ambigua Scourfield	0	0	0	0	0	0	0
Daphnia galeata mendotae Birge	390	95	20	41	256	156	232
Daphnia parvula Fordyce	3	0	0	3	0	1	0
Daphnia retrocurva Forbes	1,372	923	519	671	1,120	815	1,252
Diaphanosoma leuchtenbergiana Fischer	457	129	53	163	262	140	395
Bosminidae	2,647	2,186	2,452	2,244	2,546	2,279	2,754
Holopedium gibberum Zaddach	5	4	6	0	8	7	2
Ilyocryptus spinifer Herrick	0	0	0	0	0	0	0
Leptodora kindtii (Focke)	163	34	42	82	86	70	113
Leydigia quadrangularis (Leydig)	0	1	6	6	0	3	0
COPEPODA							
HARPACTICOIDA							
Canthocamptus sp.	6	0	0	6	0	0	6
CYCLOPOIDA							
immature Cyclopoida	1,216	496	247	467	804	462	1,119
Cyclops bicuspidatus thomasi S.A. Forbes	688	97	13	215	334	179	509
Cyclops scutifer Sars	0	0	2	0	1	1	0
Cyclops vernalis Fischer	442	6	9	70	223	117	273
Eucyclops speratus (Lilljeborg)	0	0	0	0	0	0	0
Mesocyclops edax (S.A. Forbes)	424	111	8	73	260	125	331
Tropocyclops prasinus mexicanus Kiefer	0	0	2	0	1	1	0
CALANOIDA							
immature Calanoida	1,408	1,025	774	1,025	1,124	989	1,283
Diaptomus ashlandi Marsh	3	0	0	0	2	2	0
Diaptomus minutus Lilljeborg	0	0	0	0	0	0	0
Diaptomus oregonensis Lilljeborg	1,321	505	36	553	722	551	881
Diaptomus sicilis S.A. Forbes	0	0	0	0	0	0	0
Diaptomus siciloides Lilljeborg	416	63	4	79	229	136	256
Epischura lacustris S.A. Forbes	0	0	0	0	0	0	0
Eurytemora affinis (Poppe)	24	2	48	48	12	28	18
Mean Total Individuals per m^3	12,101	6,421	4,370	6,070	8,873	6,634	10,341

most areas but showed no distinct pattern during the remainder of the season. The calanoid copepods also presented an unclear pattern, but their contribution appeared to be least in most areas in June and August, when their numbers were especially reduced in the Cleveland area.

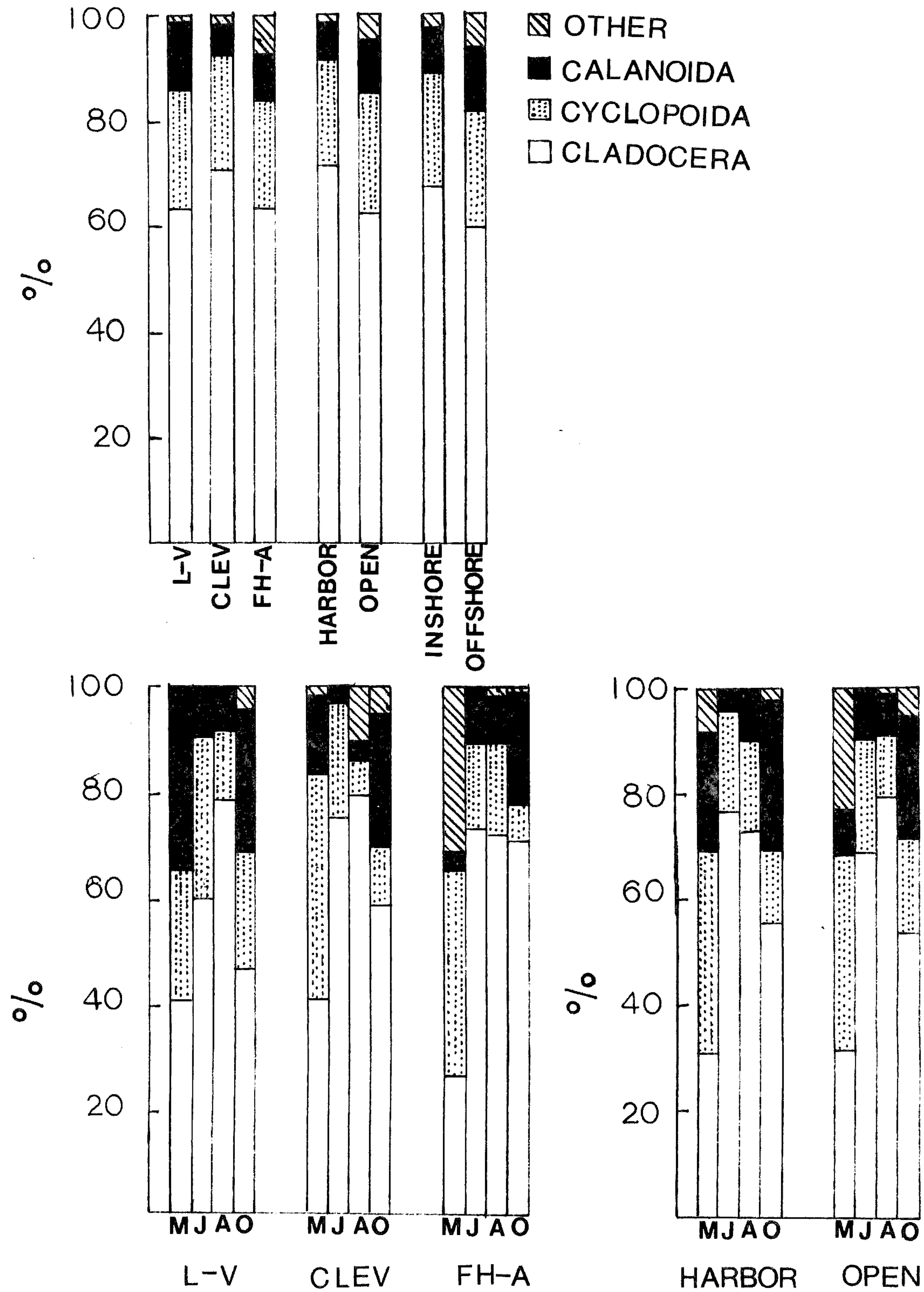

Figure 3. Percent of zooplankton abundance contributed by major crustacean groups during all cruises in 1978 (top) and during the May, June, August-September, and October 1978 cruises (bottom), estimated with a 243 micron mesh net. The "Other" category includes large rotifers of the genus Asplanchna, which were consistently retained in the net, as well as harpacticoid copepods and ostracods.

Comparison of Abundances between 1978 and 1979 (243 Micron Mesh Samples)

Of the 30 stations sampled in 1978, only three were again sampled in 1979. Table 11 provides a comparison of the numbers per m^3 of cladocerans, cyclopoids, and calanoids computed from 243 micron mesh samples obtained each year at the stations. These data represent only the relative numbers each year, as the naupliar and smaller immature copepodid and cladoceran stages were not retained in the samples.

The sampling dates for the stations each cruise were from three to 13 days apart. These differences in sampling dates make comparison of stations within a single cruise of questionable value because of the continual seasonal shifts in abundances noted above. Furthermore, because only a single sample was obtained at each station on most dates, the degree of variability of sample estimates and hence an accurate measure of the similarity of the three stations is not available. On occasions when replicate samples were obtained at a station, the variability was large; thus, the average abundances of crustaceans at the stations probably would have been more similar than were the one-sample estimates in Table 11.

At only one station on one cruise were the sampling dates similar in 1978 and 1979. Therefore, it is impossible to compare in detail the similarity of seasonal abundances between the two years. In general, June and July appear to be the months of peak zooplankton abundance in the Central Basin nearshore zone. In April and early May, calanoid copepods outnumbered cladocerans and cyclopoid copepods, and in late May through October the cladocerans were the most abundant group, especially in June and July.

Abundance Patterns at Six Stations in 1979 (64 Micron Mesh Samples)

Twenty-two crustacean zooplankton species were encountered in the 64 micron mesh samples in 1979, including 11 cladocerans, 4 cyclopoids, 6 calanoids, and one ostracod. Total zooplankton abundance in April averaged $34{,}370/m^3$. In July the average abundance was $92{,}030/m^3$ with the largest sample estimate for the study of $193{,}000/m^3$. By August the average abundance at the six stations had decreased to only $23{,}890/m^3$, but in October an average of 99,960 crustacean zooplankters/m^3 with a maximum of $185{,}000/m^3$ was obtained. By comparison, Czaika (1978), in samples obtained near Cleveland Harbor in 1973 and 1974, found a maximum mean abundance in June of $158{,}000/m^3$, and the second highest mean abundance in August of $110{,}000/m^3$, whereas her lowest numbers were in November-December, with $27{,}600/m^3$, followed in April with $47{,}300/m^3$. Figure 4 presents the mean number per m^3 $\pm$ one standard error of each major group. Samples were collected only one day at each station in April, but on three days during the remaining cruises.

The nauplii (cyclopoid and calanoid) constituted the largest group of crustaceans throughout the year except in samples obtained in July at the four westernmost stations, where the nauplii were outnumbered by the Cladocera. The nauplii usually comprised well over half of the total zooplankton except in October, when they nevertheless were the most abundant group.

Table 11. Comparison of the numbers per m^3 of cladocerans, cyclopoids, and calanoids computed from 243 micron mesh samples obtained each year at three stations.

	1978				1979		
Station 69							
	18 May	15 Jun	28 Aug	8 Oct	23 Apr	23 Jul	30 Aug
Cladocera	2423	21778	62827	6081	565	22727	3192
Cyclopoida	1139	10322	8591	2443	208	2674	67
Calanoida	2593	1247	4027	2500	826	79	1304
Total	6155	33347	75445	11024	1600	25479	4563
Station 111							
	28 May	24 Jun	6 Sep	17 Oct	14 Apr	14 Jul	21 Aug
Cladocera	17935	17167	1440	2629	230	7964	4074
Cyclopoida	30422	5129	191	100	1987	10002	471
Calanoida	1135	4292	99	800	2259	432	3030
Total	49492	26588	1730	3529	4477	18399	7576
Station 139							
	31 May	27 Jun	9 Sep		11 Apr	11 Jul	18 Aug
Cladocera	5250	64623	9386		119	17510	576
Cyclopoida	2788	14914	2805		2855	3602	50
Calanoida	398	9717	972		1689	200	104
Total	8436	89254	13163		4663	21313	731

The presence of large numbers of nauplii throughout the four cruises indicates a continuous production of new copepods during that period, although the species probably varied. The cruises showing the greatest productivity were in April and October, except at the two easternmost stations, where the most nauplii occurred in July and October (Figure 4).

As in the 243 micron samples, non-naupliar calanoids outnumbered the cladocerans in April but were themselves outnumbered by non-naupliar cyclopoids at three of the six stations during that month. In July and October the calanoids were much less abundant than either the cyclopoids or the cladocerans, but in August the three groups were present in approximately equal proportions. The total abundance of calanoids appeared to remain about

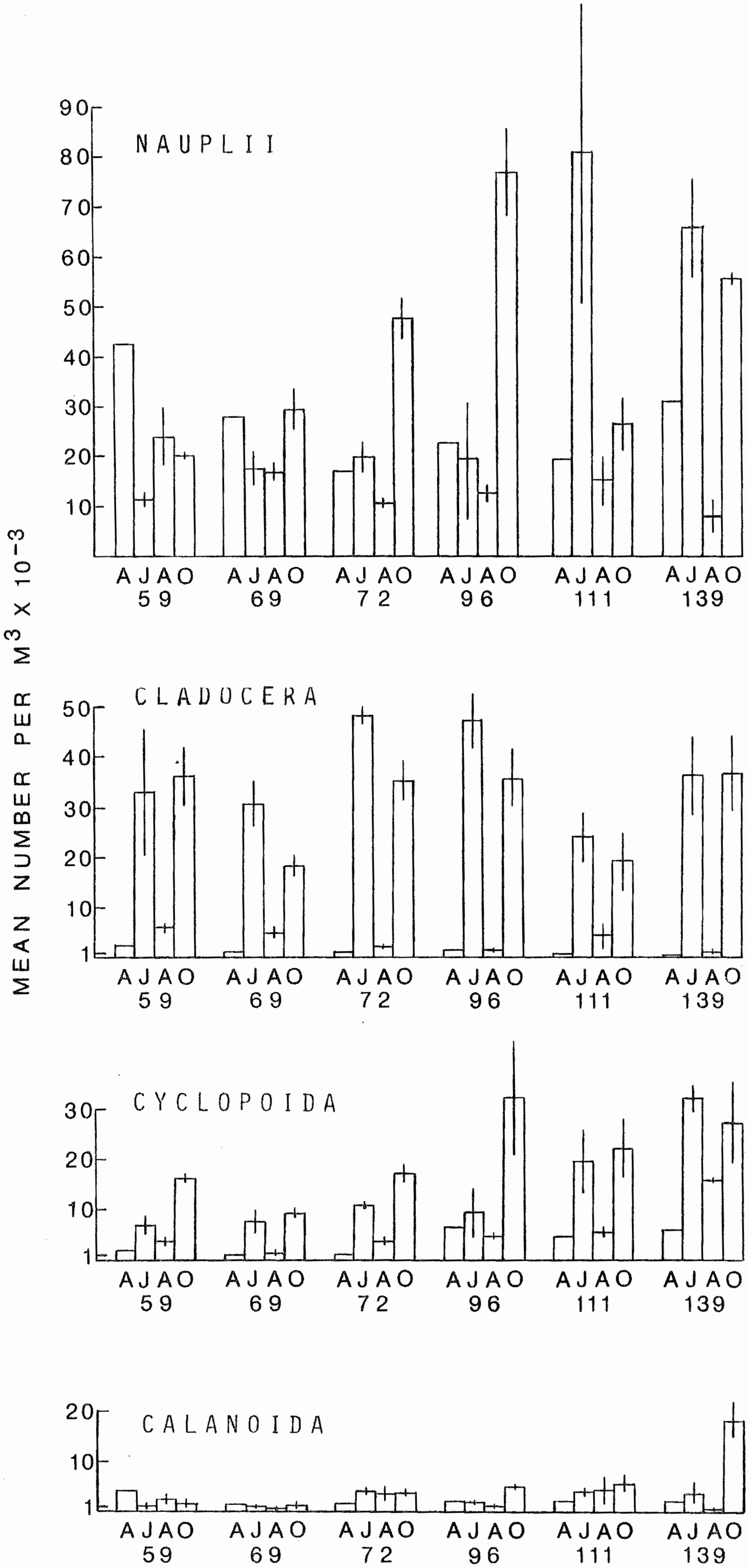

Figure 4. Mean number per cubic meter $\pm$ one standard error of each major crustacean zooplankton group at six stations during each cruise in 1979.

the same throughout all four cruises except at the easternmost station in October, when unusually high numbers were encountered.

The non-naupliar cyclopoid copepods usually maintained intermediate abundances between the cladocerans and the calanoids throughout the sampling year. Their numbers were somewhat higher at the three easternmost stations during all cruises. They demonstrated two peaks, the first in July and the second, usually larger one in October.

The Cladocera increased sharply in abundance from the least numerous group in April to the most abundant group in July. Their numbers declined again by August but during that cruise were somewhat higher than the April abundances. A second peak was encountered in October which was somewhat smaller or about the same as the July peak.

In each group, the species contributing most to the abundance of the group changed throughout the sampling season. The more abundant species, and their ecological implications, are discussed below.

Cladocera. The abundance of each species at each station during each cruise is presented in Table 12. The two most abundant species, as in 1978, were *Daphnia retrocurva* and *D. galeata mendotae* (Figure 5), which had attained approximately equal abundances in July. Both species were generally absent in April. In October a second increase in abundance was noted for both species, although *D. galeata* was less abundant and was even absent at two of the stations at that time.

In the 1978 (243 micron) samples, *D. retrocurva* had completely dominated the crustaceans in June, whereas *D. galeata* did not reach high densities until the August cruise. Both species were found to be less abundant in May and October 1978 than in June and August 1978.

Previous studies throughout Lake Erie have presented similar but slightly varying abundance patterns for these two daphnid species. Britt et al. (1973) reported that in the shallow Western Basin in 1969 *D. galeata mendotae* ". . . was the dominant cladoceran species, becoming abundant at the end of July and continuing so through the end of the summer. *D. retrocurva* was always present too, but showed two obvious pulses, one in early July and the other at the end of August and continuing into September." Davis (1969) found in his open lake samples that these two species formed most of the cladoceran biomass and that *D. galeata* was the more abundant. He found both species in relatively small numbers in October, and in still smaller numbers in January. Davis (1968) noted for his July 1967 samples that *D. galeata* occurred in similar abundances in all three basins, whereas *D. retrocurva* occurred sporadically except in the Western Basin, where it exceeded *D. galeata* at five of the eight stations. However, he reported (Davis 1962) that *D. retrocurva* was ". . . the most common daphnid in the Cleveland Harbor area of the Central Basin in 1957."

Males of *D. retrocurva* were often encountered in the June 1978 samples throughout the Central Basin nearshore zone, less commonly in October, and infrequently in May and August. In 1979, by contrast, males were encountered infrequently and only in October. A few males of *D. galeata* were found in May

Table 12. Abundance (No./m^3 ± one standard error) of cladoceran species at each station during each cruise in 1979.

		STATION					
TAXON	CRUISE	59	69	72	96	111	139
Bosmina sp.	APR	39	89	37	98	149	135
	AUG	37 ± 21	0	23 ± 13	0	15 ± 15	3 ± 3
	OCT	1861 ± 786	1667 ± 179	713 ± 40	3763 ± 972	347 ± 244	188 ± 95
Eubosmina coregoni	APR	1047	550	166	344	262	0
	JUL	1591 ± 970	991 ± 121	2651 ± 728	485 ± 53	596 ± 137	119 ± 119
	AUG	1872 ± 287	1619 ± 340	465 ± 99	374 ± 77	269 ± 147	167 ± 70
	OCT	21340 ± 2741	10360 ± 2008	15708 ± 1507	13626 ± 1749	2410 ± 489	2674 ± 339
Eubosmina with pseudomucro	APR	0	0	387	344	411	90
	JUL	660 ± 39	1544 ± 310	2972 ± 1044	1472 ± 652	708 ± 371	357 ± 357
	AUG	3151 ± 651	2954 ± 914	1252 ± 516	1156 ± 169	2431 ± 1050	613 ± 283
	OCT	73 ± 73	375 ± 156	823 ± 417	1428 ± 213	1978 ± 641	13681 ± 2044
Diaphanosoma leuchtenbergiana	JUL	0	59 ± 59	243 ± 141	0	164 ± 106	247 ± 141
	AUG	231 ± 83	129 ± 39	125 ± 56	46 ± 12	489 ± 428	13 ± 13
	OCT	404 ± 225	239 ± 26	457 ± 155	316 ± 169	446 ± 165	2561 ± 1048
Holopedium gibberum	AUG	12 ± 12	17 ± 17	0	0	0	0
	OCT	95 ± 95	0	0	0	0	752 ± 277
Chydorus sphaericus	APR	1668	373	498	738	75	0
	JUL	776 ± 621	35 ± 35	0	0	307 ± 239	169 ± 169
	AUG	386 ± 88	89 ± 14	62 ± 15	67 ± 19	700 ± 207	80 ± 45
	OCT	8454 ± 2458	4798 ± 1363	15536 ± 3270	15638 ± 4169	12965 ± 5151	8613 ± 3126
Leptodora kindtii	♀ JUL	194 ± 39	256 ± 129	161 ± 81	115 ± 59	273 ± 136	853 ± 549
	♀ AUG	60 ± 32	37 ± 19	54 ± 20	11 ± 11	53 ± 33	8 ± 8
	♀ OCT	0	48 ± 48	0	0	0	0
	♂ OCT	73 ± 73	0	0	0	0	0
Daphnia retrocurva	♀ APR	39	0	0	0	0	0
	♀ JUL	13934 ± 5861	12459 ± 3215	10218 ± 810	27617 ± 7556	13936 ± 4363	13407 ± 1834
	♀ AUG	368 ± 157	137 ± 51	148 ± 92	34 ± 34	686 ± 498	151 ± 127
	♀ OCT	3394 ± 1124	620 ± 209	1511 ± 285	919 ± 481	1082 ± 488	5795 ± 4144
	♂ OCT	232 ± 127	82 ± 43	315 ± 198	64 ± 64	0	0
Daphnia galeata mendotae	♀ JUL	16147 ± 4813	15416 ± 5026	31749 ± 2728	17673 ± 7670	8090 ± 797	21141 ± 6551
	♀ AUG	49 ± 12	0	46 ± 27	0	37 ± 37	26 ± 21
	♀ OCT	168 ± 86	86 ± 44	253 ± 154	0	0	2362 ± 1729
Daphnia parvula	♀ APR	78	71	74	0	0	0
Ceriodaphnia lacustris	♀ OCT	0	0	0	0	51 ± 51	86 ± 86

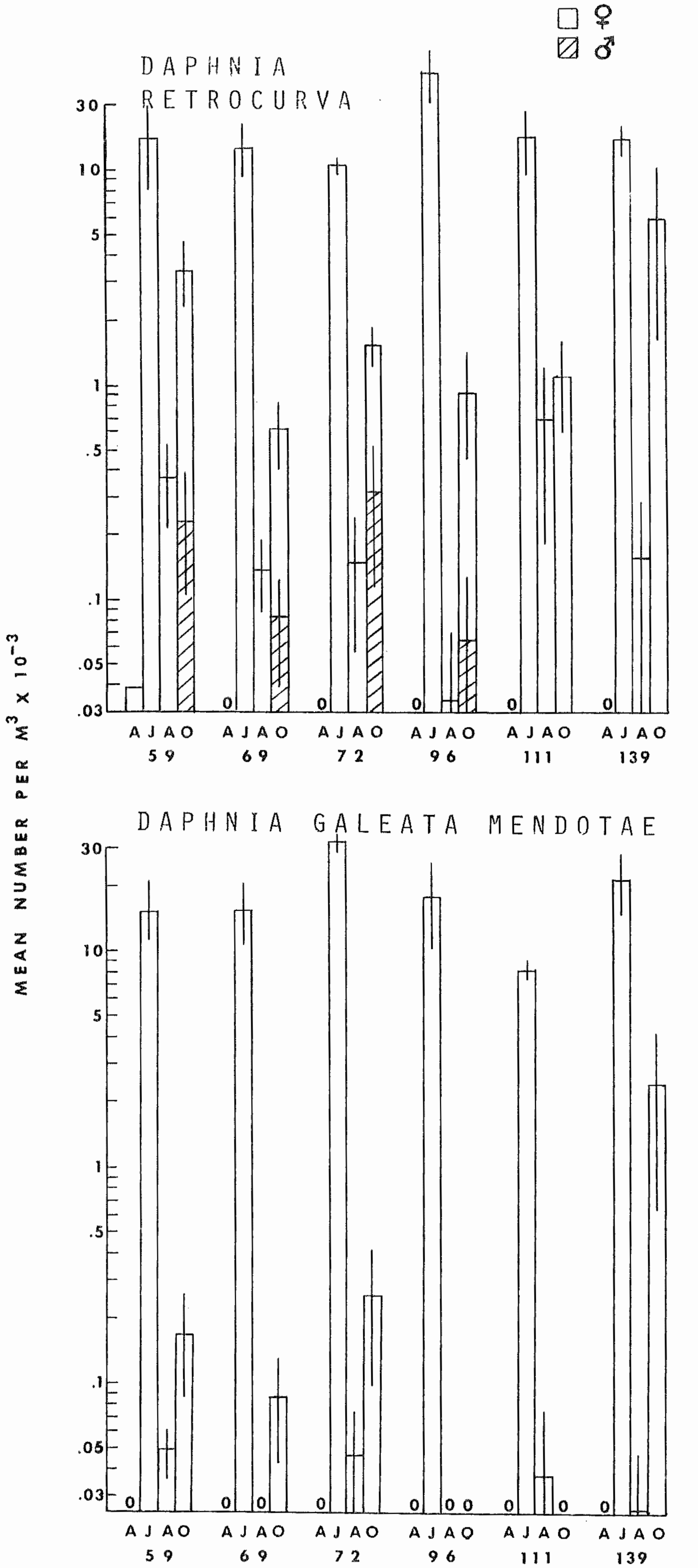

Figure 5. Mean number per cubic meter $\pm$ one standard error of Daphnia retrocurva and D. galeata mendotae at six stations during each cruise in 1979.

and October 1978 but none were found in the 1979 samples. Previous investigators have not recorded the occurrence of male cladocerans.

Species of *Bosmina* and *Eubosmina* were major contributors to the Cladocera throughout the 1979 sampling period (Figure 6), as they were in 1978, although their abundance never approached that of the daphnids. They were the most numerous cladocerans in October both years. *Bosmina* was present in relatively low numbers in April and August 1979 and was entirely absent from the samples in July. It was collected in greatest numbers in October 1979. *Eubosmina coregoni* was present every cruise, showing a continual increase in abundance from April through October. *Eubosmina coregoni* attained about five times the abundance of *Bosmina*. Intermediate forms of *Eubosmina* (some of which may actually be cyclomorphic forms of *Bosmina*; see Kerfoot 1980) showed an increase similar to that of *E. coregoni*, although their abundance was declining during the October cruise.

Davis (1969) reported that the Bosminidae, along with *Chydorus sphaericus*, were the important crustacean zooplankters in October and January in the open lake. He reported (Davis 1968) a maximum of 238,000 bosminids/m^3 in the Western Basin in July, with an average of 92,000/m^3, whereas in his open lake samples from the Central and Eastern basins in October (Davis 1969) they were considerably less numerous than in the October 1979 samples.

Of the remaining cladoceran species, only *Chydorus sphaericus* contributed over 10,000 individuals/m^3 during the 1979 sampling period (Table 12). It showed inconsistent but relatively low abundances at the six stations except in October, when it reached peak abundances of about 5,000 to 15,000/m^3 (Figure 6). In 1978 *Chydorus* was present in all areas of the Central Basin nearshore zone during all cruises, and it also demonstrated an October peak as in 1979. Thus, this species along with the bosminids comprised the predominant cladocerans in Lake Erie during the fall. Britt et al. (1973) stated that *Chydorus* was the predominant cladoceran in the Western Basin in late August 1961. Davis (1968) reported it to be present in very low numbers in the Central Basin in July 1967 and to be apparently absent in the Eastern Basin. He later found it to be common and actively reproducing in the Central Basin in October 1967 (Davis 1969). Earlier counts have shown densities of *Chydorus* as high as 24,000/m^3 in October 1967 in the Cleveland vicinity (Davis 1962), an abundance very similar to that encountered in 1979 at the three stations nearest Cleveland (Figure 6), and 8,500/m in October 1967 near the center of the Central Basin (Davis 1969). Vorce in 1882 (cited by Davis 1969) reported the species to be common in Lake Erie.

Cyclopoida. Immature cyclopoid copepods were present throughout the 1979 sampling period. Relatively low numbers were encountered in April and August, and the greatest abundances were recorded in October (except in July at the easternmost station), when densities approached 31,000/m^3 (Figure 7). It was possible to identify the larger stages of the immature cyclopoid copepods to species (Table 13). Immature specimens of three of the four species were found during each cruise. Immature *Tropocyclops prasinus mexicanus* were observed during all except the April cruise.

Of the four cyclopoid species identified in 1979, *Cyclops bicuspidatus thomasi* occurred in the greatest numbers, with a maximum abundance of up to

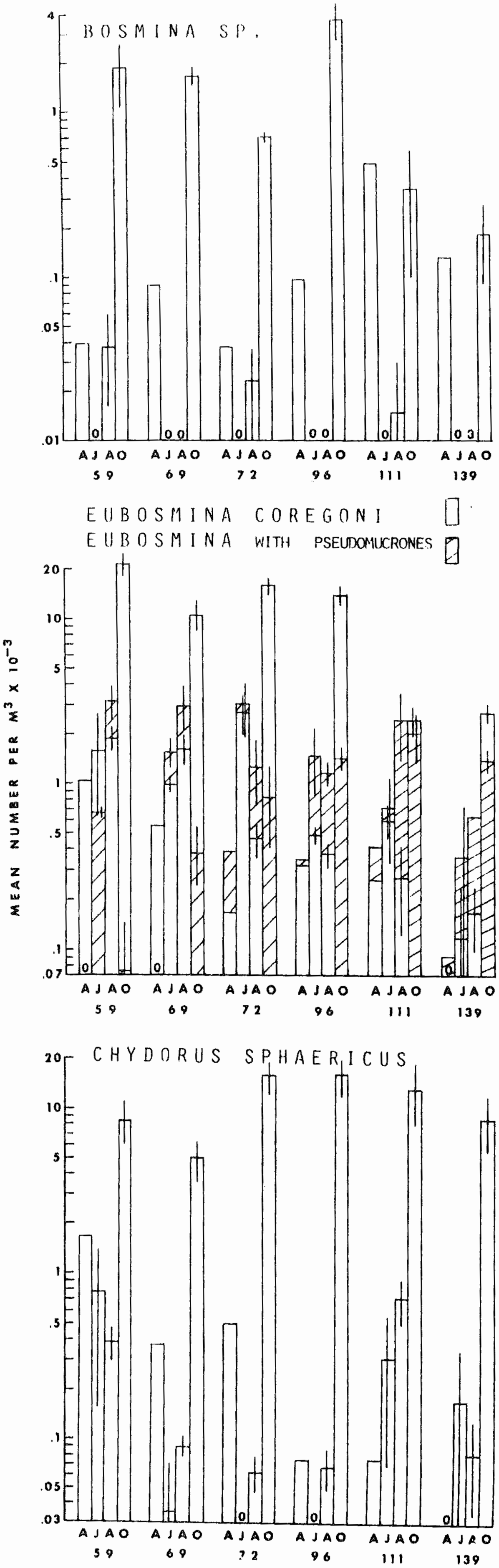

Figure 6. Mean number per cubic meter ± one standard error of Bosmina sp., Eubosmina spp., and Chydorus sphaericus at six stations during each cruise in 1979.

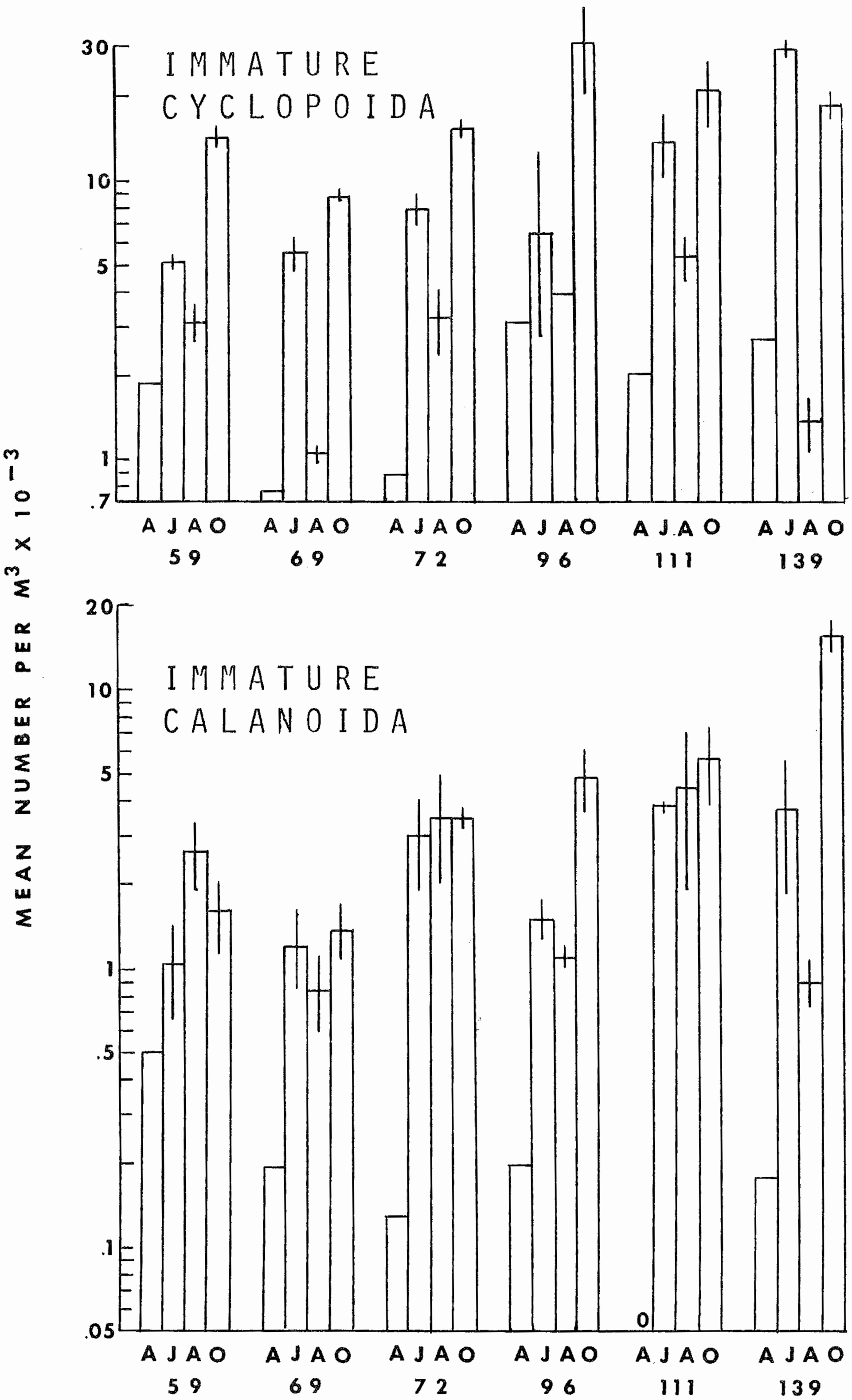

Figure 7. Mean number per cubic meter $\pm$ one standard error of immature Cyclopoida and immature Calanoida at six stations during each cruise in 1979.

Table 13. Species of immature copepods identified at each station each cruise in 1979. P indicates that the species was present; U indicates that species were not identified for the samples.

TAXON	CRUISE	STATION 59	69	72	96	111	139
Cyclops bicuspidatus thomasi	APR	U	P	P	P	P	P
	JUL	U	P	P	P	P	P
	AUG	P	P	P	P	P	P
	OCT	P	P	P	P	P	P
Cyclops vernalis	APR	U			P	P	P
	JUL	U	P	P	P	P	P
	AUG	P		P	P	P	P
	OCT	P	P	P	P	P	P
Mesocyclops edax	APR	P	P			P	
	JUL	U	P	P	P	P	P
	AUG	P	P	P	P	P	P
	OCT	P	P	P	P	P	P
Tropocyclops prasinus mexicanus	APR	U					
	JUL	U	P			P	P
	AUG		P	P	P	P	P
	OCT	P	P	P	P	P	P
Diaptomus spp.	APR	U		P	P	P	P
	JUL	U	P	P	P	P	P
	AUG	P	P	P	P	P	P
	OCT	P	P	P	P	P	P
Eurytemora affinis	APR	U			P	P	P
	JUL	U					P
	AUG	P		P		P	P
	OCT	P	P	P	P	P	P

5,000 adults/m^3 in July (Table 14). A somewhat lower abundance was encountered in April, and adults of this species were uncommon in August and October. Mesocyclops edax also was most abundant in July (less so than C. bicuspidatus), was entirely absent in April, and occurred infrequently in August and October. Tropocyclops prasinus mexicanus was generally absent in April 1979 but the number of adults increased each cruise to a maximum in October. Cyclops vernalis was the least abundant adult cyclopoid, being generally absent in April and present in minimal numbers during the other cruises. This species was not found in the samples from the easternmost station.

The ratio of adult males to adult females of each cyclopoid species

Table 14. Abundance (No./m^3 $\pm$ one standard error) of nauplii and cyclopoid copepods at each station during each cruise in 1979.

		STATION					
TAXON	CRUISE	59	69	72	96	111	139
Nauplii	APR	42747	28223	17205	22878	19801	30641
	JUL	11644 ± 1397	17664 ± 2936	19771 ± 3008	19412 ± 11281	80910 ± 29999	65827 ± 9902
	AUG	23962 ± 5599	16942 ± 1827	10706 ± 845	12972 ± 1071	15121 ± 4505	7866 ± 3135
	OCT	20127 ± 404	29500 ± 3747	47763 ± 4100	76993 ± 8481	26531 ± 5224	55342 ± 628
Immature	APR	1862	763	885	3100	2055	2659
	JUL	5162 ± 272	5489 ± 747	7881 ± 813	6514 ± 3738	13575 ± 3355	29322 ± 1913
	AUG	3095 ± 440	1034 ± 60	3222 ± 811	3899 ± 118	5344 ± 908	1369 ± 296
	OCT	14260 ± 1158	8745 ± 467	15304 ± 983	30955 ± 10756	20778 ± 5476	18422 ± 1901
Cyclops bicuspidatus thomasi	♀ APR	78	124	313	1870*	1532*	2433*
	♀ APR	194	195	221	1771	1196	946*
	♀ JUL	388 ± 388	782 ± 535	1211 ± 250*	545 ± 248*	2582 ± 1455*	1057 ± 451*
	♂ JUL	388 ± 388	912 ± 471	244 ± 244	147 ± 147	2440 ± 1836	166 ± 83
	♀ AUG	49 ± 49	0	30 ± 30*	0	0	0
	♂ AUG	24 ± 24	0	30 ± 30	0	90 ± 68	0
	♀ OCT	86 ± 86	37 ± 37	76 ± 76	0	0	0
	♂ OCT	73 ± 73	0	44 ± 44	0	0	289 ± 177
Cyclops vernalis	♀ APR	0	18	0	0	0	0
	♀ JUL	0	0	0	0	47 ± 47*	0
	♂ JUL	272 ± 39	0	0	131 ± 131	147 ± 77	0
	♀ AUG	37 ± 21	0	31 ± 31	0	0	0
	♂ AUG	51 ± 25	0	198 ± 198	25 ± 13	37 ± 37	0
	♀ OCT	245 ± 150	0	76 ± 76	0	51 ± 51	0
	♂ OCT	73 ± 73	86 ± 44	457 ± 155	245 ± 122	353 ± 221	0
Mesocyclops edax	♀ JUL	349 ± 116	68 ± 68	563 ± 79*	913 ± 632*	195 ± 34	200 ± 105
	♂ JUL	621 ± 621	199 ± 11	965 ± 366	1190 ± 446	579 ± 188	1234 ± 305
	♂ AUG	0	0	15 ± 15	11 ± 11	0	15 ± 15
	♀ OCT	0	0	0	246 ± 246	151 ± 88	86 ± 86
	♂ OCT	86 ± 86	0	76 ± 76	246 ± 246	151 ± 88	792 ± 510
Tropocyclops prasinus mexicanus	♀ APR	0	18	0	0	0	0
	♀ JUL	0	199 ± 11	81 ± 81	66 ± 66	182 ± 182*	0
	♂ JUL	0	35 ± 35	0	120 ± 63	0	0
	♀ AUG	291 ± 158	251 ± 99*	118 ± 26*	400 ± 163*	131 ± 80	54 ± 17*
	♂ AUG	377 ± 218	145 ± 29	133 ± 28	404 ± 145	59 ± 41	156 ± 114
	♀ OCT	1055 ± 470	311 ± 14	887 ± 447*	186 ± 106*	331 ± 156*	290 ± 177*
	♂ OCT	633 ± 395	105 ± 59	430 ± 160	379 ± 223	474 ± 172	782 ± 544

* Ovigerous females present.

varied considerably from station to station and from cruise to cruise (Table 14). Ovigerous (egg-bearing) females of C. bicuspidatus were observed in the April, July, and August samples, but only at the four easternmost stations. Ovigerous females of M. edax occurred in July at two Cleveland area stations, and ovigerous Tropocyclops were observed in July, August, and October, but not at the westernmost station. Only one ovigerous female of C. vernalis was seen, in July near Fairport Harbor.

Within the limitations of the cruise dates, the periods of maximum abundance of Cyclops bicuspidatus and M. edax agree with earlier studies. Davis (1968) reported a mean density of C. bicuspidatus in July 1967 in the middle of the Central Basin of 5,950 adults/m^3 with a maximum of 11,900/m^3. He reported (Davis 1962) a June 1957 maximum of 20,400/m^3 in the Cleveland Harbor area. Davis (1968) found that M. edax was distinctly less abundant than C. bicuspidatus in July 1967, as was true in the present study, and reported a maximum abundance of 5,730/m^3, as compared to a maximum of 4,138 in July 1979 in the Cleveland Harbor area (station 96). Davis (1962) reported a similar August 1957 maximum for this species of 4,300/m^3 in the Cleveland Harbor area.

The data of Britt et al. (1973) show that C. vernalis was generally more abundant than M. edax in the Western Basin in 1961. However, Davis (1962) found C. vernalis only in October 1956 in his Cleveland Harbor area study, and in 1967-1968 (Davis 1968, 1969) he found only very small numbers of C. vernalis in the Central Basin, which corresponds to the present results for the nearshore zone.

Calanoida. Immature calanoid copepods were present in minimal numbers in April 1979 but during July, August, and October maintained relatively high numbers, with a very large abundance (15,800/m^3) in October at the easternmost station (Figure 7). They were usually much less abundant than the immature cyclopoids. Five of the six calanoid species found in 1979 belonged to the genus Diaptomus. Adults were present in low numbers during every cruise, although a few samples yielded over 1,500/m^3 (Table 15). Immature diaptomids were found in the samples every cruise at every station (Table 13), but D. oregonensis was the only species for which adults were found during all four cruises. It occurred only sporadically in April and July, and never attained large numbers except at the easternmost station in October.

Adult Diaptomus siciloides were found in July, August, and October 1979, but always sporadically and in small numbers. Both D. ashlandi and D. sicilis were found in April at all stations and in July were represented by females at a single station. D. ashlandi in April attained the largest abundance of all the diaptomid species. Adult D. minutus were seen only in the April samples.

The period of greatest diaptomid reproduction appeared to be in April, as ovigerous females of three of the five species were observed only at that time (Table 15). Ovigerous females of D. oregonensis were seen in the August and October samples, and no ovigerous females of D. siciloides were observed.

The only other calanoid species observed in the 1979 samples was Eurytemora affinis. Immature Eurytemora were observed sporadically in the April, July, and August samples but consistently in the October samples (Table

Table 15. Abundance (No./m^3 $\pm$ one standard error) of calanoid copepod species at each station during each cruise in 1979.

		STATION					
TAXON	CRUISE	59	69	72	96	111	139
Immature	APR	504	195	129	197	0	180
	JUL	1048 ± 349	1208 ± 392	2969 ± 1035	1522 ± 225	3856 ± 67	3691 ± 1809
	AUG	2576 ± 716	845 ± 253	3483 ± 1424	1112 ± 95	4475 ± 2560	903 ± 178
	OCT	1604 ± 449	1385 ± 301	3482 ± 299	4808 ± 1251	5651 ± 1723	15857 ± 1947
Diaptomus	♀ APR	1086	249	369*	344*	486	586*
ashlandi	♂ APR	776	479	443	836	486	1036
	♀ JUL	0	0	0	0	0	119 ± 119
Diaptomus	♀ APR	1009	107	332*	148*	187*	90
minutus	♂ APR	543	479	203	295	448	225
Diaptomus	♀ APR	78	0	55	0	37	0
oregonensis	♂ APR	39	0	18	0	75	45
	♀ JUL	0	0	486 ± 282	359 ± 188	364 ± 364	0
	♂ JUL	0	0	723 ± 238	207 ± 123	108 ± 55	0
	♀ AUG	0	21 ± 21	31 ± 16*	48 ± 16	53 ± 33*	0
	♂ AUG	51 ± 25	21 ± 21	109 ± 87	65 ± 13	59 ± 41	7 ± 7
	♀ OCT	0	37 ± 37	106 ± 106	0	25 ± 25	696 ± 571*
	♂ OCT	73 ± 73	48 ± 48	76 ± 76	123 ± 123	50 ± 50	2174 ± 1683
Diaptomus	♀ APR	78	71	184*	49*	75*	135*
sicilis	♂ APR	155	53	129	344	411	225
	♀ JUL	0	0	81 ± 81	0	0	0
Diaptomus	♀ JUL	78 ± 78	0	0	0	47 ± 47	119 ± 119
siciloides	♀ AUG	12 ± 12	0	8 ± 8	0	0	0
	♂ AUG	0	0	0	0	13 ± 13	0
	♀ OCT	0	0	97 ± 49	0	0	0
	♂ OCT	0	0	195 ± 135	0	0	0
Eurytemora	♂ JUL	0	0	80 ± 80	0	0	0
affinis	♀ OCT	0	0	44 ± 44	123 ± 123	0	0
	♂ OCT	0	0	76 ± 76	64 ± 64	0	177 ± 141

* Ovigerous females present.

13), and adults were found occasionally in small numbers in July and October (Table 15). No egg-bearing females were observed.

Previous reports on the calanoid copepods compare favorably with the present results. Britt et al. (1973) found that mature and immature calanoids were most numerous in late August 1961, although peak abundance in 1979 appeared to occur from July through October. Davis (1968) found a July 1967 maximum of D. oregonensis of 1,640/m^3 at a station in the middle of the Central Basin, with an average of only 700/m^3. He reported (Davis 1962) as many as 2,700/m^3 in the Cleveland Harbor area in September 1957.

Davis (1968) found that D. siciloides was more abundant than D. oregonensis at several open-lake Central Basin stations in July 1967 and obtained a maximum abundance there of 1,570/m^3 at two stations, as opposed to a lake-wide maximum of 6,470/m^3 in the Island Region. In the present study, the average October abundance of D. siciloides was slightly greater than that of D. oregonensis at one station.

Although we found D. minutus only in April 1979 and in May and June 1978, Britt et al. (1973) found it in June and July in the Western Basin in numbers fewer than 100/m^3, and Davis (1968, 1969) only rarely recorded the species in the western Central Basin, in July and January.

Both Davis (1968, 1969) and Britt et al. (1973) found only the five diaptomid species reported in the present study. Diaptomus pallidus Herrick, though not found in these studies, has been reported from Lake Erie (Watson 1974), most recently from the Eastern Basin in 1976 but previously only from the Central Basin (Cap 1979).

In this study, D. ashlandi was found in April and July 1979 and in May, June, and October 1978. The studies by Britt et al. (1973) and Davis (1962, 1968, 1969) described similar abundances and temporal patterns. D. sicilis was infrequently found in all of these studies.

The euryhaline calanoid E. affinis was first recorded in the Great Lakes system in 1959 from Lake Ontario and has subsequently invaded the other Great Lakes (Watson 1974). It was first reported in Lake Erie in 1962 in the Western Basin (Faber and Jermolajev 1966). Davis (1968, 1969) found adult E. affinis in July and October. In the present study, adults were found throughout the nearshore zone in May, June, and October 1978 and July and October 1979, being absent entirely in August both years.

The calanoid Epischura lacustris was found in low numbers in June and August 1978 but did not appear in our 1979 samples. This species has been reported previously in low numbers at sporadic locations (Britt et al. 1973; Davis 1962, 1968, 1969).

Trophic Status of the Nearshore Zone

All except two of the crustacean zooplankton species listed by Watson (1974) as occurring in Lake Erie, as well as all those reported by Davis (1968, 1969) for the middle of the Central Basin, were recorded in the present study. Watson (1974) also listed the calanoids Limnocalanus macrurus, usually found in cold, deep water, and Diaptomus pallidus. Britt et al. (1973), who sampled the shallow Western Basin, also reported L. macrurus, as well as the cladocerans Daphnia pulex and Eurycerus lamellatus, neither of which was found in the present study.

Several cladoceran species appeared rarely in the 1978 samples from the Central Basin nearshore zone which have not often been reported for Lake Erie. One of these, Ilyocryptus spinifer, was previously found in the Islands Region in 1960 and 1962 (Bradshaw 1964). Leydigia quadrangularis apparently has not been reported earlier from Lake Erie. These two species appear to be characteristically benthic (Pennak 1978) or tychoplanktonic and probably only occasionally venture into or become suspended in the water column.

In order to evaluate whether or not major changes have occurred in the crustacean zooplankton composition of the Central Basin since the beginning of detailed studies, the present results were compared with earlier investigations. Table 16 summarizes nine major studies which have been conducted on the crustacean zooplankton of Lake Erie from 1928 to 1979 and lists in descending order the most abundant species encountered in each study. Comparison of the studies is difficult because different areas of the lake and often different stations within areas were sampled, sampling methods and mesh sizes varied, and sampling dates were often considerably different. As demonstrated above, the month of sampling may have an important influence on which species are encountered, and of those encountered which ones are abundant. Taxonomic uncertainties in most of the analyses further complicate attempts at comparison.

With the many variables involved, the overall similarity of the predominant species in many of the investigations is remarkable. No one species has consistently been the most abundant species in all studies, probably due largely to these variables. Daphnia galeata mendotae, often referred to earlier by various synonyms (see Cap 1980), has been among the most important crustaceans since the 1928 study of Fish and associates (1929) and has ranged from the most abundant species to the eighth most abundant species. Daphnia retrocurva has ranked among the three most abundant species at least since 1950-1951 (Davis 1954), although it was not abundant in Fish's study. Cyclops bicuspidatus has been an important species in most studies except in 1928, whereas M. edax has been shown to be abundant from 1928 to the present. Both of these cyclopoids have consistently been relatively less abundant in the Western Basin than in the Central and Eastern Basins. Diaptomus ashlandi, whose appearance in the samples is very seasonal, has occasionally been encountered in relative abundance from the 1928 study to the present time.

Changes in the relative abundance of several species seem to have occurred since 1928, and these may relate to changes in the trophic status of the lake. Gannon and Stemberger (1978) have noted that because most crustacean zooplankton species occur in a wide variety of lake types, their utility as indicators of the trophic status of lakes is limited to conditions of extreme oligotrophy or eutrophy. They emphasize, however, that the relative abundance of species can serve as a sensitive indicator of subtle differences in physicochemical characteristics. Such factors as toxic substances, eutrophication, and imbalance between planktivorous and piscivorous fishes, can cause shifts in the composition and relative abundances of crustacean species. Nutrient loading and pollution by toxic

Table 16. Comparison of sampling areas, methods, and dates as well as the most abundant crustacean species in nine major Lake Erie studies.

Author	Areas and No. of Stations	Tow Type, Net Size, Mesh Size	Cruise Dates	Most Abundant Species, in Descending Order
Fish, 1929 (cited by Cap 1980)	Eastern Basin, No. not stated.	horizontal, 1 m diam., 112 µ and 119 µ	July, Aug., Sep. 1928	Daphnia pulex, Diaptomus ashlandi, Daphnia galeata mendotae, Mesocyclops edax, *Sida crystallina, *Diaptomus sicilis, *Epischura lacustris
Davis, 1954	Cleveland Harbor area 9 (NS)**	10 l Juday plankton trap, surface and 6.5 m	Approx. biweekly, Sep. 1950 - Sep. 1951	Daphnia retrocurva, D. pulex, Daphnia longispina (= D. g. mendotae?), D. ashlandi, M. edax, D. sicilis, Cyclops bicuspidatus thomasi
Davis, 1962	Cleveland Harbor area 3 (NS)	10 l Juday plankton trap, surface, 6 m, and 12 m	Biweekly, Sep. 1956 - Oct. 1957	Bosmina longirostris, D. retrocurva, C. bicuspidatus, Chydorus sphaericus, M. edax, Diaphanosoma leuchtenbergianum, Diaptomus oregonensis, D. "longispina", Diaptomus siciloides, Tropocyclops prasinus
Davis, 1968	Eastern Basin, 8	vertical from 2 m above bottom, 0.5 m diam., No. 20 bolting silk (76 µ)	July 1967	D. g. mendotae, C. bicuspidatus, D. retrocurva, D. oregonensis, Holopedium gibberum, Leptodora kindtii, D. siciloides
	Central Basin, 11			D. g. mendotae, C. bicuspidatus, Bosmina coregoni, M. edax, D. oregonensis, D. siciloides, H. gibberum
	Western Basin, 8			B. coregoni, D. retrocurva, D. g. mendotae, Cyclops vernalis, D. siciloides, L. kindtii, C. bicuspidatus
Davis, 1969	Eastern Basin, 8	vertical from 2 m above bottom, 0.5 m diam., No. 20 bolting silk (76 µ)	Oct. 1967, Jan. 1968	B. longirostris, B. coregoni, C. bicuspidatus, C. sphaericus, D. galeata, D. retrocurva, T. prasinus, *M. edax, *D. oregonensis
	Central Basin, 11			C. sphaericus, B. coregoni, B. longirostris, C. bicuspidatus, D. galeata, D. oregonensis, D. retrocurva, M. edax
	Western Basin, 11			B. longirostris, B. coregoni, C. sphaericus, Diaptomus minutus, D. ashlandi, C. bicuspidatus, T. prasinus, D. retrocurva
Patalas, 1972	Eastern Basin, 11, and Central Basin, 21 (NS)	vertical 50 m to surface or bottom to surface, 12 cm diam., 90 µ	29 July - 3 August 1968	C. bicuspidatus thomasi, D. g. mendotae, D. retrocurva, B. longirostris, D. oregonensis, M. edax, D. longiremis, D. siciloides
	Western Basin, 3 (NS?)			C. vernalis, C. b. thomasi, B. coregoni coregoni, D. retrocurva, D. g. mendotae, M. edax

Table 16 continued.

Author	Areas and No. of Stations	Tow Type, Net Size, Mesh Size	Cruise Dates	Most Abundant Species, in Descending Order
Czaika, 1978	off Cleveland Harbor, 5 (NS)	vertical just off bottom, 0.5 m diam., 64 µ	June, Aug., Nov., 1973, Apr. 1974	Bosminids with mucro, Eubosmina coregoni, D. retrocurva, C. b. thomasi, D. g. mendotae, C. vernalis, Ceriodaphnia lacustris, M. edax
Cap, 1980	Eastern Basin, No. not stated.	vertical, 0.5 m diam., 64 µ	June, July, Aug., Sep., 1974	D. g. mendotae, D. retrocurva, C. b. thomasi, D. oregonensis, M. edax, mucronate bosminids, *nonmucronate bosminids, *D. longiremis, *D. leuchtenbergianum
this study	Central Basin, 30 (NS)	vertical from 2 m above bottom, 0.5 m diam., 243 µ	May, June, Aug.-Sep., Oct. 1978	D. retrocurva, E. coregoni, C. b. thomasi, D. g. mendotae, mucronate bosminids, D. leuchtenbergiana, D. oregonensis, D. siciloides, Eubosmina with pseudomucro, C. vernalis
this study	Central Basin, 6 (NS)	vertical from 1 m above bottom, 0.5 m diam., 64 µ and 243 µ	Apr., June, Aug., Oct. 1979	D. g. mendotae, D. retrocurva, E. coregoni, C. sphaericus, Eubosmina with pseudomucro, C. b. thomasi, Bosmina sp., T. prasinus mexicanus, M. edax, D. ashlandi, D. oregonensis

* Present in approximately equal proportions.
** Study area included nearshore (NS) stations.

substances, which influence zooplankton species in various ways, often occur at the same locations, and it may thus be difficult to separate the influence of the types of pollutants (Gannon and Stemberger 1978). These complex interactions probably are especially operative in the harbors of the southern nearshore zone of the Central Basin, where the zooplankton abundance in 1978 differed noticeably from harbor to harbor.

Gannon and Stemberger (1978) have summarized the literature concerning indicator crustacean zooplankton species in the Laurentian Great Lakes. The calanoid copepods Limnocalanus macrurus and Senecella calanoides appear to be reliable indicators of oligotrophic conditions. Both are rarely encountered in waters warmer than 15 C and below 0.6 mg/L dissolved oxygen. Because of their stringent environmental requirements, changes in the populations of these two species may serve as an early indicator of changes in lake conditions. Limnocalanus, which was relatively abundant in Lake Erie during the 1920's, became rare by the late 1950's (Gannon and Beeton 1971, cited by Gannon and Stemberger 1978) and early 1960's (Britt et al. 1973). Diaptomus sicilis, another cold stenotherm, appears to be a characteristic oligotrophic species in the Great Lakes. It has only been found in low numbers at sporadic locations in Lake Erie in recent years (Cap 1980, Britt et al. 1973, Davis

1968, 1969), including the present study, when it was found during both cool and warm water periods. However, it was an important species numerically in the 1928 study (Fish 1929, Wilson 1960).

The cladocerans Bosmina and Eubosmina have been considered to be trophic indicators (Watson 1974, Deevey and Deevey 1971, Gannon and Stemberger 1978), demonstrating a species shift during eutrophication from the oligotrophic Eubosmina coregoni to the eutrophic Bosmina longirostris. However, as reviewed by these same authors, the continuing uncertainty as to the systematics and ecological tolerances of the several morphotypes in the Great Lakes greatly reduces their role as indicator organisms. Nevertheless, this species shift seems to have occurred to some degree in Lake Erie within the past 30 years (Table 16). Although Bosmina longirostris ("mucronate bosminids") was relatively scarce in the summer of 1928, it was the most abundant species in the Cleveland area in 1956-1957 and ranged from most abundant to fifth most abundant in later studies. Eubosmina coregoni ("nonmucronate bosminids") first appeared as an important component of the zooplankton in the July 1967 study of the open lake, generally ranging from first to third in abundance through the present study.

Chydorus sphaericus has also been employed as an indicator of eutrophy. Based on the reports in Table 16, this species first appeared in relatively large numbers in 1956-1957, but its abundance has been inconsistent since that time, due possibly to the varying sampling dates.

Diaptomus siciloides and Cyclops vernalis may be good indicators of eutrophic conditions, although C. vernalis may be less reliable because of morphological variability and cryptic speciation. Both species were found only at eutrophic locations in western Lake Erie in 1930 but were found throughout the lake by 1967. In the upper Great Lakes these species are mainly restricted to the most eutrophic areas (Gannon and Stemberger 1978). Table 16 reveals that D. siciloides was an abundant species only after the early 1950's, whereas D. sicilis was no longer one of the most abundant species after that time. Davis (1962) noted that D. siciloides had been absent or nearly so in Lake Erie in 1929 but by 1956 had become one of the two most abundant diaptomids in all three basins. He postulated that this change may indicate eutrophication or a gradual warming of the lake reported by other investigators. In the present study, D. siciloides was the second most abundant calanoid in 1978, but was relatively scarce in 1979.

Because the calanoid copepods appear to be the crustacean group best adapted for oligotrophic conditions, several investigators (Patalas 1972, Gannon and Stemberger 1978) have considered the ratio of calanoid copepods to cyclopoid copepods plus cladocerans as a measure of the extent of eutrophy. Gannon and Stemberger (1978) successfully demonstrated the application of this ratio in several areas in Lake Michigan and in the Straits of Mackinac region where water masses demonstrated only subtle differences in water quality. In the latter study they obtained ratios between 0.2 and 6.6 (with one value of 13.2). They did not, however, suggest ranges of values which would indicate the particular trophic status of a lake.

This ratio was applied to the semiquantitative data from the 1978 samples (Table 17) and to the quantitative data from the 1979 samples (Table 18). The 1978 data produced ratios for the different areas between 0.03 and 0.62, with

Table 17. Ratios of Calanoida to Cyclopoida plus Cladocera in areas of the southern nearshore zone of the Central Basin in 1978.

Area	Cruise May	June	August	October	All
Lorain-Vermilion	.62	.10	.09	.38	.14
Cleveland	.18	.03	.04	.36	.06
Fairport Harbor-Ashtabula	.07	.11	.09	.25	.11
Harbor	.30	.04	.10	.40	.07
Open	.14	.10	.08	.33	.12

Table 18. Ratios of Calanoida to Cyclopoida plus Cladocera at six stations in the southern nearshore zone of the Central Basin in 1979.

Cruise	Station 59	69	72	96	111	139
April	.85	.74	.72	.27	.39	.40
July	.03	.03	.07	.04	.11	.06
August	.26	.14	.61	.19	.44	.34
October	.03	.05	.08	.08	.14	.29

a station maximum of 1.06. Similarly, the 1979 data produced ratios at the individual stations of 0.03 to 0.85. By grouping the 30 stations sampled in 1978 into several geographical areas, it was possible to compare different parts of the nearshore zone (Table 17). The ratio did not reveal any consistent differences from cruise to cruise between alongshore areas nor between harbor and open areas. When the data for all of the cruises were combined, however, the ratios for the Cleveland and harbor station groupings

Table 19. Ratio of calanoids to cyclopoids plus cladocerans in studies on Lakes Erie and Lanao.

Author	Lake	Ratio	Comments
Lewis, 1979	Lanao (Phillipines)	0.14	Based on total copepodids collected weekly and monthly Sep. 1970 to Nov. 1971.
Lewis, 1979	Lanao	0.073	As above, except ratio includes nauplii.
Davis, 1968, 1969	Erie		Based on copepodid stages. Stations on midlake transect.
	Eastern Basin	0.067	July 1967
		0.054	October 1967 and January 1968
	Central Basin	0.098	July 1967
		0.066	October 1967 and January 1968
	Western Basin	0.024	July 1967
		0.10	October 1967 and January 1968
Britt et al., 1973	Erie		Based on copepodids, station 4, east of South Bass Island.
		0.13	13 June 1961
		0.0097	11 July 1961
		0.027	14 August 1961
		0.13	12 September 1961
Britt et al., 1973	Erie		As above, station 6, n.w. of Pelee Island.
		0.12	13 June 1961
		0.091	11 July 1961
		0.30	14 August 1961
		0.27	21 September 1961

indicated that the abundance of calanoid copepods was relatively suppressed, which may reflect adverse environmental conditions in those areas.

The ratio was further applied (Table 19) to other studies on Lake Erie and, for general comparison, to a detailed study on the zooplankton of Lake Lanao, a highly productive but nitrogen limited tropical lake in the Phillipines (Lewis 1979). The Lake Lanao study reveals the effect that inclusion or exclusion of the naupliar stages can exert on the ratio, although a two-fold difference may be irrelevant to its interpretation. The fact that both ratios are low compared to those reported by Gannon and Stemberger (1978) in the Straits of Mackinac confirms the association of low ratios with eutrophic and highly productive waters. The studies of Davis (1968, 1969) along a midlake transect of the three basins of Lake Erie also yielded low ratios for each basin. Differences in the ratio between the basins were not consistent, however, indicating, as in the present study, that small differences in the ratio are not meaningful. The same conclusions derive from the ratios computed from the data of Britt et al. (1973) for two stations in the Western Basin.

Compared to the high ratios found by Gannon and Stemberger (1978) in the Straits of Mackinac, all regions of Lake Erie appear to be relatively eutrophic. It is obvious that this ratio is heavily influenced by the seasonal dynamics of the cladoceran populations: The ratios in the present study were highest in April and August, when the Cladocera were present in relatively low numbers. A similar pattern is evident in the ratios for the data of Britt et al. (1973). A more accurate indication of the trophic status of a lake by use of this ratio might be obtained by deriving an average ratio from the individual ratios calculated from samples gathered at regular intervals (e.g., biweekly or monthly) during the ice-free months, or by some other compositing technique. Such a method would smooth out the effects of population pulses of particular species at the individual sampling times. Additional application of the ratio to studies in the Great Lakes and elsewhere is necessary before its utility in assessing the extent of freshwater eutrophication can be established.

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