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Phytoplankton and Zooplankton Composition, Abundance and Distribution and Trophic Interactions: Offshore Region of Lakes Erie, Lake Huron and Lake Michigan, 1985

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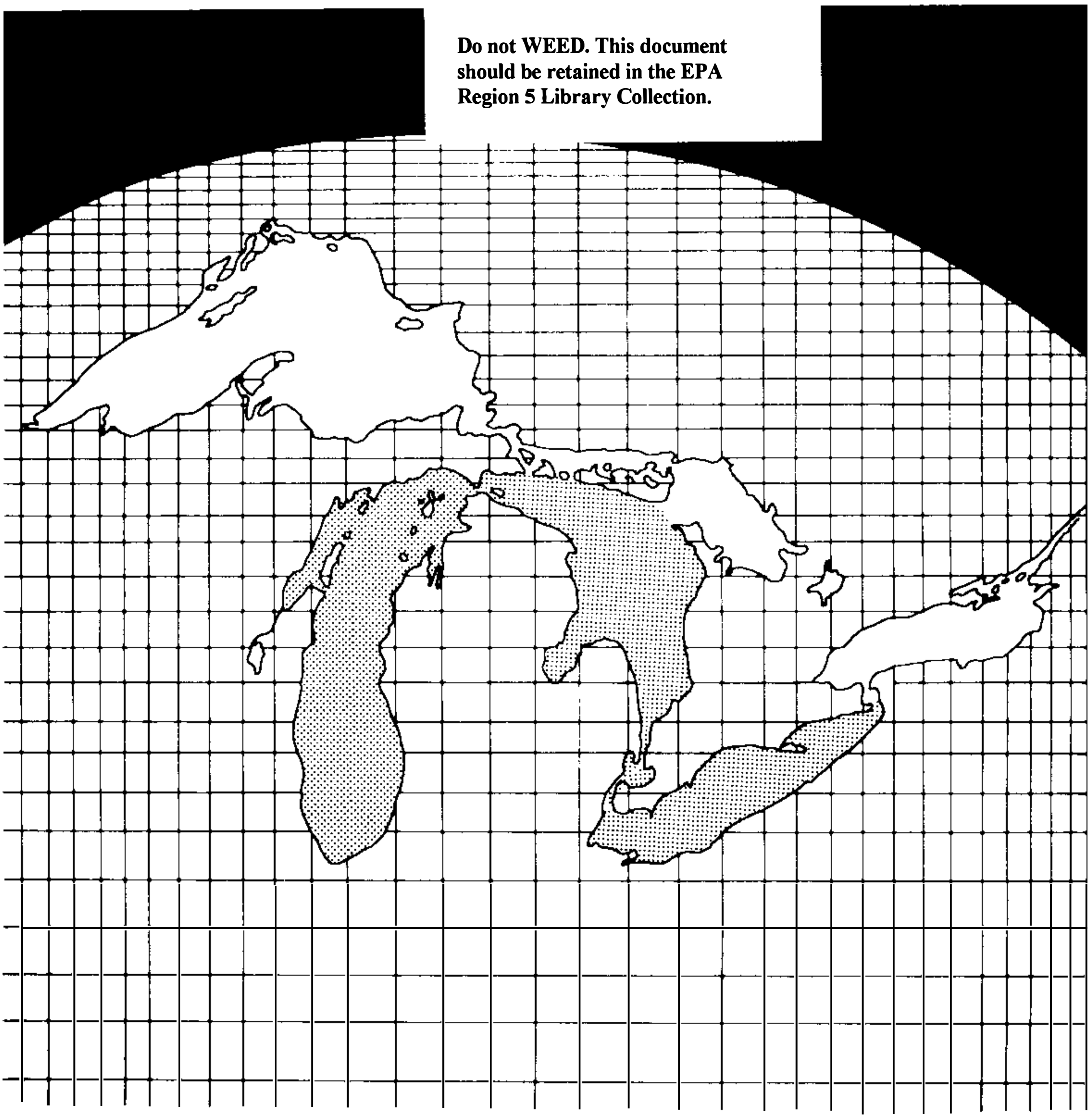

Phytoplankton and Zooplankton Composition, Abundance and Distribution and Trophic Interactions: Offshore Region of Lakes Erie, Lake Huron and Lake Michigan, 1985

Volume 1 - Interpretive Report

by

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Abstract

With the acknowledgement that biological monitoring was fundamental to charting ecosystem health (Great Lakes Water Quality Agreement 1978), EPA's program was developed for Lakes Erie, Huron and Michigan to: 1) monitor seasonal patterns, ranges of abundance and, in general, structure of the phytoplankton and zooplankton communities; 2) relate the biological components to variations in the physical, nutrient and biological environment; and 3) assess the annual variance to allow better long-term assessments of trophic structure and state. Several offshore stations (7-10 per cruise) on several cruises (5-6) during the spring, summer and autumn of 1985 were sampled.

By examining changes in the phytoplankton and zooplankton in relation to water chemistry, evidence was found suggesting little change in the trophic status of Lakes Huron and Michigan while an improvement in the trophic status of Lake Erie was evident. The offshore region of Lake Michigan is experiencing changes in phytoplankton and zooplankton composition consistent with nutrient control and top-down control by fish. Even so, the biomass of phytoplankton and zooplankton and the trophic status of the lake have not changed significantly. The appearance and establishment of *Daphnia pulicaria* in offshore waters of Lake Huron suggest a change in the forage fish base. Plankton composition has changed little since the 60's. However, dramatic reductions in biomass of nuisance and eutrophic indicator species have occurred. These changes are consistent with expectations of long-term nutrient control. However, a change in piscivory is evident that has apparently allowed the establishment of the large cladoceran *Daphnia pulicaria*. The exotic predaceous cladoceran *Bythotrephes cederstroemii* has become established in all three lakes.

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FOREWARD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago, to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by universities, private firms, State, Federal and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. actions in fulfillment of the Great Lakes Water Quality Agreement of 1978 between Canada and the United States of America.

This report presents results of the phytoplankton and zooplankton portions of the water quality surveillance program conducted by GLNPO on Lakes Michigan, Huron and Erie in 1984 and in winter of 1985. Results of the physical and chemical portions of the surveillance program may be found in a companion report:

Rockwell, David C., D. K. Salisbury and B.M. Lesht. 1989.
Water Quality in the Middle Great Lakes: Results of the 1985 USEPA Survey of Lakes Erie, Huron and Michigan.
Publication Number EPA-905/6/89-001. Great Lakes National Program Office.
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OVERVIEW

With the acknowledgement that biological monitoring was fundamental to charting ecosystem health (Great Lakes Water Quality Agreement 1978), EPA's program was developed for Lakes Erie, Huron and Michigan to: 1) assess the annual variance to allow better long-term assessments of trophic structure and state and 2) relate the biological components to variations in the physical, nutrient and biological environment. The program has proven successful. By examining changes in the phytoplankton and zooplankton in relation to water chemistry, evidence was found suggesting little change in the trophic status of Lakes Huron and Michigan while an improvement in the trophic status of Lake Erie was evident within the past ten years. The offshore region of Lake Michigan is experiencing changes in phytoplankton and zooplankton composition consistent with nutrient control and top-down control by fish. Even so, the biomass of phytoplankton and zooplankton and the trophic status of the lake have not changed significantly. The appearance and establishment of *Daphnia pulicaria* in offshore waters of Lake Huron suggest a change in the forage fish base. Plankton composition has changed little since the 60's. However, dramatic reductions in biomass of nuisance and eutrophic indicator species have occurred. These changes are consistent with expectations of long-term nutrient control. However, a change in piscivory is evident that has apparently allowed the establishment of the large cladoceran *Daphnia pulicaria*. The exotic predaceous cladoceran *Bythotrephes cederstroemii* has become established in all three lakes.

The following summaries for Lakes Michigan, Huron and Erie outline the major observations of the 1985 intensive sampling of the offshore region. As such, the 1983 (Makarewicz 1987), 1984 (Makarewicz 1988) and 1985 studies provide a basis for long-term monitoring of the structure and functioning of the Great Lakes.

SUMMARY

Lake Michigan

1. Compared to 1983 and 1984, when 379 and 327 phytoplankton species were observed, there was a substantial reduction in the number of species observed (238) in 1985. Since there were no significant differences in the sampling regime and water chemistry between years, the differences in species number observed are attributed to changes in personnel responsible for enumeration and identification. The number of zooplankton species observed were the same in 1984 and 1985 (52).

2. Picoplankton represented 85.5% (1984: 82.9%) of the total abundance but only 1.6 % (1984: 1.4%) of the algal biomass. Because the picoplankton have not been historically considered in the Great Lakes, they are not included in abundance and biomass trends reported.

3. Even though there was a decrease in the number of species identified from 1984 to 1985, the average phytoplankton and zooplankton abundances (mean±S.E.) were not significantly different between 1984 and 1985 (phytoplankton: 1985 - 2,841±241 cells/mL; 1984 - 3,602±244) (zooplankton: 1985 - 34,950±4,085 organisms/m^3; 1984 - 59,764±8,284) for the study period. Mean algal and zooplankton biomass were 0.45±0.043 g/m^3 (1984: 0.55±.038) and 47.9±5.2 mg/m^3 (1984: 33.2±4.9) for the study period.

4. As in Lakes Erie and Huron in 1983 and 1984, diatoms possessed the greatest number of species (90) and biomass (63.9% of the total) in 1985. Similar to 1984, the Cryptophyta accounted for the second highest biomass in 1985.

5. Unlike 1984, but similar to 1983, diatoms were dominant in the spring and autumn accounting for as much as 80% of the phytoplankton biomass. During August, the prevalence of diatoms decreased dramatically to 8% (1983: 10%) of

the biomass. Unlike 1984, a seasonal succession of the plankton was observed by August of 1985 similar to the one observed in 1983, where Cryptophyta, Pyrrophyta and Cyanophyta succeeded the diatoms.

6. The large drop in diatom biomass observed in August of 1983 and 1985 was not observed in 1984. The occurrence of a bloom of *Rhizosolenia eriensis* during 1984, not observed in 1983 and 1985, was the major cause of the dominance of diatoms in August of 1984. The prevalence of *R. eriensis* appears to determine whether or not a divisional succession occurs during the summer.

7. The 1985 sampling pattern differed from 1983 and 1984 in that the far northern stations (Stations 56, 57, 64 and 77) and the most southern stations (Station 6) were not sampled. In 1983 and 1984, abundance of phytoplankton decreased from the most northern station to Station 57 and remained the same southward to the most southerly station, where it increased slightly. With the absense of the most northern and southern stations in the 1985 sampling pattern, total phytoplankton abundance was not significantly different between the northern and southern half of the lake in the 1985. However, Cyanophyta abundance was significantly higher in the southern basin compared to the northern basin in 1985.

8. The phytoplankton composition of Lake Michigan has changed. The following subdominant or dominant species have decreased in abundance from the 60's and 70's: *Cyclotella michiganiana, Cyclotella stelligera, Melosira islandica,* Synedr*a acus* and *Ankistrodesmus falcatus*. *Oscillatoria limnetica* has increased in abundance. Abundance of *Rhizosolenia eriensis* increased in 1984 after a general decrease since the 60's and 70's, but decreased in 1985.

9. Considerable variability in dominant diatoms has occurred from 1983 to 1985. In 1984, the dominant diatom species included the mesotrophic forms *Tabellaria flocculosa* and *Fragilaria crotonensis* and the oligotrophic forms *Cyclotella ocellata* and *Rhizosolenia eriensis*. Comparing the 1984 data to the

1983 cruises where mesotrophic forms were predominant, the same mesotrophic forms were present in 1984 along with the oligotrophic indicators. In 1985 a considerable change occurred in the predominant diatom species. The species of *Cyclotella* and *Tabellaria flocculosa* were present but were not dominant or common. The eutrophic indicator *Stephanodiscus niagarae* was the dominant species on a biomass basis, while *Rhizosolenia longiseta* and the mesotrophic indicator species *Melosira islandica* were dominant on a numerical basis. Only *Melosira italica* subsp. *subartica* and *Fragilaria crotonensis* were predominant diatom species in 1983, 1984 and 1985.

10. The ratio of mesotrophic to eutrophic algal species (trophic ratio) suggests a eutrophic status for nearshore waters in 1977, while the offshore waters in 1970-71, 1983, 1984 and 1985 would be in the oligotrophic-mesotrophic range.

11. Based on the classification scheme of Munawar and Munawar (1982), Lake Michigan's algal biomass in 1983 (0.42 mg/m^3), 1984 (0.55 mg/m^3) and 1985 (0.45 mg/m^3) suggests an oligotrophic status for the offshore waters of Lake Michigan.

12. Phytoplankton abundance of the offshore waters appears to have increased from 1962-63 to 1976-77 but has not significantly changed from 1976 to 1985. Because of the difference in enumeration methodology used in the 1962-63 study compared with the other surveys, the suggested increase in algal abundance from 1962-63 to 1976-77 has to be interpreted cautiously.

13. The trend in zooplankton biomass was similar to the phytoplankton trend between 1976 and 1985 in that no significant change in zooplankton biomass was observed.

14. The Rotifera possessed the largest number of species (29, 1984 and 1985) and relative abundance 39.9% (1984: 67.5%). The Rotifera contributed only 1.1% (1984: 2.6%) of the biomass, while the Calanoida, rather than the Cladocera as in 1984, accounted for 67.4% of the zooplankton biomass.

15. Abundance of zooplankton generally increased from north to south in 1984. The far northern stations (64 and 77) had a significantly higher abundance than the rest of the lake in 1984. In 1985 this pattern was not observed due to a change in the sampling regime which did not include these stations.

16. In 1983, 1984 and 1985, the dominant rotifer composition was similar to the nearshore and to Ahlstrom's (1936) offshore composition.

17. The species composition of the predominant rotifers suggests an oligotrophic offshore assemblage. Further support is provided by the high relative abundance of *Diaptomus sicilis* and *Limnocalanus macrurus* and the occurrence of *Senecella calanoides*, all oligotrophic crustacean indicator species.

18. The plankton ratio (Calanoida/Cladocera + Cyclopoida) was high relative to Lake Erie but lower than Lake Huron. In general, the ratio was high and similar indicating a similar high quality of water throughout the offshore area sampled.

19. The changing nature of the zooplankton community of Lake Michigan was evident from 1983 to 1985. The abundance of *Daphnia pulicaria*, first observed in 1978, dropped from $376/m^3$ in 1983 to $78/m^3$ in 1984, but increased in 1985 to $161/m^3$. Abundance of *D. galeata* in 1984 and 1985, rare in 1966 and 1968, was 2-3 times the density observed in 1954 ($1200/m^3$). Abundance of the large cladoceran *Leptodora kindtii* appears to be increasing from 1954. In general, the larger cladocerans, calanoids and cyclopoid copepods, observed to have decreased in the early 60's, had increased in abundance to values similar to those in August of 1954.

20. The presence of the oligotrophic rotifer association, the presence of the oligotrophic crustacean indicator species *Diaptomus sicilis* and *Limnocalanus macrurus*, the predominance of mesotrophic diatom species, the similarity of the plankton ratio on the north-south axis and a phytoplankton and zooplankton abundance and biomass between those of the eutrophic Lake Erie and oligotrophic Lake Huron suggest that the offshore waters of Lake Michigan are currently in the oligotrophic-mesotrophic range (i.e. meso-oligotrophic). A similar conclusion was reached in 1983 and 1984. Only the dominance (biomass) of *Stephanodiscus niagarae*, a eutrophic indicator, in 1985 suggests otherwise.

21. A significant change in zooplankton composition has occurred with the establishment of *Daphnia pulicaria* in the entire offshore region of Lake Michigan. Decline of the alewife population has apparently reduced predatory pressure from alewife releasing the suppressed large-bodied zooplankton such as *Daphnia pulicaria* (Scavia *et al* 1986). In addition, abundances of *Leptodora kindtii, Daphnia galeata mendotae, Diaptomus ashlandi* and *Cyclops bicuspidatus* have returned to or exceeded abundances observed in 1954 during a period of low alewife abundances.

22. The mean seasonal size of the edible phytoplankton community decreased as the abundance of the herbivorous *Daphnia* spp. increased.

24. Correlation analysis suggests that the increases in *Daphnia galeata mendotae*, as well as *D. pulicaria*, have exerted greater grazing pressures on the phytoplankton community.

SUMMARY

Lake Huron

1. Compared to 1983 and 1984, when 329 and 315 phytoplankton species were observed, there was a substantial reduction in the number of species observed (213) in 1985. Since there were no significant differences in the sampling regime and water chemistry between years, the differences in species number observed are attributed to changes in personnel responsible for enumeration and identification. The number of zooplankton species observed in 1983 (58), 1984 (53) and 1985 (57)were similar.

2. Picoplankton accounted for 92.3% (1984: 83.9%) of the total abundance but only 3.4% (1984: 1.4%) of the biomass. This finding is similar to that of 1983 and 1984. Because the picoplankton have not been historically considered in the Great Lakes, they are not included in abundance and biomass trends reported.

3. Even though there was a decrease in the number of species identified from 1984 to 1985, the average phytoplankton and zooplankton abundances (mean$\pm$S.E.) were not significantly different between 1984 and 1985 (phytoplankton: 1985 - 2,020$\pm$113 cells/mL; 1984 - 2,772$\pm$196) (zooplankton: 1985 - 67,668$\pm$9,390 organisms/m^3; 1984 - 55,400$\pm$7,200) for the study period. Mean algal and zooplankton biomass were 0.34$\pm$.021 g/m^3 (1984: 0.38$\pm$0.10) and 59.2$\pm$7.03 mg/m^3 (1984: 27.3$\pm$2.3) for the study period.

4. As in 1984, diatoms possessed the greatest number of species (120) and biomass (67.4% of the total, 1984: 62.9%). Similar to 1984, the Chrysophyta was the second most important division (10.0% of the total; 1984: 9.7%).

5. Considering biomass, the diatoms were dominant throughout the study period accounting for as much as 78% but never less than 42% of the biomass. The large drop in the relative importance of diatoms in August of 1983 was again observed in 1985 but not in 1984. A bloom of *Rhizosolenia eriensis* in August

of 1984, not observed in 1983, was considered a major cause of the dominance of diatoms throughout the summer of 1984. Even though a bloom of *R. eriensis* did occur in 1985, a drop in the mid-summer importance of diatoms occurred.

6. Average phytoplankton biomass decreased from the northern Lake Huron stations to ~Station 32, where abundance increased and then decreased slightly southward.

7. In general, offshore species composition of phytoplankton has changed little since the early 70's. *Stephanodiscus minutus* was not common in 1971, 1974, 1975, 1980, 1983 and 1985. In 1984, it was common with an average density of 19.4 cells/mL because of the inclusion of winter samples. Abundance averaged 63 cells/mL in February.

8. From 1983 to 1985, the dominant diatom assemblages were species characterized as indicators of oligotrophic or mesotrophic conditions.

9. The ratio of mesotrophic to eutrophic algal species (trophic ratio) has not changed since 1971. This suggests that the trophic status of the offshore waters of Lake Huron has not changed since 1971.

10. As in 1984, the Rotifera possessed the largest number of species (30, 1984: 31) and relative abundance (40.3%, 1984: 56.0%). The Calanoida (48.5%, 1984: 42.0%) dominated on a biomass basis followed by the Cladocera (26.3%, 1984: 27.5%). Rotifera contributed only 1.5% (1984: 2.5%) of the zooplankton biomass.

11. Species composition of zooplankton was similar in 1971, 1974, 1983, 1984 and 1985. Abundance of *Diaptomus ashlandi* and *D. sicilis* has increased steadily since 1971, while abundance of *D. minutus* and *D. oregonensis* has increased since 1984. The oligotrophic indicator species, *Limnocalanus macrurus*, appeared not to have significant changes in abundance since 1971. Abundance of *Bosmina longirostris* has steadily decreased since 1971.

12. *Daphnia pulicaria* was first observed in offshore waters in 1983. Average abundance has steadily decreased since 1983. Within the Cladocera, rank abundance dropped from third in 1983 to fifth in 1984 and fourth in 1985.

13. A new cladoceran species, *Bythotrephes cederstromii*, was observed in the offshore waters of Lake Huron. By 1985, it had become established throughout the lake.

14. The rotifer community was dominated by an assemblage indicative of oligotrophic conditions from 1983 to 1985. In addition, the calanoid *Diaptomus sicilis*, an oligotrophic indicator, was fairly abundant.

15. The plankton ratio (Calanoida/Cladocera + Cyclopoid) was high compared to Lake Erie but similar for the entire offshore region, which suggests a similar high quality of water over the entire offshore region except for the far northern Station 61 and perhaps Station 6 at the south end of the lake.

16. The presence of the oligotrophic rotifer assemblage, the domination of the calanoids, the fairly abundant oligotrophic *Diaptomus sicilis*, and the low zooplankton abundance compared to those of Lakes Erie and Michigan, suggest the offshore waters of Lake Huron in 1983, 1984 and 1985 were oligotrophic.

17. Zooplankton abundance of the offshore waters of Lake Huron in 1970, 1974/75, 1983, 1984 and 1985 was not significantly different.

18. The consistency of the trophic ratio and algal biomass through time, the insignificant difference in zooplankton abundance from 1970-1985, the occurrence of oligotrophic and mesotrophic algal indicator species, the oligotrophic zooplankton assemblage and the similarity of the plankton ratio over the entire offshore suggest that no significant change in the trophic status of the offshore waters of Lake Huron has occurred since 1970.

19. With a mean algal biomass of 0.35, 0.38 and 0.42 g/m^3 for 1985, 1984 and 1983, respectively, Lake Huron would be classified as oligotrophic by the classification scheme of Munawar and Munawar (1982).

20. The appearance of *Daphnia pulicaria* in Lake Huron suggests that the zooplankton community has been released from size-selective planktivory.

21. The correlation of phytoplankton abundance with total phosphorus and zooplankton abundance within individual cruises suggests that "top down" and "bottom up" control of the trophic web of lake ecosystems exists simultaneously and varies with season.

SUMMARY

LAKE ERIE

SUMMARY

Lake Erie

1. The phytoplankton assemblage of 1985 was comprised of 369 species (1984: 356, 1983: 372) representing 101 genera. The zooplamkton assemblage of 1985 comprised 80 species (1984: 81, 1983: 66) representing 44 genera.

2. Picoplankton accounted for 83.6% (1984: 89.6%) of the total abundance. A similar finding was observed in 1983. Because the picoplankton have not been historically considered in the Great Lakes, they are not included in abundance and biomass trends reported.

3. Mean phytoplankton and zooplankton abundance (mean+S.E.) were 4,483±570 cells/mL (1984: 6,187±750, 1983: 5,331±462) and 221,577±26,988 (1984: 159,600±25,300) organisms/m^3 for the study period. Average biomass of phytoplankton and zooplankton was 1.22±.11 and 0.106±0.0098 g/m^3, respectively (1984: 0.86±.08 and .053±.0062 g/m^3).

4. Phytoplankton biomass varied within Lake Erie. The Western basin possessed a greater biomass (1.62±0.33 g/m^3) than the Eastern (0.54±0.08 g/m^3) and Central (1.38±0.15 g/m^3) basins. Zooplankton abundance increased in a similar fashion into the Western basin in 1984 and 1985 but not zooplankton biomass.

5. Diatoms possessed the greatest number of species (162, 1984: 171) and biomass (63.2%, 1984: 47.8% of the total) in 1985. Compared to 1970, a significant change in diversity of phytoplankton has occurred. In 1970 only 21 diatom species were observed that accounted for 53% of the biomass. The Chlorophyta possessed the largest number of species (78) in 1970.

6. Diatoms were dominant in April and May and were succeeded by the Chlorophyta in August. By November, the diatoms were again dominant. A similar seasonal pattern was observed in 1983 and 1984.

7. The historically highly productive Western basin has had a steady decrease in algal biomass from 1958 to 1985. Similarly, chlorophyll *a* levels have decreased in all basins, but most dramatically in the Western basin. However, algal biomass is still higher in the Western basin than in the Central and Eastern basins.

8. Lakewide, the mean weighted algal biomass was 3.4, 1.5, 0.8 and 1.26 g/m^3 in 1970, 1983, 1984 and 1985, respectively. A 56 to 76% reduction in algal biomass has occurred in offshore waters of the lake from 1970 to 1983-85.

9. Although occurrences of common and dominant species were similar in 1970, 1983, 1984 and 1985, dramatic decreases in the biomass of these species were evident. For example, a 96% reduction in the maximum biomass of the nuisance species *Aphanizomenon flos-aquae* has occurred since 1970. The eutrophic indicator species *Stephanodiscus binderanus* and *Fragilaria capucina* have had a >90.% reduction in maximum biomass.

10. *Asterionella formosa* has not been prevalent in Lake Erie since prior to 1950. In the 1984 spring cruises, *A. formosa* was the dominant species on a biomass basis. In 1985 *A. formosa* was not prevalent in the spring and was not a common species. *Melosira islandica*, a mesotrophic indicator was not common in 1983 and 1985 but common in 1984.

11. Evidence of a shift in trophic status since 1970 is provided by a comparison of predominant diatom indicator species in 1970, 1983, 1984 and 1985. The number of eutrophic species has decreased, while the number of mesotrophic species has increased.

12. The Rotifera possessd the largest number of species (49, 1984: 48) and relative abundance (70.8, 1984: 80.1%) of the zooplankton. On a biomass basis, the Rotifera represented only 5.5% (1984: 13.6%) of the zooplankton biomass while the Cladocera contributed 35.1% (1984: 40.5%) of the biomass.

13. A shift in zooplankton composition is occurring with a new species *Daphnia pulicaria* being observed for the first time in 1984. On a biomass basis, *D. pulicaria* was the dominant Cladocera in the lake with a major bloom in August of 1984. In 1985 it was not even a common species. Another new species, *Bythotrephes cederstroemi*, was observed throughout the entire lake in October of 1985. Although not a common species in 1985, its large size and its potential to effectively crop down *Daphnia* populations and thus affect lower trophic levels make it a species of interest.

14. By virtual of its high abundance in the Western Basin in 1985, the eutrophic cyclopoid *Cyclops vernalis* was considered to be a common species in 1985. Prior to 1985, it appeared to be decreasing in abundance.

15. A decrease in summer Cladocera and Copepoda abundance in the Western Basin is suggested from 1961 to 1985. Rotifera abundance in the Western Basin has increased since 1934. A number of eutrophic rotifer indicator species had abundances restricted to or significantly higher in the Western Basin. The plankton ratio also suggests a more productive status for the Western Basin.

16. There is a lack of dominance of eutrophic rotifer indicator species for the entire lake. This suggests that Lake Erie in 1984, as well as 1985, as a unit is not eutrophic. The number of dominant eutrophic algal species has decreased, while the number of dominant mesotrophic species has increased; that is, the trophic ratio has increased, suggesting an improvement in water quality.

17. Evidence of a shift in trophic status of Lake Erie since 1970 is provided by the trophic ratio, the plankton ratio, phytoplankton and zooplankton indicator species, declines in total abundance and biomass of total phytoplankton and zooplankton since the mid-60's and 70's, declines in abundance of nuisance species and eutrophic species, declines in total phosphorus and chlorophyll *a*, and the current total biomass and abundance of plankton.

18. The trophic condition of Lake Erie appears to be improving. However, compared to Lakes Huron and Michigan in 1983 and 1984, biomass of phytoplankton and zooplankton was higher, the plankton and trophic ratios were lower, and the phytoplankton and zooplankton species compositions suggest a more productive status for Lake Erie.

19. Based on the classification schemes of Vollenweider (1968) and Munawar and Munawar (1982) utilizing maximum and average algal biomass, the Western Basin would be meso-eutrophic, the Central Basin mesotrophic, and the Eastern oligo-mesotrophic. This conclusion reached in 1984 and 1985 is supported by other indicators of the trophic status noted above.

20. Models, experimentally verified, of size-structured plankton communities predict shifts to small algae at low biomass of small grazers and shifts to larger algae as larger sized grazers or biomass increase. This was observed in Lake Erie during the summer. The size of the algal community is inversely related to the abundance of Crustacea and *Daphnia* (r^2=-0.787) and size of the Crustacea. This inverse relationship was also observed in 1983 (r^2=-0.943) and 1984 (r^2=-0.441).

21. The decreases in phytoplankton abundance, chlorophyll, total phosphorus and turbidity are consistent with expectations of long-term nutrient control. However, the significant changes in the composition of the zooplankton community with the appearance and establishment of the large cladoceran *Daphnia pulicaria* are attributed to a change in planktivory. The planktivorous emerald and spottail shiners have dramatically declined, perhaps due to a resurgence of the walleye and the salmonine stocking programs.

INTRODUCTION

The project reported here was initiated by the United States Environmental Protection Agency, Great Lakes National Program Office (GLNPO), to analyze phytoplankton and zooplankton samples taken in 1985 from the offshore waters of Lakes Erie, Huron and Michigan. Along with the report on water chemistry (Rockwell *et al* 1989), the two reports represent the results of the 1985 Surveillance Program designed to evaluate the progress of the phosphorus remedial control efforts. This program is an outgrowth of the Great Lakes International Surveillance Program (GLISP) (International Joint Commission 1975), the purpose of which is to comply with the provisions of the 1978 Canada-United States Water Quality Agreement that calls for periodic monitoring of the Great Lakes to determine the degree to which the objectives of the agreement are being met.

Nutrient loading of lakes and rivers, navigation, fish management policies, fishing, shoreline alteration, contaminant production and, in general, economic development, ultimately affect the lake ecosystem. Effects of perturbations are not always known and can not always be monitored individually in large, complex systems such as the Great Lakes. Biological monitoring is an integrative monitoring strategy (Johannson *et al* 1985). Ecosystems respond to stress with compensatory changes in community structure and function mediated at the population level (Boesch and Rosenberg 1981). Therefore, changes in ecosytem health can be detected by monitoring changes in the biotic community (Nicholls *et al* 1980, Dillon *et al* 1978).

Any monitoring program must first document the state of the ecosystem, namely, the species composition, biomass and production of each community component, including the normal range of temporal and spatial variation. The second step is to examine the relationship and interactions amongst the ecosystem components in order to interpret and possibly predict future changes in community structure or function. Thus, the value of such monitoring programs goes far beyond its surveillance capabilities; it can form the backbone for research activities, thereby encouraging a detailed understanding of the system.

An in-depth planktonic (phyto- and zooplankton) comparison is presented based on extensive seasonal lake-wide surveys. This comparison was achieved by the application of standard and consistent identification, enumeration and data-processing techniques of plankton that were collected from the offshore waters of Lakes Huron, Michigan and Lake Erie. The primary objectives of this report include: (1) To organize plankton data for use in eutrophication models; (2) To characterize the composition and abundance of the phytoplankton and zooplankton for comparison with past conditions to the extent that they are known; (3) To provide firm documentation with which future assessment of the changes in water quality of the lakes can be made; (4) To characterize the water quality by studying the abundance and autecology of phytoplankton and zooplankton; and (5) To characterize within and between year plankton variance to allow better long-term assessments of plankton structure.

METHODS

Sampling Sites

Phytoplankton and zooplankton samples from Lakes Erie, Huron and Michigan were collected by GLNPO personnel during six cruises during the spring, summer and autumn of 1985. Phytoplankton were also collected during an additional late spring cruise on Lakes Michigan and Huron. Collection dates and station locations of routine plankton sampling are given in Tables 1-5 and in Figures 1 - 3. The far northern stations (Stations 47, 56, 64, 77) and the most southern station (Station 6) in Lake Michigam, sampled in 1983 and 1984, were not sampled in 1985 because of refinements in the monitoring program. Locations of sampling sites on Lake Huron were not consistent for the year (Table 4). Instead, alternate east-west stations were sampled (e.g. 54 or 53, 45 or 43; Fig. 3) on various cruises. For geographic analyses, east-west stations were combined, assuming that no significant difference in species abundance and composition existed between east-west stations in Lake Huron, to give a single north-south transect. Because abundance of phytoplankton and zooplankton between north-south stations (30,31,32; 43,42; 38,37,36; 15,63; 9,10) were not significantly different in Lake Erie, north-south stations were averaged to give a single east-west transect (Table 6 and 7). All sites are part of the Great Lakes International Surveillance Program.

Chemistry

Only selected water quality variables collected during the study are presented in this report. Results of the complete water chemistry investigation are reported elsewhere (Rockwell *et al* 1989). Methods used were standard procedures (Rockwell *et al* 1989).

Phytoplankton

An 8-liter PVC Niskin bottle mounted on a General Oceanics Rossette sampler with a Guildline electrobathythermograph (EBT) was used to collect phytoplankton. One-liter composite phytoplankton samples were obtained by compositing equal aliquots from samples collected at depths of 1, 5 , 10 and 20m as allowed by depth. Vertical distribution samples were taken at 1m, 5m and 10-m intervals to the bottom. Phytoplankton samples were immediately preserved with 10 mL of Lugol's solution, while formaldehyde was added upon arrival in the laboratory. The settling chamber procedure (Utermohl 1958) was used to identify (except for diatoms) and enumerate phytoplankton at a magnification of 500x. A second identification and enumeration of diatoms at 1250x was performed after the organic portion was oxidized with 30% H_2O_2 and HNO_3. The cleaned diatom concentrate was air dried on a #1 cover slip and mounted on a slide (75x25mm) with HYRAX™ mounting medium.

Identifications and counts were done by Dr. Norman A. Andresen, R. Flakne, M. Lamb, L. Lipsey, R. Harvey, D. Wagner, K. Verhage, J. Kranzfelder and S. Radzyminski of the Bionetics Corporation. The cell volume of each species was computed by applying average dimensions from each sampling station and date to the geometrical shape such as sphere, cylinder, prolate spheroid, etc., that most closely resembled the species form. At least 10 specimens of each species of each sample were measured for the cell volume calculation. When fewer than 10 specimens were present, those present were measured as they occurred. For most organisms, the measurements were taken from the outside wall to outside wall. The protoplast was measured with loricated forms, while the individual cells of filaments and colonial forms were measured. For comparative purposes, biovolume (um^3/L) was converted to biomass (mg/m^3) assuming the specific gravity of phytoplankton to be 1.0 ($mm^3/L = mg/m^3$) (Willen 1959, Nauwerck 1963).

Zooplankton

A Wildco Model 30-E28 conical style net (62-um mesh net; D:L ratio = 1:3) with 0.5-m opening (radius=0.25m) was used to collect a vertical zooplankton sample at each station. Vertical tows were taken from 20m to the surface. At Lake Erie stations, where water depth was less than 20m, the tow was taken from 1m above the bottom to the surface. Filtration volume and towing efficiency were determined with a Kahl flow meter (Model 00SWA200) mounted in the center of the net. Filtration efficiency averaged 86.4, 74.5 and 93.3%, respectively, for Lakes Erie, Huron and Michigan for the entire sampling season. Following collection, the net contents were quantitatively transferred to 500-mL sample bottles, narcotized with club soda and preserved with 5% formalin.

Zooplankton data from Lake Michigan Cruise #5, 21-23 August 1985, were unrealistically high compared to the samples taken just three days before on Cruise #4, 17-20 August 1985. Net efficiencies for Cruise #5 were exceedingly low (37.9% for the 20m hauls) compared to Cruise #4 (92.5%). Phytoplankton abundance during Cruise #5 was not abnormally high suggesting that the low efficiencies were caused by some other factor. In the data sheets, there was a note questioning the reliability of the flow meter. Since a set of samples were taken just three days before, Cruise #5 was not included in the analysis reported here.

Identification and enumeration of zooplankton follow Gannon (1971) and Stemberger (1979) and were performed by J.L. Schmitz and L.A. Stokes of the Bionetics Corporation. Raw counts were converted to number/mL by Bionetics, Inc. The volume of each rotifer species was computed by using the geometrical shape that most closely resembled the species (Downing and Rigler 1984). It is essential that the measurements are made on the population being studied since they vary in different habitats for some species up to 100% and more (Bottrell *et al* 1976). For each cruise, length of at least 20 specimens of each rotifer species was measured in each lake. Width and depth were also measured on one date for each lake to develop length-width and length-depth ratios for use in the simplified formulas of Bottrell *et al* (1976). Assuming a specific gravity of one, volume was converted to fresh weight and to dry weight assuming a ratio of dry to wet weight of 0.1 (Doohan 1973) for all rotifer species except *Asplanchna* spp. A dry weight/wet weight ratio of 0.039 was used for *Asplanchna* spp. (Dumont *et al* 1975).

Because of the considerable variability in length and thus weight encountered in the Crustacea, the dry weights of Crustacea were calculated using length-weight relationships (Downing and Rigler 1984). Average length of crustaceans (maximum of 20 for each station) was determined for each station of each cruise. A comparison of calculated weights to measured weights of Crustacea in Lake Michigan suggests good agreement at the minimum weight range (Makarewicz 1988). The weight of the Copepoda nauplii followed Hawkins and Evans (1979).

Data Organization

Abundances and dimensions of each species of phytoplankton and zooplankton were entered into a Prime 6350 computer using the INFO (Henco Software, Inc., 100 Fifth Avenue, Waltham, Mass.) data management system. Biomass was calculated for phytoplankton and zooplankton and placed into summaries for each sampling station containing density (cells/mL), biovolume (um^3/mL) and relative abundances of species. In addition, each division was summarized by station.

Definitions

Common phytoplankton species were defined as having an abundance of >0.5% of the total cells or >0.5% of the total biovolume.

Common zooplankton species were defined as having >0.1% of the total abundance or >1.0% of the total biomass. Rotifer species were considered common if they accounted for >1.0% of the total abundance.

Species diversity refers simply to the number of species observed.

Dominance refers to a community property reflected in the relative abundance pattern of a species. A species was considered to be dominant if it possessed the highest relative abundance or biomass of a taxonomic grouping (e.g. Division).

Importance refers to a group of measurements by which the species in a community can be compared (Whittaker 1975). Abundance or biomass was the importance value used in this report.

RESULTS AND DISCUSSION

LAKE MICHIGAN

Phytoplankton

The species list (Table A1) and summary tables of abundance (Table A2) and biovolume (Table A3) are in Volume 2 - Data Report (ATTACHED FICHE). A summary of selected water chemistry parameters is presented in Table 8.

Picoplankton

Picoplankton abundance in 1985 (mean = 16,685; maximum of 5.9×10^4 cells/mL) was not dissimilar from 1984 (mean = 18,409; maximum of 4.3×10^4 cells/mL) or from 1983 (mean = 23,607; maximum of 1×10^5 cells/mL). On a numerical basis, the picoplankton represented 85.5% of the total cells in 1985 but because of their small biomass, only 1.6% of the total biovolume. Their relative numerical dominance in 1985 was comparable to 1983 (89.4%) and 1984 (82.8%) (Makarewicz 1987, 1988). Historically the picoplankton have not been considered in evaluations of the plankton community of Lake Michigan. Their high abundance tends to distort relative abundance values and does not allow reasonable comparisons with the historical data. For this reason, they are not considered further in this discussion.

Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1985 was comprised of 222 species representing 79 genera from eight divisions (Table 9). Compared to 1983 and 1984, a sizeable reduction in the number of genera (1983 - 90 genera; 1984 - 91) and species (1983 - 336 species; 1984 - 327 species) was observed. Much of the reduction in species occurred with the diatoms. 167 and 166 species of diatoms were observed in 1983 and 1984, respectively, while only a total of 90 species was observed in 1985. With no significant changes in the sampling regime and water chemistry between years, these differences are attributable to changes in personnel responsible for enumeration and identification that occurred during this year.

Similar to 1983 and 1984, the Bacillariophyta possessed the largest number of species (90) and biovolume (64.0% of the total, Table 9 and 10), while the second largest number of species (41), as in 1983 and 1984, was observed for the Chlorophyta (Table 10). Similar to 1983 and 1984, the Cryptophyta accounted for the second highest biovolume (17.2%). Highest overall densities were attained by the Cyanophyta (34.4% of the total). The Pyrrophyta had a much lower biovolume in 1984 and 1985 than in 1983 (Table 10). Unidentified organisms represented 31.1% of the total organisms identified.

The annual average phytoplankton density and biomass in 1985 were 2,841±241 cells/mL (mean±S.E.)(3,602±244 cells/mL, 1984; 3,159±203 cells/mL, 1983) and 0.45 g/m^3±0.043 (0.52 g/m^3±.038, 1984; 0.41±.05 g/m^3, 1983), respectively.

Seasonal Abundance and Distribution of Major Algal Groups

Seasonally, abundance (cells/mL) was low during the spring and increased slightly by June. Because sampling in the present study was designed to monitor the early pre-bloom conditions, the spring bloom observed in May, June and July of 1976 (Bartone and Schelske 1982) was not observed in 1984 (Makarewicz 1988) or 1985 (Fig. 4). Similar to 1984, a secondary abundance maxima was observed in August (Fig. 4a) but was not observed in the biovolume seasonal distribution in 1985 (Fig. 4b). During August, a general downward trend in biomass occurred. Because samples were not taken in October, the large autumn peak observed in 1983 (Makarewicz 1987) was not observed in 1984 (Makarewicz 1988) or 1985. Similarly, a fall bloom was not observed in 1976 by Bartone and Schelske (1982). This was attributed either to a weak bloom that was not observed or to the occurrence of the bloom at a time when samples were not taken.

Considering biovolume, the Bacillariophyta were dominant in the spring and fall accounting for as much as 80% of the phytoplankton biovolume (Fig. 5). The large drop in biovolume of Bacillariophyta (to 8%, ~10% in 1983) observed in August of 1985 and in 1983, was not observed in 1984 (Makarewicz 1987, 1988). Makarewicz (1988) attributed the predominance of the diatoms throughout the summer of 1984 to a bloom of *Rhizosolenia eriensis*. A bloom of *R. eriensis* was not observed in 1983 or 1985 (Table 11), suggesting that the prevalence of *R. eriensis* determines whether or not a divisional succession occurs as suggested by Makarewicz (1987).

The small decrease in diatoms in August of 1984 corresponded with an increase in the Cryptophyta, while in 1983 the major decline in diatoms corresponded with an increase in the Pyrrophyta (Makarewicz 1987, 1988). In 1985, the decrease in diatoms corresponded with a major increase in the Cryptophyta, Pyrrophyta and the Cyanophyta (Fig. 5). A shift in biovolume composition was observed in 1976 with diatoms decreasing to 17% in August when greens and blue-green algae predominated (Bartone and Schelske 1982).

Regional and Seasonal Trends in the Abundance of Common Taxa

The definition of common species (Makarewicz 1987, 1988) has been revised to accommodate the removal of the picoplankton. Common species (Table 12 - 14) were arbitrarily defined as those possessing a relative abundance of >0.5% of the total cells or >0.5% of the total biovolume. Using the new definition, the data from 1983 (Table 12) and 1984 (Table 13) were revised. Eight new common species were observed in 1985 from 1983 and 1984. Two of these species, *Cymatopleura solea* var. *apiculata* and *Stephanodiscus* sp.#9, were actually rare - abundance being less than 0.2 cells/mL. Because of their large size, these species attained a biomass exceeding 0.5% of the total biomass. Because of the similarity of the 1985 common species list to the 1983 and 1984 list, a species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987, 1988). Only new common species, with the exception of *Cymatopleura solea* var. *apiculata* and *Stephanodiscus* sp.#9, are discussed below.

Cryptophyta

Chroomonas acuta Uterm.

Stoermer and Kopczynska (1967a&b) did not identify flagellates to the species level but did conclude that their abundance was low. In the nearshore zone in 1970, abundance of *Chroomonas* sp. reached 68.6 cells/mL (Stoermer and Tuchman 1979). In Green Bay, *Chroomonas* spp. was sporadically represented in May and August (mean = 58.9 cells/mL)(Stoermer and Stevenson 1979). The intensive study of 1976 and 1977 that included the offshore region did not report this genus (Rockwell *et al* 1980). However, the authors report that the results may be affected by the low magnification (400x) used in enumeration and identification. It is apparent that abundance of this genus has been high in Lake Michigan. Average abundance in 1983 (7.9 cells/mL) and 1984 (7.4 cells/mL) was comparable to 1985 (16.3 cells/mL)(Table 14). A maximum abundance of 155 cells/mL was observed on the 17-20 August, 1985 cruise.

Cryptomonas ovata Ehr.

Stoermer and Kopczynka (1967b) reported cryptomonads and other flagellates as a numerically minor component of the total plankton in Lake Michigan in 1963. However, Munawar and Munawar (1975) found that flagellates contributed between 6 and 31% of the biomass in 1973. Claflin (1975) also found small flagellates (particularly *Rhodomonas* spp. and *Cryptomonas* spp.) to be very abundant in 1971. In the nearshore zone, *C. ovata* abundance averaged 28.6 cells/mL with a maximum of 98.4 cells/mL in 1977 (Stoermer and Tuchman 1979). In the intensive survey of 1977 (Rockwell *et al* 1980) that included the offshore, as well as the nearshore, abundance of *C. ovata* ranged from 60 cells/mL in April to 101 cells/mL in August. Although a common species in 1985 by virtue of its large size, abundance averaged only 1.7 cells/mL with a maximum of 25 cells/mL (Table 14). Abundance was also low in 1983 (1.6 cells/mL) and 1984 (2.1 cells/mL). No obvious geographical pattern was observed (Fig. 6). Except for the 1963 work, *Cryptomonas* appears to be prevalent at times within Lake Michigan.

Cryptomonas rostratiformis Skuja

This species was not reported by Stoermer and Kopczynska (1967a&b), Stoermer and Tuchman (1979), Stoermer and Stevenson (1979) or Rockwell *et al* (1980) in the nearshore and offshore or in the waters of Green Bay. Abundance in 1983 (mean = 1.4 cells/mL) and 1984 (mean = 0.3 cells/mL) was similar to 1985 (1.2 cells/ mL). In 1985, it was most prevalent throughout the lake in May and August. Maximum abundance was observed in early May at Station 19 (12.3 cells/mL).

Rhodomonas lens Pasch. & Rutt.

Rhodomonas minuta and *R. minuta* var. *nannoplanktica* have been the forms of *Rhodomonas* observed in Lake Michigan. Although an exhaustive search of the literature was not performed, a review of the generally cited comprehensive phytoplankton studies of Lake Michigan (Stoermer and Kopczynka 1967a, Claflin 1975, Munawar and Munawar 1975, Rockwell *et al* 1980, Stoermer and Tuchman 1979, Makarewicz 1987, 1988) did not reveal any other previous occurrences of this species except for the work done in 1983 (mean = 8.3 cells/mL), 1984 (mean = 8.7 cells/mL) and 1985 (Makarewicz 1987, 1988, this study). Although a common species in 1985 by virtue of its large size, abundance averaged only 25.1 cells/mL with a maximum of 139 cells/mL (Table 14). Seasonally, maxima in abundance occurred in the spring and autumn (Fig. 7)

Cyanophyta

Anabaena sp.

Species of *Anabaena* were present in low quantities (<5 cells/mL) in the fall, but rare during the spring of 1962-63 (Stoermer and Kopczynska 1967a). Stoermer and Tuchman (1979), working in the nearshore of Lake Michigan, reported *Anabaena flos-aquae* as the prevalent species of *Anabaena* (mean = 24.5 cells/mL). Other forms of *Anabaena* were not identified, but densities were low (<0.5 cells/mL). Similarly, abundance of *Anabaena flos-aquae* was high (mean = 79.4 cells/mL) in Green Bay in 1977 (Stoermer and Stevenson 1979). In the intensive study of Lake Michigan, which also included offshore waters, filamentous bluegreens were considered relatively unimportant (Rockwell *et al* 1980). Abundance in 1983 (mean = 8.0 cells/mL) and 1984 (mean = 12.0 cells/mL) was slightly lower than 1985 (mean = 21.8 cells/mL)(Table 14). An isolated bloom that occurred in August at Station 47 (1,309 cells/mL) was the cause of the increase reported in 1985 from 1983.

Pyrrophyta

Gymnodinium helveticum f. *achroum* Penard

Historical information on this species is inadequate for comparison to the 1985 data. Stoermer and Stevenson (1979) did report *G. helveticum* (0.67 cells/mL) present in Green Bay in 1977. Stoermer and Tuchman (1979), working in the nearshore zone of southern Lake Michigan in 1977, reported an average abundance of 0.64 cells/mL (Maximum = 20.7 cells/mL) for *Gymnodinium* spp. In 1985, average abundance of *G. helveticum* var. *achroum* and *Gymnodinium* sp. was 0.8 cells/mL (Table 14). Occurrence of *G. helveticum* f. *achroum* in 1985 was restricted to southern Lake Michigan during the spring (Fig. 8).

Historical Changes in Species Composition

Division Trends

In August of 1962, an analysis of samples from southern Lake Michigan revealed that the diatoms were numerically dominant (Stoermer and Kopczynka 1967a). Relative abundance of diatoms was never lower than ~70% of the total assemblage at all stations. By 1969 green, blue-green and golden brown algae were the major phytoplankton components (Schelske and Stoermer 1972). Similarly, Schelske *et al* (1971) observed that blue-green and green algae constituted 56 to 85% of the phytoplankton during August and September. In a detailed study of southern Lake Michigan, Stoermer (cited in Tarapchak and Stoermer 1976) observed that blue-green algae contributed up to 80% of the phytoplankton cells in August of 1971.

Another shift in algae composition was evident by 1977. Relative abundance of blue-greens dropped to 22.9% in August. However, flagellates (~42%) rather than diatoms (22%) were the dominant group of algae (Rockwell *et al* 1980). A similar composition to 1977 was observed in August of 1984 (diatoms = 12.2%, blue-greens = 16.4%, unidentified flagellates = 42.1%) when picoplankton were not included in the analysis (Makarewicz 1988). From 1983 to 1985, in addition to the cyanophytes being more prevalent than the diatoms, the chrysophytes were numerically more important than the diatoms (Table 9). In addition, the cryptophytes were more prevalent in 1983 and 1985. The numerical decline of the diatoms has been attributed to the high phosphorus loading and concomitant silica depletion (Schelske and Stoermer 1971). On a biomass basis, however, diatoms were the dominant group in 1983, 1984 and 1985.

Species Trends

The Haptophyceae, *Monoraphidium contortum* (Chlorophyta), *Dinobryon sociale* var. *americanum* (83 and 84 only)(Chrysophyta), *Rhodomonas minuta* var.

nannoplanktica and *Chroomonas norstedii* (Cryptophyta), *Anacystis montana* var. *minor* and *Oscillatoria limnetica* (83 and 84 only) (Cyanophyta) were numerically dominant in 1983, 1984 and 1985. Dominant diatoms in 1983 included the numerically dominant *Cyclotella comensis*, *Fragilaria crotonensis* and *Melosira italica subsp. subartica*; on a biomass basis, *Tabellaria flocculosa* was predominant (Makarewicz 1987). In 1984 *Cyclotella comensis* and *Fragilaria crotonensis*, along with *Cyclotella ocellata*, were numerically dominant. *M. italica* subsp. *subarctica* was common but not dominant. On a biomass basis, *Rhizosolenia eriensis* and *Tabellaria flocculosa* were predominant in 1984. In 1985 *Rhizosolenia longiseta*, *Melosira islandica* and *Melosira italica* subsp. *subartica* were dominant on a numerical basis while *Stephanodiscus niagarae* was the dominant species on a biomass basis. *Fragilaria crotonensis* was common in 1985 but not dominant.

Of the 1983, 1984 and 1985 dominant diatoms, only *Fragilaria crotonensis* and perhaps *Tabellaria flocculosa* were major components of the diatom assemblage in 1962-63. Stoermer and Kopczynska (1967a) noted taxonomic difficulties with *Tabellaria* and noted that most populations of *Tabellaria* "are probably to be referred to *T. fenestrata* ...."

The dominant species of *Cyclotella* in 1962-63 was *C. michiganiana*. Rockwell *et al* (1980) reported that *Cyclotella* spp. were common in 1977 but were never dominant. A dramatic decrease in some species of *Cyclotella*, such as *C. michiganiana* and *C. stelligera*, which were offshore dominants in August of 1970, was evident by 1983 (Table 15). *Cyclotella comensis*, believed to be tolerant of higher nutrient and lower silica concentrations than most members of this genus, was the numerically dominant diatom in the offshore waters in 1983 and 1984 (Makarewicz 1987, 1988), but not 1985 (Fig. 9). *Cyclotella ocellata*, a species generally associated with oligotrophic conditions, was also dominant in 1984 but not in 1985.

Yearly variation in dominance of species of *Melosira* was evident. *Melosira islandica* was dominant in 1962-63. In 1983 *M. islandica* was present (mean = 12.1 cells/mL), but *M. italica* subsp. *subarctica* (mean = 37.6 cells/mL) was more abundant. In 1984 *M. islandica* and *M. italica* subsp. *subartica* had similar abundances (~10-12 cells/mL) but were not dominant (Makarewicz 1988). In 1985 these two species, along with *Stephanodiscus niagarae*, were the dominant diatoms (Table 14).

Synedra acus was common throughout the southern basin in 1977 (Rockwell et al 1980) but represented only <0.1% of the total cells from 1983 to 1985.

Makarewicz (1987) has suggested an apparent decline in *R. eriensis* since 1962. In May of 1962, relatively high (100 cells/mL) populations were observed in southern Lake Michigan (Stoermer and Kopczynska 1967a). During May and June of 1970, mean abundances for offshore stations were 63 and 611 cells/mL, respectively (Holland and Beeton 1972). Rockwell *et al* (1980) reported a mean density of 28.7 cells/mL for *R. eriensis* during June of 1977. Abundance in 1983 was 2.6 cells/mL for the entire lake. A bloom (133 cells/mL) in the northern Station 77 did occur in October. In 1984, mean lake abundance increased to 18.2 cells/mL, but decreased to 3.3 cells/mL in 1985. Similar to species of *Melosira*, considerable yearly variation in abundance of *Rhizosolenia* from 1983 to 1985 was observed.

Ankistrodesmus falcatus increased in abundance to 1977 and had decreased by 1983. Ahlstrom (1936) reported this species as rare, but Stoermer and Kopczynska (1967a) noted that it had increased by 1962-63 (range = 20-60 cells/mL). Rockwell *et al* (1980) suggested that by 1977 it had increased further (range = 20-160 cells/mL). In 1983 this species was observed only once during the study at Station 32 (6.5 cells/mL) and was not observed in 1984 and 1985.

Dominant chrysophytes in 1962-63 were *Dinobryon divergens*, *D. cylindricum* and *D. sociale* (Stoermer and Kopczynska 1967a). Rockwell *et al* (1980) reported them as dominant or subdominant offshore. With the exception of *D. cylindricum* in 1984, *D. divergens*, *D. cylindricum* and *D. sociale* were common species in 1983 and 1984. None of these chrysophytes was common in 1985 (Table 14). As in 1983 and 1984, the haptophytes were numerically the dominant group within the chrysophytes in 1985.

Dominant and common cryptophytes between 1983 and 1985 included *Cryptomonas erosa* var. *reflexa*, *C. erosa* and *Rhodomonas minuta* var. *nannoplanktica.* Stoermer and Kopczynska (1967b) and Stoermer (1978) reported these species as uncommon in Lake Michigan, but Vollenweider *et al* (1974) noted these species as commonly found. Similarly, Munawar and Munawar (1975), Claflin (1975) and Rockwell *et al* (1980) had reported *C. erosa* and *R. minuta* var. *nannoplanktica* to be dominant, abundant and perhaps increasing in number. From the 1983, 1984 and 1985 work, it is apparent that *C. erosa* was numerically uncommon but on a biomass basis was the most important cryptophyte (second in 1984, Makarewicz 1988) (Table 14). Evaluation of abundance of *R. minuta* in earlier studies was not possible because it was grouped into phytoflagellates, flagellates or simply *Rhodomonas*. What can be reported about *Rhodomonas minuta* var. *nannoplanktica* is that in 1983, 1984 and 1985 it was the dominant cryptophyte on a numerical basis.

Oscillatoria limnetica has become more prevalent in the lake. Ahlstrom (1936) and Stoermer and Kopczynska (1967a) listed *O. mougeotii* as the only species of this genus abundant in their collections. Stoermer and Ladewski (1976) reported that *O. limnetica* had generally increased in abundance in Lake Michigan. Rockwell *et al* (1980) observed that *O. limnetica* was common throughout the basin in April and June and was especially abundant in September of 1977 at certain stations. *O. limnetica* was the numerically dominant offshore blue-green algae in 1983 (Makarewicz 1987), was second and third in abundance in 1984 (Makarewicz 1988) and 1985 (Table 14), respectively. *Anacystis montana* var. *minor* was the dominant blue-green algae in 1984 and 1985 (Table 14).

Geographical Abundance and Distribution

The 1985 sampling pattern in Lake Michigan differed from 1983 and 1984 (Makarewicz 1987, 1988) in that the far northern stations (Stations 57, 56 64 and 77) and the most southern station (Station 6) were not sampled not allowing a comparative geographical analysis between years. In 1985 total phytoplankton abundance was not significantly different between the northern and southern half of the lake. A peak in abundance did occur at Station 27 caused by the high abundance of picoplankton at this station (Fig. 10). A similar peak at Station 27 occurred in the geographic biomass distribution pattern, except that the peak was caused by diatoms (Fig. 11). Cyanophyta abundance was significantly ($P<0.05$) higher in the southern basin compared to the northern basin. Station 47 at the northern end of the sampling pattern also had a high Cyanophyta abundance.

No obvious geographical abundance pattern was observed in the other algae divisions. Considering biomass, a different pattern emerges (Fig. 11). Chrysophyta biomass progressively increases from north to south. As with abundance, blue-green biomass increases south of Station 27. Compared to the rest of the lake, Pyrrophyta and Cyanophyta biomass are high at Station 47.

Seasonally, the two summer cruises possessed a geographical abundance pattern similar to the mean annual phytoplankton distribution with abundance peaks at Station 27 (Fig. 12). The peak at Station 27 during the summer was caused by a bloom of picoplankton (spheres). No obvious geographic patterns were observed during the spring and fall cruises (Fig. 12).

Indicator Species

Stoermer and Yang (1970), in a comparison of modern and historic records, reported that taxa characteristic of disturbed situations were rapidly increasing in relative abundance in Lake Michigan in the 60's. In the nearshore area, a shift in oligotrophic forms to those which dominate under eutrophic conditions was evident. Occurrence of certain eutrophic species was also evident in offshore waters (Stoermer and Yang 1970).

Dominant diatom species in the offshore waters in 1983 were *Cyclotella* comensis, C. comta, T*abellaria flocculosa, Fragilaria crotonensis* and *Melosira italica subsp. subartica* (Makarewicz 1987). The same five diatoms were dominant in 1984 with the exception of *C. comta* and the addition of *Rhizosolenia eriensis* and *Cyclotella ocellata* (Makarewicz 1988). In fact, *R. eriensis* accounted for ~25% of the total biomass of phytoplankton during 1984.

Rhizosolenia eriensis may be an opportunistic species which is able to rapidly develop fairly high abundances when conditions are favorable (Stoermer and Ladewski 1976). Stoermer and Yang (1970) listed *R. eriensis* with the oligotrophic offshore dominants, which includes *C. ocellata*, but noted that *R. eriensis* seemed to occur in greater abundance in areas that have received some degree of nutrient enrichment. *Tabellaria flocculosa* and *F. crotonensis* are mesotrophic forms, while the ecological affinities of *C. comensis* are poorly understood. *Cyclotella comensis* was formerly found in primarily oligotrophic areas (Stoermer and Stevenson 1979) under some nutrient stress (Stoermer and Tuchman 1979). Dominant diatom species in the offshore waters in 1985 were *Stephanodiscus niagarae, Melosira islandica, Rhizosolenia longiseta, Melosira italica subsp. subarctica* and *Fragilaria crotonensis*.

Compared to 1983 (Makarewicz 1987) when mesotrophic diatoms species were predominant, the same mesotrophic forms were present in 1984 along with oligotrophic indicators (Makarewicz 1988). A change occurred in 1985 in the predominant diatom species. The species of *Cyclotella* and *Tabellaria flocculosa* predominant in 1983 and 1984 were present but were not dominant or common. The eutrophic indicator species *Stephanodiscus niagarae* was the dominant species on a biomass basis, while *Rhizosolenia longiseta* and the mesotrophic indicator species *Melosira islandica* were dominant on a numerical basis. Only *Melosira italica subsp. subarctica* and *Fragilaria crotonensis* were predominant diatom species observed in 1983, 1984 and 1985.

The indicator diatom species and the distribution of them (trophic ratio) (Table 16) suggest a eutrophic status for nearshore waters in 1977, mesotrophic-eutrophic for offshore waters in 1970-71, and an oligotrophic-mesotrophic range for offshore waters in 1983, 1984 and 1985. With the low mesotrophic/eutrophic ratio in 1970-71 (M/E = 2.3) as compared to 1983, 1984 and 1985 (mean M/E = 6.8), it is tempting to suggest a slightly more mesotrophic status in more recent years. The M/E ratio has to be interpreted conservatively as it is influenced somewhat by the definition of the predominant species (e.g. 1% of biomass). Nevertheless, the trophic status as determined by indicator species and the M/E ratio agrees well with the 1976 assessment based on particulate phosphorus concentrations that place the open lake waters of Lake Michigan in the oligotrophic-mesotrophic range (Bartone and Schelske 1982).

Historical Changes in Community Abundance

A comparison of abundance trends over the entire lake was not possible because of the lack of comparable offshore data prior to 1983. Figure 13 plots the 1962-63 and the 1976-77 data of Stoermer and Kopczynska (1967a and b) and Rockwell *et al* (1980), which are representative of the southern portion of the lake. Only a range of abundance is available for 1962-63, while the mean, standard error and range are plotted for the other data. Because picoplankton were not counted prior to 1983, they are removed from the 1983, 1984 and 1985 data presented in Figure 13. Although a mean is not available, it is apparent that phytoplankton abundance increased from 1962-63 to 1976-77. From 1976 to 1983 to 1985, abundance was not significantly different ($P<0.05$). Based on the classification scheme of Munawar and Munawar (1982) which utilizes the mean phytoplankton biomass as an indicator of trophic status, Lake Michigan would be classified as oligotrophic in 1985, as it was in 1984 (Makarewicz 1988). However, the trophic ratio and composition of indicator species suggest a mesotrophic status.

LAKE MICHIGAN

Zooplankton

Annual Abundance of Zooplankton Groups

Species lists (Table A4) and summary tables of abundance (Table A5) and biomass (Table A6) are in Volume 2 - Data Report (ATTACHED FICHE). The zooplankton assemblage of 1985 comprised 52 species representing 29 genera from the Calanoida, Cladocera, Cyclopoida, Harpacticoida, Mysidacea and Rotifera. Compared to 1984, the same number of species was observed in 1985, which represented a 21% reduction from the number of species observed in 1983. The total number of genera has declined steadily from 43 in 1983 to 34 in 1984 to 29 in 1985. This difference is mostly attributable to a decrease in the number of Rotifera species observed.

As in 1983 (Makarewicz 1987) and 1984 (Makarewicz 1988), the Rotifera possessed the largest number of species (29) and relative abundance (39.9%). Unlike 1984, the Calanoida, rather than the Cladocera, accounted for a major portion (67.4%) of the zooplankton biomass (Table 17). The Rotifera contributed only 1.1% of the total biomass (Table 17). Average density and biomass for the study period were 34,950$\pm$4,085 organisms/m^3 (mean+S.E.) (1983 - 69,353, 1984 - 59,764) and 47.9$\pm$ 5.2 mg/m^3 (mean+S.E.)(1984 - 33.2$\pm$4.9).

Seasonal Abundance and Distribution of Major Zooplankton Groups

The seasonal abundance patterns were virtually identical between 1985 and 1984 (Makarewicz 1988, Fig. 14) with a maximum in abundance observed in August of each year. The secondary maximum observed in October of 1983 (Makarewicz 1987) was not observed in 1984 and 1985. This difference is apparent and is probably related to the difference in the seasonal sampling pattern between years. Samples were not taken in September and October of 1984 and 1985.

Seasonally, abundance and biomass of all groups, except the Calanoida, were higher in August as compared to the early spring and late fall (Figs. 15 and 16). The lack of a maximum in total zooplankton biomass (Fig. 14) during August is attributed to the low Calanoida biomass observed during this period. The high abundance of Cyclopoida, Cladocera and Copepoda nauplii in August of 1984 (Makarewicz 1988) and 1985 was not observed in 1983 (Makarewicz 1987).

Geographical Abundance and Distribution of Zooplankton Groups

A definite trend of increasing zooplankton abundance occurred from south to north in Lake Michigan in 1984 (Makarewicz 1988). Specifically, zooplankton abundance at the far northern Stations 64 and 77 was higher than in the rest of the lake. Abundances of Rotifera, Cladocera and Copepoda nauplii were all higher at these far northern stations. Biomass, however, was similar southward from Station 77 to Station 18, after which biomass decreased southward. These patterns were not observed in 1983 (Makarewicz 1987) or in 1985. In 1985, the far northern sites (Stations 64 and 77) and the most southern site (Station 6), where the differences in abundance were observed in 1984, were not sampled.

Previous work has suggested that abundance of several species of zooplankton peaked at the far northern stations (Makarewicz 1987, 1988). *Conochilus unicornis*, *Bosmina longirostris*, *Eubosmina coregoni*, *Notholca laurentiae*, *N. squamula*, *N. foliacea*, *Holopedium gibberum*, *Polyarthra vulgaris* (1984 only) and *P. remata* (1984 only) all had abundance peaks at the far northern end of the lake in 1983 and 1984. Similarly, abundance of *Diaptomus sicilis* was higher in southern Lake Michigan (Makarewicz 1987) in 1983 and 1984. Abundance of *D. sicilis* appeared to be higher in the southern basin (Fig. 17) in 1985. Similarly, *C. unicornis* and *H. gibberum* had higher abundances at Station 47; the most northern station samples in 1985 (Fig. 18). Because samples were not taken at the far northern stations in 1985, it was not possible to fully evaluate geographical trends for the entire lake. In general, the limited geographical data available in 1985 suggest little difference in abundance of the stations sampled (Fig. 20).

Common Species

Common Crustacea species (Table 18) were arbitrarily defined as those possessing a relative abundance of >0.1% of the total abundance or 1.0% of the total biomass. Rotifera species were considered common if they accounted for >1.0% of the total zooplankton abundance or biomass. The number of common species (1983 = 25 species; 1984 = 24 species; 1985 = 22) and common species composition were essentially the same between 1983 and 1985. Some of the compositional difference can be attributed to the rotifers and the differences in sampling schemes between years. For example, *Notholca foliacea, N. laurentiae*, *Polyarthra remata*, *Bosmina longirostris* and *Holopedium gibberum* were common in 1984 but not in 1983 and 1985. In 1985 the far northern stations, where these organisms predominated, were not sampled.

Historic Changes in Species Composition

Crustacea

Numerous recent studies (Williams 1966; Johnson 1972; Gannon *et al* 1982a, 1982b; Evans *et al* 1980) of the nearshore region of Lake Michigan exist, along with data from as far back as 1927 (Eddy 1927). Several researchers have compared the nearshore with the offshore zooplankton in discussions of eutrophication of the entire lake. Comparisons of the inshore with the offshore stations should be viewed with caution because effects are not necessarily due to eutrophication or fish predation (Evans *et al* 1980).

Although no intensive zooplankton studies of the offshore waters of the entire lake basin have taken place, some offshore studies of Lake Michigan zooplankton do exist. Wells (1960, 1970) sampled Crustacea with a number 2 (366um) net on four dates in June, July and August in 1954, 1966 and 1968 from the offshore region off Grand Haven, Michigan. On six dates (March 1969 to January 1970), Gannon (1975) collected crustaceans with a 64-um mesh net from the offshore and inshore of Lake Michigan along a cross-lake transect from Milwaukee to Ludington. In September of 1973, northern Lake Michigan was sampled with a 250-um mesh net (Schelske *et al* 1976). Also, Stemberger and Evans (1984) provided abundance data (76-um net) for a few zooplankters from offshore waters of the southeastern Lake Michigan area.

The data of Wells (1960, 1970) and Gannon (1975) are useful but have to be used with caution. A 366-um and a 250-um net are probably quantitative for larger crustaceans but certainly would not be for smaller crustaceans such as *Chydorus sphaericus*, *Bosmina longirostris*, *Eubosmina coregoni*, *Ceriodaphnia spp.*, *Tropocyclops prasinus* and copepods (Makarewicz and Likens 1979).

The zooplankton populations in Lake Michigan underwent striking size-related changes between 1954 and 1966 (Wells 1970). Species that declined sharply were the largest cladocerans (*Leptodora kindtii*, *Daphnia galeata mendotae and D. retrocurva*), the largest calanoid copepods (*Limnocalanus macrurus*, *Epischura lacustris* and *Diaptomus sicilis*) and the largest cyclopoid copepod (*Mesocyclops edax*). Medium-sized or small species (*D. longiremis*, *H. gibberum*, *Polyphemus pediculus*, *Bosmina longirostris*, *Ceriodaphnia sp.*, *Cyclops bicuspidatus*, *Cyclops vernalis*, *Diaptomus ashlandi*) increased in number, probably in response to selective alewife predation. After the alewife dieback, *M. edax* and *D. galeata mendotae* were still rare in 1968 when the composition of the zooplankton community shifted back toward one similar of 1954 (Wells 1970).

In northern Lake Michigan during September of 1973, predominant species were *Daphnia galeata mendotae*, *D. retrocurva*, *Limnocalanus macrurus*, *Diaptomus oregonensis*, *Eubosmina coregoni and Diaptomus sicilis*. Cyclopoid copepods were a minor component of the fauna in 1973 (Schelske *et al* 1976).

The changing nature of the zooplankton community of Lake Michigan was evident in 1983. *Daphnia galeata mendotae*, *D. pulicaria* and *D. retrocurva* were the second, third and fourth most abundant cladocerans in the lake (Makarewicz 1987). *D. galeata mendotae* and *D. retrocurva* were again the prominent daphnids in 1984 along with the dominant cladoceran *Bosmina longirostris*. In 1985 *D. galeata mendotae*, *Daphnia pulicaria* and *Daphnia retrocurva* were the common cladocerans. *Bosmina longirostris* the dominant cladoceran in 1983 and 1984, was not even a common species in 1985. This is partialy attributed to the dropping of the far northern stations where this organism predominated in 1983 and 1984. However, removal of the far northern stations from the 83 and 84 data still suggests an increase in *B. longirostris* from the 60's (Table 19). Annual abundance of *Daphnia pulicaria* dropped from an average of $376/m^3$ in 1983 to $78/m^3$ in 1984 and increased to $161/m^3$ in 1985. In August of 1983, abundances of *D. galeata*, rare in 1966 and 1968, were half of those in 1954 ($1,200/m^3$) and 2-3 times the 1954 abundance in 1984 and 1985 (Table 19).

The 1983 August abundance of *Daphnia retrocurva* was similar to the August 1966 abundance rather than to those of 1954 or 1968. However, maximum abundance in October of 1983 ($3,161/m^3$) was comparable to the 1954 or 1968 observations. Perhaps related to the low abundance of *D. retrocurva* in August of 1983 was the appearance of the large (~2 mm) (Evans 1985) cladoceran *Daphnia pulicaria*, which reached a maximum abundance in August. When *D. pulicaria* dropped in abundance in 1984, *D. retrocurva* abundance increased to a density comparable to those of 1954 and 1968 (Table 19). Similarly in 1985, *D. retrocurva* abundance decreased when *D. pulicaria* abundance increased (Table 19)

Evans (1985) recently reported that *D. pulicaria* was first observed in Lake Michigan in 1978. Abundance remained low in southeastern Lake Michigan until 1982 and 1983 when they dominated the offshore summer *Daphnia* community and at an offshore station southwest of Grand Haven, Michigan. In 1983 this species was the dominant cladoceran in the offshore waters of Lake Michigan (Makarewicz 1987). Mean annual station abundance in 1983 reached 1,741 organisms/m^3 in early August with a maximum of 6,056/m^3. In 1985 August abundance of *D. pulicaria* increased to 694/m^3 from a mean of 248/m^3 in 1984 (Table 19).

The large cladoceran *Leptodora kindtii* appeared to be increasing in abundance from 1954 to 1984 (Makarewicz 1988, Table 19). Although average abundance was down in 1985 compared to 1984, abundance in 1985 was still higher than in the 60's. *Eubosmina coregoni* has also increased in abundance since 1954 (Table 19). Abundance of *B. longirostris* and the larger *Holopedium gibberum* decreased significantly from 1984 to 1985. In fact, abundances observed in 1985 were similar to 1954, 1966 and 1968. The decrease in abundance from 1984 to 1985 of *H. gibberum*, but not *B. longirostris*, is related to the deletion of the far northern sampling stations routinely sampled in 1983 and 1984. The decrease in *B. longirostris* appears to be real and not due to the changes in the sampling regime.

Cyclops bicuspidatus was the dominant cyclopoid in 1983, 1984 and 1985 with *Diaptomus ashlandi* or *D. sicilis* being the dominant calanoid (Makarewicz 1987, 1988, Table 20). Abundance of *Mesocyclops edax* was low in August of 1983, 1984 and 1985 compared to 1954. However, abundance of this species has obviously increased since the 60's and appears to be approaching levels observed in 1954. Abundance of *M. edax* in early October of 1983 reached a level comparable to 1954 (151 organisms/m^3, mean station abundance).

Diaptomus minutus appears to have decreased in abundance since 1968, while *D. oregonensis* abundance remained similar to 1954 (Table 20). August abundance of *D. sicilis* increased from 1968 to 1984 and then decreased in 1985. This decrease was not due to the change in sampling stations in 1985 (Table 20). Abundance of *Limnocalanus macrurus* was lower during August of 1983 and 1985 than in 1954-68. However, abundance in 1984 was similar to

1954 and 1966. The abundance of *Epischura lacustris* in August was low in 1983 and 1984 relative to 1954, but not in 1985, when abundance was similar to 1954. Mean station abundance reached 111 organisms/m^3 in late October of 1984.

Between 1983 and 1985, the large cladocerans, calanoids and cyclopoid copepods, observed by Wells (1970) to have decreased sharply in the early 60's, had increased in abundance to densities similar to those in August of 1954. In some instances, abundance was not as high in August but was as high at other times of the year. In addition, a new large cladoceran, *Daphnia pulicaria*, has become established in the offshore waters of Lake Michigan.

The resurgence of larger zooplankton in Lake Michigan is probably related to the sharp decline in the abundance of the planktivorous alewife in 1982 and 1983. The lakewide catch of adult alewifes was only 31% of that of 1982 and only 12% of the 1981 catch. Bloater chubs are replacing the alewifes and have been experiencing a dramatic increase in abundance since 1970 (Wells and Hatch 1983). Bloaters above ~18 cm in size primarily feed on *Mysis* and *Pontoporeia*. Only smaller individuals feed on zooplankton (Wells and Beeton 1963). The decrease in *B. longirostris* may be related to interference competition (Vanni 1986) expected from the resurgence of large daphnids in Lake Michigan.

Rotifera

Rotifer studies reported in the literature are primarily from the nearshore region of the lake. In the nearshore, *Keratella cochlearis*, *Polyarthra vulgaris*, *Kellicottia longispina*, *Synchaeta stylata* and *Synchaeta tremula* were dominant in 1926-27 (Eddy 1927). *Keratella* and *Polyarthra* were the dominant genera in 1962 (Williams 1966), while *K. cochlearis* and *P. vulgaris* were dominant in 1970 (Johnson 1972). Gannon *et al* (1982a) noted that the following rotifers were predominant in 1977: *Keratella cochlearis*, *K. crassa*, *Conochilus* unicornis, Kellicottia longispina, Polyarthra vulgaris and *P. remata*.

Abundance of rotifers in Lake Michigan generally decreased from the nearshore into the offshore (Gannon *et al* 1982a, Stemberger and Evans 1984) although the species composition of the nearshore and offshore was relatively similar. In 1983 the predominant offshore rotifers were in descending order: *Polyarthra vulgaris*, *Synchaeta sp.*, *Keratella cochlearis*, *Polyarthra major*, *Kellicottia longispina*, *Keratella crassa*, *Gastropus stylifer* and *Colletheca* sp. (Makarewicz 1987). The predominant rotifers in 1984 and 1985 were *Keratella cochlearis*, *Kellicottia longispina*, *Polyarthra vulgaris* and *Synchaeta* sp. (Makarewicz 1988, Table 18). The dominant rotifer composition of 1983 to 1985 is similar to the nearshore and to Ahlstrom's (1936) offshore observations of predominant species (*Keratella cochlearis*, *Synchaeta stylata* and *Polyarthra vulgaris*).

Historical Changes in Zooplankton Biomass

Offshore crustacean zooplankton biomass data is available from 1976 (Bartone and Schelske 1982) for northern Lake Michigan. No information is presented on sampling intensity or technique. A comparison with the 1984 and 1985 biomass data (Table 21) revealed that no significant difference in crustacean biomass exists between 1976 and 1984/1985.

Another longer sequence of data is described by Scavia *et al* (1986). Except for 1977, 1982, 1983 and 1984, zooplankton samples were primarily from an offshore station (40-m depth) west of Benton Harbor, MI. A comparison of the mean offshore 1984 and 1985 lake-wide biomass data to Scavia's station indicates good agreement (Fig. 21). From Figure 21, there appears to be no obvious trends in zooplankton biomass.

Indicators of Trophic Status

Zooplankton have potential value as assessors of trophic status (Gannon and Stemberger 1978). Rotifers, in particular, respond more quickly to environmental changes than do the crustacean plankton and, therefore, are more sensitive indicators of changes in water quality. Composition of the rotifer community (Gannon and Stemberger 1978) can be used to evaluate trophic status.

In 1983 the six predominant rotifers in descending order of relative abundance were *P. vulgaris*, *Synchaeta sp.*, *K. cochlearis*, *P. major*, *K. longispina* and *C. unicornis*, while in 1984 an 1985 the predominant rotifers were *K. cochlearis*, *K. longispina*, *P. vulgaris and Synchaeta* sp. The 1983 and 1984 rotifer composition suggests an oligotrophic association. A rotifer community dominated by *Polyarthra vulgaris*, *Keratella cochlearis*, *Conochilus unicornis* and *Kellicottia longispina* has been considered to be an association indicative of an oligotrophic community by Gannon and Stemberger (1978).

The high relative abundance of *Diaptomus sicilis* and *Limnocalanus macrurus* (Table 18) and the occurrence of *Senecella calanoides* ($1.0/m^3$, 1984; $0.8/m^3$, 1985), all oligotrophic indicators (Gannon and Stemberger 1978, McNaught *et al* 1980a), also suggested oligotrophic offshore conditions for the entire lake.

The calanoid/cyclopoid plus cladoceran ratio has been used as a measure of trophic status in the Great Lakes (Gannon and Stemberger 1978, McNaught *et al* 1980a). Calanoid copepods generally appear best adapted for oligotrophic waters, while cladocerans and cylopoid copepods are relatively more abundant in eutrophic waters. In 1983 and 1984 along the north-south transect, the plankton ratios were high and similar, except at the far north and the southern extreme of the lake (Table 22). In 1985 the calanoida/cyclopoid plus cladoceran ratio was high and similar with a slight increase from north to south. Makarewicz (1988) suggested that a lower quality of water occurred south of Station 18 and north of Station 57 in 1983 and 1984. In addition, the eutrophic rotifer indicator species *Trichocerca pusilla* and *Trichocerca multicrinis* were observed exclusively at Station 6 and the northern stations, reinforcing the idea that a lower water quality exists at these locations. Because the northern stations (Stations 57, 64 and 77) and Station 6 were not sampled in 1985, further discussion on geographical differences observed in previous years is not possible.

The low plankton ratios (0.20 - .41; Table 22) in 1983 and 1984 at the far northern end of Lake Michigan (Stations 64 and 77) were very similar to those observed in 1973 at the Straits of Mackinac (Gannon and Stemberger 1978). Gannon and Stemberger (1978) implied that more eutrophic conditions exist within this area of a low calanoid to cladoceran plus cyclopoid ratio. Abundance of the oligotropic *Limnocalanus macrurus* and *Diaptomus sicilis* was significantly lower in these far northern stations, while *Eubosmina coregoni* and *Bosmina longirostris*, often associated with more productive conditions, increased at the far northern stations in 1983 and 1984 (Makarewicz 1988). In addition, several mesotrophic algal species were more predominant at the northern stations (Makarewicz 1988).

With a zooplankton abundance between those of Lakes Erie and Huron (Table 8), the presence of an oligotrophic rotifer association, a plankton ratio between those of Huron and Erie, the domination of the calanoids and the fairly abundant presence of the oligotrophic indicator species *Diaptomus sicilis* and *Limnocalanus macrurus*, the offshore waters of Lake Michigan in 1985 are best characterized as mesotrophic/oligotrophic. A similar conclusion utilizing zooplankton abundance and species composition was drawn in 1984. Phytoplankton composition and abundance and water chemistry suggest a similar trophic status (This Study).

Trophic Interactions

Between 1975 and 1984, gradual declines in spring total phosphorus and summer epilimnetic chlorophyll *a* are reported (Scavia *et al* 1986). However, long-term changes of phytoplankton and zooplankton biomass are not apparent in this study. Perhaps, the minimal changes observed in chlorophyll *a* are not reflected in the high variability phytoplankton and zooplankton estimates. Scavia *et al* (1986) points out that the changes in total phosphorus and chlorophyll *a* are consistent with expectations of nutrient load control.

However, the significant lake-wide changes in zooplankton and phytoplankton composition may not be expected from nutrient control. A species new to the plankton assemblage, *Daphnia pulicaria*, is at least a subdominant organism within the offshore. In addition, *Leptodora kindtii, Daphnia galeata mendotae, Diaptomus ashlandi* and *Cyclops bicuspidatus* have returned to and exceeded abundances observed in 1954 during a period of low alewife abundance.

Scavia *et al* (1986) suggests that predatory pressure from alewife suppressed large-bodied zooplankton until the early 1980's. Decline of the alewife population as the major forage fish (Jude and Tesar 1985, Wells and Hatch 1983) has been linked to the increasing population of stocked salmonines in Lake Michigan (Stewart *et al* 1981, Jude and Tesar 1985). The decrease in alewife abundance has reduced size-selective predation on larger zooplankton allowing larger zooplankton to return (Scavia *et al* 1986, Wells 1970, Kitchell and Carpenter 1986).

Table 23 lists correlation coefficients of phytoplankton abundance versus total phosphorus and zooplankton for each cruise. For each cruise, 11 stations covering the entire length of the lake were sampled over a short period of time. Interpretations of the correlations were as follows: A negative correlation between a zooplankton group and phytoplankton implied grazing pressure on phytoplankton, while a positive correlation between total phosphorus and phytoplankton abundance would suggest an enhancement of phytoplankton abundance due to phosphorus availability. Except for the late autumn cruises, correlation of total phosphorus to phytoplankton abundance was weak.

As suggested by Scavia *et al* (1986), *D. pulicaria* appears to have a negative impact on phytoplankton abundance especially during mid-August when abundance is high. Interestingly, when *Daphnia galeata mendotae* is added to the correlation analysis, the correlation coefficient increases from -.25 to -.60 suggesting that *D. galeata mendotae* is also having a major effect on phytoplankton abundance and size during August. A similar correlation existed in 1984 (Makarewicz 1988). This would be an added effect in that *D. galeata* has increased since 1954 apparently in response to decreased selective pressure by the alewife. The calanoids appear to exert grazing pressure throughout the sampling season but more heavily in the spring (Table 23).

The causes of the changes in species composition of phytoplankton are much more difficult to evaluate. Changes in herbivore species composition could affect algal species composition. Certain zooplankton feed on a wide variety of algae of different sizes and shapes, and with or without sheaths (Gliwicz 1980, McNaught et al. 1980b, Porter and Orcutt 1980). Other zooplankton are highly selective in the algal types ingested. Cellular forms are ingested more readily than filamentous or spinuosus forms and zooplanktonic filtration rates, growth and survivorship are greater when feeding on cellular forms (Porter 1973, Arnold 1971). Selective grazing and utilization can remove species, reduce population size and change the size composition in the algal community. Figure 22 demonstrates the apparent effect of *Daphnia* abundance on the mean size of Lake Michigan phytoplankton community. The size of the edible algae (non-filamentous and colonial forms) decreased during the summer and early autumn when *Daphnia* were present. A decrease in *Daphnia* appeared to result in an increase in edible plankton size. However, biomass of filamentous algae did not increase as might be expected by the Bergquist *et al* (1985) model. Alternatively, grazer utilization of an algal species can result in enhancement of primary productivity of that species by increased selection for faster growing genotypes (Crumpton and Wetzel 1982).

Nutrient effects can also affect composition of phytoplankton. For example, *Asterionella* is a successful competitor at high Si/P ratios, *Fragillaria* can dominate at intermediate ratios and *Stephanodiscus* grows well when Si/P ratios are low (Kilham and Kilham 1978; Kilham and Tilman 1979; Tilman 1978, 1980). At high Si/P ratios, diatoms can effectively out compete blue-green algae (Holm and Armstrong 1981). Similarly, as silica is reduced and combined nitrogen declines, green algae can compete less effectively with nitrogen-fixing blue-greens (Smith 1983). Effects on phytoplankton composition from both top-down and bottom-up routes are expected but are difficult to separate in this descriptive study.

LAKE HURON

Phytoplankton

Species lists (Table A7) and summary tables of abundance (Table A8) and biovolume (Table A9) are in Volume 2 - Data Report (ATTACHED FICHE). A summary of water chemistry parameters is presented in Table 8.

Picoplankton

Picoplankton abundance in 1985 (mean = 22,923; maximum of 4.4×10^4) was not dissimilar from 1983 (mean = 19,343; maximum of 6.3×10^4 cells/mL) and 1984 (mean = 14,396; maximum of 3.5×10^4 cells/mL). On a numerical basis, the picoplankton represented 92.3% of the total cells in 1985 but because of their small biomass, only 3.4% of the total biovolume. Their relative numerical dominance in 1985 was comparable to 1983 (86.6%) and 1984 (83.9%) (Makarewicz 1987, 1988). Historically, the picoplankton have not been considered in evaluations of the plankton community of Lake Huron. Their high abundance tends to distort relative abundance values and does not allow reasonable comparisons with the historical data. For this reason, they are not considered further in this discussion.

Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1985 was comprised of 213 species representing 70 genera from eight divisions (Table 24). Compared to 1983 and 1984, a sizeable reduction in the number of species (1983 - 35%; 1984 - 32% and genera (1983 - 20%; 1984 - 24%) was observed. With no significant changes in the sampling regime and water chemistry between years, these differences are attributable to changes in counters that occurred in this year.

The annual average phytoplankton density and biovolume in 1985 (mean±S.E.) were 2,020 ±113 cells/mL (2,567±178 cells/mL, 1983; 2,772±196 cells/mL, 1984) and 0.34±.021 mm^3/L (0.37±.040 mm^3/L, 1983; 0.39±.039 mm^3/L, 1984), respectively. Similar to 1983 and 1984, the Bacillariophyta possessed the largest number of species (120) and biovolume (67.4% of the total, Table 25), while the second largest number of species (32) was observed for the Chlorophyta (Table 24). The Chrysophyta accounted for the second highest biovolume (10.0%). The relative biovolume of the Cryptophyta in 1985 (9.3%) was similar to 1983 (8.5%) and 1984 (9.2%) while Chlorophyta biovolume was higher than 1984 but similar to 1983 (Table 25). Cyanophyta biovolume was higher in 1985 than 1984. Pyrrophyta biovolume was considerably lower in 1985 than in 1983 and 1984 (Table 25). Highest overall densities were attained by the Cyanophyta (19.5% of the total abundance) and the Bacillariophyta (18.2% of the total abundance). Unidentified organisms represented 26.1% of the total cells.

Seasonal Abundance and Distribution of Major Algal Groups

Seasonally, abundance (cells/mL) increased from April to a maximum (31,428 cells/mL) in mid June (Fig. 23). After a decline in abundance during early August, algal abundance increased in late August, similar to 1984 (Makarewicz 1988). Unlike 1984, abundance increased by the autumn sampling dates. The seasonal biovolume distribution generally followed the seasonal abundance distribution (Fig. 23). Abundance was not significantly different between the late spring and fall (Fig. 23).

Considering biovolume, the Bacillariophyta were dominant throughout the study period accounting for as much as 78.2% but never less than 41.7% of the phytoplankton biovolume (Fig. 24). The large drop in the relative importance of diatoms in August of 1983 (to ~30% of the total biovolume, Makarewicz 1987), which was not observed in 1984, was observed in August of 1985 (41.7% of the total biovolume). The bloom of *Rhizosolenia eriensis* in August of 1984, which was suggested as the cause of the dominance of the diatoms throughout the summer of 1984 (Makarewicz 1988), was again observed in 1985 (Table 26) even though there was a drop in relative importance of diatoms.

With the decrease in importance of diatoms, the Chrysophyta, as in 1984, accounted for 29% of the biovolume by late August. Diatoms regained their spring predominant position by autumn (Fig. 24). As in 1984, the Cryptophyta appeared to increase in importance during the study period.

Geographical Abundance and Distribution of Major Algal Groups

In 1983 the mean phytoplankton abundance for the sampling period generally decreased from north to south to Station 15, where abundance increased and then decreased slightly southward (Fig. 26 in Makarewicz 1987). *Asterionella formosa*, *Cyclotella comensis*, *C. comta*, and *C. ocellata* all had a higher biomass at Station 61 in 1983 (Makarewicz 1987). A similar algal geographical distribution was not observed during 1984 (Makarewicz 1988) but was observed in the 1985 geographical biomass distribution (Fig. 25). Algal biomass decreased from northern Lake Huron to Station 32 (northeast of Saginaw Bay), where biomass increased and then decreased south of Station 27. This geographical pattern was determined by the diatoms (Fig. 25). The Chrysophyta, Chlorophyta, Pyrrophyta and Cyanophyta had a higher biomass south of Station 32 than north of Saginaw Bay (Fig. 25). Cyanophyta biomass was generally higher in northern Lake Huron, except for Station 61, and decreased precipitously to Station 32 before increasing in southern Lake Huron (Stations 27, 12, 9 and 6).

The annual geographical pattern of higher algal biomass south of Station 32 was generally observed seasonally during the spring and fall cruises and somewhat evident for the summer cruise (Fig. 26). The annual pattern of a decrease in algal biomass from the northern Station 54 to the centrally located Station 37 was observed only during the spring and summer but not the autumn (Fig. 26). The increase in biomass south of Station 27 in the spring was caused predominately by diatoms and somewhat by chrysophytes. The increase in biomass north of Station 32 was caused solely by diatoms. During the summer, the increase in biomass south of Station 27 was caused by an increase in chrysophytes (mainly *Chrysosphaerella longispina*), while north of Station 32 , the diatoms were the cause of the biomass increase. In the autumn, the small but general increase in biomass in southern Lake Huron was generally caused by the cryptophyte, *Rhodomonas minuta* var. *nannoplanktica*.

Regional and Seasonal Trends in the Abundance of Common Taxa

The definition of common species (Makarewicz 1987, 1988) has been revised to accommodate the removal of the picoplankton. Common species (Table 27 - 29) were arbitrarily defined as those possessing a relative abundance of >0.5% of the total cells or >0.5% of the total biovolume. Using the new definition, the data from 1983 (Table 27) and 1984 (Table 28) were revised. Seven new common species were observed in 1985 from 1983 and 1984 (Table 30).

Because of the similarity of the 1985 common species list to the 1983 and 1984 list, a species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987, 1988). Only new common species are discussed below.

Bacillariophyta

Diatoma tenue var. *elongatum* Lyngb.

This species is widely distributed in the Great Lakes. Its greatest abundance generally occurs in areas that have undergone significant eutrophication (Stoermer and Kreis 1980). In 1974 significant population densities were generally restricted to stations in Saginaw Bay and stations near shore. Average density in southern Lake Huron in 1974 was 0.94 cells/mL with a maximum abundance of 77.5 cells/mL (Stoermer and Kreis 1980).

In 1983 and 1984, abundance averaged 5.4 and 1.3 cells/mL, respectively. Maximum and average abundance in 1985 was 23 (Station 9, June) and 2.2

cells/mL, respectively. Abundance was higher at those stations (92 and 27) just south and east of Saginaw Bay during the spring (Fig. 27). A bloom was evident throughout the lake in early June (Fig. 27).

Synedra ulna var. *chaseana* Thomas

Stoermer and Yang (1970) considered this species to be an oligotrophic offshore dominant in the Great Lakes. Abundance in southern Lake Huron in 1974 was 2.2 cellls/mL with a maximum bloom of 25 cells/mL (Stoermer and Kreis 1980). In 1983 and 1984, this organism was not observed. In 1985, average abundance was low (0.2 cells/mL) and maximum abundance reached only 4 cells/mL. Because of this organism's relatively large size (411um x 3.95um x 3.00um), it has a high biomass relative to its abundance. Biomass was highest during June in the northern waters of Lake Huron (Fig. 28).

Cryptophyta

Rhodomonas lens Pasch. & Rutt.

Stoermer and Kreis (1980), in their intensive survey of southern of Lake Huron in 1974, did not observe this species. Average abundance in 1984 and 1985 was similar (3.4 cells/mL-1983, 26.4 cells/mL-1984, 24.2 cells/mL-1985). A bloom (maximum = 90 cells/mL) of this species was evident throughout the lake in late April (Fig. 29).

Cyanophyta

Agmenellum quadruplicatum (Menegh.) Breb.

Huber-Pestalozzi (1938) notes that isolated specimens of *A. quadruplicatum* are found in a wide variety of habitats but that it often becomes abundant in waters which are organically enriched. Stoermer and Ladewski (1976) state that records of distribution from the Great Lakes are insufficient to determine its range of occurrence. In southern Lake Huron, average abundance was low in 1974 (0.87 cells/mL) with a maximum bloom of 238 cells/mL (Stoermer and Kreis 1980). Abundance in 1984 (15.4 cells/mL) was similar to the average abundance in 1985 (29.9 cells/mL). A maximum abundance of 1,145 cells/mL (Table 29) occurred at Station 27 in June. The August bloom of this species appeared to be restricted to southern Lake Huron (Fig. 30).

Anabaena sp.

No species of *Anabaena* were identified in 1985. In 1974 at least two species, *Anabaena flos-aquae* and *Anabaena subcylindrica* were observed. In 1974 *A. flos-aquae* reached a densitiy as high as 55.9 cells/mL (mean = 20.6 cells/mL) in southern Lake Huron (Stoermer and Kreis 1980). Mean abundance of all species of *Anabaena* in 1983 (2.1 cells/mL) and 1984 (1.4 cells/mL) was lower than 1985 (12 cells/mL). Abundance appears to have increased in 1985 from 1983 and 1984 but generally to have decreased from 1974.

Chlorophyta

Green coccoid - ovoid

Abundance in 1983 and 1984 averaged 1.5 cells/mL. Abundance in 1985 increased to 21.8 cells/mL with one bloom reaching 123 cells/mL. If abundance levels increase further, identification of this organism(s) is warranted.

Monoraphidium setiformae (Nyg.)Kom.-Legn.

This species was not observed in the intensive study of 1974 (Stoermer and Kreis 1980). Average abundance was low in 1983 (0.2 cells/mL) and 1984 (0.9 cells/mL) compared to 1985 (22.6 cells/mL). A bloom (maximum = 164 cells/mL) was observed at Station 32 in June of 1985.

Colorless flagellates

Stelexomonas dichotoma Lack.

This species appears to be increasing in importance within Lake Huron. Stoermer and Kreis (1980) in their intensive study of southern Lake

Huron and Makarewicz (1988) in a lake-wide study did not observe this organism. Abundance in 1984 was 3.9 cells/mL. In 1985 average abundance was 21.7 cells/mL. A maximum abundance of 237 cells/mL was observed April, 1985 at Station 6.

Historical Changes in Species Composition

The literature pertaining to phytoplankton of the offshore waters of Lake Huron is sparse. Fenwick (1962, 1968) published some qualitative data, and Parkos *et al* (1969) listed species observed. Quantitative data from a single offshore station in 1971 exists (Munawar and Munawar 1982, Vollenweider *et al* 1974) and preliminary data covering 21 stations in 1971 are partially analyzed (Munawar and Munawar 1979). Stoermer and Kreis (1980) reported on an extensive sampling program in southern Lake Huron including Saginaw Bay during 1974 and provided an extensive bibliography on Huron algal research. Lin and Schelske (1978) reported on a single offshore station sampled in 1975. An intensive study of the entire lake basin was performed in 1980 (Stevenson 1985), but only a few offshore stations were sampled.

Diatoms have been the dominant division since 1971. Dominant diatoms in 1971 included species of *Asterionella formosa*, *A. gracillima*, *Cyclotella comta*, *C. glomerata*, *C. ocellata*, *C. michiganiana*, *Melosira islandica* and *M. granulata*. In addition, species such as *Fragilaria crotonensis* and *Tabellaria fenestrata* were common, while cryptomonads, such as *Rhodomonas minuta* and *Cryptomonas erosa*, contributed very heavily during different seasons. The following similar common diatoms were observed in 1974, 1983, 1984 and 1985: *Asterionella formosa*, *Cyclotella comensis*, *C. ocellata*, *Fragilaria crotonensis*, *Tabellaria flocculosa* and *Rhizosolenia* spp. *Synedra filiformis* was present in 1983, 1984 and 1985 (2.1 cells/mL) but was not as common as in the 1974 southern Lake Huron plus Saginaw Bay data (52.4 cells/mL). The lower abundance of *C. stelligera* in 1983, 1984 (Makarewicz 1987, 1988) and 1985 compared to 1971 (Munawar and Munawar 1979), 1974 (Stoermer and Kreis 1980) and 1975 (Lin and Schelske 1978) was caused by the lack of sampling during mid and late July when this species is dominant.

Both *Cryptomonas erosa* and *Rhodomonas minuta* var. *nannoplanktica* were dominant in 1971, 1974, 1983, 1984 and 1985. Dominant chrysophytes in 1971 were *Dinobryon divergens* and *Chrysosphaerella longispina*. In 1983, 1984 and 1985, these two species were common along with *D. cylindricum* and *D. sociale* (Table 29). Haptophytes were also numerically abundant. In general, the diatom *Synedra filiformis* decreased in abundance after 1974, while *D.* cylindricum and *D. sociale* var. *americanum* have increased in abundance. In general, species composition of common offshore algae has changed little since 1971.

Indicator Species

Dominant diatoms in Lake Huron in 1983, 1984 and 1985 were *Rhizosolenia* sp. (*R. eriensis* in 1984 and 1985), *Tabellaria flocculosa* (biomass) and *Cyclotella comensis* (numerically). Four species of *Cyclotella* (*C. comensis, C. comta, C. kuetzingiana* var. *planetophora* and *C. ocellata*) represented 9.4%, 6.6% and 7.5% of the total biomass in 1983, 1984 and 1985 (Makarewicz 1987; 1988, Table 29). *R. eriensis* is often grouped with oligotrophic offshore dominants even though it may occur in greater abundance in areas receiving some degree of nutrient enrichment (Stoermer and Yang 1970). Except for *C. comensis*, whose ecological affinities are poorly understood (Stoermer and Kreis 1980), these species are associated with oligotrophic or mesotrophic conditions. *Tabellaria flocculosa* is commonly associated with mesotrophic conditions (Tarapchak and Stoermer 1976).

Dominant chrysophytes (1983-1985) included *Dinobryon sociale* var. *americanum, D. divergens* and *D. cylindricum*, which are often associated with several small members of the genus *Cyclotella* (Schelske *et al* 1972, 1974) included in the classical oligotrophic diatom plankton association of Hutchinson (1967). Dominant cryptophytes, cyanophytes and dinoflagellates were *Rhodomonas minuta* var. *nannoplanktica, Cryptomonas erosa* (not in 1983), *Anacystis montana* var. *minor* and *Ceratium hirundinella* from 1983 to 1985.

Because of the limited number of studies of the Lake Huron offshore phytoplankton assemblage, a limited basis for evaluating the long-term effects of eutrophication exists. The ratio of mesotrophic to eutrophic species in Lake Huron has not changed since 1971 (Table 31). This suggests that the trophic status of the lake has not changed.

Those studies available (Munawar and Munawar 1979, Nicholls *et al* 1977a, Schelske *et al* 1972, 1974) indicate that the waters of northern Lake Huron generally contain phytoplankton assemblages indicative of oligotrophic conditions. The designation of the offshore waters of southern Lake Huron as oligotrophic based on phytoplankton composition in 1983, 1984 and 1985 is not unlike the trophic status suggested by Stoermer and Kreis (1980) for the offshore waters of southern Lake Huron in 1974. This agrees well with the trophic status as determined by the biomass classification scheme of Munawar and Munawar (1982). With a mean biomass of 0.38, 0.42 and 0.35 g/m^3 for 1983, 1984 and 1985, respectively, Lake Huron would be classified as oligotrophic.

Historical Changes in Community Abundance and Biomass

Quantitative phytoplankton data exist for the offshore waters of Lake Huron from at least 1971. The collections of Stoermer and Kreis (1980) were from 44 stations in southern Lake Huron and Saginaw Bay. Lin and Schelske (1978) collected from one offshore station in 1975. In both studies, phytoplankton were concentrated on millipore filters rather than by the settling chamber procedure used in the 1980 (GLNPO Data Base), 1983 (Makarewicz 1987), 1984 (Makarewicz 1988) and 1985 studies. Thus, data sets are not strictly comparable.

Munawar and Munawar (1982) collected with a 20-m integrating sampler from April to December of 1971. Because Utermohl's (1958) procedure for enumeration of algae was employed, these data were directly comparable to the 1980, 1983, 1984 and 1985 data sets. Unfortunately, biomass data for only one offshore station of Lake Huron was available for 1971 (Munawar and Munawar 1979). Phytoplankton biomass between 1971, 1980, 1983, 1984 and 1985 was not significantly different (Fig. 31). The consistency of the mesotrophic-eutrophic ratio through time, the similarity of dominant species and the occurrence of oligotrophic and mesotrophic indicator species suggest little change in the trophic status of the offshore waters of Lake Huron.

LAKE HURON

Zooplankton

Annual Abundance of Zooplankton Groups

Species lists (Table A10) and summary tables of abundance (Table A11) and biomass (Table A12) are in Volume 2 - ATTACHED FICHE. The zooplankton assemblage of 1985 comprised 57 species representing 34 genera from the Calanoida, Cladocera, Cyclopoida, Mysidacea and Rotifera. The diversity of species was similar to 1983 (58 species, 33 genera) and 1984 (53 species, 31 genera).

The Rotifera possessed the largest number of species (30) and relative abundance (40.3%) followed by the Calanoida and Cyclopoida. The Copepoda nauplii accounted for 30.4% of the total zooplankton abundance (Table 32). The Calanoida (48.5%) followed by the Cladocera (26.3%) contributed the most biomass to the zooplankton community. Rotifera represented only 1.5% of the zooplankton biomass. Average density and biomass were 67,668 ± 9,390 (mean + S.E.) organisms/m^3 (46,230 - 1983; 55,369 ± 7,176 - 1984) and 59.2 ± 7.03 mg/m^3 (mean + S.E.) (27.3 ± 2.3 mg/m^3 - 1984).

Seasonal Abundance and Distribution of Major Zooplankton Groups

Seasonally, abundance and biomass distributions were essentially identical (Fig. 32) with abundance and biomass increasing from the spring through the fall and decreasing precipitously on the last sampling day in November. The maximum in abundance and biomass observed in August of 1984 (Makarewicz 1988) was not observed in 1985.

Cladocera abundance and biomass was low in the spring and fall and high in the summer (Fig. 33 and 34). Abundance of the nauplius stage of the Copepoda was inversely related to the abundance of the Calanoida and Cyclopoida; that is, abundance of the nauplius stage decreased from June onward, and Cyclopoida and Calanoida generally increased into the autumn. Rotifera abundance and biomass increased from the spring to mid November and then decreased by the last sampling date in late November (Fig. 33 and 34).

Common Species

Common Crustacea species (Table 33) were arbitrarily defined as those possessing a relative abundance of >0.1% of the total zooplankton abundance or 1.0% of the total biomass. Rotifera species were considered common if they accounted for >1.0% of the total zooplankton abundance or biomass. Although the number of common species were essentially identical in 1983 (22) (Makarewicz 1987) and 1984 (22)(Makarewicz 1988) and 1985 (21), some small differences in common species composition were evident.

Limnocalanus macrurus and *Notholca squamula*, common in 1985, were not common species in 1983, while *Tropocyclops prasinus mexicanus* was not common in 1984. *Mesocyclops edax* and *Eubosmina coregoni* were common in 1983 and 1984 but not in 1985. *Polyarthra remata* and *Leptodora kindtii* were common in 1984 but not in 1985. *Daphnia retrocurva*, *D. schodleri* and *D. catawba* were common in 1983 but not in 1984 and 1985. *D. catawba* was observed only in the zooplankton tows that included the hypolimnion (long hauls) in 1983 (Makarewicz 1987), but data from hypolimnion tows taken in 1984 and 1985 are not included in this report.

Changes in Species Composition

Crustacean studies of the offshore waters of the Lake Huron basin are few in number. Patalas (1972) sampled 51 stations including Saginaw Bay in August of 1968 with a 77-um mesh net. In 1971 eleven stations on a transect from the Straits of Mackinac to the origin of the St. Clair River were sampled from May to November with a 64-um net (Watson and Carpenter 1974). A 64-um mesh net was used to sample ~18 stations on eight dates from April to October of 1974 in southern Lake Huron including Saginaw Bay (McNaught *et al* 1980a). The 1980 study of Evans (1983, 1986) included stations mostly from the near-shore rather than the offshore. The 1983 sampling cruises included 10 stations sampled (64-um mesh net) for each of the three sampling dates between August and September. In 1984 eight stations on five cruises (64-um mesh net) from May-December 1984 were sampled.

In August of 1968, calanoids were dominated by *Diaptomus sicilis, D. ashlandi* and *D. minutus* (Patalas 1972). These same three species were predominant in 1971, 1974/75, 1983, 1984 and 1985 with the addition of *Diaptomus oregonensis* in 1983, 1984 and 1985 (Table 34). Abundance of *Diaptomus ashlandi* and *Diaptomus sicilis* appears to have increased since 1971 (Table 34). The 1974 *D. minutus* abundance was similar to the 1985 abundance but higher than either the 1971, 1983 or 1984 samples. The 1971, 1983, 1984 and 1985 data were only from offshore sites, while the 1974 data included samples from the eutrophic waters of Saginaw Bay. The oligotrophic indicator species, *Limnocalanus macrurus*, appeared not to have significant changes in abundance (Table 34), when the limited 1983 data set are excluded.

In 1971, 1974/75, 1983, 1984 and 1985, the dominant cyclopoid was

Cyclops bicuspidatus thomasi (Table 34). *Tropocyclops prasinus mexicanus* increased in abundance from 1971 to 1983 (Table 34). However, a notable decline occurred from 1983 (577/m^3) to 1984 (21/m^3) to 1985 (72/m^3), which may be related to the differences in the timing of the fall sampling in these two years. *Mesocyclops edax* appears to have increased in abundance (Table 34) from 1971 to 1983. Abundance was lower in 1984 and 1985 than in 1983. *Cyclops vernalis*, often associated with eutrophic conditions in Lake Erie, was higher in abundance in the 1974 data. The higher abundance in 1971 may again have been due to the inclusion of the eutrophic Saginaw Bay stations in the 1974 data set.

Dominant cladoceran species in August of 1968 were *Bosmina longirostris* and *Holopedium gibberum*. Similarly, *H. gibberum, B. longirostris* and *Eubosmina coregoni* were dominant in the August-October period in 1974. Comparison of the offshore data from 1971 with 1984 and 1985 suggests a decrease in the abundance of *Bosmina longirostris* (Table 34). A comparison to the 1983 data is not warranted because samples were taken only during the August through October period (Makarewicz 1987).

Quantitative data on species of daphnids were not available for 1971, but *Daphnia retrocurva*, *Daphnia galeata mendotae* and *D. longiremis* were commonly found in Lake Huron (Watson and Carpenter 1974). The dominant daphnid species in 1983, 1984 and 1985 was *D. galeata mendotae*.

Evans (1985) recently reported that *Daphnia pulicaria* was a new species dominating Lake Michigan. In 1983 in Lake Huron, *D. pulicaria* was observed to be the third most important cladoceran, while in 1984 it dropped to fifth in rank abundance (Makarewicz 1987, 1988). Mean station abundance increased from north to south with a mean density of 431 organisms/m^3 for stations south of Saginaw Bay in 1983. In 1985 abundance never reached the levels of 1983 and 1984 (Fig. 35), even though it was the second most abundant daphnid.

D. catawba was first reported in waters of Lake Huron in 1983 (Makarewicz 1987). This species was not considered to be either a common or a less common species of the Great Lakes (Balcer *et al* 1984). It appeared exclusively in the long hauls from Lake Huron in 1983. A maximum abundance of 1,610 organisms/m^3 was observed in August at Station 12. It was not observed in 1984 and 1985.

Bythotrephes cederstroemi was first reported by Bur *et al* (1986) in Lake Huron in December of 1984. In fact, Bur *et al*'s report of this predaceous cladoceran species in Lake Huron is from the data base collected by GLNPO and reported on in Makarewicz (1988). Abundance was very low with only one observation (3.5/m^3) in December of 1984 in southern Lake Huron (Station 12). In 1985 this species was found throughout the lake by August and November (Table 35). Average abundance was 4.3/m^3 with a maximum density of 72/m^3 at Station 61 in November.

Rotifera

Stemberger *et al* (1979) collected rotifers with a Nisken bottle at 5-m intervals to 20m followed by 10-m intervals to the bottom of the lake at a number of offshore and nearshore areas. Samples were pooled and filtered through a 54-um mesh net on the vessel. The greatest abundance of rotifers in Lake Huron in 1974 occurred in late spring and early summer (Stemberger *et al* 1979), a period in which samples were taken in 1984 and 1985 but not in 1983. Comparison of these data indicate that abundant rotifer species in 1974 and 1984/1985 were *Conochilus unicornis*, *Polyarthra vulgaris*, *Keratella cochlearis* and *Kellicottia longispina*. *C. unicornis* was the dominant rotifer, while *K. cochlearis* was the co-dominant in 1983 to 1985 (Table 36). *Keratella* cochlearis was dominant in 1974.

Evans' (1986) study of mostly nearshore areas suggests a difference in dominant rotifer species between the offshore and nearshore waters. Dominant rotifer species in Evans' study included in descending rank: *Keratella cochlearis*, *Kellicottia longispina*, *Synchaeta* sp. and *Conochilus unicornis*. *Polyarthra vulgaris* and *Conochilus unicornis*, which were co-dominant in the offshore waters in 1974, 1983, 1984 and 1985, were less abundant in the nearshore waters. These differences in horizontal distribution of zooplankton are expected in Lake Huron and are affected by the physical limnology of the lake (McNaught *et al* 1980a). For example, in the warmer inshore areas, cladocerans grow best, while calanoids tend to be found in offshore waters (McNaught *et al* 1980a). Nearshore waters are also influenced by the movement of the zooplankton-rich eutrophic waters of Saginaw Bay into the nearshore zone south of the Bay. In general, inshore zooplankton densities are greater than offshore densities (McNaught *et al* 1980a).

Geographical Abundance and Distribution of Zooplankton Groups

The mean station zooplankton abundance and biomass decreased from Station 61 in the north to Station 32, opposite of Saginaw Bay and then increased in southern Lake Huron (Fig. 36 and 37). The Cladocera, Calanoida, Cyclopoida, Rotifera and the nauplius stage of the Copepoda all followed this same pattern of decreasing abundance/biomass southward from the north to Station 32 and then an increase southward into Southern Lake Huron. A similar geographical abundance and biomass pattern was observed in 1983 and 1984 (Makarewicz 1987, 1988). McNaught *et al* (1980a) observed abundance increases of the cyclopoid copepodites, *C. bicuspidatus* and *T. prasinus*, north to south in southern Lake Huron.

An interesting trend exists in the 1983 and 1985 data sets. Total zooplankton abundance from Station 12 increased northward with the exception of Station 32 in 1983 and 27 in 1985. Station 32, located northeast, and Station 27, located east of the mouth of Saginaw Bay, would appear to be too far offshore to be influenced by the higher abundances in the Bay. However, Stoermer and Kreis (1980) have observed midlake stations in southern Lake Huron to be affected by populations of phytoplankton from Saginaw Bay in 1974. Although the transport of eutrophication-tolerant algal populations into Lake Huron from Saginaw Bay has been mitigated in recent years (Stoermer and Theriot 1985), the transport of zooplankton could still take place.

A number of zooplankton species possessed horizontal distributions that varied along the north-south axis. These differed between 1983, 1984 and 1985. In 1983 and 1984, *Diaptomus minutus* abundance was lower in the northern portion of the lake, but not in 1985 (Fig. 38). Geographical abundance of *D. minutus*, *D. ashlandi* and *D. sicilis* were similar in 1985; abundance was higher at Stations 61 and 54 in the north and Station 9 in the south (Fig. 38). Geographically, no obvious abundance pattern of *D. sicilis* and *D. ashlandi* were obvious in 1983 and 1984.

Abundance of *Daphnia pulicaria* was higher in southern Lake Huron in 1983 but not in 1984 and 1985 (Fig. 39). Yet *Holopedium gibberum* abundance was consistently higher at the northern stations from 1983 to 1985. The rotifer, *Conochilus unicornis*, also had a geographical abundance pattern restricted to northern Lake Huron (Fig. 40). *Notholca squamula* and *Synchaeta* sp. had higher abundances in southern Lake Huron in 1984 and 1985 (Fig. 41). *Daphnia galaeta mendotae*, *Kellicottia longispina*, *Keratella cochlearis* and *Gastroper stylifer* had no consistent geographical pattern from 1983 to 1985.

Indicators of Trophic Status

The calanoid/cyclopoid plus cladoceran ratio (the plankton ratio) has been employed as a measure of trophic status in the Great Lakes (Gannon and Stemberger 1978, McNaught *et al* 1980a). Calanoid copepods generally appear best adapted for oligotrophic conditions, while cladocerans and cyclopoid copepods are relatively more abundant in eutrophic waters. Using this ratio, McNaught *et al* (1980a) identified the offshore waters of southern Lake Huron to have a higher quality water than the nearshore waters. Because the 1983, 1984 and 1985 samples were all from the offshore, no such comparison could be made. However, the 1985 and the 1983 and 1984 plankton ratio was high and variable from north to south (Table 37). The far northern station (Station 61) and perhaps the far southern station (Station 6) appear to have a lower water quality, as indicated by the plankton ratio. A comparison of the 1983, 1984 and 1985 mean phytoplankton ratio suggests a lower quality of water at Stations 6 and 9 and perhaps at Station 61. Water chemistry data from 1987 and 1988 suggest these southern stations have higher chloride, sulfate, total phosphorus and turbidity levels and lower silica levels than the rest of the lake (Makarewicz 1987, 1988).

Station 61 might be influenced by waters from Lake Michigan. The plankton ratio at Station 61 in Lake Huron is comparable more to northern Lake Michigan than the rest of Lake Huron (Table 38). The physical transport of plankton populations by water currents from Lake Michigan into Lake Huron through the Straits of Mackinac has been demonstrated (Schelske *et al* 1976). A similar conclusion was arrived at in 1984 (Makarewicz 1988).

Species considered to be indicators of eutrophic waters were rare compared to the Western Basin of Lake Erie and possessed limited distributions. Interestingly, the eutrophic indicator *Filinia longiseta*, was observed at only three sites at the extreme southern ($52/m^3$-Station 6) and northern stations ($331/m^3$-Station 61) and just east of the eutrophic waters of Saginaw Bay ($317/m^3$-Station 27). *Brachionus* spp. was not observed, while *Trichocerca multicrinis* ($91/m^3$) another eutrophic species was found only at Station 90 in southern Lake Huron.

The rotifer community in 1983 (Makarewicz 1987), 1984 (Makarewicz 1988) and 1985 was dominated by *Polyarthra vulgaris*, *Keratella cochlearis*, *Conochilus unicornis* and *Kellicottia longispina*. This association has been considered to be indicative of an oligotrophic lake (Gannon and Stemberger 1978). The offshore abundances of *Holopedium gibberum, Conochilus unicornis* and *Kellicottia longispina* were greater north of Saginaw Bay than south of it (Table 39) suggesting better water quality in northern Lake Huron. *H. gibberum* has been reported as an indicator of oligotrophic lakes in Sweden (Pejler 1965) but was widely distributed in both oligotrophic and eutrophic waters in the Laurentian Great Lakes region (Gannon and Stemberger 1978).

The low zooplankton abundance, compared to that of Lake Erie (Table 8), the presence of the oligotrophic rotifer association, the domination of the calanoids, and the fairly abundant presence of the oligotrophic *Diaptomus sicilis* (McNaught *et al* 1980a) suggest oligotrophic offshore waters for Lake Huron in 1983, 1984 and 1985.

Historical Trends in Abundance

Offshore crustacean zooplankton data collected with similar mesh size nets (64 um) exist for Lake Huron. The 1970 study (Watson and Carpenter 1974; 88 collections) sampled the whole lake, while the 1974/75 work (McNaught *et al* 1980a; 46 collections) was from southern Lake Huron. A comparison of the cruise averages for Crustacea (excluding nauplii) (Fig. 42) suggests changes in abundance from 1970 to 1985. However, these differences are not statistically significant ($P<0.05$). A similar conclusion of no change in trophic status since 1970 was reached with phytoplankton abundance.

Stemberger *et al* (1979) collected Rotifera samples from 44 stations in southern Lake Huron in 1974. Samples were taken with a Nisken bottle at 5-m intervals to 20 m and at 10-m intervals below that. After collection, samples were immediately pooled and filtered through a 54-um net. In 1983 (Makarewicz 1987), 1984 (Makarewicz 1988) and 1985, a vertical tow (64-um net) was taken from 20 m to the surface. Both studies are not directly comparable in that Stemberger's *et al* (1979) work represented the entire water column, while the

1983 and 1984 studies were basically samples from the epilimnion. The 1974 , 1984 and 1985 sampling periods were not significantly different. A comparison of mean station seasonal abundance suggests that the spring abundance in 1984 and 1985 was lower than in 1974 (Fig. 42). Also, abundance of major species was lower in 1983, 1984 and 1985 than in 1974 (Table 36). This difference in abundance is related to two things: (1) Stemberger *et al* (1979) used a smaller meshed net which gives a more accurate quantitative sample and thus a higher abundance (Likens and Gilbert 1970); and (2) two different segments of water were sampled and compared. For example, Makarewicz and Likens (1979) observed higher abundances and different species composition between the hypolimnion and epilimnion of Mirror Lake, New Hampshire.

Trophic Interactions

Within the offshore, there appears to be few changes that could be attributed to nutrient control. Phytoplankton biomass and zooplankton abundance of the offshore waters of Lake Huron in 1971, 1980, 1983, 1984 and 1985 are not significantly different. In general, offshore species composition of phytoplankton has changed little since the early 70's. However, there has been a significant lake-wide change in species composition of zooplankton. Prior to 1983, there are no records of *Daphnia pulicaria* in Lake Huron. From 1983 to 1985, this species was the third to fifth most abundant cladoceran in Lake Huron. The appearance of the large *D. pulicaria* in the Great Lakes is generally attributed to a release from size-selective predation of forage fish in Lake Michigan (Scavia *et al* 1986, Makarewicz 1988) and Lake Erie (Makarewicz 1988). In 1984 *D. pulicaria* abundance was negatively correlated with decreased phytoplankton abundance, which suggested an additional grazing pressure on phytoplankton stocks in Lake Huron. This may have influenced the mean size of the phytoplankton. When abundance of *Daphnia* increased during the summer of 1983, 1984 and 1985, the mean size of the phytoplankton community decreased (Fig. 44-47). In the autumn, the high negative correlation between phytoplankton abundance and *D. pulicaria* and Calanoida abundance (Table 40) suggests the diminished size of the phytoplankton community is related to grazing of *D. pulicaria* and calanoids. The addition of the exotic cladoceran species *Bythotrephes* to the zooplankton community may cause further changes in both the zooplankton and the phytoplankton. *Bythotrephes* has been implicated in causing a decrease in *Daphnia* populations in Lake Michigan (Lehman 1988).

LAKE ERIE

Phytoplankton

The species lists (Table A13) and summary tables of abundance (Table A14) and biovolume (Table A15) are in Volume 2 - Data Report (ATTACHED FICHE). A summary of water chemistry paramters is presented in Table 8.

Picoplankton

Picoplankton abundance in 1985 (mean = 22,988 cells/mL; maximum of 1.4×10^5 cells/mL) was lower than in 1983 (33,171 cells/mL) and 1984 (38,075 cells/mL). On a numerical basis, the picoplankton represented 83.6% of the total cells and 1.2% of the total biomass. Historically the picoplankton have not been considered in evaluations of the plankton community of Lake Erie. Their high abundance tends to distort relative abundance values and does not allow reasonable comparisons with the historical data. For this reason, they are not considered further in this discussion.

Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1985 was comprised of 369 species representing 101 genera (Table 41). The number of species and genera observed annually have changed only a few percentage points from the 1983 to 1985. The total number of species in 1983 (372), 1984 (356) and 1985 (369) was considerably higher than the 125 to 150 species observed in all basins in 1970 (Munawar and Munawar 1976).

In 1985, as in 1983 and 1984, the diatoms possessed the greatest number of species (162, 43.9% of the total species) and biovolume (63.3%) of the total) (Tables 41 and 43), while the second largest number of species (115) was observed for the Chlorophyta (Table 41). These diversity observations represent significant changes from 1970, when the Chlorophyta possessed the largest number of species (78) and only 21 diatom species were observed (16.3% of the species) (Table 42). However, diatoms were still the dominant group in 1970 accounting for 53% of the biomass (Munawar and Munawar 1976).

Highest relative densities were attained by the Cyanophyta (25.8%) in 1985, as well as in 1983 and 1984. In 1983 and 1985, the Chlorophyta had the second highest biomass, while in 1984 they were fourth, slightly lower than the Pyrrophyta and Cryptophyta (Table 43).

Seasonal Abundance and Disbribution of Major Algal Groups

The average density and biomass for the sampling period were 4,483 cells/mL (6,187 cells/mL, 1983; 5,331 cells/mL, 1984) and 1.22 g/m^3 (1.35 g/m^3, 1983; 0.86 g/m^3, 1984) (Table 44). Seasonally, abundance (cells/mL) peaked in late April, leveled off during August before reaching a minimum in late November. The fall/early winter secondary maximum observed in 1984 (Makarewicz 1988) was not observed in 1985 (Fig. 48a).

A different pattern emerged from the seasonal biovolume totals. Similar to the seasonal abundance pattern, a peak in biomass occurred in April. However, biovolume was low in early August followed by a major peak in biomass later in August (Fig. 48b). A second peak in biomass occurred in late November (Fig. 48b). Except for the lower biomass in 1983, 1984 and 1985, the timing of the spring and autumn biomass peaks is similar to that observed in 1970 (Munawar and Munawar 1976).

The biomass peak during the summer was due to a bloom of *Actinocyclus normanii* in the Western Basin. During the summer cruise, biomass for the Western Basin was high (3.04 g/m^3) compared to the Central (0.80 g/m^3)and Eastern Basin (mean = 0.64 g/m^3). *A. normanii* accounted for as much as 29% of the biomass in the Western Basin on this cruise. It was not abundant in the Central Basin and was not observed on this cruise in the Eastern Basin.

As in 1983 and 1984, diatoms were the dominant group throughout 1985

(62.3% of the total biovolume). However, seasonally their importance varied considerably (Fig. 49) but in a pattern similar to 1983 and 1984 (Makarewicz 1987, 1988). Diatoms were dominant during the first cruise in April (~60% of the biovolume) and became co-dominants with the Chlorophyta in August. A similar succession and relative importance were observed in 1970 (Munawar and Munawar 1976) and 1983 and 1984 (Makarewicz 1987 and 1988).

Geographical Abundance and Distribution of Major Algal Groups

Abundance for the sampling period varied geographically and was similar to the 1983 and 1984 observations (Makarewicz 1987 and 1988). Abundance generally decreased eastward (Fig. 50). The Western Basin possessed a greater biomass (1.62 g/m^3, S.E.=.27) than the Central Basin (1.38 g/m^3, S.E.=.14) and the Eastern Basin (0.54 g/m^3, S.E.=.08) (Table 44). The considerably greater abundance of the Western Basin was attributed to the picoplankton (Fig. 50). However, the higher biomass of the Western Basin (Table 42) was due to the greater abundance and biomass of the Bacillariophyta, Cyanophyta, Chlorophyta, Cryptophyta and Chlorophyta in the Western Basin (Fig. 51).

As in 1983 and 1984, the general pattern of higher abundance in the Western Basin was observed on each sampling date (Fig. 52). In 1983 at least 12 common species had higher abundances in the Western Basin (Makarewicz 1987). Similarly in 1984 and 1985, many of the same species had geographical abundance pattern with maxima in the Western or Central Basin (Table 45). A difference in species abundance from the various basins of Lake Erie has been documented previously (Munawar and Munawar 1976, Davis 1969b).

Regional and Seasonal Trends in the Abundance of Common Species

The definition of common species (Makarewicz 1987, 1988) has been revised to accommodate the removal of the picoplankton. Common species (Table 46 - 48) were arbitrarily defined as those possessing a relative abundance of >0.5% of the total cells or >0.5% of the total biovolume. Using the new definition, the data from 1983 (Table 46) and 1984 (Table 47) were revised. Twelve new common species were observed in 1985 from 1983 and 1984 (Table 49). A species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987, 1988). Only new common species are discussed below.

Bacillariophyta

Skeletonema potamos (Weber) Hasle & Evens

In Europe, this species is sometimes present in large quantities in eutrophic lakes and appears to be favored by slightly saline conditions (Hustedt 1930 cited in Stoermer and Ladewski 1976). Although this is a new common species in 1985 compared to 1983 and 1984, abundance was slightly higher in 1983 (23.7 cells/mL) compared to 1985 (22.7 cells/mL). This species was prevalent in the Western Basin in 1985 and was not observed in the Central and Eastern Basins. This species does appear to be a eutrophic indicator.

Suriella biseriata var. *bifrons*

This large species (96um) was not observed in 1984, while average cruise densities were <0.1 cells per mL in 1983. In 1985 abundance averaged only 0.1 cell/mL with a maximum abundance of 7 cells/mL at Station 55 in the Western Basin in November.

Rhizosolenia eriensis H.L. Sm.

Hohn (1969) concluded that *R. eriensis* was present in large numbers in the Western Basin prior to 1930, had disappeared and was only occasionally observed through the 60's. Vorce (1882) in a non-quantitative study noted *R. eriensis* to be very abundant from February to May in the 1880's. Munawar and Munawar (1976) categorized this species as a "less common" (less than 5% of the total phytoplankton biomass) in 1970.

In 1985 this mesotrophic species had a high biomass in the Western Basin in April (9.1% of the total phytoplankton biomass in Cruise 1 and 2) and November (20.6% in Cruise 5) (Fig. 53). In 1983 and 1984, this species was not considered to be common even though abundance was higher in 1983 than in 1985 (Table 48). The high biomass in 1985 was due to a much larger size of this species than in 1983. In 1985 only two length and width measurements were taken. This paucity of measurements may bias the data and may affect the interpretation of the data.

Cyanophyta

Anabaena flos-aquae

This species was frequent during summer in the Western Basin in 1970 (Munawar and Munawar 1976). Average whole lake abundance in 1983 (2.1 cells/mL) and 1984 (0.3 cells/mL) was considerably lower than the 1985 average (36 cells/mL). Although this eutrophic species was observed in all basins during the summer of 1985 (range = 0 to 200 cells/mL), maximum abundance was observed in a bloom in the Western Basin (Station 57) during August that reached 3,199 cells/mL. This one bloom is the cause of this species being designated a common species in 1985.

Anabaena spiroides

As *Anabaena flos-aquae*, this eutrophic species was frequent in the Western Basin during the summer of 1970 (Munawar and Munawar 1976). Average abundance was substantially higher in 1985 (68.2 cells/mL) compared to 1983 (12.1 cells/mL) and 1984 (25.3 cells/mL). In fact, this species was observed only once in 1985 at station #57 (abundance = 6,283 cells/mL).

Pyrrophyta

Amphidinium sp.

This flagellate was a dominant species in the Central Basin during the spring accounting for 9.7% of the total phytoplankton biomass (Fig. 54). Although abundances in 1983 and 1985 were similar, biomass was considerably higher in 1985 due to the considerably larger length in 1985 (19.1 um = mean length) than in 1983 (14.6 um = mean length) (Table 50). 59 size measurements were made between 1983 and 1985. Thus the increase in biomass appears to be real and could be due to a new species. *Amphidinium* was abundant, but not common (> %5 of the total biomass), in the Eastern Basin in 1970 (Munawar and Munawar 1976). Prescott (1964) comments that this genus is mostly marine but may be found in brackish water or in fresh water near the sea.

Chlorophyta

Botryococcus sp.

This organism was not observed in 1983 or 1984. Only one occurrence of this species (1,554 cells/mL) was noted in 1985 at Station 30 in November.

Scenedesmus quadricauda

Abundance of this species has increased slightly from 1983 (mean = 11.3 cells/mL) and 1984 (14.4 cells/mL) to 1985 (22.9 cells/mL). A bloom (311 cells/mL) of this species occurred in November, 1985 at Station 55 in the Western Basin. Munawar and Munawar (1976) in the intensive study of Lake Erie in 1970 did not list this species as common.

Oeogonium sp.

Stoermer and Ladewski (1976) have found large populations only in highly eutrophied areas such as western Lake Erie, Saginaw Bay of Lake Huron and a few localities in Lake Ontario. In 1985 *Oedogonium* was a dominant species in the Central Basin but in not the Western Basin (Fig. 55). In the Central Basin, it accounted for 11.5% of the total phytoplankton biomass in Cruise 4

(August). Similarly in August of 1970, this species was prevalent (10.0 % of the total biomass) in the Central Basin (Munawar and Munawar 1976). Abundance in 1983 and 1984 was lower than in 1985 (Table 50).

Changes in Species Composition

Davis (1969b) has reviewed the extensive earlier work on Lake Erie, while Munawar and Munawar (1982), Gladish and Munawar (1980) and Nicholls (1981) discuss the more recent material. Verduin (1964) has concluded that before 1950 the phytoplankton of western Lake Erie had been dominated by *Asterionella formosa*, *Tabellaria fenestrata* and *Melosira ambigua*, whereas in 1960-61 the dominant forms had been *Fragilaria capucina*, *Coscinodiscus radiatus* (probably *Actinocyclus normanii f. subsalsa*) and *Melosira binderana* (=*Stephanodiscus binderanus*).

As with Munawar and Munawar (1976), the 1983 study (Makarewicz 1987) confirmed Verduin's (1964) observations that those species dominant before 1950 (*A. formosa*, *T. fenestrata* and *M. ambigua*) continued to be less important in the 1983 collections. *Actinocyclus normanii f. subsalsa (=Coscinodiscus rothii)* and *Stephanodiscus binderanus* were dominant in 1961-62 (Verduin 1964) and in 1970 (Munawar and Munawar 1976). In 1983 *Actinocyclus normanii f.* subsalsa was only the fifth most prevalent diatom and in 1984 was not even a common species (Makarewicz 1988). In 1985 it was the second most prevalent diatom on a biomass basis (Table 48).

Fragilaria capucina was a dominant in 1961 but not in 1970. In 1983 and 1984, *Fragilaria capucina* was the second most prevalent diatom in the Western Basin and in the entire lake (Makarewicz, 1987; 1988). In 1985 *F. capucina* was the dominant diatom on a numerical basis with an average abundance of 188 cells/mL.

Dominant species in 1983, 1984 and 1985 were *Stephanodiscus niagarae*, *Fragilaria crotonensis*, *Fragilaria capucina*, *Cosmarium sp.*, *Cryptomonas erosa*, *Rhodomonas var. nannoplanktica, Oscillatoria subbrevis,* and *Ceratium hirundinella* (Table 46-48). *Asterionella formosa, Coelastrum microporum, Oscillatoria subbrevis, Anabaena sp., Aphanizomenon flos-aquae* and *Peridinium* sp. were also dominant occasionally from 1983 to 1985.

Asterionella formosa has not been prevalent in Lake Erie since prior to 1950. Verduin (1964) stated that before 1950 *Asterionella formosa* was a dominant species in western Lake Erie. Similarly, Davis (1969b) reported *Asterionella* as the dominant organism in the spring pulse of the Central Basin prior to 1949. Numerous workers (Hohn 1969, Nichols *et al* 1977b, Munawar and Munawar 1976, Gladish and Munawar 1980) reported a decline in *A. formosa* after 1950. The low abundance of *A. formosa* was apparent into 1983 (mean = 8.7 cells/mL, Makarewicz 1987).

Average density was 73.4 cells/mL in 1984 representing 5.6% of the biomass (Makarewicz 1988). Maximum density in March of 1938 was 96.6 cells/mL with a March mean of 553 cells/mL (Hohn 1969). No samples were taken in March of 1984, but the April average was 226 cells/mL (maximum abundance = 942 cells/mL in May). In 1984 during the three cruises in April and May, *Asterionella formosa* was the dominant spring species on a biomass basis and the second most important diatom on a numerical basis (Table 51). In 1985 average density was only 15.4 cells/mL.

Although occurrences of common and dominant species in 1970, 1983, 1984 and 1985 were similar, dramatic decreases in abundance of these species were evident (Table 52). This pattern was evident in all three basins.

Indicator Species

Munawar and Munawar (1982) concluded that the species of phytoplankton found in 1970 usually occurred in mesotrophic and eutrophic conditions. Common species in 1983 included eutrophic indicators (*Fragilaria capucina*, Melosira *granulata*, *Peridinium aciculiferum*, *Pediastrum simplex*, *Scenedesmus ecornis*) and mesotrophic indicators (*Stephanodiscus niagarae*, *Fragilaria crotonensis*, *Tabellaria flocculosa*) (Makarewicz 1987). A similar set of major common species occurred in 1984, including the mesotrophic indicators *Stephanodiscus niagarae*, *Fragilaria crotonensis* and *Tabellaria flocculosa* and the eutrophic indicators *Fragilaria capucina*, *Peridinium aciculiferum* and *Pediastrum simplex*. The eutrophic indicators *Melosira granulata* and *Scenedesmus ecornis*, common in 1983, were present in 1984 and 1985 but were not common (>0.1% of the total cells or >0.5% of the total biovolume). Interestingly, a mesotrophic indicator, *Melosira islandica*, not common in 1983, was common in 1984, accounting for 4.1% of the total biomass, but not common in 1985 (Table 48).

Evidence of a shift in trophic status since 1970 is provided by a comparison of distribution of dominant diatom indicator species in 1970, 1983, 1984 and 1985 (Table 53). The number of dominant eutrophic species has decreased, while the number of dominant mesotrophic species has increased. The mesotrophic-eutrophic ratio suggests a shift to mesotrophic conditions for the Western Basin.

Historical Changes in Community Biomass

Between 1927 and 1964, a large and consistent increase in the total quantity of phytoplankton of the Central Basin had occurred (Davis 1964, 1969b). Nichols *et al* (1977b) observed that a decline in nearshore phytoplankton of the Western Basin occurred between 1967 and 1975. However, Gladish and Munawar (1980) discounted this finding and suggested that no realistic conclusion could be drawn from a comparison of biomass between 1970 and 1975.

The mean basin weighted biomass was 3.4, 1.49, 0.8 and 1.26 g/m^3 in 1970, 1983, 1984 and 1985, respectively. A 56 to 76% reduction in algal biomass has occurred in offshore waters of Lake Erie from 1970 to 1983 - 85.

This reduction in biomass is evident for all seasons of the year (Fig. 56). The historically highly productive Western Basin (Munawar and Burns 1976) has had a steady decrease in biomass from 1958 to 1985 (Fig. 57). Similar decreases in phytoplankton biomass were observed in the Central and Eastern Basin (Fig. 58). Since 1975, chlorophyll concentrations have decreased in all basins (Fig. 59). Phosphorus levels have also decreased in all basins (Fig. 60). Between 1970 and 1983-1985, dramatic reductions in maximum biomass of common species have occurred (Table 52). For example, in the nuisance species *Aphanizomenon flos-aquae*, a 96% reduction in the maximum biomass observed has occurred since 1970. *Stephanodiscus binderanus*, a eutrophic indicator species, has decreased in biomass by 90% in the Western Basin. Similary, *Fragilaria capucina*, another eutrophic indicator, has decreased (99% reduction) dramatically within the phytoplankton community.

Based on maximum biomass concentrations (Vollenweider 1968), Munawar and Munawar (1976) classified the Western Basin as highly eutrophic, the Eastern Basin as mesotrophic and the central basin between the mesotrophic and eutrophic conditions. Using the same classification system of Vollenweider (1968):

Ultra-oligotrophic	<1 g/m^3
Mesotrophic	3 to 5 g/m^3
Highly eutrophic	>10 g/m^3

the Western Basin (maximum biomass = 5.4 g/m^3, Station 57, August) in 1985 would be between mesotrophic and eutrophic, the Central Basin (maximum biomass = 4.5 g/m^3, Station 36, November) would be mesotrophic and the Eastern Basin (maximum biomass = 1.6 g/m^3, Station 10, April) would be between oligotrophic and mesotrophic. Similarly, the classification scheme of Munawar and Munawar (1982), based on mean phytoplankton biomass, suggests an improvement in water quality between 1970 and 1983-85 (Table 54) in all basins of Lake Erie. Similar conclusions were arrived at using the 1984 data base (Makarewicz 1988).

LAKE ERIE

Zooplankton

Annual Abundance of Zooplankton Groups

The species list (Table A16) and summary tables of abundance (Table A17) and biomass (Table A18) are in Volume 2 - Data Report (ATTACHED FICHE). Average density and biomass (mean ± S.E.) for the study period was 221,577 ± 26,988 (159,615/m3 ± 34,000 - 1984; 288,341/m^3 ± 27,443 - 1983) and 105.8 ± 9.9 mg/m3 (53.6 ± 6.2 mg/m^3 - 1984) (Table 44). The zooplankton assemblage of 1985 comprised 89 species representing 44 genera from the Calanoida, Cladocera, Cyclopoida, Harpacticoida and the Rotifera. Compared to 1983 (37 genera, 66 species) and 1984 (39 genera, 81 species), a 25.8% and a 8.9% increase, respectively, in the number of species was observed. This difference was attributable to an increase in the number of rotifers from 1983 to 1984 (34 to 48, 49 in 1985). The increase in species numbers from 1984 to 1985 is generally due to an increase in cyclopoid species (4 to 9).

The Rotifera possessed the largest number of species (49) and relative abundance (70.8%) followed by the Cyclopoida and Calanoida. The nauplius stage of the Copepoda accounted for 15.2% of the total zooplankton abundance (Table 55). On a biomass basis, the importance of the Rotifera dropped to 5.5% of the zooplankton biomass because of their small size, while the Cladocera contributed 35.1% of the biomass (Table 55). The relative abundance and biomass patterns were fairly consistent over the past three years (Table 55).

Seasonal Abundance and Distribution of Major Zooplankton Groups

Seasonally, abundance and biomass distribution (Fig. 61) was greatest in August than in other times of the year. Similar seasonal patterns in abundance and biomass were observed in 1983 (Makarewicz 1987) and 1984 (Makarewicz 1988). In 1983 and 1984, a second peak in abundance was observed in the spring generally due to a pulse in rotifer populations.

The 1985 seasonal abundance pattern (Fig. 62) of the various zooplankton groups was similar to 1983 and 1984 (Makarewicz 1987, 1988). Cladocera and Calanoida abundance was low in the spring, peaked in early August and decreased the rest of the year. Similar to 1983 and 1984, Cyclopoida abundance varied little (Fig. 62). Unlike 1983 and 1984, Rotifera abundance did not peak in the spring but a population peak was observed in August as other years (Fig. 62). The rotifer peak in 1983 and 1984 was in May, a month not sampled in 1985. The biomass seasonal distribution pattern of the major zooplankton groups generally mimicked the abundance pattern (Fig. 63).

Geographical Abundance and Distribution of Zooplankton Groups

Geographically, zooplankton abundance was similar to 1983 and 1984 (Makarewicz 1987, 1988), with abundance being higher in the Western Basin and decreasing easterly to Station 78 (Fig. 64). Within the Western Basin, abundance and biomass peaked at the far eastern station (Station 55), rather than the the most western station (Station 60) as in 1985. Similar to 1984, abundance increased east of Station 78 but remained low in the Eastern Basin (Stations 15 and 9). Similar to 1984, the Rotifera were the cause of the high zooplankton abundance in the Western Basin although the Copepoda nauplii also had a slightly higher abundance in the Western Basin (Stations 60, 57, 55) (Fig. 64).

In 1984 biomass was similar in all three basins of Lake Erie (Fig. 60a, Makarewicz 1988). In 1985 this was not the situation. Average biomass was higher in the Central Basin than in the Western or Eastern Basin (Table 44). The low biomass in the Western Basin compared to the Central Basin was due to a lower biomass at Station 60 of all zooplankton groups (Fig. 65). Similarly in 1985, a low Cladocera abundance was observed at Station 60 in 1983 and 1984 (Makarewicz 1987, 1988).

Cladocera abundance peaked at Station 55 and generally decreased eastward through the Central Basin to Station 31 (Fig. 64). At Station 31 a major peak in Cladocera biomass occurred; it was caused by a bloom of *Daphnia* galaeta mendotae (Fig. 65). In the Eastern Basin, Cladocera biomass (Fig. 65) was similar to the Central Basin except for Station 31. Cyclopoida and Calanoida abundance was higher in the Central and Eastern Basin as compared to the Western Basin.

Common Taxa

Common Crustacea species (Table 56) were arbitrarily defined as those possessing a relative abundance >0.1% of the total abundance or 1.0% of the total biomass. Rotifera species were considered common if they accounted for >1.0% of the total zooplankton abundance or biomass. The number of common species in 1983 (25), 1984 (27) and 1985 (28) was similar, but there were changes in composition of the common species (Table 57). The most notable difference was the absence of *Daphnia pulicaria* from the common species list in 1985. This species was common in 1984 but not in 1983 or 1985. Much of the variability in common species was due to changes in common rotifer species from year to year. A group, such as rotifers, that typically have a short lifespan and explosive population growth over a short period would have different species succeeding each other very quickly. A few weeks difference in the sampling schedule, similar to what occurs each year with the EPA monitoring network, would result in different rotifer species being common as observed.

Changes in Species Composition

Brooks (1969) suggested that a shift in the Lake Erie cladoceran assemblage was evident by 1948-49 with smaller cladocerans, such as *Daphnia galeata mendotae*, *D. retrocurva* and *Diaphanosoma* sp., being more abundant than in 1938-39. In 1970 the most commonly found *Daphnia* species were *D. retrocurva*, *D. galeata mendotae* and *D. longiremis* (Watson and Carpenter 1974); *Bosmina* longirostris and *Eubosmina coregoni* were more abundant (Watson and Carpenter 1974). Predominant cladoceran species in 1983 were small forms similar to those observed in 1970. In 1983 the predominant Cladocera in descending order were *Eubosmina coregoni*, *Daphnia galeata mendotae*, *Bosmina longirostris*, *Diaphanosoma leuchtenbergianum* and *Chydorus sphaericus* (Makarewicz 1987). In 1984, on a numerical basis, the predominant Cladocera were *Daphnia galaeta mendotae*, *Eubosmina coregoni*, *Bosmina longirostris*, *Daphnia pulicaria*, *Daphnia retrocurva* and *Chydorus sphaericus* (Makarewicz 1988). In 1985, on a numerical basis, the predominant Cladocera in descending order were *Eubosmina coregoni*, *Daphnia galaeta mendotae*, *Bosmina longirostris*, *Daphnia retrocurva*, *Diaphanosoma* sp. and *Chydorus sphaericus* (Table 55). Between 1983 and 1985, essentially the same dominant species, with the exception of *D. pulicaria*, were present with minimal change in rank abundance. These small changes in rank order may be attributed to the difference in the seasonal sampling pattern between 1983 and 1985.

On a biomass basis, *Daphnia pulicaria* (mean biomass = 7.5mg/m^3) was the dominant Cladocera for the lake, with a major bloom in August of 1984 (Makarewicz 1988). Although *D. pulicaria* was present in August of 1985, average lakewide biomass was low (0.7mg/m^3) compared to 1984 (7.8 mg/m^3). Instead in 1985, *Daphnia galaeta mentodae* was the dominant Cladocera (on a biomass basis) and was most prominent in the Central and Eastern Basins (Fig. 66). Average biomass for the study period was 13.0 mg/m^3 with a maximum biomass of 23.7 mg/m^3 observed at Station 31 in August.

A rare species in the offshore waters of the Western Basin in 1929-30 (Tidd 1955), *Chydorus sphaericus* was a prominent constituent in the 1950's (Davis 1962) and in 1970 with a higher abundance in the Western Basin (Watson and Carpenter 1974). In 1983, 1984 and 1985, this species contributed 0.2%, 0.1% and 0.3%, respectively, of the total abundance (Makarewicz 1987, 1988)

(Table 56). *Chydorus sphaericus* has established itself as a common species in Lake Erie and is prevalent in the Central Basin (Fig. 67 and 68).

Although not a common species, the discovery of *Bythotrephes cederstroemi* in Lake Erie has attracted considerable attention from Great Lakes researchers (Bur *et al* 1986, Berg and Garton 1988). Its large size (>10 mm) and its potential to effectively crop down *Daphnia* populations (Lehman 1988) and thus affect lower trophic levels, make it a species of interest. Bur *et al* (1986) first reported this organism in Lake Erie in the stomachs of yellow perch and walleye and from vertical zooplankton hauls. The vertical zooplankton hauls cited, but not presented in Bur *et al*, are in fact the data presented here. *B. cederstroemi* was observed throughout the entire lake during the October cruise (Fig. 69). Average density was $4.5/m^3$ with a maximum density of $72/m^3$.

In Europe *Bythotrephes* sp. is found typically in the plankton from May to December (Andrew and Herzig 1984, Nauwerk 1963, Hakkari 1978, de Bernadi and Canali 1975). Although first observed in the autumn in Lake Michigan (Evans 1988), it was detected in June with highest abundance in July and August in the second year of occurrence (Evans 1988, Lehman 1988). In addition to Lake Erie, *Bythotrephes* was observed only during the autumn in Lakes Huron and Ontario (Lange and Cap 1986, Makarewicz 1988, Makarewicz In Press). The autumn predominance of *Bythotrephes* may be related to differences in the forage fish base of Lake Michigan compared to Erie and Ontario and to relaxation of predator pressure during the autumn (Makarewicz In Press).

The prevalence of *Cyclops vernalis* has changed over the past 50 years. In the 1930's, *C. vernalis* was found only in the extreme western end of Lake Erie at the mouth of the Detroit and Maumee Rivers (Tidd 1955). By 1967 it had spread rapidly throughout the lake (Davis 1969a). Patalas (1972) and Watson

(1976) reported it as numerous in the Western Basin of Lake Erie during the late 60's and 70's. This species was not observed in 1983 (Makarewicz 1987), while in 1984 it was not common (Makarewicz 1988) but did average 25.9 organisms/m^3 for the entire lake. In 1985 it was a common species with an average biomass of 1.2 mg/m^3. As in 1984, it was more prevalent in the Western Basin (Fig. 70).

The dominant cyclopoid copepod in 1970 was *Cyclops bicuspidatus thomasi* with *Mesocyclops edax* common in the summer (Watson and Carpenter 1974). Cap (1980) documented a shift in predominant copepods in the Eastern Basin from calanoids in 1928 to cyclopoid copepods, mainly *Cyclops bicuspidatus thomasi*, in 1974. *Tropocyclops prasinus* was present in low numbers (Watson and Carpenter 1974). In 1983, 1984 and 1985, the same three species (*C. bicuspidatus thomasi, M. edax and T. prasinus*) predominated (Makarewicz 1987, 1988, Table 56) with the addition of *C. vernalis* in 1985.

Abundance of *Diaptomus siciloides* has increased in Lake Erie (Gannon 1981). It was most prevalent in the Western Basin and western portion of the Central Basin in the late 60's and 70's (Patalas 1972, Watson 1976). Abundant diaptomids in the Eastern and Central Basins in 1970 were *Diaptomus oregonensis* and *D. siciloides*, which were also the predominant calanoids in Lake Erie in 1983, 1984 and 1985 (Makarewicz 1987, 1988) (Table 56). *D. siciloides* was not a common species (1.0% of total zooplankton abundance) in 1984 and 1985 but was the second most abundant calanoid in both years.

Davis' studies (1968, 1969a) of the zooplankton of Lake Erie included rotifers. Certain soft-bodied rotifers were not identified nor were the samples quantitative for rotifers as a #20 net was employed. However, it is apparently the only lake-wide study of the offshore that included the rotifers.

Species observed to be abundant in 1967 were *Brachionus angularis, B.*

calyciflorus, *Conochilus unicornis*, *Keratella cochlearis*, *K. quadrata*, *Kellicottia longispina*, *Synchaeta stylata* and *Polyarthra vulgaris* (Davis 1968, 1969a). In 1983, 1984 and 1985, a similar group of rotifers was found (Table 58, Makarewicz 1987, 1988). In particular, *Polyarthra vulgaris*, *Conochilus unicornis*, *Keratella cochlearis*, and *Synchaeta* sp. were abundant in the 1967 and the 1983-1985 period (40.9% of the total zooplankton from 1983 to 1985).

East-West Species Distribution

Numerous researchers (e.g. Davis 1969a, Watson 1974, Patalas 1972, Gannon 1981) have documented the differences in species composition and abundance from the Central, Western and Eastern basins of Lake Erie. In 1983 and 1984 (Makarewicz 1987, 1988), a number of species, mostly rotifers, had higher abundances in the Western Basin. Abundances of rotifers were higher in the Western Basin in 1985. However, the geographical pattern was different. Instead of a gradient of high to low from the most western station eastward as in 1984 (e.g. Fig. 59, Makarewicz 1988), rotifer abundance peaked at Station 55, the far eastern station of the Western Basin (Fig. 64). At present we have no explanation for this observation. Phytoplankton abundance and chemistry do not correlate with the rotifer geographical abundance pattern. Rotifera and Crustacea with geographical abundance peaks in the Western Basin are presented in Fig. 66.

Geographically, *Cyclops bicuspidatus thomasi* had a geographical abundance pattern with a maximum in the Central Basin in 1983, 1984 and 1985 (Makarewicz 1987, 1988, Fig. 67). *Mesocyclops edax* and *Diaptomus oregonensis*, which had maxima in the Central Basin in 1983 and 1984, were more prevalent in the Central Basin than in the Western Basin but were not obviously higher than in the Eastern Basin (Fig. 67). *Daphnia pulicaria* was more prevalent in the Central Basin in 1984 and 1985. Its abundance in Lake Erie in 1983 was minimal. *Ascomorpha ovalis*, a rotifer, had a maximum in the Central Basin in

1985 (Fig. 67). *Holopedium gibberum* (1983 and 1985), *Tropocyclops prasinus mexicanus* (1983, 1984 and 1985) and *Ceriodaphnia lacustris* were more prevalent in the Eastern Basin (Fig. 67). Five species, *Cyclopd bicuspidatus thomasi*, *Conochilus unicornis*, *Daphnia galaeta mendotae*, *Daphnia pulicaria* and *Diaptomus oregonensis*, had low abundances in the Western Basin relative to the rest of the lake (Fig. 67)

Indicators of Trophic Status

Geographical distribution of selected zooplankton in Lake Erie is consistent from year to year and often unique to a basin. These geographical distribution patterns of zooplankton probably reflect environmental factors unique to the various basins of Lake Erie. Thus zooplankton have potential value as assessors of trophic status (Gannon and Stemberger 1978). Rotifers, in particular, respond more quickly to environmental changes than do the crustacean plankton and appear to be sensitive indicators of changes in water quality (Gannon and Stemberger 1978). *Brachionus angularis*, *B. calyciflorus*, Filinia longiseta and *Trichocerca multicrinis* are four rotifer species indicative of eutrophy. Also, species in the genus *Brachionus* are particularly good indicators of eutrophy in the Great Lakes (Gannon 1981). Of the three dominant rotifer species in Lake Erie, *Polyarthra vulgaris* is a eurytopic species; *Notholca squamula* is a cold stenotherm often associated with oligo-mesotrophic lakes (Gannon and Stemberger 1978); while some species of *Synchaeta* are eutrophic indicators (Gannon and Stemberger 1978). The lack of dominance of eutrophic indicator species for the entire lake suggests that Lake Erie in 1985, as a unit, is not eutrophic. This would agree with the conclusion derived from phytoplankton indicator species and the algal biomass classification of trophic status.

However, the eutrophic indicators *Brachionus caudatus*, *B. calyciflorus*, *B. angularis*, *Filinia longiseta*, *Trichocerca multicrinis* and *Trichocerca* *cylindrica* had abundances restricted to or significantly higher in the Western Basin (Table 59). Total zooplankton abundance was also higher in the Western Basin. As with phytoplankton biomass and species composition, both rotifer abundance and species composition indicated a greater degree of eutrophy in the Western Basin than in the Central or Eastern Basin.

Another measure of trophic status is the calanoid/cylopoid plus cladoceran ratio (plankton ratio) (Gannon and Stemberger 1978, McNaught *et al* 1980, Krieger 1981). Calanoid copepods generally appear best adapted for oligotrophic conditions, while cladocerans and cyclopoid copepods are relatively more abundant in eutrophic waters (Gannon and Stemberger 1978). In Lake Erie, this ratio increased from west to east in 1983 and 1984 (Table 60) indicating a more productive status for the Western Basin as compared to the rest of the lake.

The higher algal biomass (Table 44) of the Western Basin as compared to the Central and Eastern Basins was reflected in the abundance of zooplankton, species composition and the plankton ratio. Compared to Lakes Huron and Michigan in 1983 and 1984, abundance of zooplankton was greatest and the plankton ratio was lower in Lake Erie (Table 8), indicating the higher trophic status of Lake Erie compared to Lakes Huron and Michigan.

Historical Changes in Abundances

Zooplankton data exist for the Western Basin of Lake Erie from 1939 to 1984. The 1939 (Chandler 1940; 49 collections), 1949 (Bradshaw 1964; 30 collections) and 1959 (Hubschmann 1960; daily collections July and August) collections were taken with a 10-liter Juday trap equipped with a 64-um mesh net in the Western Basin. A 1970 study by Nalepa (1972) is not included in the analysis because it is from the far western end of the basin and may not be representative of the entire Western Basin. The 1961 study of Britt *et al* (1973) sampled twice monthly from mid-June to mid-September, while Davis

(1968) used a 76-um mesh net in July of 1967. Because of the comparable net sizes, all these studies, with the exception of Nalepa's (1972), are comparable to the 1983, 1984 (Makarewicz 1987, 1988) and 1985 work.

A comparison of the April-December Crustacea means of 1939, 1949, 1983 and 1984 suggests an increase in zooplankton abundance from 1939 to 1949 (Fig. 71). Similarly, the mean abundance for July and August from 1939 to 1961 suggests a similar increase in zooplankton (Fig. 72). Both Bradshaw (1964) and Gannon (1981) concluded similarly. Average ice-free abundances from 1949 to 1983 suggest a decreasing but insignificant downward trend (Fig. 71). The decrease in zooplankton abundance from 1983 to 1984 was followed by an increase in 1985 (Fig. 71). No obvious historical trend is evident from these data. Focusing on July and August, where more data are available, an abundance decrease in Cladocera, Copepoda and total Crustacea from the 1961 maximum (Fig. 73) is evident.

A data point in the early 70's would be of interest. Data do exist for the 70's. However, Nalepa's (1972) study is from the far western portion of the Western Basin. Watson and Carpenter (1974) sampled the Western Basin, as well as the Central and Eastern Basins in 1970. Their data are reported as a weighted lake average and are not available to compare with other years in the Western Basin. As the sampling method (1970; vertical hauls, 64-um mesh) is comparable to those used in 1983 and 1984, these data are also directly comparable on a lake-wide basis. A seasonal comparison of weighted lake-wide means suggests little change in zooplankton abundance during the spring and autumn from 1970 to 1983-85 (Fig. 73). Abundance of zooplankton has generally increased from 1983 to 1985 (Fig. 74).

The 1939 and 1961 rotifer samples were collected with a 64-um mesh net, as in the 1983 through 1985 work. An increase in Rotifera abundance in the Western Basin is suggested since 1939 (Fig. 75).

Trophic Interactions

Long-term changes of phytoplankton and zooplankton abundance were apparent. A 56 to 76% reduction in lake-wide offshore algal biomass has occurred from 1970 to 1983 to 1984. Total phosphorus and chlorophyll *a* levels in each basin decreased (Figs. 59 and 60). Similarly, where comparable data are available, zooplankton abundance and biomass decreased in the Western Basin. With the N/P ratio currently exceeding 30 to 1, apparently due to P-control, nuisance blue-green algae species, such as *Aphanizomenon flos-aqua*, decreased. These changes are consistent with expectations of long-term nutrient control.

There are, however, significant changes in the composition of the zooplankton community that can not be attributed solely to nutrient control. The appearance of the large cladoceran *Daphnia pulicaria* in Lake Erie was evident in 1983 and 1984 (Makarewicz 1988). Its dominance with a major bloom in August of 1984 was surprising for it suggested changes in planktivory in Lake Erie (Wells 1970, Brooks and Dodson 1965, Carpenter *et al* 1985, Scavia *et al* 1986). *D. pulicaria* was present in 1985 (mean = $44/m^3$) but because abundance was lower than in 1984 (mean = $492/m^3$), it was not considered a common species (Table 56).

A recovery in the walleye fishery of Lake Erie is evident by the increasing harvest and abundance (Fig. 76 and 77). Annual walleye harvest rapidly increased from 112,000 fish in 1975 to 2.2 million fish in 1977 in the Ohio Lake Erie waters (Western and Central Basins) (Ohio Department of Natural Resources 1989). Annual harvests since 1978 have stayed high but ranged from 1.7 million to the record 4.1 million in 1984 (Ohio Department of Natural Resources 1989). Central Basin harvests have increased dramatically from 1982-1988 (Fig. 77). The initial recovery of the walleye fishery is attributed to the closing of the walleye fishery in 1970 due to mercury contamination and to the exclusion of commercial fishing for walleyes in U.S. waters since 1972 (Kutkahn *et al* 1976).

In addition, salmonid stocking programs exist in New York, Pennsylvania, Ohio and Ontario. New York, which has the largest stocking program, had a target stocking of ~1 million fish in 1987 (F. Cornelius, Personal Communication). Lake trout, Chinook and Coho salmon and various strains of rainbow/steelhead trout are stocked in New York waters. These fish are primarily feeding on smelt (NYSDEC 1987). Seasonal diets of walleye closely followed changes in forage-fish availability (Knight *et al* 1984). Between 1979 and 1981 in the Western Basin of Lake Erie, walleye ate (100% by volume) age-1 shiners *Notropis atherinoides* (emerald shiner) and *N. hudsonius* (spottail shiner) in spring but switched to age-0 clupeids (60-90%) *Dorosoma cepedianum* (gizzard shad) and *Alosa pseudoharengus* (alewife) in late July. Clupeids and shiners composed 25-70% and 10-40%, respectively, of the diets of age-1 or older walleyes in autumn (Knight et al 1984). There does appear to be a difference in walleye foraging from west to east. Recent stomach analyses of walleye from New York and Pennsylvania waters indicate that smelt represent 90% of their diet (NYSDEC 1987 and R. Kenyon, Personal Communication). Smelt are not abundant in the Western and Central Basins.

Dramatic changes have occurred in the forage species of Erie. It is apparent that alewife, spottail shiner and emerald shiner have declined in the Western and Central Basins (Fig. 78) and in Pennsylvania waters (R. Kenyon, Personal Communication). The decline of spottail and emerald shiners between 1982-1985 is impressive in view of the massive increase in walleye harvest in the Central Basin since 1982 (Fig. 77). Fishery biologists have no specific reason for this decline. Besides predation, other possible causes of the decline include climatic factors, turbidity changes, toxic chemicals and the commercial bait industry. Whatever the cause, a decrease in planktivorous shiners has occurred.

Emerald and spottail shiners feed heavily on microcrustacea, some midge larvae and algae (Scott and Crossman 1973, Smith and Kramer 1964, McCann 1959). Evidence gathered by Gray (1942) in Lake Erie during December indicated that *Diaptomus*, *Daphnia*, *Cyclops* and *Bosmina* were all important in the diet of the emerald shiner but at different times of the day. Dymond (1926) noted that in the spottail shiner of Lake Nipigon, *Daphnia* formed 40% of the diet although *Bosmina*, *Sida* and *Leptodora* were also eaten. A good study on shiner diets is needed.

There is good evidence that planktivorous fish abundance has changed as a result of the walleye resurgence but perhaps also from the salmonid stocking program in Lake Erie. Release from planktivore pressure has led to the establishment of the large *Daphnia pulicaria* in Lake Erie by 1984 (Makarewicz 1988). The causes of the decrease in *D. pulicaria* abundance in 1985 ($44/m^3$) from 1984 ($492/m^3$) are not known. It my be related to the establishment and occurrence of *Bythotrephes cederstroemii* in Lake Erie during this study year (this study). Lehman (1988) has suggested that *Daphnia* populations in Lake Michigan have decreased in response to *Bythotrephes* predation. However, *Bythotrephes* was observed in Lake Erie only in the autumn of 1985 (Fig. 69).

Other top-down effects are difficult to evaluate. For example, the decrease in *Aphanizomenon flos-aquae* in Lake Erie is more readily attributed to decreased phosphorus concentration and the increasing N/P ratio (Smith 1983) than by *Daphnia pulicaria* cropping (Lynch 1980, Bergquist *et al* 1985). A clearer water column, as observed in Lake Michigan and attributed to cascading effects (Scavia *et al* 1986), is difficult to evaluate in Lake Erie because of storm induced events in the shallow waters of the Western Basin (Rockwell 1989). However, the reappearance and dominance of *Asterionella formosa* in 1984 may be related to the presence of *D. pulicaria* (e.g. Bergquist *et al* 1985).

In an aquatic ecosystem dominated by large and efficient herbivores, such as *D. pulicaria* and *D. galeata mentodae*, a grazing effect on phytoplankton would be expected. Each year in the annual succession of the zooplankton, the plankton community of Lake Erie changes from one dominated by rotifers and copepods in the spring to rotifers, copepods and cladocerans, including large *Daphnia* species, in the summer. In Lake Erie in 1985, phytoplankton biomass during the summer was inversely correlated with crustacean size (r=-0.81), *Daphnia* biomass (r=-0.63) and Calanoida biomass (r=-0.67)(Fig. 79). However, biomass of filamentous algae (mostly blue-greens) was positively correlated with *Daphnia* (r=0.98) and Calanoida biomass (r=0.92); i.e., biomass of potentially inedible filamentous algae increased to 17% of the total algal biomass during the summer compared to <1.5% in the spring and autumn (Fig.79). Similarly, the dominance of the large diatom *Asterionella formosa* in 1984 and its decline in 1985 may be related to the presence and dominance of *D. pulicaria* in 1984 and its decrease in importance within the ecosystem in 1985 (Bergquist *et al* 1985). Biomass of large unicells, such as *Pediastrum*, and colonial algae either did not change or decreased. Not all changes were attributable to top-down control, however. The decrease in *Aphanizomenon flos-aquae* in Lake Erie is more readily attributed to decreased phosphorus concentration and the increasing N/P ratio (> 30 to 1)(Smith 1983) than by *Daphnia* cropping (Lynch 1980, Hawkins and Lampert 1989, Scavia *et al* 1986).

The size (greatest linear axial dimension) of the algal community in 1985 (minus the filaments and colonials) was inversely related to the abundance of Crustacea and *Daphnia* (r = -0.787) and to the size of the Crustacea (Fig. 79). That is, the weighted mean cell size of the edible portion of the algal community decreased during the summer when the larger Cladocera, such as *D. pulicaria* and *D. galeata mendotae*, were abundant and grazing. These results agree well with models (Carpenter and Kitchell 1984), experimentally verified (Bergquist *et al* 1985) of size-structured plankton communities, that predict shifts to small algae at low biomass of small grazers and shifts to larger algae as grazer size or biomass increase. However, the shifts in algal size and biomass reported here in Lake Erie are changes that occur each summer and do not necessarily represent permanent shifts in size structure of the algal community. The mechanism for the decrease in algal biomass may be similar to that for the spring "clear-water" phase described in some temperate lakes and experimentally shown to be caused by high *Daphnia* biomass (Lampert *et al* 1986).

Top-down and bottom-up control of phytoplankton can be inferred from data on a short-term basis. Correlation coefficients of phytoplankton abundance versus total phosphorus and zooplankton abundance for each cruise on Lake Erie in 1985 are presented in Table 61. For each cruise, 11 stations were sampled covering the entire length of the lake over a two-day period in 1985. Interpretation of the correlations is as follows: A negative correlation between a zooplankton group and phytoplankton implies grazing pressure on phytoplankton, while a positive correlation between total phosphorus and phytoplankton abundance suggests an enhancement of phytoplankton abundance due to phosphorus. All correlations were positive in April suggesting that bottom-up effects were influencing the food web. A different situation was evident by August. Phytoplankton were blooming, and all zooplankton groups had increased in abundance. High negative correlations existed for *Daphnia* spp. and the Calanoida suggesting a top-down influence on phytoplankton abundance. When *D. pulicaria* became dominant in August, a negative fairly high correlation existed between *D. pulicaria* and phytoplankton. By November, other species of *Daphnia* and Calanoida exerted some influence on phytoplankton abundance.

Calanoids were also negatively correlated with phytoplankton abundance throughout the year, except April, suggesting a constant baseline effect on phytoplankton.

At least two factors appear to regulate phytoplankton abundance. In Lake Erie, phosphorus control was evident during the summer, but there were also fairly high negative correlations between phytoplankton and *Daphnia pulicaria*, *Daphnia* spp. and calanoids. Thus top down and bottom up control of the trophic web of lake ecosystems exist simultaneously and either of the two mechanisms of control can vary with season. This support for the bottom up : top down theory of regulation of trophic biomass suggests a stronger coupling of the zooplankton-phytoplankton link in Lake Erie than might be expected for a eutrophic lake (McQueen *et al* 1989).

Comparison of Lakes Michigan, Huron and Erie

A comparison of the phytoplankton assemblage between Lakes Michigan, Huron and Erie reveals lake-specific differences superimposed on a common base. Bacillariophyta comprised 63% to 67% of the average biomass in all three lakes (Fig. 80), with varying percentages of the other Divisions in each lake. Cryptophyta were more common in Lake Michigan (16.1% of biomass) than in the other lakes, Chrysophyta were best represented in Lake Huron (8.7% of biomass), and both Chlorophyta and Pyrrophyta were most abundant in Lake Erie (8.8% and 10.7% of biomass, respectively.

The phytoplankton assemblange from the Western basin of Lake Erie was different from that of the other two basins, and thereby influenced the lake-wide average biovolume statistics for Lake Erie (Fig. 81). For example, Cyanophyta represented 13.13% of the common species biomass in the Western basin but only 1.2% and 0.6% in the Central and Eastern basins, respectively. Likewise, Pyrrophyta comprised 16.9% and 12.1% of the common biomass in the Central and Eastern basins, respectively, but only 2.2% in the Western basin.

The number of common phytoplankton species shared between lake basin pairs ranged from 18 for Lake Michigan and Lake Erie Central Basin to 30 for the Central and Eastern basins of Lake Erie (Table 62). In general, the greatest number of shared species occurred between the three basins of Lake Erie, and the fewest number occurred between Lake Michigan and the Central and Eastern basins of Lake Erie.

A Percentage of Similarity Index (Southwood 1966) was calculated between basin pairs as the sum of the lesser of the percent of total biomass contributed by each shared common species (Table 62; Fig. 82). By this index, the greatest similarity in phytoplankton community structure occurred between the Central and Eastern basins of Lake Erie (70.42%), followed by the phytoplankton in Lakes Michigan and Huron (51.36%), and in Lake Michigan and the Western basin of Lake Erie (42.77%). The least similar phytoplankton communities were between Lake Huron and the Central and Eastern basins of Lake Erie (18.26% and 19.19%, respectively).

The relative contribution to the total biomass of common species was not always similar between lake basins, however. The Relative Percent Difference between biovolumes of each common shared species in each basin pair was calculated as the difference in percent biovolume of each shared species between two lake basins dividied by the average percent biovolume for that species, i.e., RPD = $(|a - b|)/[(a + b)/2]$, where a and b are percent biovolume of a species in lake basin a and b, respectively. An index was then constructed as the percent of shared common species between lake basins with RPD > 1. (An RPD of 1 equates to a difference of magnitude 3). By this index, lower percentages imply more similar plankton communities, and the least different communities were found between Lakes Michigan and Huron (17%), and between the Central and Eastern basins of Lake Erie (17%)(Table 63). The greatest differences in shared species biovolumes were between the Central basin of Lake Erie and Lake Michigan (50%) and between the Central and Western basins of Lake Erie (41%).

Taken together, these analyses indicate that the phytoplankton assemblages were most similar between Lakes Michigan and Huron and between the Central and Eastern basins of Lake Erie. The assemblage from the Western basin was different in many ways from that of the rest of Lake Erie. It appeared to be more similar to that from Lakes Michigan and Huron than from the other two basins of Lake Erie.

Results of a comparison of the zooplankton community structure between lakes are consistent with those of the phytoplankton data. The distribution of biomass among major zooplankton taxa was similar between Lakes Michigan and Huron, except that Lake Huron had about twice the Cladoceran biomass at the expense of the Calanoid copepod biomass (Fig. 83). In Lake Erie, a much lower biomass of calanoid copepods was observed relative to the increases in cyclopoid copepods, cladocerans and rotifers. The Percentage of Similarity Index between lake basins based on zooplankton biomass was, for Lakes Michigan and Huron -59.21%, for Lakes Huron and Erie - 41.95%, and for Lakes Michigan and Erie - 35.42%.

The zooplankton ratio (abundance of calanoid copepods/cyclopoid copepods + cladocerans) for 1983-1985 was similar for Lakes Michigan and Huron, and for the Central and Eastern basins of Lake Erie (Fig. 84), although the Lake Michigan and Lake Huron ratios were about three times greater than those for the Lake Erie basins. Lowest ratios were always associated with the Western basin of Lake Erie, implying more eutrophic conditions there.

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Table 1. Latitude and longitude of plankton sampling stations, 1985.

Station Number	Latitude	Longitude
LAKE ERIE		
LE60	41°53'30"	83°11'48"
LE57	41 49 54	83 01 06
LE55	41 44 18	82 44 00
LE43	41 47 18	81 56 42
LE42	41 57 54	82 02 30
LE73	41 58 40	81 45 25
LE38	42 16 54	81 40 18
LE37	42 06 36	81 34 30
LE36	41 56 06	81 28 42
LE78	42 07 00	81 15 00
LE30	42 25 48	81 12 18
LE31	42 15 12	81 06 24
LE32	42 04 54	81 00 42
LE15	42 31 00	79 53 36
LE63	42 25 00	79 48 00
LE10	42 40 48	79 41 30
LE09	42 32 18	79 37 00
LAKE HURON		
LH93	44°06'00"	82°07'00"
LH92	43 48 30	82 22 00
LH91	43 42 00	82 01 00
LH90	43 24 00	82 18 00
LH61	45 45 00	83 55 00
LH57	45 40 00	83 43 36
LH54	45 31 00	83 25 00
LH53	45 27 00	82 54 54
LH48	45 16 42	82 27 06
LH45	45 08 12	82 59 00
LH43	45 00 48	82 00 30
LH38	44 44 24	82 03 36
LH37	44 45 42	82 47 00
LH32	44 27 12	82 20 30
LH29	44 22 00	81 50 00
LH27	44 11 54	82 30 12
LH15	44 00 00	82 21 00
LH12	43 53 24	82 03 24
LH09	43 38 00	82 13 00
LH06	43 28 00	82 00 00
LAKE MICHIGAN		
LM11	42°23'00"	87°00'00"
LM17	42 44 00	87 25 00
LM18	42 44 00	87 00 00
LM19	42 44 00	86 35 00
LM23	43 08 00	87 00 00
LM27	43 36 00	86 55 00
LM32	44 08 24	87 14 00
LM34	44 05 24	86 46 00
LM40	44 45 36	86 58 00
LM41	44 44 12	86 43 18
LM47	45 10 42	86 22 30

Table 2. Plankton sampling dates for Lakes Michigan, Huron and Erie in 1985.

Cruise	Lake Michigan	Lake Huron	Lake Erie
1	4/15-22	4/22-23	4/24-26
2	5/1-2	4/29-30	4/27-28
3	6/5-6[a]	6/9-10	-
4	8/17-20	8/15-16	8/6-8
5	8/21-23	8/23-25	8/12-14
6	11/14-16	11/18-19	11/21-22
7	11/29-12/4	11/27-28	11/23-25

[a]phytoplankton collections only

Table 3. Sample dates and stations for Lake Erie, 1985. NS=not sampled.

Station Number	4/24-26	4/27-29	8/6-8	8/12-14	11/21-22	11/23-25
60	x	x	x	x	x	x
57	x	x	x	x	x	x
55	x	x	x	x	x	x
43	x	x	x	x	x	x
42	x	x	x	x	x	x
73	x	x	x	x	x	x
36	x	x	x	x	x	x
37	x	x	x	x	x	x
38	x	x	x	x	x	x
78	x	x	x	x	x	x
32	ns	ns	x	x	x	x
31	x	x	x	x	x	x
30	x	x	x	x	x	x
63	x	x	x	x	x	x
15	x	x	x	x	x	x
10	x	x	x	x	x	x
09	x	x	x	x	x	x

Table 4. Sample dates and stations for Lake Huron, 1985.

Station Number	4/22-23	4/29-30	6/9-10	8/15-16	8/23-25	11/18-19	11/27-28
61		X	X		X		X
57	X			X		X	
54		X	X		X		X
53	X			X		X	
48	X			X		X	
45		X	X		X		X
43	X			X		X	
37		X	X		X		X
38	X			X		X	
32		X	X		X		X
29	X			X		X	
27		X	X		X		X
93	X			X		X	
15		X	X		X		X
12		X	X		X		X
92	X			X		X	
9		X	X		X		X
91	X			X		X	
6		X	X		X		X
90	X			X		X	

Table 5. Sample dates and stations for Lake Michigan, 1985.

Station Number	4/15-22	5/1-2	6/5-6	8/17-20	8/21-23	11/14-16	11/29-12/4
11	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X
18	X	X	X	X	X	X	X
19	X	X	X	X	X	X	X
23	X	X	X	X	X	X	X
27	X	X	X	X	X	X	X
32	X	X	X	X	X	X	X
34	X	X	X	X	X	X	X
40	X	X	X	X	X	X	X
41	X	X	X	X	X	X	X
47	X	X	X	X	X	X	X

Table 6. Statistical comparison of zooplankton abundance and biomass from north-south transects, Lake Erie. Average values for all cruises are compared by ANOVA. Listed are probability values. In all cases P>0.05.

	Station 42,47		Station 36,37,38		Station 30,31,32	
	Abundance	Biomass	Abundance	Biomass	Abundance	Biomass
Total	.771	.490	.835	.588	.518	.875
Calanoida	.834	.880	.794	.807	.895	.840
Cyclopoida	.606	.607	.155	.374	.099	.539
Copepoda nauplii	.906	.906	.671	.671	.524	.524
Cladocera	.487	.451	.446	.615	.966	.956
Rotifera	.533	.080	.848	.269	.590	.714

Table 7. Statistical comparison of phytoplankton abundance and biomass from north-south transects, Lake Erie. Average values for all cruises are compared by ANOVA. Listed are probability values. In all cases P>0.05.

	Station 42,47		Station 36,37,38		Station 30,31,32	
	Abundance	Biomass	Abundance	Biomass	Abundance	Biomass
Total	.616	.875	.965	.620	.731	.453
BAC	.827	.529	.650	.367	.959	.300
CHL	.425	.355	.431	.374	.798	.790
CHR	.162	.097	.989	.758	.315	.319
CRY	.552	.236	.184	.315	.174	.329
COL	.330	.774	.490	.180	.269	.251
CYA	.938	.582	.317	.485	.845	.742
PIC	.456	.337	.773	.782	.453	.310
UNI	.896	.494	.422	.541	.114	.167
PYR	.887	.378	.643	.479	.150	.193

Table 8. Average biological and chemical parameters (April-November) from a 1-m depth for Lakes Erie, Michigan and Huron, 1985. The trophic ratio and zooplankton ratio are discussed in the text.

	Erie (n=100)	Michigan (n=64)	Huron (n=58)
Turbidity (FTU)	2.64±.32	0.35±.02	0.31±.01
Total phosphorus (ug/L)	14.84±.82	4.28±.24	3.09±.29
Soluble Reactive Phosphorus (ug/L)	2.20±.19	0.50±.06	0.33±.06
Nitrite + Nitrate (mg/L)	0.23±.015	0.23±.008	0.29±.004
Chlorophyll *a* (ug/L)	3.06±.32	0.79±.06	0.79±.06
Phytoplankton			
(1000x#/mL)	4.48±.57	2.84±.24	2.02±.11
(g/m^3)	1.22±.11	0.45±.043	0.34±.021
Zooplankton			
($1000x\#/m^3$)	222±27	34.9±4.1	67.7±9.4
(mg/m^3)	105.8±9.9	47.9±5.2	59.2±7.0
Trophic Ratio	2.0	8.0	2.7
Zooplankton Ratio	0.41	1.53	2.9

Table 9. Relative abundance of major phytoplankton divisions in Lake Michigan, 1983, 1984 and 1985. Picoplankton are not included. Bac=Bacillariophyta, Cat=Chloromanophyta, Chl=Chlorophyta, Chr=Chrysophyta, Col=Colorless flagellates, Cry=Cryptophyta, Cya=Cyanophyta, Eug=Euglenophyta, Pyr=Pyrrophyta, Uni=Unidentified.

	% Biovolume/mL			% Cells/mL		
Division	1983	1984	1985	1983	1984	1985
Bac	57.79	69.72	63.95	10.08	2.04	7.38
Cat	0.02	0.00	0.00	0.01	0.00	0.00
Chl	5.38	2.05	2.16	6.10	0.67	5.95
Chr	6.70	5.13	3.31	14.12	2.18	8.58
Col	1.04	0.16	0.28	1.61	0.30	1.74
Cry	13.76	12.53	17.22	11.67	1.50	10.74
Cya	3.24	1.85	3.26	26.40	3.54	34.36
Eug	0.04	0.07	0.01	<0.01	<0.01	<0.01
Pyr	7.50	2.66	3.91	0.12	0.02	0.15
Uni	4.52	5.83	5.90	19.90	6.89	31.10

Table 10. Number of species and genera observed in each algal division or grouping in Lake Michigan, 1983 to 1985. Results are for the non-winter period.

Division	Species			Genera		
	1983	1984	1985	1983	1984	1985
Bacillariophyta	168	166	90	33	29	23
Chlorophyta	86	63	41	36	26	21
Chrysophyta	49	33	36	13	11	11
Cryptophyta	23	20	21	4	4	4
Cyanophyta	21	13	12	10	8	7
Picoplankton	(2)[1]	3	3	(2)[1]	3	3
Colorless flagellates	16	15	10	6	5	4
Pyrrophyta	9	7	5	4	3	5
Euglenophyta	1	1	1	1	1	1
Unidentified	5	5	3	-	-	-
Chloromanophyta	1	0	0	1	0	0
Total	379	327	222	108	91	79

[1] Picoplankton were grouped with the Cyanophyta

Table 11. Abundance of *Rhizosolenia eriensis* in Lake Michigan in 1983, 1984 and 1985. Values in parentheses represent *R. eriensis*+*R. longiseta*.

	1983		1984		1985	
	cells mL^{-1}	% biovolume	cells mL^{-1}	% biovolume	cells mL^{-1}	% biovolume
April	0.0	0.0	10.3	17.5(30.5)	6.5	10.7(15.9)
	0.0	0.0				
May	0.2	0.1	9.3	8.6(17.4)	6.7	7.7(11.0)
June	-	-	-	-	8.0	5.4(30.2)
July	0.0	0.0	52.4	33.4(36.1)	-	-
August	0.0	0.0(0.5)	22.6	23.2(30.1)	0.4	0.8(1.2)
	0.0	0.0	17.5	26.9(30.1)	0.0	0.0(1.9)
	-	-	21.9	39.2(44.6)	-	-
October	10.9	9.1(9.2)	-	-	-	-
	7.1	2.1(10.7)	-	-	-	-
November	-	-	3.2	7.9(8.3)	0.8	1.6(3.5)
December	-	-	8.3	16.4(5.2)	0.7	3.8(7.4)
February	-	-	4.8	4.6(5.2)	-	-

Table 12. Summary of common phytoplankton species occurrence in Lake Michigan during 1983. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Asterionella formosa	206	12.6	0.40	3,787	0.93
Cyclotella comensis v. 1	834	56.4	1.78	2,094	0.51
Cyclotella comta	158	6.8	0.21	16,734	4.11
Cyclotella michiganiana	117	12.9	0.41	2,849	0.70
Cymatopleura solea	5	0.3	0.01	6,407	1.57
Entomoneis ornata	4	0.2	0.00	3,578	0.88
Fragilaria crotonensis	755	63.5	2.01	45,316	11.12
Fragilaria vaucheriae	115	10.7	0.34	4,889	1.20
Melosira islandica	137	12.9	0.41	11,679	2.87
Melosira italica subsp. subarctica	357	39.1	1.24	7,130	1.75
Rhizosolenia eriensis	53	2.8	0.09	6,593	1.62
Rhizosolenia sp.	133	1.8	0.06	7,705	1.89
Stephanodiscus alpinus	22	3.2	0.10	20,720	5.09
Stephanodiscus niagarae	18	0.8	0.03	10,562	2.59
Stephanodiscus transilvanicus	6	0.3	0.01	6,765	1.66
Tabellaria fenestrata	79	4.4	0.14	7,751	1.90
Tabellaria flocculosa	202	18.0	0.57	52,393	12.86
Total			7.81		53.26
CHLOROPHYTA					
Cosmarium sp.	8	0.4	0.01	7,470	1.83
Green coccoid - bacilliform	376	42.3	1.34	889	0.22
Monoraphidium contortum	201	40.8	1.29	332	0.08
Stichococcus sp.	761	24.6	0.78	2,106	0.52
Total			3.42		2.65
CHRYSOPHYTA					
Dinobryon bavaricum	262	20.4	0.64	1,636	0.40
Dinobryon cylindricum	311	19.0	0.60	6,130	1.50
Dinobryon divergens	258	16.5	0.52	2,478	0.61
Dinobryon sociale v. americanum	802	51.0	1.62	6,659	1.63
Haptophyte sp.	785	197.9	6.26	2,466	0.61
Unidentified coccoids	540	49.7	1.57	512	0.13
Total			11.22		4.88
COLORLESS FLAGELLATES					
Colorless flagellates	810	30.9	0.98	1,457	0.36
Stylotheca aurea	172	7.2	0.23	2,291	0.56
Total			1.21		0.92
CRYPTOPHYTA					
Chroomonas norstedtii	202	30.8	0.97	699	0.17
Cryptomonas erosa	25	7.1	0.23	15,341	3.77
Cryptomonas erosa v. reflexa	11	1.3	0.04	2,635	0.65
Cryptomonas marssonii	25	2.6	0.08	2,405	0.59
Cryptomonas pyrenoidifera	49	6.5	0.21	2,976	0.73
Rhodomonas minuta v. nannoplanktica	777	287.5	9.10	23,929	5.87
Total			10.63		11.78

Table 12(cont.). Summary of common phytoplankton species occurrence in Lake Michigan during 1983. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

CYANOPHYTA					
Anacystis montana v. minor	3,289	482.5	15.27	3,201	0.79
Coccochloris elabans	694	22.6	0.71	392	0.10
Coelosphaerium naegelianum	1,227	42.0	1.33	176	0.04
Gomphosphaeria lacustris	818	40.6	1.28	283	0.07
Oscillatoria agardhii	344	15.2	0.48	2,985	0.73
Oscillatoria limnetica	2,266	149.0	4.72	1,104	0.27
Oscillatoria minima	399	23.4	0.74	315	0.08
Oscillatoria subbrevis	736	15.9	0.50	625	0.15
			----------		----------
Total			25.04		2.23
PYRROPHYTA					
Ceratium hirundinella	8	0.2	0.01	22,349	5.49
Gymnodinium sp. #2	16	0.3	0.01	4,026	0.99
Peridinium sp.	8	0.4	0.01	2,764	0.68
			----------		----------
Total			0.03		7.15
UNIDENTIFIED					
Unidentified flagellate - ovoid	1,630	409.5	12.96	9,287	2.28
Unidentified flagellate - spherical	1,859	533.8	16.90	8,999	2.21
			----------		----------
			29.86		4.49
			==========		==========
Total			89.22		87.36

Table 13. Summary of common phytoplankton species occurrence in Lake Michigan during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Asterionella formosa	184	21.2	0.59	5,865	1.14
Cyclotella comensis v. 1	2,568	105.0	2.91	3,212	0.62
Cyclotella comta	96	4.0	0.11	10,488	2.04
Cyclotella ocellata	265	21.5	0.60	1,905	0.37
Fragilaria capucina	161	11.2	0.31	3,688	0.72
Fragilaria crotonensis	376	68.7	1.91	44,659	8.67
Melosira islandica	96	12.1	0.34	12,959	2.52
Melosira italica subsp. subarctica	74	10.5	0.29	2,693	0.52
Nitzschia lauenburgiana	10	0.7	0.02	4,418	0.86
Rhizosolenia eriensis	110	17.0	0.47	118,337	22.98
Rhizosolenia longiseta	162	19.4	0.54	21,867	4.25
Stephanodiscus alpinus	18	2.3	0.06	9,303	1.81
Stephanodiscus alpinus?	11	0.6	0.02	3,871	0.75
Stephanodiscus niagarae	14	1.1	0.03	17,126	3.33
Stephanodiscus transilvanicus	7	0.8	0.02	15,111	2.93
Synedra filiformis	118	10.4	0.29	3,953	0.77
Synedra ulna v. chaseana	23	2.1	0.06	16,754	3.25
Tabellaria flocculosa	82	13.7	0.38	40,391	7.84
Total			8.94		65.36
CHLOROPHYTA					
Dictyosphaerium ehrenbergianum	278	23.6	0.65	178	0.03
Monoraphidium contortum	344	38.5	1.07	401	0.08
Oocystis submarina	254	23.4	0.65	378	0.07
Total			2.37		0.19
CHRYSOPHYTA					
Chrysophycean coccoids	630	75.4	2.09	291	0.06
Dinobryon divergens	303	24.0	0.67	4,938	0.96
Dinobryon sociale v. americanum	1,743	101.4	2.81	10,032	1.95
Haptophyceae	1,456	169.3	4.70	1,666	0.32
Monosiga ovata	352	22.2	0.62	281	0.05
Total			10.89		3.34
COLORLESS FLAGELLATES					
Colorless flagellates	311	25.7	0.71	443	0.09
CRYPTOPHYTA					
Chroomonas norstedtii	270	44.9	1.25	1,365	0.27
Cryptomonas erosa	65	10.5	0.29	24,275	4.71
Cryptomonas marssonii	25	3.8	0.11	4,995	0.97
Cryptomonas rostratiformis	25	1.4	0.04	4,986	0.97
Rhodomonas minuta v. nannoplanktica	965	225.5	6.26	17,924	3.48
Total			7.94		10.40
CYANOPHYTA					
Anacystis montana v. minor	2,790	277.8	7.71	1,215	0.24
Coelosphaerium naegelianum	982	28.9	0.80	138	0.03
Gomphosphaeria lacustris	655	20.7	0.57	97	0.02
Oscillatoria limnetica	2,070	198.9	5.52	2,109	0.41
Oscillatoria minima	4,132	166.0	4.61	3,532	0.69
Total			19.22		1.38

Table 13(cont.). Summary of common phytoplankton species occurrence in Lake Michigan during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

PYRROPHYTA					
Gymnodinium sp.	16	0.6	0.02	5,151	1.00
Peridinium sp.	16	1.6	0.04	4,218	0.82
			----------		----------
Total			0.06		1.82
UNIDENTIFIED					
Unidentified flagellate - ovoid	4,287	985.0	27.35	23,202	4.51
Unidentified flagellate - spherical	1,350	465.0	12.91	6,471	1.26
			----------		----------
			40.26		5.76
			==========		==========
Total			90.40		88.33

Table 14. Summary of common phytoplankton species occurrence in Lake Michigan during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Asterionella formosa	221	16.1	0.57	5,181	1.16
Cymatopleura solea	4	0.1	0.00	5,889	1.32
Cymatopleura solea v. apiculata	2	0.0	0.00	2,954	0.66
Fragilaria crotonensis	157	20.3	0.71	16,274	3.64
Melosira islandica	208	30.2	1.06	34,830	7.80
Melosira italica subsp. subarctica	146	27.0	0.95	6,624	1.48
Rhizosolenia eriensis	41	3.3	0.12	23,593	5.28
Rhizosolenia longiseta	503	31.8	1.12	30,333	6.79
Stephanodiscus alpinus	52	4.4	0.15	30,205	6.76
Stephanodiscus niagarae	17	2.2	0.08	48,153	10.78
Stephanodiscus sp. #09	17	0.2	0.01	6,881	1.54
Stephanodiscus transilvanicus	8	1.2	0.04	18,292	4.10
Synedra filiformis	95	5.0	0.18	2,521	0.56
Synedra ulna v. chaseana	33	1.8	0.06	15,363	3.44
Tabellaria flocculosa	133	7.5	0.26	24,291	5.44
Total			5.32		60.77
CHLOROPHYTA					
Dictyosphaerium ehrenbergianum	565	30.7	1.08	242	0.05
Green coccoid - bacilliform	1,145	44.6	1.57	1,156	0.26
Monoraphidium contortum	352	47.3	1.66	546	0.12
Total			4.32		0.44
CHRYSOPHYTA					
Haptophyceae	524	125.8	4.43	2,807	0.63
COLORLESS FLAGELLATES					
Colorless flagellate - ovoid	393	25.0	0.88	610	0.14
CRYPTOPHYTA					
Chroomonas acuta	155	16.3	0.57	531	0.12
Chroomonas norstedtii	295	30.8	1.08	1,241	0.28
Cryptomonas erosa	65	10.9	0.38	27,597	6.18
Cryptomonas marssonii	25	2.2	0.08	2,976	0.67
Cryptomonas ovata	25	1.7	0.06	3,474	0.78
Cryptomonas pyrenoidifera	82	8.9	0.31	4,767	1.07
Cryptomonas rostratiformis	12	1.2	0.04	4,867	1.09
Cryptomonas sp.	65	6.1	0.22	2,464	0.55
Rhodomonas lens	139	25.1	0.88	4,711	1.06
Rhodomonas minuta v. nannoplanktica	466	193.5	6.81	19,335	4.33
Total			10.45		16.11
CYANOPHYTA					
Anabaena sp.	1,309	21.8	0.77	2,418	0.54
Anacystis montana	4,639	60.2	2.12	106	0.02
Anacystis montana v. minor	5,285	446.0	15.70	5,363	1.20
Gomphosphaeria lacustris	3,068	181.7	6.40	908	0.20
Oscillatoria limnetica	1,530	139.5	4.91	713	0.16
Oscillatoria minima	843	90.2	3.17	1,580	0.35
Oscillatoria subbrevis	744	16.8	0.59	821	0.18
Total			33.66		2.67

Table 14(cont.). Summary of common phytoplankton species occurrence in Lake Michigan during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

PYRROPHYTA					
Ceratium hirundinella	8	0.2	0.01	4,119	0.92
Gymnodinium helveticum f. achroum	8	0.2	0.01	2,543	0.57
Gymnodinium sp.	8	0.6	0.02	2,770	0.62
Peridinium sp.	16	1.5	0.05	5,760	1.29
			----------		----------
Total			0.09		3.40
UNIDENTIFIED					
Unidentified flagellate - ovoid	2,675	691.2	24.33	19,974	4.47
Unidentified flagellate - spherical	638	190.0	6.69	6,045	1.35
			----------		----------
Total			31.02		5.83
			==========		==========
Total			90.15		89.98

Table 15. Comparison of abundance of *Cyclotella* species at offshore sites in August of 1970, 1983, 1984 and 1985, Lake Michigan. Data from Holland and Beeton (1972), Makarewicz (1987, 1988) and this study. Stations 22, 23 and 27 are geographically comparable to Holland and Beeton's offshore sites. Values are in cells/mL.

	11/8/70 Offshore Stations	17/8/83 Stations 22&27	15/8/84 Stations 22&27	20-21/8/85 Stations 23&27
Cyclotella michiganiana	71-182	0.44-6.8	0.38-4.5	1.4-16.4
Cyclotella stelligera	300-613	0.17-2.2	1.7-2.8	0.9-6.4

Table 16. Distribution of indicator diatom species in Lake Michigan. The classification scheme followed Tarapchak and Stoermer (1976). M_1- mesotrophic but intolerant of nutrient enrichment, M_2- mesotrophic and tolerant of moderate nutrient enrichment, E- eutrophic. 1970-71, 1977, 1983 and 1984 data are from Holland and Beeton (1972), Stoermer and Tuchman (1979), Makarewicz (1987, 1988) and this study.

	M_1	M_2	E	M_1+M_2/E
1977[2] (Nearshore)	6	5	7	1.6
1970-71[3]	4	5	4	2.3
1983[1]	5	3	1	8
1984[1]	4	5	2	4.5
1985[1]	4	4	1	8

1 Only diatoms contributing >0.5% of the total biomass or > 0.1% of the total abundance are classified.

2 Only diatoms contributing >0.1% of the abundance are classified.

3 Only "predominant" species are classified.

Table 17. Relative abundance of zooplankton in Lake Michigan.

	Percent Biomass			Percent Abundance		
	1983	1984	1985	1983	1984	1985
Rotifera	NOT CALCULATED	2.6	1.1	59.7	67.5	39.9
Cladocera		39.8	14.2	3.2	4.1	2.1
Copepoda nauplii		11.2	10.2	21.3	15.6	34.8
Cyclopoida		15.8	7.0	5.7	6.2	8.1
Calanoida		30.4	67.4	10.1	6.6	15.1
Mysidacea		0.2	0.1	<.1	<.1	<.1
Harpacticoida		<.1	<.1	<.1	<.1	<.1

Table 18. Summary of common zooplankton species occurrence in Lake Michigan during 1985. Species were arbitrarily classified as common if they accounted for ≥0.1% of the total abundance or ≥1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for ≥1.0% of the total abundance.

TAXON	MAXIMUM DENSITY (#/m^3)	AVERAGE DENSITY (#/m^3)	% OF TOTAL ABUNDANCE	MEAN BIOMASS (ug/m^3)	% OF TOTAL BIOMASS
COPEPODA					
Copepoda - nauplii	62,951	12,162.6	34.80	4,865	10.16
Cyclopoida					
Cyclopoid - copepodite	12,808	2,289.2	6.55	1,488	3.11
Cyclops bicuspidatus thomasi	2,772	417.2	1.19	1,640	3.42
Tropocyclops prasinus mexicanus	858	66.4	0.19	89	0.19
Calanoida					
Diaptomus - copepodite	18,704	3,242.7	9.28	23,510	49.08
Diaptomus ashlandi	9,352	1,004.5	2.87	2,461	5.14
Diaptomus minutus	1,105	252.2	0.72	588	1.23
Diaptomus oregonensis	375	52.1	0.15	253	0.53
Diaptomus sicilis	2,009	494.6	1.42	3,235	6.75
Limnocalanus - copepodite	1,030	146.3	0.42	565	1.18
Limnocalanus macrurus	438	53.1	0.15	1,432	2.99
	Total		57.74		83.76
CLADOCERA					
Daphnia galaeta mendotae	6,402	447.9	1.28	3,664	7.65
Daphnia pulicaria	2,467	161.3	0.46	2,654	5.54
Daphnia retrocurva	1,266	47.3	0.14	169	0.35
	Total		1.88		13.54
ROTIFERA					
Collotheca sp.	5,484	604.5	1.73	2	0.00
Conochilus unicornis	10,091	976.6	2.79	15	0.03
Gastropus stylifer	12,970	743.6	2.13	22	0.05
Kellicottia longispina	11,945	1,166.3	3.34	15	0.03
Keratella cochlearis	25,683	1,747.7	5.00	7	0.01
Keratella crassa	18,208	524.4	1.50	23	0.05
Ploesoma truncatum	31,589	493.1	1.41	10	0.02
Polyarthra major	19,048	833.8	2.39	111	0.23
Polyarthra vulgaris	63,902	3,913.5	11.20	193	0.40
Synchaeta sp.	25,581	1,819.0	5.20	44	0.09
	Total		36.69		0.92
	Total		96.31		98.23

Table 19. Early August Cladocera abundance in 1954, 1966, 1968, 1983, 1984 and 1985 in Lake Michigan. Data from Wells (1970), Makarewicz (1987, 1988) and this study. Values represent the mean station number/m^3. Values in parentheses do not include Stations 6, 56, 64 and 77 and are directly comparable to the 1985 data.

	1954	1966	1968	1983	1984	1985
Leptodora kindtii	29	4	16	34 (42)	98 (66)	43
Daphnia galeata	1200	0	0.4	514 (883)	3508 (4650)	2150
Daphnia retrocurva	1400	79	2100	82 (87)	1061 (1061)	266
Diaphanosoma brachyurum	2	0	0	1	0	1
Daphnia longiremis	0	16	0	0	14	47
Daphnia pulicaria	0	0	0	1011 (2447)	248 (303)	694
Holopedium gibberum	0	2	5	456 (23)	536 (66)	8
Polyphemus pediculus	2	15	10	13	7	0
Bosmina longirostris	26	98	16	342 (318)	5231 (169)	33
Eubosmina coregoni	0	1	16	159 (80)	208 (202)	66
Ceriodaphnia quadrangula	0	4	1	0	0	0

Table 20. Early August Copepoda abundance in 1954, 1966, 1968, 1983, 1984 and 1985 in Lake Michigan. Data from Wells (1970), Makarewicz (1987, 1988) and this study. Values represent the mean station number/m^3. Values in parentheses do not include Stations 6, 56, 64 and 77 and are directly comparable to the 1985 data.

	1954	1966	1968	1983	1984	1985
Limnocalanus macrurus	91	34	270	18 (13)	64 (55)	9
Epischura lacustris	41	7	21	19 (17)	14 (16)	43
Diaptomus sicilis	3	1	3	79 (85)	155 (73)	12
Mesocyclops edax	200	0	0	13 (7)	31 (48)	107
Senecella calanoides	0.2	0.2	0.1	1.4	0	0
Cyclops bicuspidatus	310	1000	860	1457 (2118)	2807 (2737)	1074
Diaptomus ashlandi	140	220	13	1256 (2185)	1733 (2363)	1148
Cyclops vernalis	0	0	0	0	16	0
Eurytemora affinis	0	33	3	0	0	3
Diaptomus oregonensis	63	58	100	138 (92)	58 (29)	78
Diaptomus minutus	39	25	1500	151 (245)	183 (254)	342

Table 21. Average crustacean zooplankton biomass (dry weight) for 1976, 1984 and 1985, Lake Michigan. Values are the mean± S.E. The 1976 data (Bartone and Schelske 1982) were converted to dry weight assuming carbon content was 50% of dry weight.

1976	50.0±14.8 mg/m^3
1984	33.6±14.7 mg/m^3
1985	47.9±5.2 mg/m^3

Table 22. The ratio of calanoids to cyclopoids plus cladocerans geographically in Lake Michigan, 1983, 1984 and 1985. ns=no sample.

Station		Calanoida / Cyclopoida + Cladocera 1983	1984	1985
77	(North)	0.37	0.23	ns
64		0.41	0.20	ns
57		1.74	0.69	ns
47		1.52	0.57	1.01
41		1.10	0.57	1.22
34		1.03	0.80	1.29
27		1.53	0.84	1.76
23		1.15	1.32	1.36
18		3.01	1.93	1.92
11		1.71	1.09	2.12
6	(South)	0.87	0.75	ns

Table 23. Correlation (r) of phytoplankton abundance with total phosphorus concentrations and zooplankton abundance within individual cruises (11 stations) in Lake Michigan, 1985. NO = observed.

	Daphnia pulicaria	*Daphnia* spp.	Rotifera	Calanoida	Total Phosphorus
4/15-22	NO	.021	-.136	-.682	-.118
5/1-2	NO	.104	-.014	-.600	.043
6/5-6	NO	.162	.292	.458	.025
8/17-20	-.247	-.599	-.186	-.348	.390
11/14-16	.131	-.040	-.336	-.157	.666
11/29-12/4	.462	.465	.093	.093	.401

Table 24. Number of species and genera observed in each algal division or grouping, Lake Huron, 1983, 1984 and 1985.

Division	Species			Genera		
	1983	1984	1985	1983	1984	1985
BAC	158	156	120	29	28	26
CHL	73	64	32	28	28	16
CHR	36	35	25	10	12	10
CRY	22	17	14	3	4	3
CYA	13	13	9	6	7	6
PIC	(2)*	3	3	(2)*	3	3
COL	13	13	3	4	5	2
PYR	10	9	3	4	4	3
EUG	4	1	0	3	1	0
UNI	3	4	3	-	-	-
CAT	1	0	1	1	0	1
Total	329	315	213	88	92	70

* Included in Cyanophyta in 1982

Table 25. Relative abundance of major phytoplankton divisions in Lake Huron, 1983, 1984 and 1985. The picoplankton are not included. BAC-Bacillariophyta, CAT-Chloromanophyta, CHL-Chlorophyta, CHR-Chrysophyta, COL-Colorless Flagellates, CRY-Cryptophyta, CYA-Cyanophyta, EUG-Euglenophyta, PYR-Pyrrophyta, UNI-Unidentified.

Division	% Biovolume/mL			% Cells/mL		
	1983	1984	1985	1983	1984	1985
BAC	70.05	62.90	67.37	8.65	17.26	18.18
CAT	.02	0.00	.02	<0.01	0.00	<.01
CHL	3.55	2.77	3.70	3.11	3.56	4.56
CHR	7.30	9.67	10.03	11.92	13.01	14.31
COL	.15	.13	.74	.42	.77	6.02
CRY	8.51	9.25	9.26	8.41	7.68	11.24
CYA	1.72	1.44	2.02	21.92	25.72	19.48
EUG	.12	.06	.00	.01	.01	.00
PYR	3.33	7.27	1.27	.11	.15	.11
UNI	5.24	6.52	5.89	45.43	31.83	26.08

Table 26. Abundance of *Rhizosolenia eriensis* in Lake Huron, 1983, 1984 and 1985. Values in parentheses in 1983 represent *Rhizosolenia* sp. and in 1984 *R. longiseta*.

	1983		1984		1985	
Date	cells/mL	% biomass	cells/mL	% biomass	cells/mL	% biomass
April	0.1	0.01	6.3(0.43)	9.0	106.4	16(4)
	-	-	-	-	40.9	4(4)
May	0.2	0.01(38.3)	5.4(0.46)	6.3	-	-
June	-	-	-	-	200.4	15(7)
July	0.0	0.0(59.2)	51.0(0,81)	18.1	-	-
August	0.0	0.0(11.3)	26.7(0.92)	30.4	86.4	14(9)
	0.0	0.0(12.1)	33.1(0.15)	35.1	24.5	3(8)
	-	-	9.9(0.51)	29.1	-	-
October	0.4	1.0(6.1)	5.8(0.39)	16.1	-	-
	0.0	0.0(8.7)	-	-	-	-
November	-	-	-	-	151.4	29(1)
					175.5	33(0)
December	-	-	2.9(0.44)	10.3	-	-
January	-	-	2.4(0.0)	4.4	-	-
February	-	-	10.7(0.17)	12.4	-	-

Table 27. Summary of common phytoplankton species occurrence in Lake Huron during 1983. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Asterionella formosa	103	8.3	0.32	2,534	0.68
Cyclotella comensis v. 1	385	42.2	1.64	1,456	0.39
Cyclotella comta	51	5.5	0.21	15,136	4.05
Cyclotella kuetzingiana v. planetophora	80	14.2	0.55	4,265	1.14
Cyclotella ocellata	254	25.6	1.00	1,997	0.53
Cymatopleura solea v. apiculata	3	0.1	0.01	11,525	3.08
Fragilaria crotonensis	123	23.7	0.92	19,619	5.25
Fragilaria intermedia v. fallax	60	7.0	0.27	4,302	1.15
Melosira islandica	90	10.9	0.42	14,559	3.89
Rhizosolenia sp.	143	14.7	0.57	109,236	29.20
Stephanodiscus niagarae	3	0.3	0.01	4,932	1.32
Stephanodiscus transilvanicus	8	0.8	0.03	7,575	2.03
Tabellaria flocculosa	133	17.4	0.68	51,945	13.89
Tabellaria flocculosa v. linearis	21	1.2	0.05	2,189	0.59
			----------		----------
Total			6.69		67.18
CHRYSOPHYTA					
Chrysosphaerella longispina	74	11.5	0.45	4,523	1.21
Dinobryon bavaricum	155	13.1	0.51	1,675	0.45
Dinobryon cylindricum	164	13.8	0.54	5,014	1.34
Dinobryon divergens	141	18.5	0.72	4,032	1.08
Dinobryon sociale v. americanum	524	42.1	1.64	5,140	1.37
Haptophyte sp.	859	144.0	5.61	1,346	0.36
			----------		----------
Total			9.47		5.81
CRYPTOPHYTA					
Chroomonas norstedtii	65	14.7	0.57	295	0.08
Cryptomonas erosa	16	4.6	0.18	8,754	2.34
Cryptomonas erosa v. reflexa	8	1.1	0.04	2,119	0.57
Cryptomonas pyrenoidifera	33	5.3	0.20	2,997	0.80
Rhodomonas minuta v. nannoplanktica	311	175.2	6.82	13,005	3.48
			----------		----------
Total			7.82		7.26
CYANOPHYTA					
Anacystis montana v. minor	2,556	325.7	12.69	1,429	0.38
Anacystis thermalis	115	14.8	0.58	2,079	0.56
Coccochloris elabans	434	32.3	1.26	361	0.10
Coelosphaerium naegelianum	900	63.2	2.46	285	0.08
Gomphosphaeria lacustris	920	32.2	1.25	175	0.05
Oscillatoria limnetica	974	74.8	2.91	241	0.06
			----------		----------
Total			21.15		1.22
PYRROPHYTA					
Ceratium hirundinella	2	0.1	0.00	4,791	1.28
Gymnodinium sp.	8	0.3	0.01	2,344	0.63
Gymnodinium sp. #2	2	0.2	0.01	2,892	0.77
			----------		----------
Total			0.02		2.68
UNIDENTIFIED					
Unidentified flagellate - ovoid	1,135	419.4	16.34	8,944	2.39
Unidentified flagellate - spherical	5,211	746.1	29.06	10,573	2.83
			----------		----------
Total			45.40		5.22
			==========		==========
Total			90.55		89.37

Table 28. Summary of common phytoplankton species occurrence in Lake Huron during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTRA					
Asterionella formosa	168	27.5	0.99	8,545	2.17
Cyclotella comensis v. 1	1,367	94.2	3.40	3,382	0.86
Cyclotella comensis v. 2	101	20.9	0.75	578	0.15
Cyclotella comta	35	2.3	0.08	7,576	1.92
Cyclotella kuetzingiana v. planetophora?	135	13.2	0.48	3,615	0.92
Cyclotella ocellata	1,000	113.2	4.08	9,063	2.30
Cyclotella sp.	143	15.1	0.54	684	0.17
Cyclotella stelligera	267	25.3	0.91	568	0.14
Fragilaria crotonensis	375	44.7	1.61	36,435	9.24
Fragilaria intermedia v. fallax	25	2.6	0.09	2,068	0.52
Melosira islandica	43	6.5	0.23	8,107	2.06
Rhizosolenia eriensis	131	17.2	0.62	75,628	19.17
Rhizosolenia longiseta	33	2.9	0.10	2,181	0.55
Stephanodiscus alpinus	19	1.5	0.05	3,659	0.93
Stephanodiscus minutus	85	19.4	0.70	788	0.20
Stephanodiscus niagarae	2	0.2	0.01	3,300	0.84
Tabellaria flocculosa	181	25.0	0.90	64,228	16.28
Total			15.57		58.41
CHLOROPHYTA					
Cosmarium sp.	16	0.7	0.03	2,013	0.51
Oocystis pusilla	198	15.2	0.55	1,166	0.30
Total			0.57		0.81
CHRYSOPHYTA					
Chrysophycean coccoids	160	36.2	1.31	175	0.04
Chrysosphaerella longispina	1,325	31.4	1.13	7,701	1.95
Dinobryon cylindricum	196	13.3	0.48	3,981	1.01
Dinobryon divergens	254	32.0	1.16	6,062	1.54
Dinobryon sociale	589	65.6	2.37	9,978	2.53
Dinobryon sociale v. americanum	540	27.8	1.00	4,368	1.11
Haptophyceae	589	110.1	3.97	1,353	0.34
Total			11.41		8.52
CRYPTOPHYTA					
Chroomonas norstedtii	115	22.8	0.82	670	0.17
Cryptomonas erosa	31	4.5	0.16	9,572	2.43
Cryptomonas pyrenoidifera	33	4.2	0.15	2,269	0.58
Cryptomonas rostratiformis	8	0.8	0.03	3,049	0.77
Rhodomonas minuta v. nannoplanktica	360	155.1	5.59	12,757	3.23
Total			6.76		7.18
CYANOPHYTA					
Anacystis montana v. minor	4,606	445.4	16.07	2,042	0.52
Coelosphaerium naegelianum	1,047	77.6	2.80	310	0.08
Gomphosphaeria lacustris	851	79.0	2.85	352	0.09
Oscillatoria limnetica	942	45.9	1.66	203	0.05
Oscillatoria minima	335	17.3	0.62	419	0.11
Total			24.00		0.84

Table 28(cont.). Summary of common phytoplankton species occurrence in Lake Huron during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

PYRROPHYTA					
Ceratium hirundinella	8	0.1	0.00	13,887	3.52
Gymnodinium helveticum f. achroum	6	0.2	0.01	3,303	0.84
Gymnodinium sp.	8	0.5	0.02	3,068	0.78
Gymnodinium sp. #2	8	0.3	0.01	5,388	1.37
			----------		----------
Total			0.04		6.50
UNIDENTIFIED					
Unidentified flagellate - ovoid	1,481	615.9	22.21	16,433	4.17
Unidentified flagellate - spherical	2,193	264.7	9.55	9,047	2.29
			----------		----------
Total			31.76		6.46
			==========		==========
Total			90.11		88.72

Table 29. Summary of common phytoplankton species occurrence in Lake Huron during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Asterionella formosa	99	23.8	1.18	8,603	2.51
Cyclotella comensis	260	10.9	0.54	1,488	0.43
Cyclotella comensis v. 1	779	42.9	2.12	1,239	0.36
Cyclotella comensis v. 2	95	18.4	0.91	562	0.16
Cyclotella comta	72	4.9	0.24	15,636	4.56
Cyclotella kuetzingiana v. planetophora	446	48.7	2.41	7,393	2.15
Cyclotella ocellata	264	34.2	1.69	2,224	0.65
Cyclotella sp.	148	25.1	1.24	1,035	0.30
Cyclotella stelligera	255	13.4	0.66	226	0.07
Cymatopleura solea v. apiculata	1	0.0	0.00	2,907	0.85
Diatoma tenue v. elongatum	23	2.2	0.11	1,810	0.53
Fragilaria crotonensis	153	30.7	1.52	24,552	7.16
Fragilaria intermedia v. fallax	25	2.6	0.13	2,466	0.72
Melosira islandica	122	20.6	1.02	26,636	7.76
Rhizosolenia eriensis	57	11.2	0.56	50,115	14.61
Rhizosolenia longiseta	295	24.0	1.19	18,131	5.28
Stephanodiscus alpinus	14	0.7	0.03	2,823	0.82
Stephanodiscus minutus	102	12.2	0.60	452	0.13
Stephanodiscus niagarae	5	0.2	0.01	6,771	1.97
Stephanodiscus transilvanicus	8	0.5	0.03	9,194	2.68
Synedra ulna v. chaseana	4	0.2	0.01	1,833	0.53
Tabellaria flocculosa	68	12.5	0.62	33,315	9.71
Total			16.83		63.95
CHLOROPHYTA					
Cosmarium sp.	8	0.3	0.02	4,406	1.28
Green coccoid - ovoid	123	21.8	1.08	691	0.20
Monoraphidium setiformae	164	22.6	1.12	792	0.23
Total			2.22		1.72
CHRYSOPHYTA					
Chrysophycean coccoids	106	14.8	0.73	87	0.03
Chrysosphaerella longispina	1,317	66.9	3.31	18,985	5.53
Dinobryon divergens	80	6.9	0.34	2,725	0.79
Dinobryon sociale	319	27.6	1.37	5,238	1.53
Haptophyceae	630	138.6	6.86	2,834	0.83
Total			12.62		8.71
COLORLESS FLAGELLATES					
Colorless flagellates	387	99.5	4.93	1,972	0.57
Stelexmonas dichotoma	237	21.7	1.07	526	0.15
Total			6.00		0.73
CRYPTOPHYTA					
Chroomonas norstedtii	98	22.3	1.10	688	0.20
Cryptomonas erosa	25	7.3	0.36	13,000	3.79
Rhodomonas lens	90	24.2	1.20	3,126	0.91
Rhodomonas minuta v. nannoplanktica	360	164.9	8.16	11,901	3.47
Total			10.82		8.37

Table 29(cont.). Summary of common phytoplankton species occurrence in Lake Huron during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

CYANOPHYTA					
Agmenellum quadruplicatum	1,145	29.9	1.48	16	0.00
Anabaena sp.	483	12.0	0.59	1,667	0.49
Anacystis montana v. minor	1,407	138.8	6.87	785	0.23
Anacystis thermalis	245	14.7	0.73	1,460	0.43
Gomphosphaeria lacustris	1,554	81.5	4.03	341	0.10
Oscillatoria limnetica	1,080	63.1	3.12	930	0.27
Oscillatoria minima	548	33.7	1.67	410	0.12
Oscillatoria subbrevis	644	19.3	0.95	1,315	0.38
			----------		----------
Total			19.45		2.02
PYRROPHYTA					
Gymnodinium helveticum f. achroum	8	0.4	0.02	2,731	0.80
UNIDENTIFIED					
Unidentified flagellate - ovoid	1,587	400.6	19.83	15,712	4.58
Unidentified flagellate - spherical	679	123.4	6.11	3,167	0.92
			----------		----------
Total			25.95		5.50
			==========		==========
Total			93.90		91.79

Table 30. Phytoplankton common (abundance >0.1% of the total cells or >0.5% of the total biovolume) in 1985 but not in 1983 and 1984, Lake Huron.

Bacillariophyta

Diatoma tenue var. *elongatum*
Synedra ulna var. *chaseana*

Chlorophyta

Green coccoid - ovoid
Monoraphidium setiformae

Cryptophyta

Rhodomonas lens

Cyanophyta

Agmenellum quadruplicatum
Anabaena sp.
Oscillatoria subbrevis

Colorless Flagellates
Stelexmonas dichotoma

Table 31. Distribution of indicator diatom species in Lake Huron. The classification scheme of Tarapchak and Stoermer (1976) was utilized. M1=mesotrophic but intolerant of nutrient enrichment, M2=mesotrophic and tolerant of moderate nutrient enrichment, E=eutrophic. 1971, 1975-76 and 1983 data are from Munawar and Munawar (1979), Lin and Schelske (1978) and Makarewicz (1987).

	M1	M2	E	M1+M2/E
1971[1]	6	3	3	3.0
1975-76[2]	2	4	2	3.0
1983[3]	7	2	2	4.5
1984[3]	6	3	3	3.0
1985[3]	5	3	3	2.7

[1]Only diatoms cantributing >5% of the seasonal biomass are classified.
[2]Only "abundant" diatom species are classified.
[3]Only diatoms contributing >0.5% of the biomass for the study period are classified.

Table 32. Relative abundance of zooplankton in Lake Huron.

	Percent Biomass			Percent Abundance		
	1983	1984	1985	1983	1984	1985
Rotifera	NOT CALCULATED	2.5	1.5	41.1	56.0	40.3
Cladocera		27.5	26.3	4.8	2.9	1.4
Copepoda nauplii		14.7	13.9	23.1	18.6	30.4
Cyclopoida		13.3	9.8	11.2	7.3	7.6
Calanoida		42.0	48.5	19.8	15.3	20.3
Amphipoda		<.1	0.0	0.0	<.1	0.0
Mysidacea		0.0	<.1	<.1	0.0	<.1

Table 33. Summary of common zooplankton species occurrence in Lake Huron during 1985. Species were arbitrarily classified as common if they accounted for ≥0.1% of the total abundance or ≥1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for ≥1.0% of the total abundance.

TAXON	MAXIMUM DENSITY (#/m³)	AVERAGE DENSITY (#/m³)	% OF TOTAL ABUNDANCE	MEAN BIOMASS (ug/m³)	% OF TOTAL BIOMASS
COPEPODA					
Copepoda - nauplii	104,859	20,586.0	30.42	8,234	13.90
Cyclopoida					
Cyclopoid - copepodite	51,479	4,430.0	6.55	3,248	5.48
Cyclops bicuspidatus thomasi	3,744	481.6	0.71	2,116	3.57
Mesocyclops - copepodite	1,050	125.0	0.18	177	0.30
Tropocyclops prasinus mexicanus	912	71.9	0.11	96	0.16
Calanoida					
Diaptomus - copepodite	62,346	8,981.5	13.27	10,157	17.15
Diaptomus ashlandi	17,446	2,264.7	3.35	5,209	8.79
Diaptomus minutus	5,863	1,006.2	1.49	2,211	3.73
Diaptomus oregonensis	2,788	221.9	0.33	970	1.64
Diaptomus sicilis	9,524	1,134.4	1.68	6,279	10.60
Limnocalanus macrurus	715	36.8	0.05	2,532	4.27
Senecella - copepodite	86	4.0	0.01	896	1.51
			----------		----------
	Total		58.14		71.10
CLADOCERA					
Bosmina longirostris	1,359	99.6	0.15	6,649	11.22
Daphnia galaeta mendotae	5,291	514.4	0.76	3,960	6.68
Daphnia pulicaria	683	39.4	0.06	944	1.59
Holopedium gibberum	1,573	144.6	0.21	3,368	5.69
			----------		----------
	Total		1.18		25.19
ROTIFERA					
Collotheca sp.	9,126	1,163.8	1.72	4	0.01
Conochilus unicornis	160,067	11,304.1	16.71	449	0.76
Gastropus stylifer	19,841	1,599.6	2.36	53	0.09
Kellicottia longispina	41,996	3,118.3	4.61	45	0.08
Keratella cochlearis	51,917	4,473.8	6.61	19	0.03
Notholca squamula	22,546	939.5	1.39	16	0.03
Polyarthra vulgaris	14,550	1,608.7	2.38	66	0.11
Synchaeta sp.	21,041	1,018.5	1.51	40	0.07
			----------		----------
	Total		37.28		1.16
			==========		==========
	Total		96.60		97.46

Table 34. Comparison of mean crustacean abundance for the sampling period in 1971 (April-November), 1974/75 (April-November), 1983 (August-October), 1984 (April-December) and 1985 (April-November). 1971 data modified from Watson and Carpenter (1974), 1974/75 data from McNaught *et al* (1980), 1983 and 1984 data from Makarewicz (1987, 1988). NF = not found. Values are in number/m3.

	1971	1974/75**	1983***	1984	1985
Cladocera					
Bosmina longirostris	553 (1047)*	4109	518	338	100
Eubosmina coregoni	330 (765)*	2084	229	326	55
Daphnia retrocurva		361	74	36	42
Daphnia galeata mendotae	339 (852)*	692	1029	586	514
Daphnia pulicaria	0 (0)	0	363	71	39
Chydorus sphaericus	18	391	NF	NF	<.1
Holopedium gibberum	229 (580)*	576	58	158	145
Cyclopoida					
Cyclops bicuspidatus thomasi	3764 (3274)*	1271	2346	316	482
Cyclops vernalis	7.5 (5)*	117	.5	1.5	NF
Tropocyclops prasinus mexicanus	63 (61)*	310	577	21	72
Mesocyclops edax	5 (6.7)*	91	115	40	22
Calanoida					
Diaptomus ashlandi	246 (37)*	745	206	1071	2264
Diaptomus minutus	462 (322)*	966	465	369	1006
Diaptomus sicilis	117 (77)*	496	145	502	1134
Diaptomus oregonensis	109 (92)*	192	140	93	222
Limnocalanus macrurus	64 (44)*	34	9.3	20	37

* August, September and October average
** Includes Saginaw Bay
*** August and October average

Table 35. Abundance of *Bythotrephes cederstroemi* by season and geography in 1985, Lake Huron.

Station	4/22	4/29	6/9	8/15	8/23	11/18	11/27	mean
61	0	0	0	0	0	72	11	11.9
54	0	0	0	0	0	0	6	0.9
43	0	0	0	36	0	0	0	5.1
32	0	0	0	0	8	0	0	1.1
93	0	0	0	0	0	24	0	3.4
15	0	0	0	0	23	0	0	3.3
12	0	0	0	0	34	0	4	5.4
9	0	0	0	0	11	0	0	1.6
6	0	0	0	8	11	0	6	3.6

Table 36. Mean abundance of rotifers in Lake Huron in 1974, 1983, 1984 and 1985. Data from Stemberger *et al* (1979), Evans (1986), Makarewicz (1987, 1988) and this study. NF = not found in short tow.

	1974	1980	1983	1984	1985
	April-Nov. #/L	April-July #/L	Aug.-Oct. #/L	April-Dec. #/L	April-Nov. #/L
Colletheca sp.	0.8	0.0	0.90	0.67	1.16
Conochilus unicornis	15.0	0.79	7.10	10.87	11.30
Filinia longiseta	3.4	<0.1	0.004	0.007	0.01
Gastropus stylifer	5.2	0.27	1.10	1.09	1.60
Kellicottia longiseta	6.8	1.15	2.10	3.78	3.12
Keratella cochlearis	41.9	1.86	2.00	6.65	4.47
Keratella earlinae	10.9	<.01	0.08	0.10	0.03
Notholca squamula	7.4	1.8	NF	0.57	0.94
Polyarthra dolichoptera	3.0	0.12	0.07	0.43	0.58
Polyarthra remata	6.8	0.12	0.01	0.65	0.17
Polyarthra vulgaris	17.6	0.05	3.00	2.92	1.61
Synchaeta kitina	8.1	NF	NF	NF	NF
Synchaeta stylata	7.1	NF	NF	NF	Nf
Synchaeta sp.	2.4	1.03	0.10	1.5	1.02

Table 37. Ratio of Calanoida to Cladocera plus Cyclopoida in Lake Huron, 1983, 1984 and 1985.

Station		Calanoida / Cyclopoida + Cladocera 1983	1984	1985
61	(North)	0.67	0.90	1.53
54		1.11	1.36	2.38
45		1.19	1.84	2.80
37		1.57	1.33	2.32
32		2.13	1.46	2.93
27		1.37	1.16	2.10
12		1.98	1.83	2.64
09		1.31	2.00	3.19
06	(South)	1.23	1.89	2.67

Table 38. Comparison of the plankton ratio (Calanoida/Cyclopoida+Cladocera) between the northern stations of Lake Huron and Lake Michigan.

	1983	1984	mean
Lake Michigan			
Station 77	0.37	0.23	0.32
Lake Huron			
Station 61	0.67	0.90	0.78
Lake Mean	1.49	1.61	1.55

Table 39. Abundance of selected zooplankton species in northern and southern Lake Huron in 1984. Values are number/m^3. Southern Lake Huron is defined as south of Station 27.

	Conochilus unicornis		*Kellicottia longispina*		*Diaptomus minutus*		*Holopedium gibberum*	
	1984	1985	1984	1985	1984	1985	1984	1985
Northern	12,526	14,183	3,897	3,624	298	1,079	239	162
Southern	4,729	7,869	2,449	2,514	383	920	29	123

Table 40. Correlation (r) of phytoplankton abundance with total phosphorus concentrations and zooplankton abundance within individual cruises (10 stations) in Lake Huron, 1985. NO - observed.

	Daphnia pulicaria	*Daphnia* spp.	Rotifera	Calanoida	Total Phosphorus
4/22-23	NO	.772	.800	.198	.180
4/29-30	-.148	.016	.207	-.154	-.669
6/9-10	-.215	.038	-.215	-.386	-.344
8/15-16	.232	-.156	.061	-.354	-.112
8/23-25	-.030	.003	-.167	-.198	.088
11/18-19	NO	.093	-.113	-.156	.001
11/27-28	-.465	-.020	.222	-.407	-.476

Table 41. Number of species and genera observed in each algal division or grouping, Lake Erie, 1983, 1984 and 1985. Bac-Bacillariophyta, Cat-Chloromanophyta, Chl-Chlorophyta, Chr-Chrysophyta, Col-Colorless flagellates, Cry-Cryptophyta, Cya-Cyanophyta, Pic-Picoplankton, Eug-Euglenophyta, Pyr-Pyrrophyta, Uni-Unidentified.

Division	Species 1983	Species 1984	Species 1985	Genera 1983	Genera 1984	Genera 1985
BAC	176	171	162	30	30	29
CHL	108	96	115	38	38	37
CHR	29	28	29	11	14	14
CRY	14	15	19	3	4	3
CYA	16	18	20	9	10	9
PIC	-	3*	3	-	0	0
COL	15	11	8	6	4	3
PYR	8	9	6	4	4	4
EUG	2	0	2	2	0	2
UNI	3	4	4	0	0	0
CAT	1	1	1	0	0	0
TOTAL	372	356	369	103	104	101

* Included in Cyanophyta in 1983.

Table 42. Number of species identified and percentage of species belonging to various taxonomic groups. 1970 data represent the mean for the Central, Western and Eastern Basins [modified from Munawar and Munawar (1976)].

	1970	1983	1984	1985
Number of Species	134.3	372	356	369
Division		Percent Composition		
BAC	16.3	47.3	48.0	43.9
CHL	58.0	29.0	27.0	31.2
CHR	6.3	7.8	7.9	7.9
CYA	11.2	4.3	5.1	5.4
CRY	3.3	3.8	4.2	5.1
EUG	0.7	0.5	0.0	0.5
PYR	4.0	2.2	0.0	1.6
PIC	-	-	0.8	0.8
UNI	-	0.8	1.1	1.1
COL	-	4.0	3.1	2.2

Table 43. Relative abundance of major phytoplankton divisions in Lake Erie, 1983 - 1985. Picoplankton are not included. BAC=Bacillariophyta, CAT=Chloromanophyta, CHL=Chlorophyta, CHR=Chrysophyta, COL=Colorless Flagellates, CRY=Cryptophyta, CYA=Cyanophyta, EUG=Euglenophyta, PYR=Pyrrophyta, UNI=Unidentified.

Division	% Biovolume/mL			% Cells/mL		
	1983	1984	1985	1983	1984	1985
BAC	60.4	48.1	63.2	8.9	11.2	14.9
CAT	<0.1	0.0	<0.1	<0.1	0.0	<0.1
CHL	15.0	11.6	8.8	12.6	4.8	12.9
CHR	0.9	1.6	1.4	4.0	4.5	10.1
COL	0.1	0.6	0.7	0.5	2.9	5.6
CRY	9.1	13.2	7.8	11.2	12.0	15.6
CYA	3.4	3.8	4.3	32.6	31.5	25.8
EUG	<.1	0.0	<0.1	<0.1	0.0	<0.1
PYR	8.5	12.9	10.7	0.2	0.3	0.4
UNI	2.5	8.0	2.9	30.1	32.6	14.6

Table 44. Phytoplankton and zooplankton biomass, total phosphorus and chlorophyll *a* concentrations in the Western, Central and Eastern Basins of Lake Erie, 1983, 1984 and 1985. Picoplankton are not included. To allow comparisons between years, two samples from spring (April and May), summer (August) and winter (late October through December) were averaged. Values are in g/m^3 unless noted otherwise. Total phosphorus and chlorophyll *a* are the averages of the 3m samples.

	Western	Central	Eastern	Entire Lake (mean±S.E.)
Phytoplankton				
Abundance (cells/mL)				
1983	11,430	4,642	3,519	6,187±750
1984	9,479	4,186	2,953	5,331±462
1985	10,637	3,509	2,220	4,483±568
Biomass				
1983	1.48	1.59	0.83	1.35±.13
1984	1.36	0.75	0.53	0.86±.08
1985	1.62	1.38	0.54	1.22±.11
mean	1.75	1.31	0.70	
Zooplankton				
Biomass				
1984	0.055	0.052	0.054	0.053±.0062
1985	0.084	0.117	0.096	0.106±.0098
Abundance				
1984 (#/L)	295.6	94.3	130.4	159.6±25
1985	342.0	211.7	154.7	221.6±27
Total Phosphorus				
1983(ug/L)	26.8	16.8	12.8	
1984(ug/L)	23.9	19.4	12.4	
1985(ug/L)	23.8	13.9	10.3	
Chlorophyll *a*				
1983(ug/L)	5.68	4.05	2.22	
1984(ug/L)	5.10	3.27	2.11	
1985(ug/L)	6.59	2.88	0.84	

Table 45. Location of maximum abundance of selected common species in 1983, 1984 and 1985, Lake Erie.

	1983	1984	1985
Actinocyclus normanii			
f. subsalsa	Western	not common	Western
Fragilaria crotonensis	Western	Western	Western
Fragilaria capucina	Western	Western	Central
Melosira granulata	Western	not common	not common
Melosira islandica	not common	Western	not common
Stephanodiscus sp.	not common	Western	Western
Stephanodiscus binderanus	Western	Western	Western
Tabellaria flocculosa	Western	Western	Central
Oscillatoria tenuis	Western	not common	not common
Oscillatoria limnetica	Western	Western	Western
Oscillatoria subbrevis	Western	not common	Western
Anacystis montana			
var. *minor*	not common	Western	Western
Aphanizomenon flos-aquae	not common	Western	Western
spheres	Western	Western	Western
Cryptomonas erosa	Western	Western	Western
Chroomonas norstedtii	not common	Western	Western
Merismopedia tenuissima	not common	Western	not common
Pediastrum simplex			
var. *duodenarium*	Central	Western	Western
Coelosphaerium naegelianum	Central	Western	not common
Scenedesmus ecornis	Central	Western	not common
Peridinium aciculiferum	Central	Central	not common
Asterionella formosa	not common	Central	not common
Gymnodinium sp.#2	not common	Central	not common
Haptophyte	not common	Central	not common

Table 46. Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1983. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Actinocyclus normanii f. subsalsa	88	11.8	0.02	80,734	5.40
Cyclotella meneghiniana	181	19.3	0.03	7,759	0.52
Diatoma tenue v. elongatum	209	19.7	0.03	11,164	0.75
Fragilaria capucina	603	92.5	0.14	21,406	1.43
Fragilaria crotonensis	554	173.3	0.27	89,972	6.02
Fragilaria intermedia v. fallax	85	18.2	0.03	7,974	0.53
Melosira granulata	555	81.5	0.13	36,996	2.47
Melosira islandica	104	9.9	0.02	10,453	0.70
Rhizosolenia eriensis	671	40.9	0.06	17,568	1.17
Rhizosolenia sp.	507	25.7	0.04	191,069	12.77
Stephanodiscus alpinus	78	13.8	0.02	18,270	1.22
Stephanodiscus alpinus?	38	4.7	0.01	8,913	0.60
Stephanodiscus binderanus	234	50.8	0.08	26,409	1.77
Stephanodiscus niagarae	20	3.4	0.01	61,310	4.10
Synedra filiformis	482	29.4	0.05	8,980	0.60
Tabellaria flocculosa	316	39.8	0.06	103,387	6.91
Tabellaria flocculosa v. linearis	49	9.0	0.01	18,269	1.22
Tabellaria sp.	111	8.0	0.01	17,419	1.16
Total			1.01		49.34
CHLOROPHYTA					
Cosmarium sp.	25	2.3	0.00	76,094	5.09
Mougeotia sp.	352	36.2	0.06	24,055	1.61
Oocystis borgei	115	14.4	0.02	9,634	0.64
Total			0.08		7.34
CHRYSOPHYTA					
Dinobryon cylindricum	255	28.0	0.04	10,533	0.70
CRYPTOPHYTA					
Cryptomonas erosa	286	73.2	0.11	163,058	10.90
Cryptomonas marssonii	65	16.9	0.03	14,964	1.00
Cryptomonas marssonii v.?	139	18.7	0.03	9,811	0.66
Rhodomonas minuta v. nannoplanktica	1,890	701.5	1.09	35,741	2.39
Total			1.26		14.95
CYANOPHYTA					
Anabaena spiroides	687	64.7	0.10	8,455	0.57
Anacystis marina	141,208	52,613.9	81.55	14,105	0.94
Anacystis montana v. minor	5,072	560.8	0.87	5,004	0.33
Aphanizomenon flos-aquae	2,561	189.3	0.29	14,962	1.00
Coccochloris peniocystis	1,227	474.7	0.74	1,320	0.09
Merismopedia tenuissima	15,544	1,221.7	1.89	382	0.03
Oscillatoria limnetica	11,266	1,561.1	2.42	11,499	0.77
Oscillatoria subbrevis	27,399	1,421.6	2.20	55,610	3.72
Oscillatoria tenuis	5,081	291.4	0.45	16,374	1.09
Total			90.52		8.54

Table 46(cont.). Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1983. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

PYRROPHYTA					
Gymnodinium sp.	16	0.8	0.00	7,721	0.52
Peridinium sp.	25	3.7	0.01	7,987	0.53
			----------		----------
Total			0.01		1.05
UNIDENTIFIED					
Unidentified flagellate - ovoid	3,960	1,422.2	2.20	24,807	1.66
Unidentified flagellate - spherical	1,252	517.1	0.80	9,904	0.66
			----------		----------
Total			3.01		2.32
			==========		==========
Total			95.92		84.24

Table 47. Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Actinocyclus normanii f. subsalsa	16	1.0	0.01	8,220	0.60
Asterionella formosa	143	39.4	0.42	103,692	7.62
Fragilaria capucina	407	87.6	0.92	24,746	1.82
Fragilaria crotonensis	826	181.1	1.91	124,332	9.13
Melosira granulata v. granulata	247	17.9	0.19	7,706	0.57
Melosira islandica	1,564	107.6	1.13	123,141	9.05
Stephanodiscus alpinus	77	9.1	0.10	13,882	1.02
Stephanodiscus binderanus	2,506	159.1	1.68	43,676	3.21
Stephanodiscus niagarae	120	6.1	0.06	162,706	11.95
Stephanodiscus parvus	512	58.8	0.62	2,394	0.18
Stephanodiscus sp.	776	95.9	1.01	8,269	0.61
Tabellaria flocculosa	207	27.1	0.29	60,946	4.48
Total			8.34		50.22
CHLOROPHYTA					
Cosmarium sp.	25	1.7	0.02	74,100	5.44
Monoraphidium contortum	386	58.0	0.61	420	0.03
Oocystis borgei	180	13.9	0.15	10,964	0.81
Pediastrum simplex v. duodenarium	393	27.8	0.29	37,884	2.78
Total			1.07		9.06
CHRYSOPHYTA					
Chrysosphaerella longispina	1,088	36.9	0.39	10,022	0.74
Dinobryon cylindricum	360	37.9	0.40	8,790	0.65
Haptophyceae	1,317	139.6	1.47	2,905	0.21
Total			2.26		1.60
COLORLESS FLAGELLATES					
Colorless flagellates	376	49.2	0.52	1,304	0.10
Stelexmonas dichotoma	1,186	164.1	1.73	5,846	0.43
Total			2.25		0.53
CRYPTOPHYTA					
Chroomonas norstedtii	425	73.6	0.78	1,914	0.14
Cryptomonas erosa	295	49.1	0.52	95,413	7.01
Cryptomonas pyrenoidifera	344	24.5	0.26	10,641	0.78
Cryptomonas rostratiformis	33	4.0	0.04	12,958	0.95
Rhodomonas minuta v. nannoplanktica	2,348	689.3	7.27	53,586	3.94
Total			8.87		12.82

Table 47(cont.). Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1984. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

CYANOPHYTA					
Agmenellum quadruplicatum	1,047	54.5	0.58	15	0.00
Anabaena sp.	1,162	90.7	0.96	15,300	1.12
Anacystis montana v. minor	22,253	1,939.2	20.46	9,738	0.72
Anacystis montana v. montana	6,954	234.3	2.47	16,456	1.21
Aphanizomenon flos-aquae	2,643	259.6	2.74	18,707	1.37
Coelosphaerium naegelianum	3,436	276.4	2.92	1,158	0.09
Gomphosphaeria lacustris	2,544	99.3	1.05	2,677	0.20
Merismopedia tenuissima	6,218	303.5	3.20	364	0.03
Oscillatoria limnetica	5,179	395.2	4.17	1,481	0.11
Spirulina subtilissima	3,788	114.8	1.21	307	0.02
			----------		----------
Total			39.75		4.86
PYRROPHYTA					
Peridinium sp.	41	5.0	0.05	9,773	0.72
UNIDENTIFIED					
Unidentified flagellate - ovoid	4,303	1,600.5	16.88	50,524	3.71
Unidentified flagellate - spherical	2,479	806.2	8.51	27,835	2.04
			----------		----------
Total			25.39		5.76
			==========		==========
Total			87.98		85.56

Table 48. Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

TAXON	MAXIMUM CELLS/ML	AVERAGE CELLS/ML	% OF TOTAL CELLS	MEAN BIOVOLUME CU.uM/mL	% OF TOTAL BIOVOLUME
BACILLARIOPHYTA					
Actinocyclus normanii f. subsalsa	137	19.5	0.18	195,513	12.05
Asterionella formosa	173	34.4	0.32	13,835	0.85
Cyclotella comensis v. 1	612	82.6	0.78	3,216	0.20
Cyclotella meneghiniana	498	50.2	0.47	15,104	0.93
Diatoma tenue v. elongatum	335	27.3	0.26	18,681	1.15
Fragilaria capucina	598	78.4	0.74	21,506	1.33
Fragilaria crotonensis	556	124.6	1.17	79,571	4.90
Melosira islandica	202	31.1	0.29	24,829	1.53
Rhizosolenia eriensis	104	33.2	0.31	86,595	5.34
Rhizosolenia longiseta	168	16.6	0.16	16,678	1.03
Skeletonema potamos	671	125.8	1.18	7,415	0.46
Stephanodiscus alpinus	120	31.7	0.30	37,412	2.31
Stephanodiscus binderanus	167	36.0	0.34	15,982	0.99
Stephanodiscus niagarae	40	8.0	0.08	154,628	9.53
Stephanodiscus parvus	1,051	118.0	1.11	5,153	0.32
Stephanodiscus sp.	335	94.6	0.89	8,482	0.52
Tabellaria flocculosa	199	37.4	0.35	65,255	4.02
Total			8.92		47.45
CHLOROPHYTA					
Actinastrum hantzschii	393	53.6	0.50	1,590	0.10
Botryococcus sp.?	1,841	220.4	2.07	7,001	0.43
Cosmarium sp.	16	3.2	0.03	108,819	6.71
Green coccoid - ovoid	794	112.3	1.06	5,699	0.35
Green coccoid - sphere	540	88.6	0.83	9,424	0.58
Monoraphidium contortum	303	110.9	1.04	1,299	0.08
Scenedesmus acuminatus	65	11.4	0.11	12,057	0.74
Scenedesmus quadricauda	311	83.6	0.79	3,627	0.22
Total			6.43		9.21
CHRYSOPHYTA					
Chrysophycean coccoids	1,014	176.8	1.66	2,015	0.12
Dinobryon divergens	254	24.1	0.23	11,806	0.73
Haptophyceae	1,530	372.3	3.50	8,632	0.53
Total			5.39		1.38
COLORLESS FLAGELLATES					
Colorless flagellates	777	212.3	2.00	6,577	0.41
Stelexmonas dichotoma	614	113.6	1.07	4,868	0.30
Total			3.06		0.71
CRYPTOPHYTA					
Cryptomonas erosa	131	49.1	0.46	64,679	3.99
Rhodomonas minuta v. nannoplanktica	4,712	1,019.5	9.58	69,555	4.29
Total			10.05		8.28

Table 48(cont.). Summary of common phytoplankton species occurrence in western basin, Lake Erie during 1985. Summary is based on all samples analyzed with picoplankton removed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of ≥ 0.5% of the total cells or ≥0.5% of the total biovolume.

CYANOPHYTA					
Agmenellum quadruplicatum	2,806	404.5	3.80	212	0.01
Anabaena flos-aquae	3,199	177.7	1.67	4,341	0.27
Anabaena sp.	4,761	360.0	3.38	13,773	0.85
Anabaena spiroides	6,823	379.1	3.56	33,022	2.04
Anacystis montana v. minor	1,661	323.2	3.04	3,657	0.23
Aphanizomenon flos-aquae	9,228	1,047.7	9.85	128,727	7.93
Gomphosphaeria lacustris	1,064	98.2	0.92	813	0.05
Merismopedia tenuissima	1,636	127.3	1.20	67	0.00
Oscillatoria limnetica	8,271	1,139.9	10.72	12,552	0.77
Oscillatoria minima	974	98.6	0.93	1,311	0.08
Oscillatoria subbrevis	4,140	437.7	4.11	14,644	0.90
			----------		----------
Total			43.19		13.13
PYRROPHYTA					
Gymnodinium helveticum	8	0.5	0.00	10,708	0.66
Gymnodinium sp.	25	3.2	0.03	8,958	0.55
Peridinium sp.	8	1.4	0.01	15,480	0.95
			----------		----------
Total			0.05		2.17
UNIDENTIFIED					
Unidentified flagellate - ovoid	1,808	703.6	6.61	38,539	2.38
Unidentified flagellate - spherical	556	181.8	1.71	8,650	0.53
			----------		----------
			8.32		2.91
			==========		==========
Total			85.41		85.23

Table 49. Phytoplankton common (abundance >0.5% of the total cells or >0.5% of the total biovolume) in 1985 but not in 1983 and 1984, Lake Erie.

Bacillariophyta
- *Rhizosolenia eriensis*
- *Suriella biseriata* var. *bifrons*
- *Rhizosolenia eriensis*

Chlorophyta
- *Botryococcus sp.?*
- *Chlamydocapsa planktonica*
- Green coccoid - ovoid
- Green coccoid - sphere
- *Oedogonium* sp.
- *Scenedesmus quadricauda*

Cyanophyta
- *Anabaena flos-aquae*
- *Anabaena spiroides*

Chrysophyta
- Chrysophycean coccoids

Cryptophyta
- *Rhodomonas lens*

Pyrrophyta
- *Amphidinium* sp.

Table 50. Average abundance and biomass of *Rhizosolenia eriensis*, *Oedogonium* sp. and *Amphidinium* sp., Lake Erie, 1985.

	cells/mL			um^3/mL		
	1983 (n=77)	1984 (n=117)	1985 (n=100)	1983 (n=77)	1984 (n=117)	1985 (n=100)
Rhizosolenia eriensis	11.7	1.4	6.1	5,019	1,180	16,007
Oedogonium sp.	3.1	2.4	15.2	4,549	905	19,495
Amphidinium sp.	4.1	2.9	4.8	3,870	1,183	17,515

Table 51. Importance of *Asterionella formosa* during the spring of 1984 and 1985, Lake Erie. 1984 sampling dates: 4/18, 4/20, 5/1. 1985 sampling dates: 4/24, 4/27.

Rank	1984	1985
	Biovolume (g/m^3) All Species	
1	0.162 (*Asterionella formosa*)	0.406 (*Stephanodiscus niagarae*)
2	0.160 (*Fragilaria crotonensis*)	0.164 (*Peridiium* sp.)
3	0.123 (*Melosira islandica*)	0.072 (*Rhodomonas minuta*)
4	0.109 (*Gymnodinium* sp.)	0.066 (*Tabellaria flocculosa*)
	Abundance (#/mL) Diatoms Only	
1	238 (*Stephanodiscus* sp.)	88 (*Fragillaria crotonensis*)
2	224 (*Asterionella formosa*)	70 (*Stephanodiscus parvus*)
3	170 (*Fragillaria crotonensis*)	62 (*Staphanodiscus hantzschii*)
4	117 (*Stephanodiscus parvus*)	59 (*Fragillaria capucina*)

Table 52. Mean maximum biomass of selected common phytoplankton species in 1970, 1983, 1984 and 1985, Lake Erie. Data from Munawar and Munawar (1976) and this study. 1970 data - graphical accuracy. Percent reduction is from 1970 to the average of 1983 to 1985.

	BASIN	1970 g/m^3	1983 g/m^3	1984 g/m^3	1985 g/m^3	Mean 83-85 g/m^3	Percent Reduction
Actinocyclus normanii	Western	4.7	0.30	0.05	0.68	0.34	93
Stephanodiscus niagarae	Eastern	1.4	1.05	0.22	0.47	0.58	59
	Central	2.3	2.19	0.53	1.60	1.44	37
	Western	0.6	0.12	1.14	0.35	0.54	11
Stephanodiscus tenuis	Western	1.8	0.001	0.002	0.015	.006	99
Stephanodiscus binderanus	Western	0.5	0.11	0.04	0.07	0.07	85
Fragilaria crotonensis	Eastern	1.0	0.15	0.45	0.01	0.19	81
	Central	3.4	0.11	0.16	0.09	0.12	96
	Western	7.9	0.18	0.29	0.28	0.25	97
Fragilaria capucina	Central	2.4	0.02	0.03	0.33	0.14	94
	Eastern	0.4	0.04	0.01	0.01	0.02	95
Peridinium aciculiferum	Central	0.2	0.06	0.18	0.00	0.08	60
	Eastern	1.0	0.05	0.03	0.00	0.03	97
Ceratium hirundinella	Central	1.8	0.35	0.13	0.22	0.28	84
	Eastern	2.0	0.31	0.35	0.07	0.24	88
Rhodomonas minuta	Eastern	1.6	0.04	0.05	0.0002	0.03	98
	Central	0.4	0.10	0.14	0.0003	0.08	80
Cryptomonas erosa	Western	2.0	0.63	0.40	0.13	0.39	81
Pediastrum simplex	Central	0.4	0.06	0.00	0.11	0.06	86
Staurastrum paradoxum	Central	0.4	0.07	0.00	0.00	0.02	94
Aphanizomenon flos-aquae	Western	2.0	0.10	0.09	0.48	0.22	89

Table 53. Distribution of indicator species in the Western Basin of Lake Erie. The classification scheme of Tarapchak and Stoermer (1976) was utilized. Only diatoms contributing 5% or more of the biomass for a cruise are classified. M_1 = mesotrophic but intolerant of nutrient enrichment, M_2 = mesotrophic and tolerant of moderate nutrient enrichment, E = eutrophic. 1970 data are from Munawar and Munawar (1976). 1978 data are from Devault and Rockwell (1986).

	M_1	M_2	E	M_1+M_2/E
1970	0	1	5	0.2
1978	0	3	3	1.0
1983	1	2	3	1.0
1984	3	2	2	2.5
1985	2	2	2	2.0

Table 54. Trophic status of the Western, Central and Eastern basins of Lake Erie in 1970, 1983/84 and 1985. The classification scheme of Munawar and Munawar (1982) is used. 1970 data is from Munawar and Munawar (1982). Based on average biomass of basins in 1983, 1984 and 1985.

	1970	1983 + 1984	1985
Eastern Basin	mesoeutrophic	oligotrophic	oligotrophic
Central Basin	mesoeutrophic	mesotrophic	mesotrophic
Western Basin	eutrophic	mesotrophic	mesotrophic

Table 55. Relative abundance of zooplankton in Lake Erie.

	Percent Biomass			Percent Abundance		
	1983	1984	1985	1983	1984	1985
Rotifera	NOT CALCULATED	13.6	5.5	69.2	80.1	70.8
Cladocera		40.5	35.1	6.0	3.2	4.2
Copepoda nauplii		12.3	12.8	15.8	10.4	15.2
Cyclopoida		17.1	23.4	5.4	3.9	5.3
Calanoida		16.5	23.2	3.7	2.5	4.4
Harpacticoida		<0.1	<0.1	<0.1	<0.1	<0.1
Amphipoda		<0.1	0.0	0.0	<0.1	0.0

Table 56. Summary of common zooplankton species occurrence in Lake Erie during 1985. Species were arbitrarily classified as common if they accounted for ≥0.1% of the total abundance or ≥1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for ≥1.0% of the total abundance.

TAXON	MAXIMUM DENSITY (#/m^3)	AVERAGE DENSITY (#/m^3)	% OF TOTAL ABUNDANCE	MEAN BIOMASS (ug/m^3)	% OF TOTAL BIOMASS
COPEPODA					
Copepoda - nauplii	140,098	33,761.3	15.24	13,505	12.76
Cyclopoida					
Cyclopoid - copepodite	32,818	6,137.1	2.77	5,244	4.95
Cyclops bicuspidatus thomasi	10,832	1,670.1	0.75	7,941	7.50
Cyclops vernalis	8,151	220.0	0.10	1,239	1.17
Mesocyclops - copepodite	14,157	1,925.0	0.87	3,169	2.99
Mesocyclops edax	9,609	1,075.7	0.49	6,369	6.02
Tropocyclops prasinus mexicanus	2,095	528.3	0.24	718	0.68
Calanoida					
Diaptomus - copepodite	42,227	6,091.8	2.75	9,704	9.17
Diaptomus oregonensis	19,032	3,013.9	1.36	13,248	12.52
			----------		----------
			TOTAL 24.56		57.77
CLADOCERA					
Bosmina longirostris	49,548	1,834.0	0.83	2,146	2.03
Chydorus sphaericus	15,229	639.6	0.29	737	0.70
Daphnia galaeta mendotae	23,680	2,030.6	0.92	12,956	12.24
Daphnia retrocurva	11,583	1,459.0	0.66	6,975	6.59
Diaphanosoma sp.	21,621	1,194.7	0.54	2,119	2.00
Eubosmina coregoni	20,735	2,072.2	0.94	4,703	4.44
Eurycercus lamellatus	1,244	37.2	0.02	5,102	4.82
Leptodora kindtii	1,001	42.3	0.02	1,088	1.03
			----------		----------
			TOTAL 4.20		33.85
ROTIFERA					
Ascomorpha ovalis	97,548	5,048.9	2.28	102	0.10
Asplanchna priodonta	21,021	797.9	0.36	1,133	1.07
Conochilus unicornis	805,564	39,199.1	17.69	412	0.39
Kellicottia longispina	27,348	4,048.2	1.83	63	0.06
Keratella cochlearis	156,229	17,431.4	7.87	66	0.06
Keratella crassa	42,041	2,315.4	1.05	112	0.11
Keratella hiemalis	46,910	5,315.6	2.40	197	0.19
Keratella quadrata	250,959	5,443.4	2.46	368	0.35
Notholca squamula	88,817	10,191.3	4.60	209	0.20
Polyarthra dolichoptera	79,390	5,908.5	2.67	289	0.27
Polyarthra major	31,531	3,847.8	1.74	424	0.40
Polyarthra remata	107,784	3,223.2	1.45	59	0.06
Polyarthra vulgaris	1215683	27,294.5	12.32	1,150	1.09
Synchaeta sp.	468,620	16,262.1	7.34	458	0.43
			----------		----------
			TOTAL 66.04		4.76
			==========		==========
			TOTAL 94.80		96.38

Table 57. Common zooplankton species observed in either 1983, 1984 or 1985 but not in all three years, Lake Erie. 1983 and 1984 data are from Makarewicz (1987, 1989). Yes = common. No = not common.

	1983	1984	1985
Calanoida			
Diaptomus siciloides	yes	no	no
Cladocera			
Daphnia pulicaria	no	yes	no
Diaphanosoma leuchtenbergianum	yes	no	yes
Eurycercus lamellatus	no	no	yes
Leptodora kindtii	no	yes	yes
Rotifera			
Ascomorpha ovalis	no	yes	yes
Ascomorpha ecaudis	yes	no	no
Asplanchna priodonta	no	yes	yes
Brachnionus sp.	yes	yes	no
Kellicottia longispina	yes	no	no
Keratella earlinae	no	yes	no
Keratella hiemalis	yes	no	yes
Keratella quadrata	no	no	yes
Nolthoca folicea	yes	yes	no
Nolthoca laurentiae	yes	yes	no
Notholca squamala	no	yes	yes
Polyarthra remata	no	yes	yes

Table 58. Abundant (1967) and predominant (1983-1983) rotifer species in 1967, 1983 1984 and 1985, Lake Erie. Values in parentheses represent percentage of total abundance.

1967	1983	1984	1985
Brachionus angularis	*Polyarthra vulgaris*(18.4)	*Polyarthra vulgaris*(22.5)	*Conochilus unicornis*(17.7)
Brachionus calyciflorus	*Synchaeta* sp. (9.5)	*Synchaeta* sp. (9.5)	*Polyarthra vulgaris* (12.2)
Conochilus unicornis	*Keratella cochlearis*(7.3)	*Polyarthra major*(4.9)	*Keratella cochlearis*(7.9)
Keratella cochlearis	*Conochilus unicornis*(5.3)	*Notholca squamula*(11.1)	*Synchaeta* sp. (7.4)
Keratella quadrata	*Keratella hiemalis*(3.5)	*Keratella cochlearis*(4.9)	*Notholca squamula*(4.6)
Kellicottia longispina	*Brachionus* sp.(3.0)		*Polyarthra dolichoptera*(2.7)
Synchaeta sp.			
Polyarthra vulgaris			

Table 59. Occurrence of eutrophic zooplankton indicator species in Lake Erie, 1984 and 1985. Values = mean number/m^3

	BASIN					
	Western		Central		Eastern	
	84	85	84	85	84	85
Brachionus angularis	177	1,156	0	366	0	0
*B. budapestinen**	92	445	0	0	0	0
B. calyciflorus	97	72	0	0	0	0
B. caudatus	81	0	0	0	0	0
Filinia longiseta	459	563	2.8	179	0	0
Keratella cochlearis f. tecta	2,062	5,359	9.2	0	0	0
Trichocerca cylindrica	397	2,823	0	0	0	0
*T. elongata**	907	0	0	0	0	0
T. multicrinis	477	2,297	42	770	0	36
T. pusilla	36	0	0	0	0	0

* Not listed as a eutrophic species by Gannon and Stemberger (1978).

Table 60. Ratio of Calanoida abundance to Cladocera plus Cyclopoida abundance in Lake Erie, 1983 to 1985. Nauplii are not included in the ratio.

	WESTERN BASIN	CENTRAL BASIN	EASTERN BASIN	MEAN
1983	0.19	0.31	0.45	0.32
1984	0.27	0.42	0.36	0.35
1985	0.16	0.49	0.59	0.41

Table 61. Correlation (r) of phytoplankton abundance with total phosphorus concentrations and zooplankton abundance within individual cruises in Lake Erie 1984. NO = observed.

	Daphnia pulicaria	*Daphnia* spp.	Rotifera	Calanoida	Total Phosphorus
4/18-19	NO	.535	.714	.343	.801
5/1-2	NO	-.941	-.771	-.992	-.811
8/5-6	-.509	-.079	.021	-.534	.756
8/19-20	-.548	.061	.929	-.383	.910
12/4-5	NO	-.448	.097	-.345	.505

Table 62. Number of common species shared by Lake Michigan, Lake Huron and three basins in Lake Erie[a] and the Percentage of Similarity[b] between lake basin pairs in 1985.

	Lake Michigan	Lake Huron	Lake Erie-W	Lake Erie-C	Lake Erie-E
Number of Common Species	43	47	48	43	40
		Number of Shared Common Species			
Lake Michigan		24	22	18	18
Lake Huron	51.36		27	20	19
Lake Erie-W	42.77	35.65		29	27
Lake Erie-C	32.33	18.26	33.28		30
Lake Erie-E	33.91	19.19	36.03	70.42	
	Percentage of Similarity between lake basins				

[a]Erie-W: Western Basin; Erie-C: Central Basin; Erie-E:Eastern Basin
[b]Percent of Similarity was calculated as the sum of the lesser biovolume for all shared species between lake basins.

Table 63. Number of shared species with Relative Percent Difference[a] (RPD) > 1 (Upper) and percent of shared species with RPD > 1 (Lower) based on biovolume of common phytoplankton species in Lakes Michigan, Huron and Erie[b] in 1985.

	Lake Michigan	Lake Huron	Lake Erie-W	Lake Erie-C	Lake Erie-E
Number of Common Species	43	47	48	43	40
		Number of Shared Species with PPD > 1			
Lake Michigan		4	6	9	7
Lake Huron	17		6	6	7
Lake Erie-W	27	22		12	10
Lake Erie-C	50	30	41		5
Lake Erie-E	39	37	37	17	
	Percentage of Shared Species with RPD > 1				

[a]RPD = the difference in percent biovolume of each species between two lakes basins divided by the average percent biovolume for that species i.e., (:a-b:)/(a+b)/2, where a = percent biovolume in basin a, and b = percent biovolume in basin b.

[b]Erie-W: Western Basin; Erie-C: Central Basin; Erie-E: Eastern Basin.

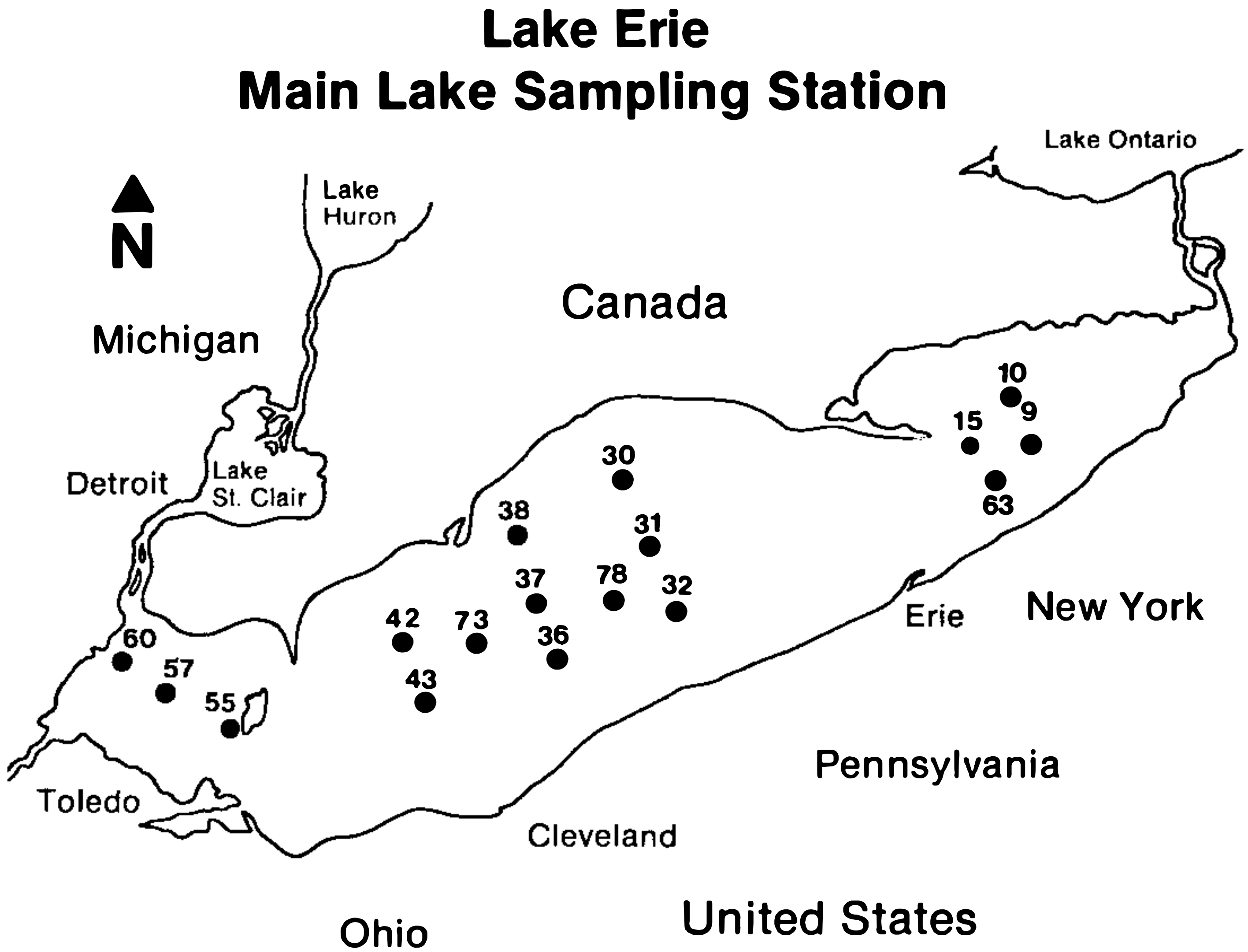


Figure 1. Lake Erie plankton sampling stations, 1985.

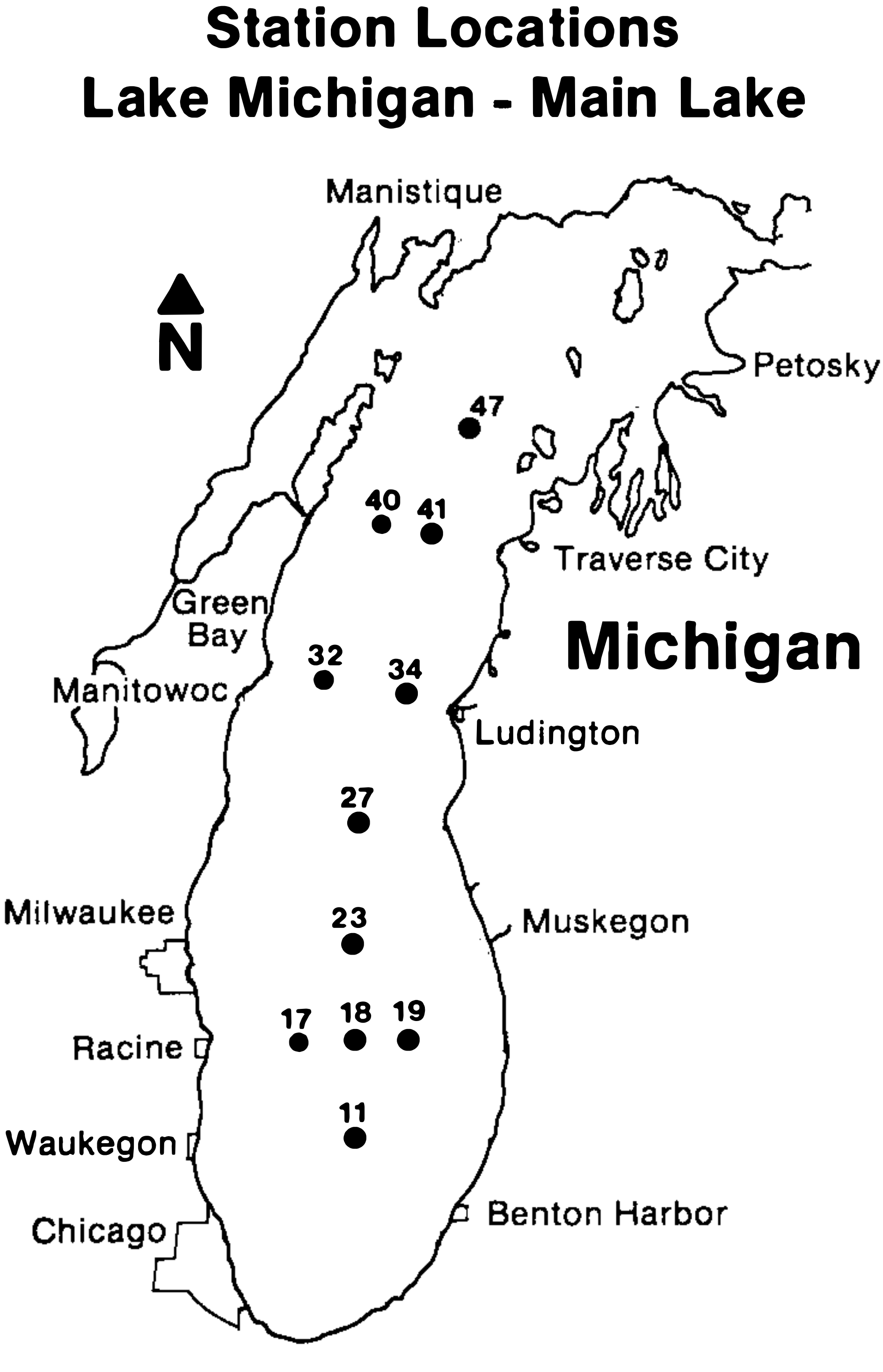


Figure 2. Lake Michigan sampling stations, 1985.

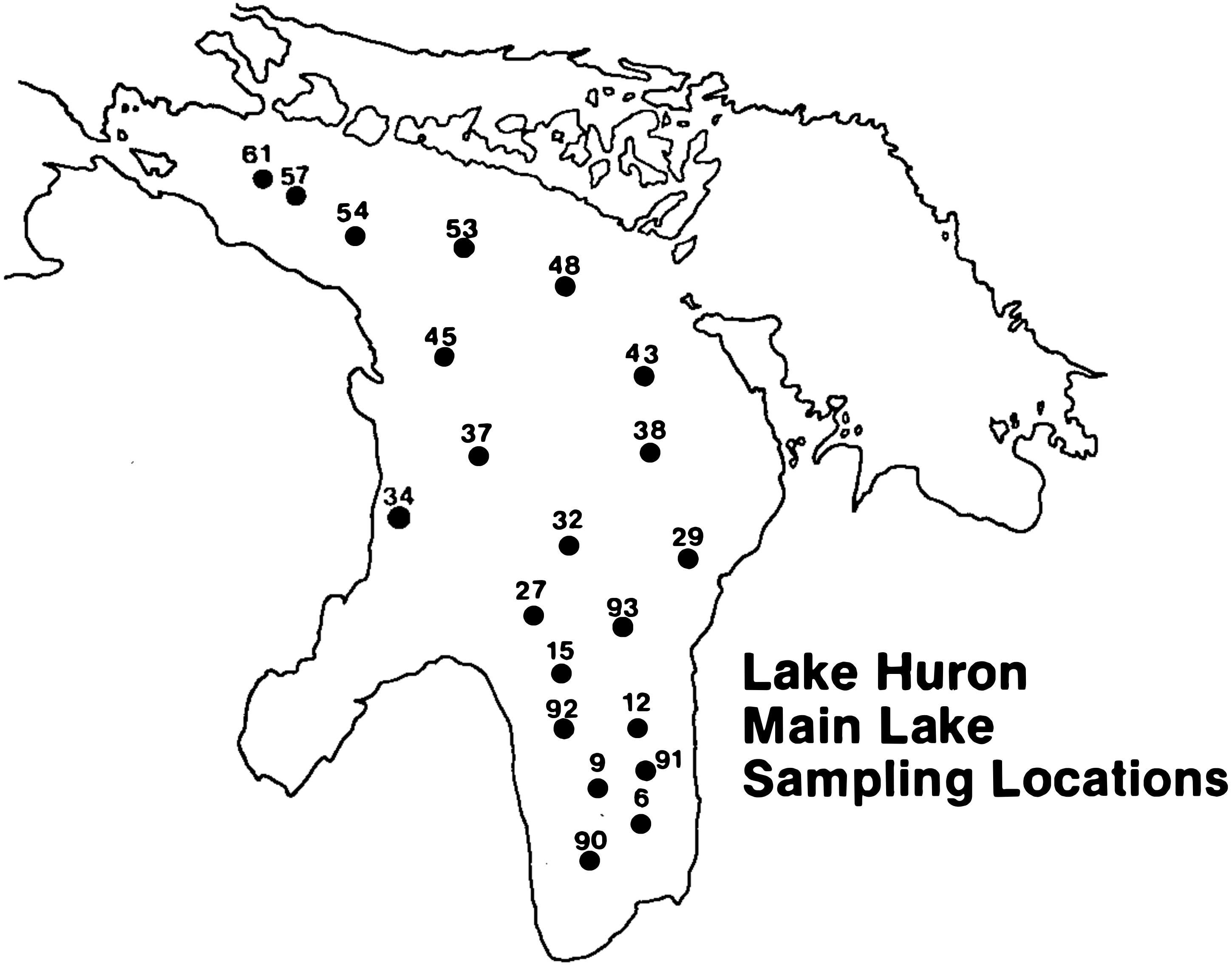


Figure 3. Lake Huron sampling stations, 1985.

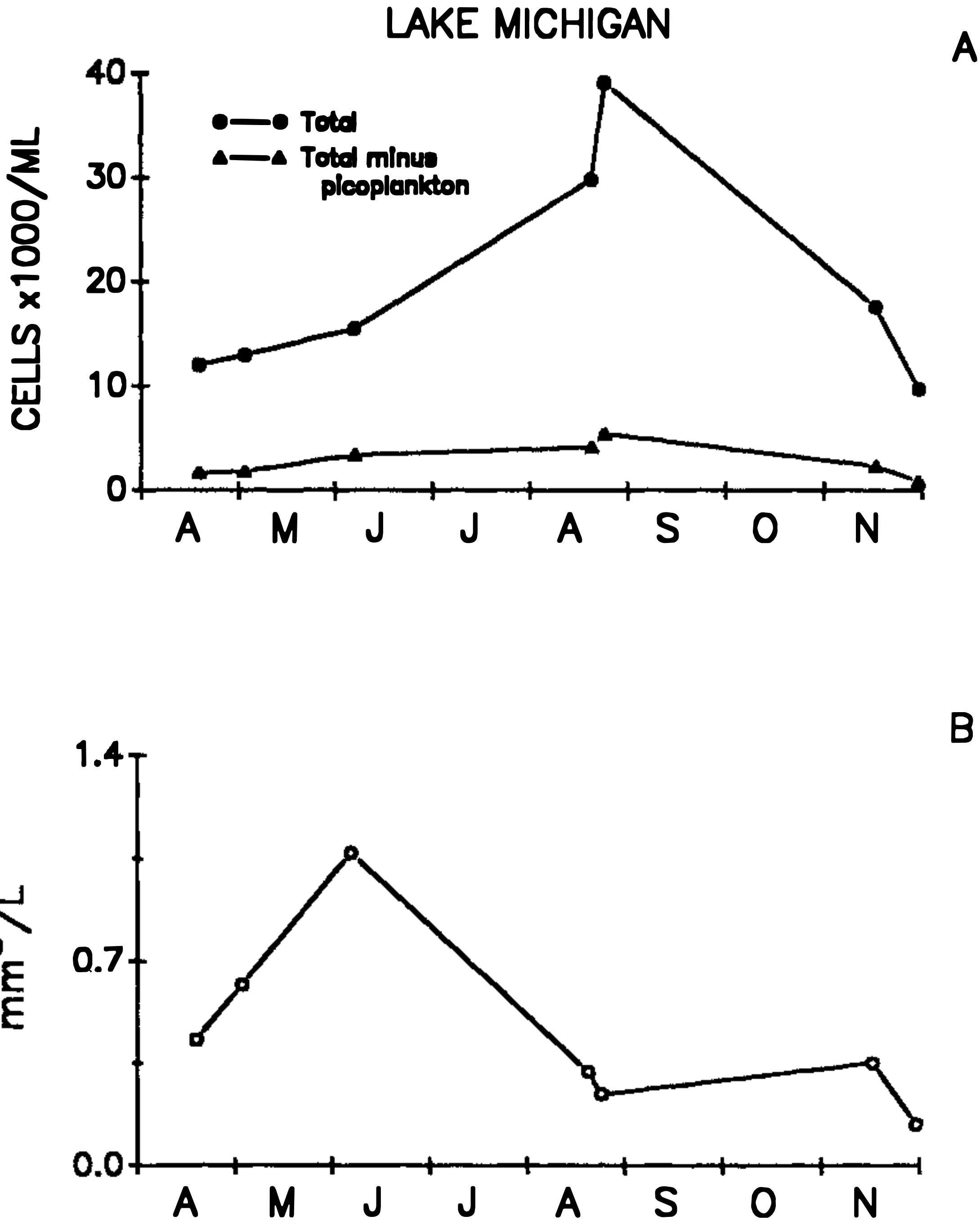


Figure 4. Seasonal phytoplankton abundance (1Ma) and biovolume (1Mb) trends in Lake Michigan, 1985.

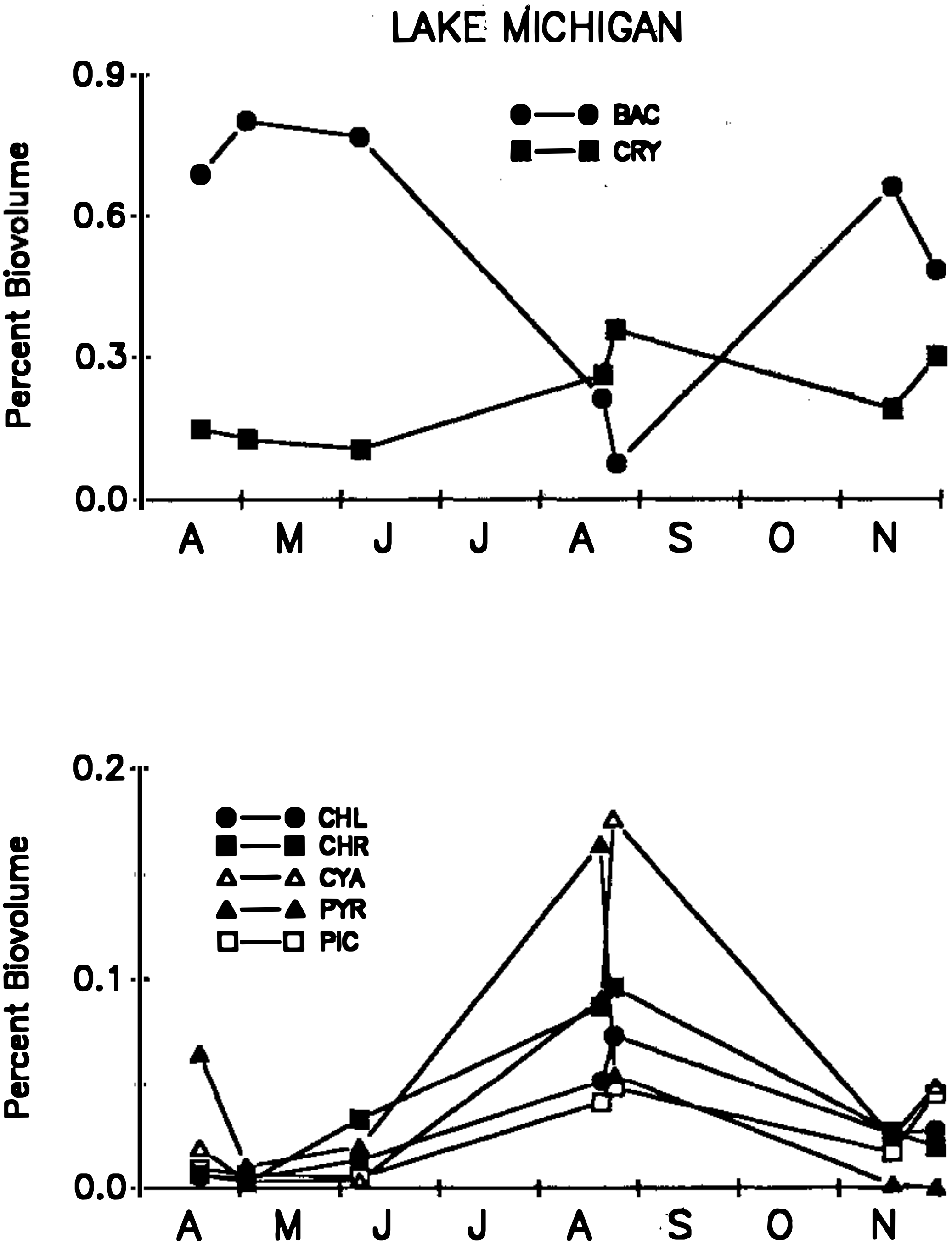


Figure 5. Seasonal distribution of algal divisions in Lake Michigan. Bac-Bacillariophyta, Chl-Chlorophyta, Chr-Chrysophyta, Col-colorless flagellates, Cry-Cryptophyta, Cya-Cyanophyta, Pic-picoplankton, Pyr-Pyrrophyta, Uni-unidentified flagellates, 1985.

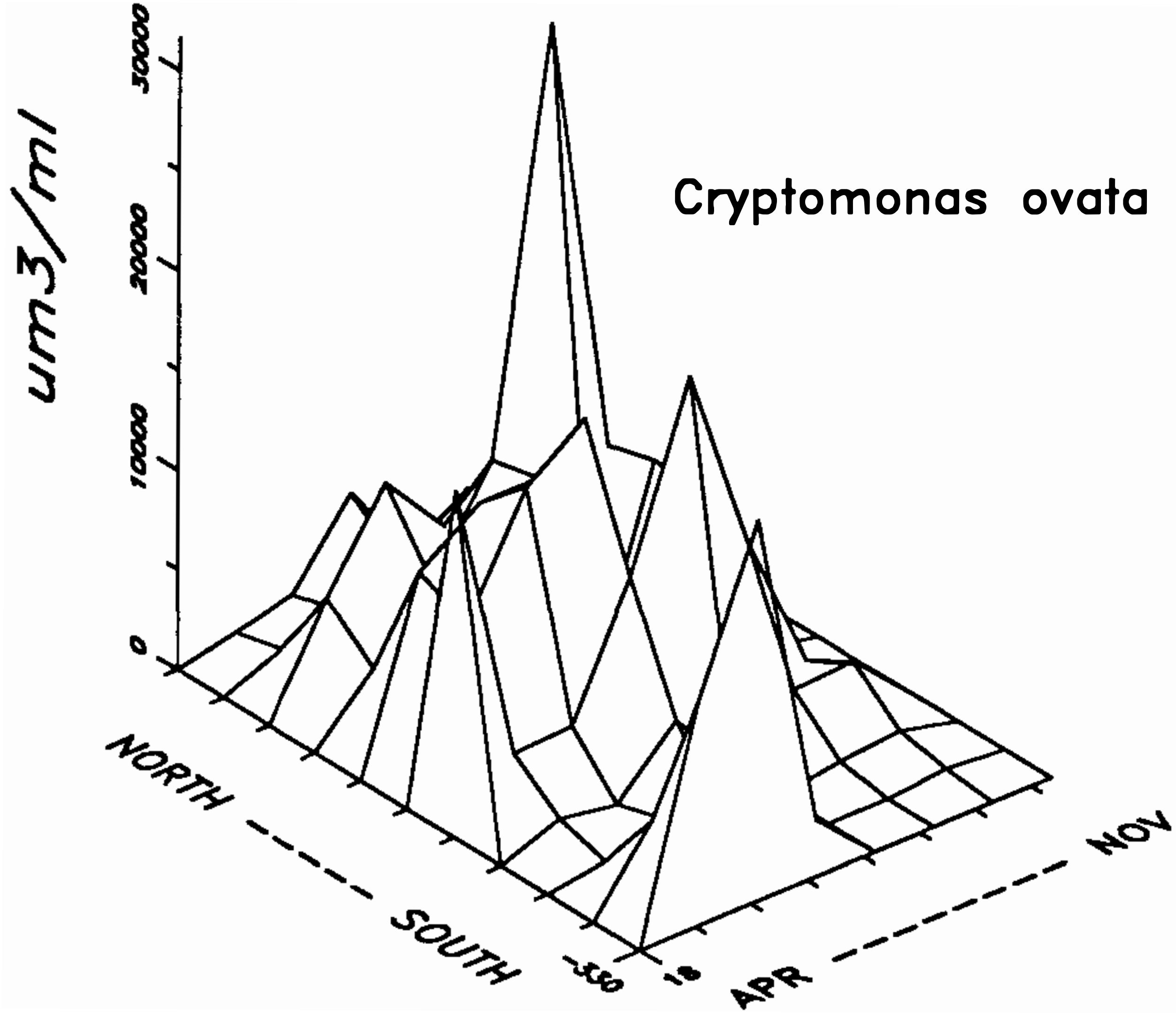


Figure 6. Seasonal distribution of *Cryptomonas ovata*, Lake Michigan, 1985.

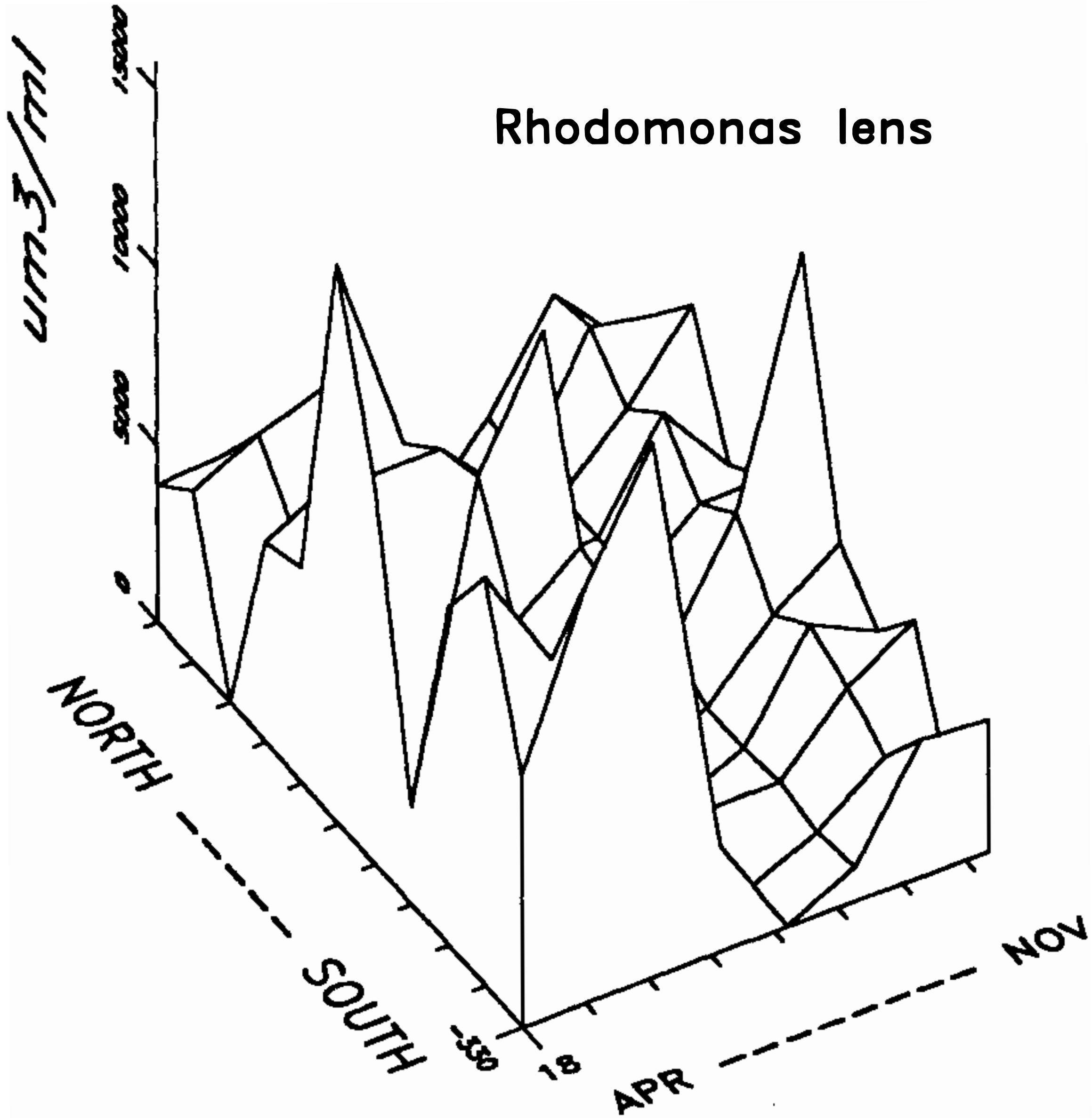


Figure 7. Seasonal distribution of *Rhodomonas lens*, Lake Michigan, 1985.

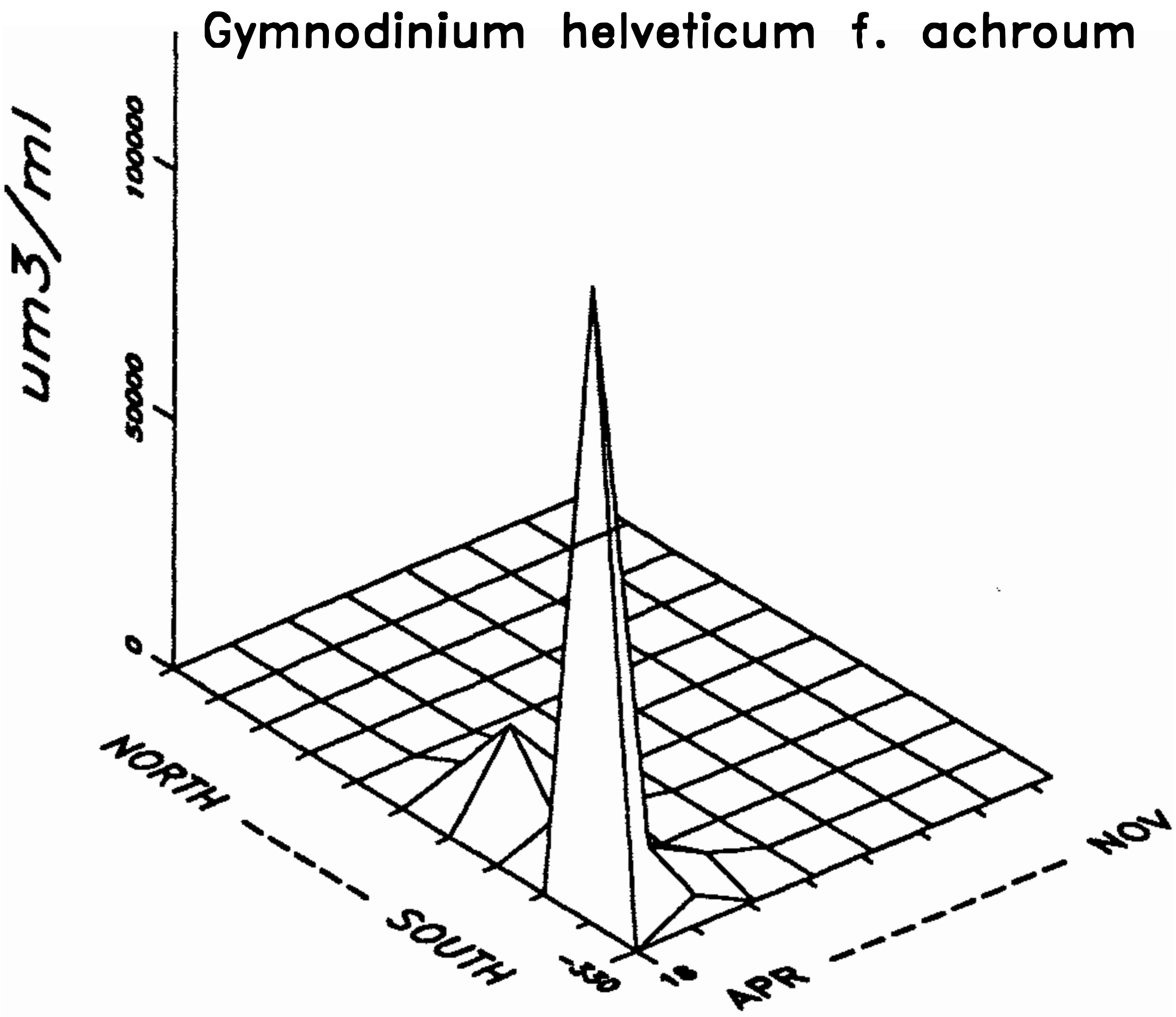


Figure 8. Seasonal distribution of *Gymnodinium helveticum*, Lake Michigan, 1985.

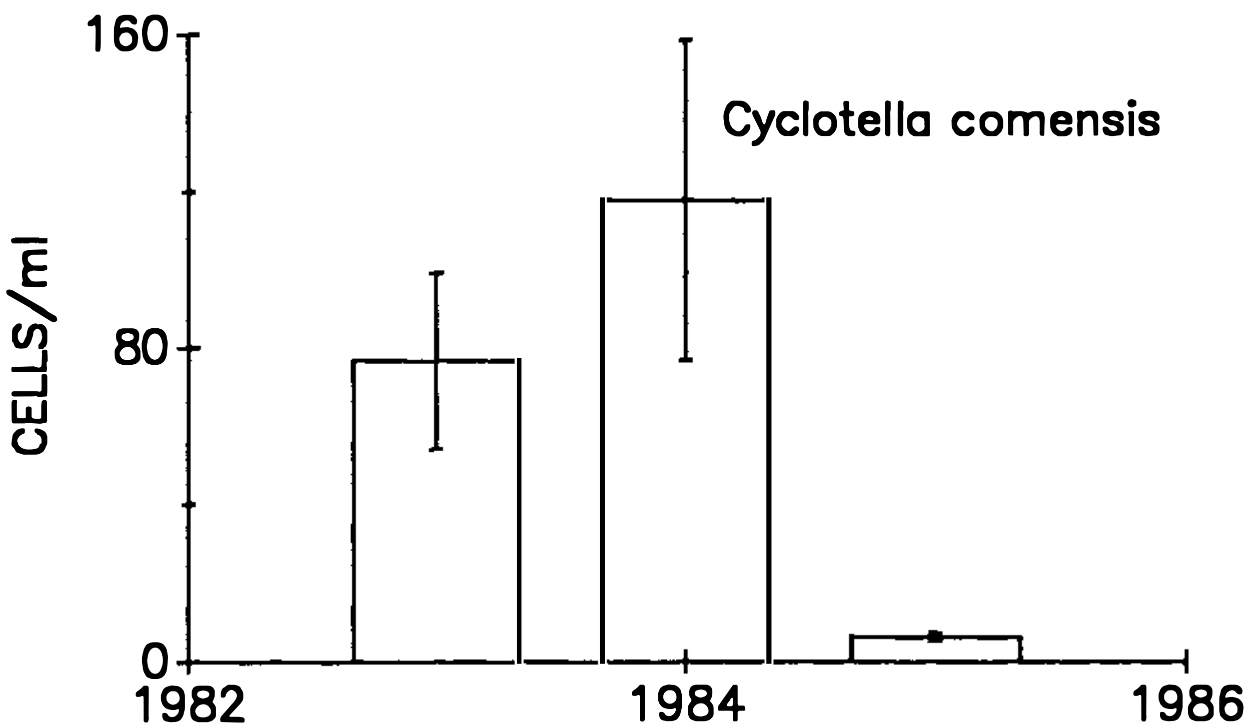


Figure 9. Average abundance of *Cyclotella comensis* in 1983, 1984 and 1985, Lake Michigan.

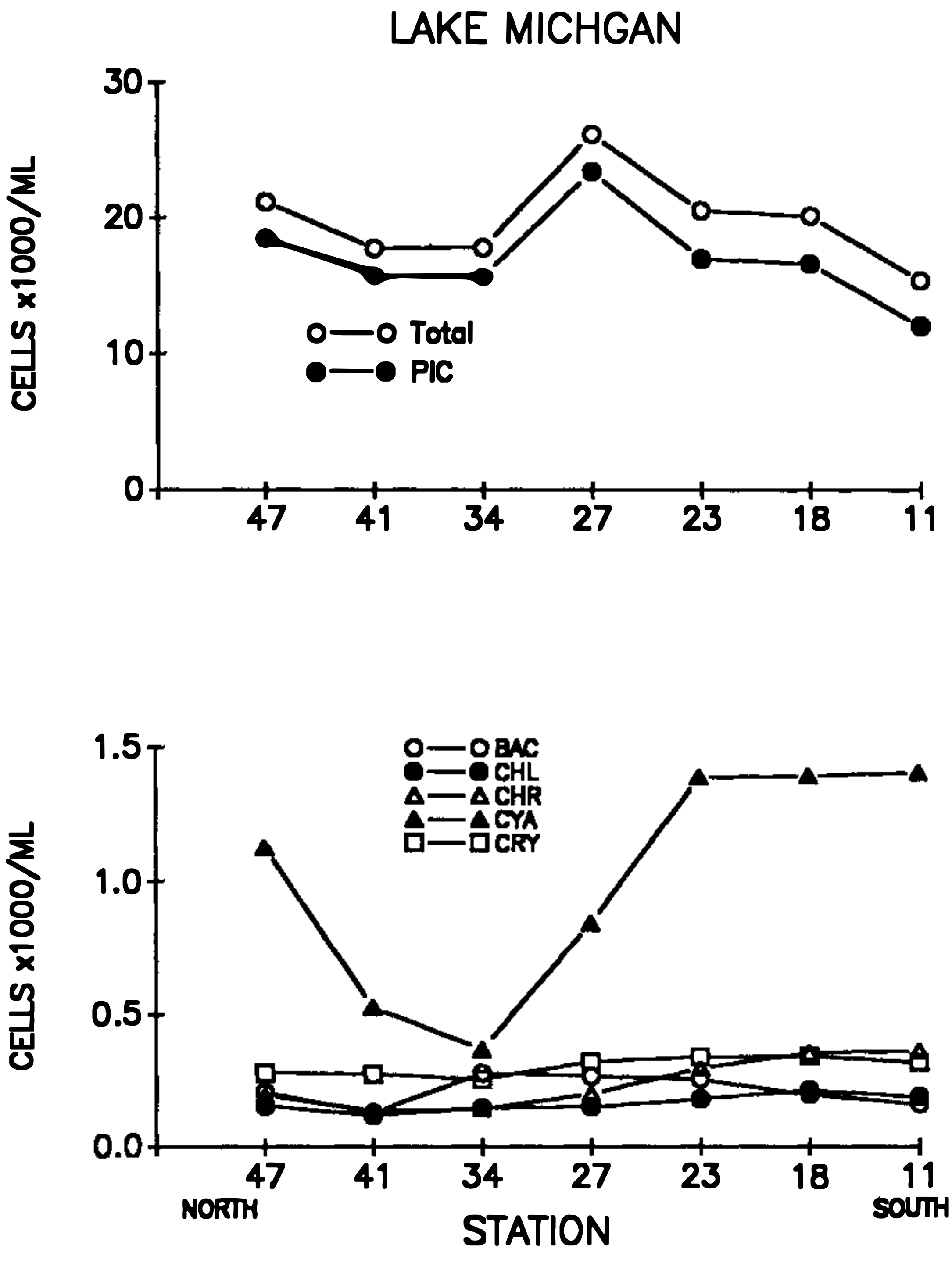


Figure 10. Annual geographical distribution of major algal divisions (numerical) in Lake Michigan. Bac-Bacillariophyta, Chl-Chlorophyta, Chr-Chrysophyta, Col-colorless flagellates, Cry-Cryptophyta, Cya-Cyanophyta, Pic-picoplankton, Pyr-Pyrrophyta, Uni-unidentified flagellates, 1985.

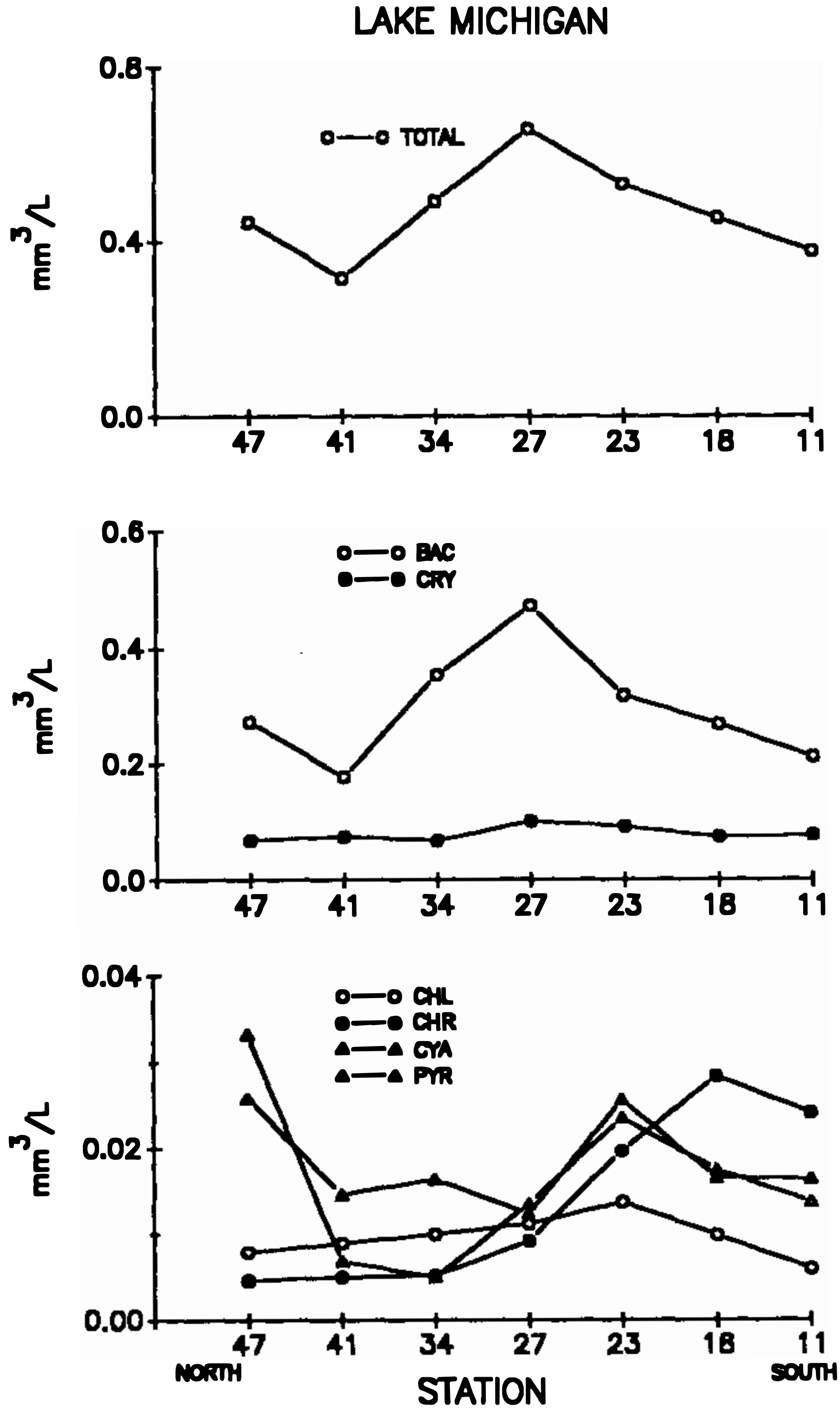


Figure 11. Annual geographical distribution of major algal divisions (biomass) in Lake Michigan. Bac-Bacillariophyta, Chl-Chlorophyta, Chr-Chrysophyta, Col-colorless flagellates, Cry-Cryptophyta, Cya-Cyanophyta, Pic-picoplankton, Pyr-Pyrrophyta, Uni-unidentified flagellates, 1985.

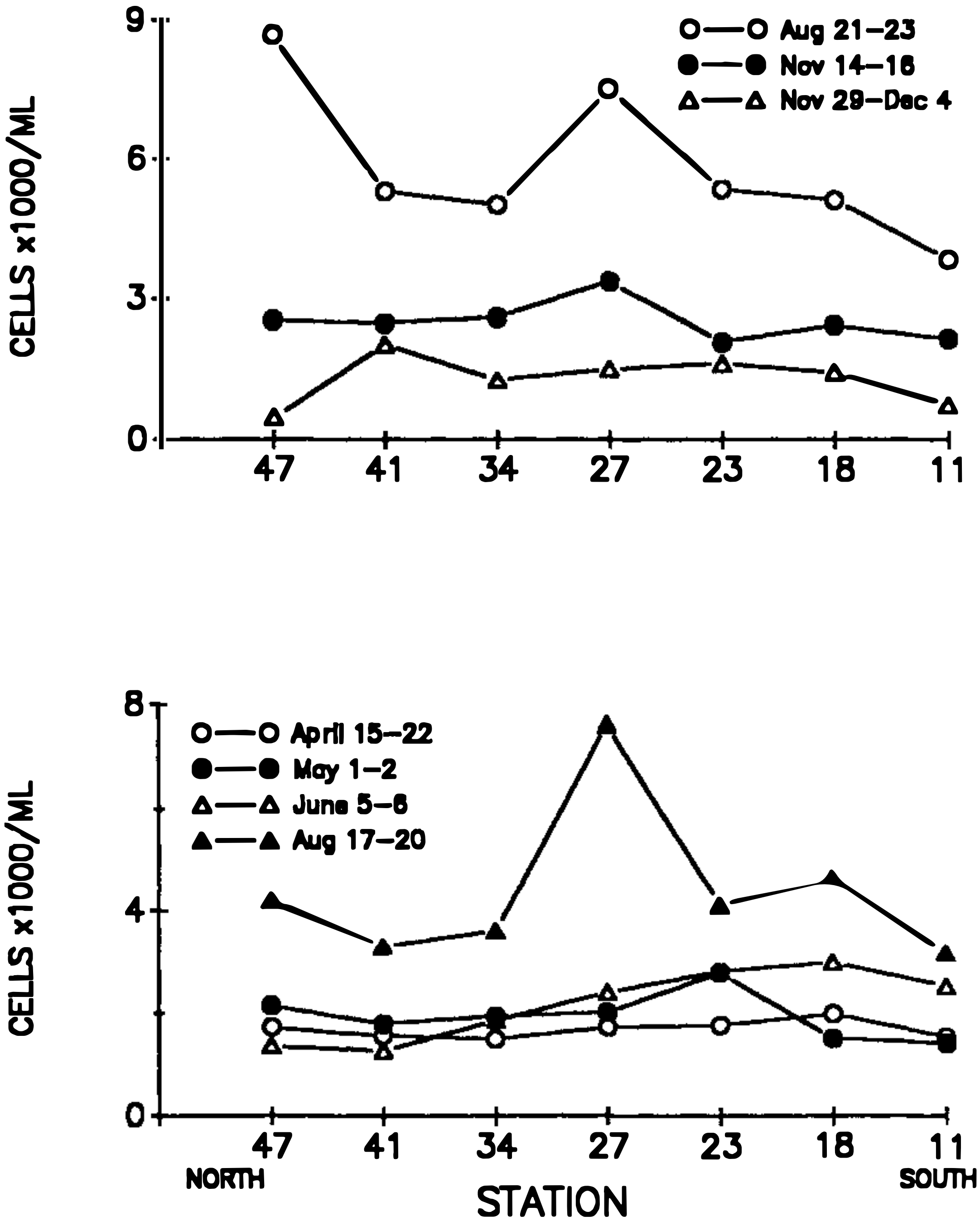


Figure 12. Geographical distribution of phytoplankton abundance on all cruises, Lake Michigan, 1985.

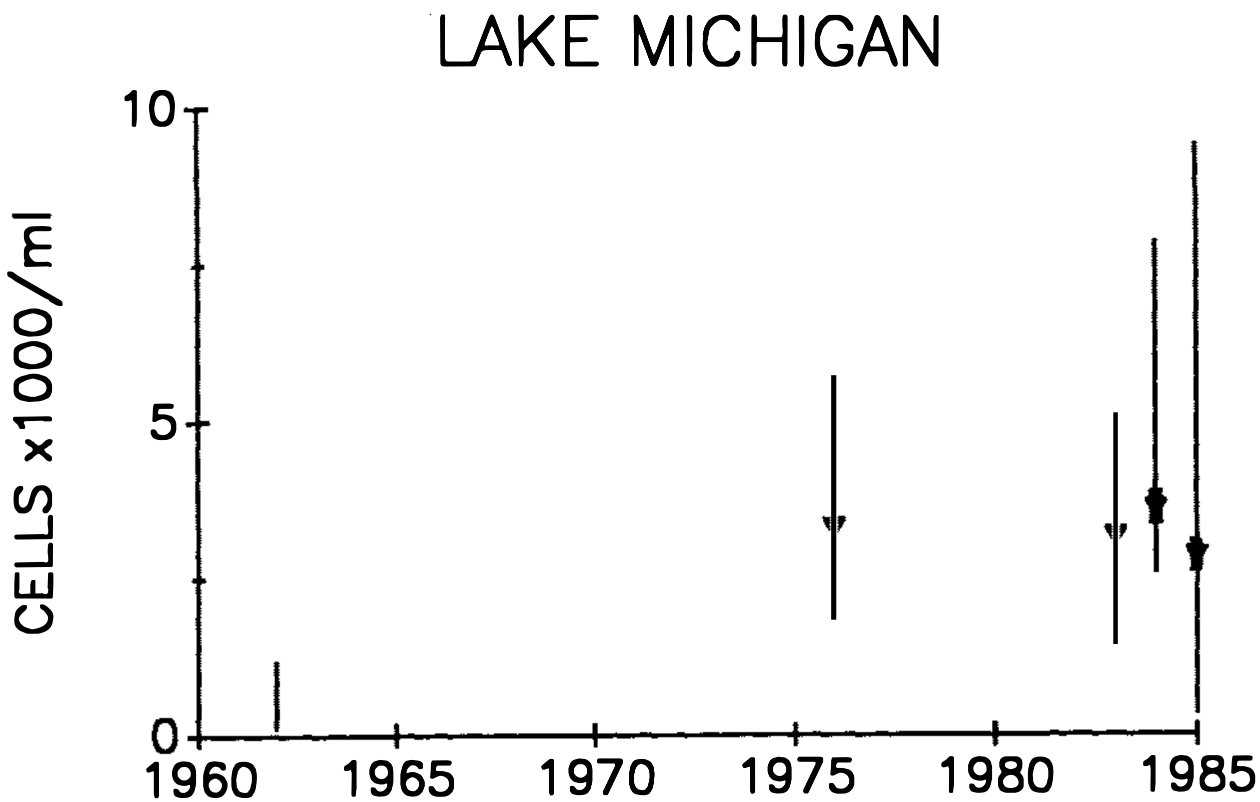


Figure 13. Historical abundance of phytoplankton in Lake Michigan. Horizontal bars are the mean. Wide vertical lines are the standard error. Thin vertical lines are the range. Data are from Stoermer and Kopczynska (1967a and b), Rockwell et al. (1980), Makarewicz (1987) and this study. Picoplankton are not included.

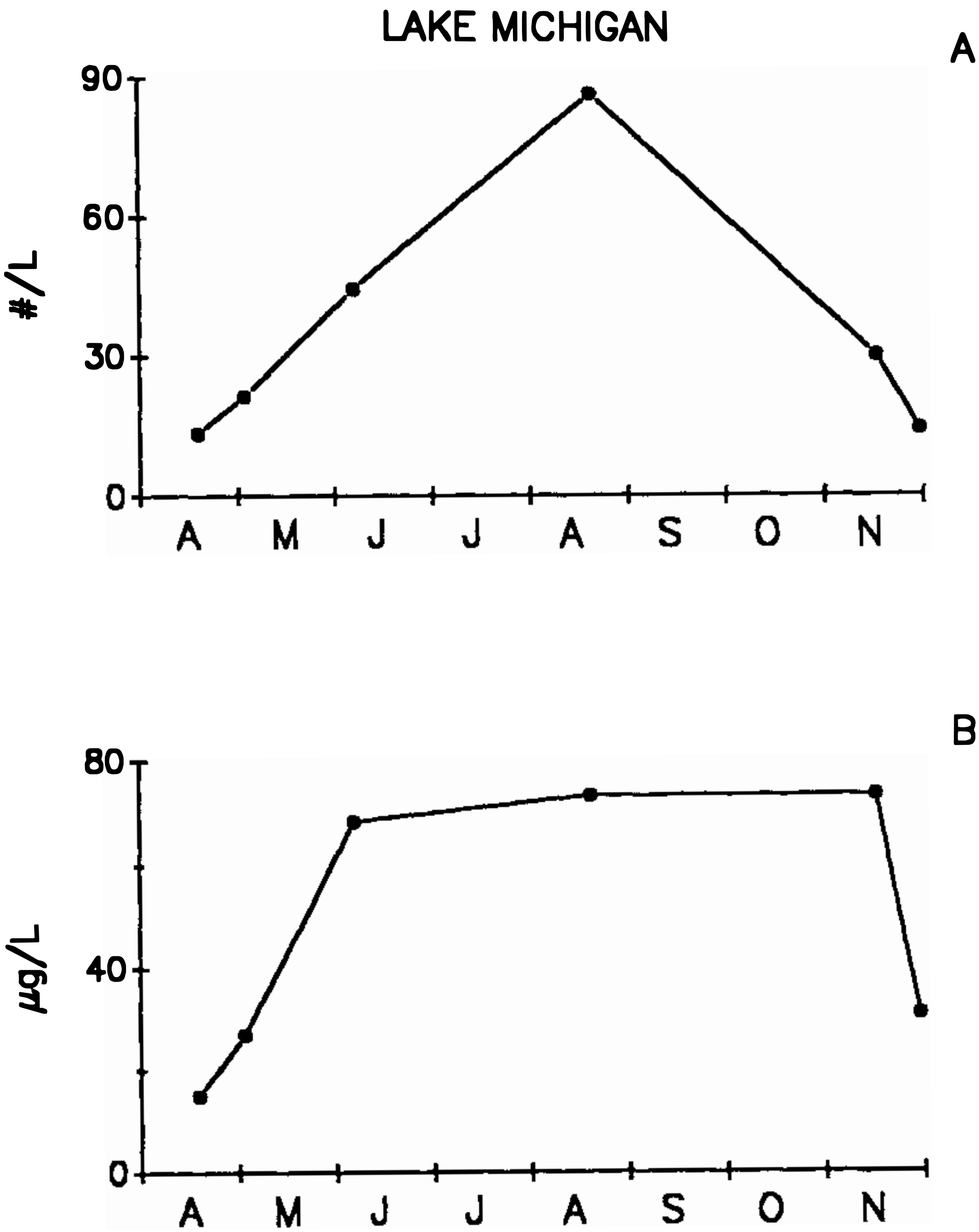


Figure 14. Seasonal zooplankton abundance in Lake Michigan, 1985.

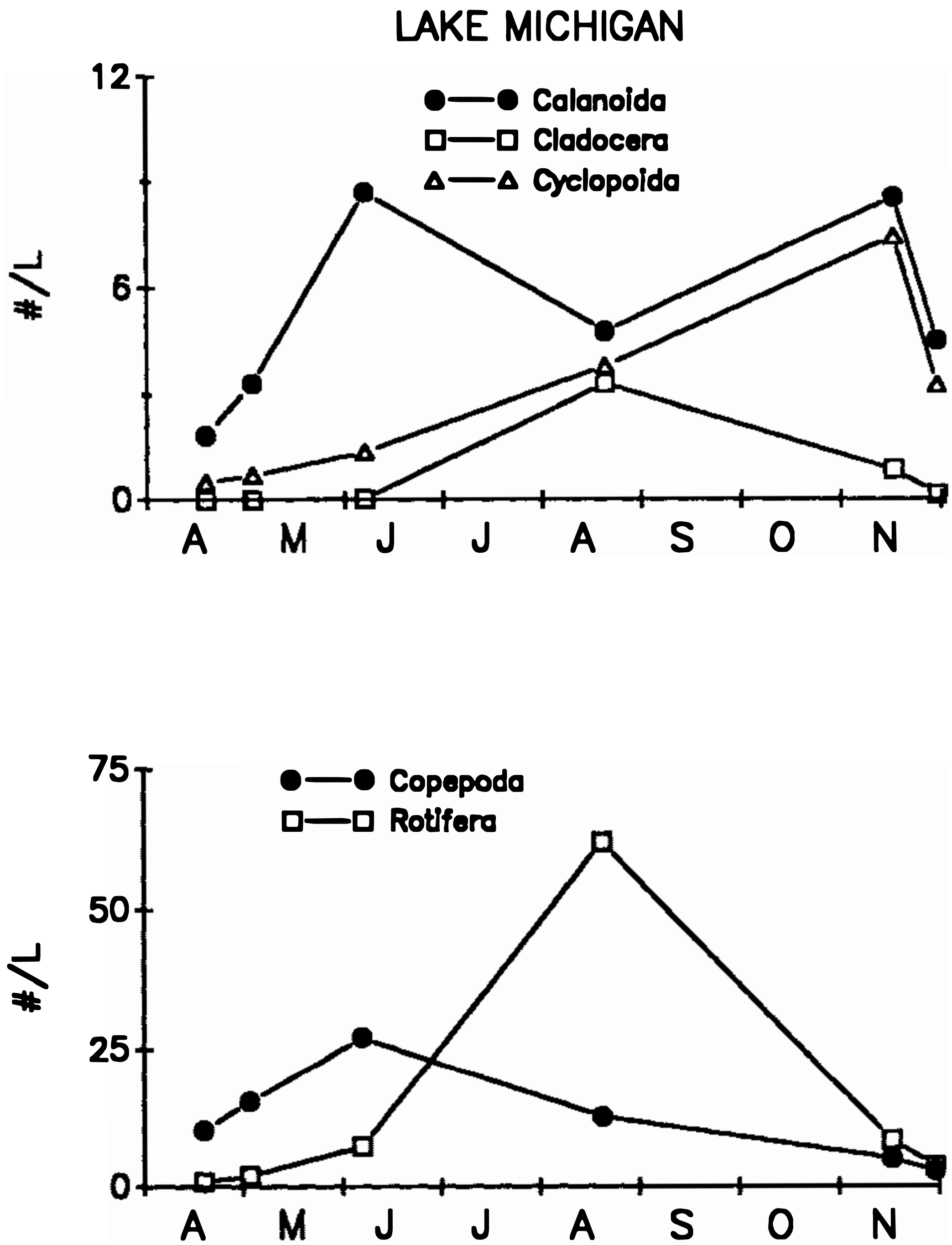


Figure 15. Seasonal flucuation (numerical) of zooplankton groups in Lake Michigan, 1985. Copepoda refers to the nauplius stage of the Copepoda.

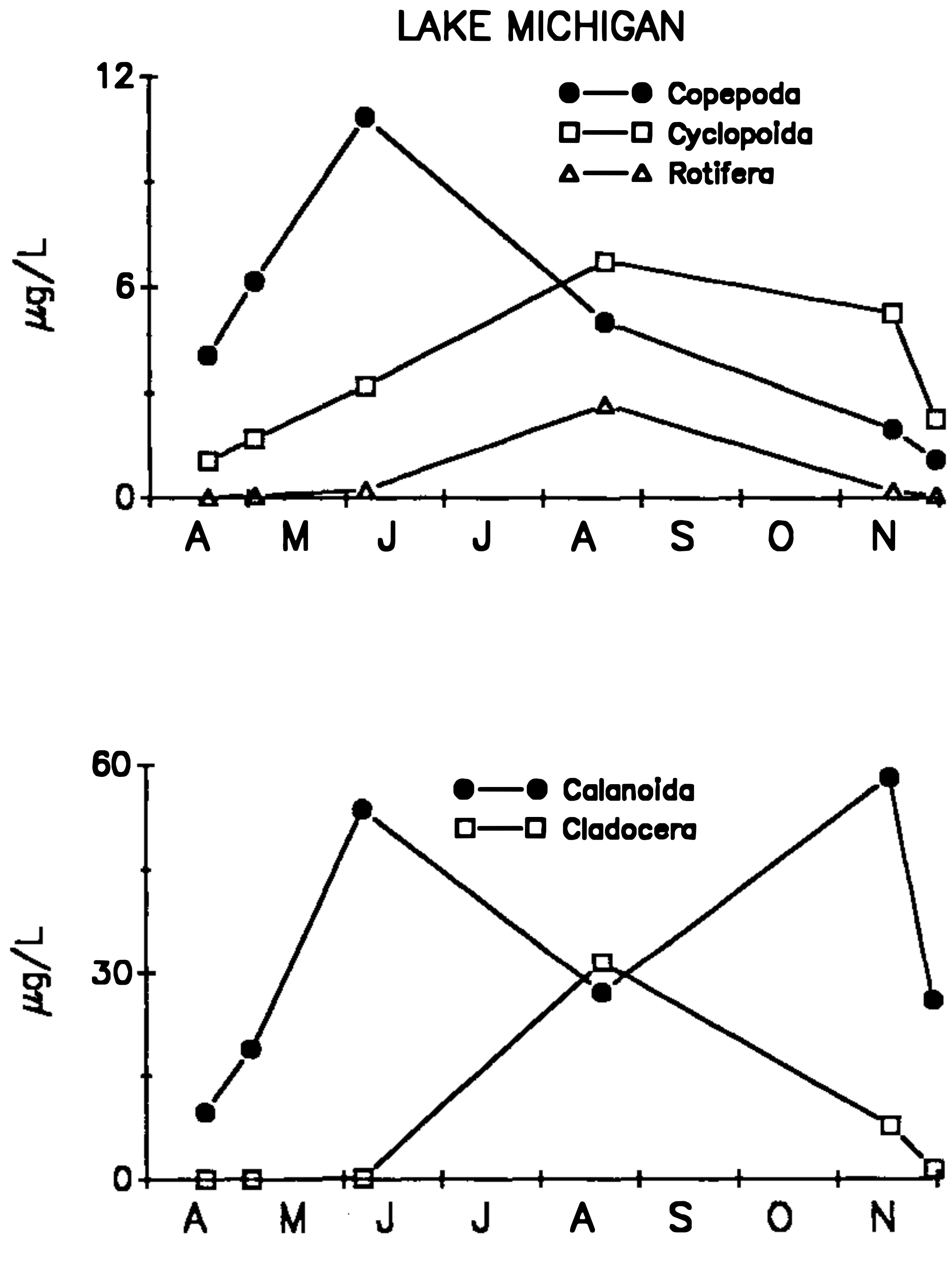


Figure 16. Seasonal flucuation (biomass) of zooplankton groups in Lake Michigan, 1985. Copepoda refers to the nauplius stage of the Copepoda.

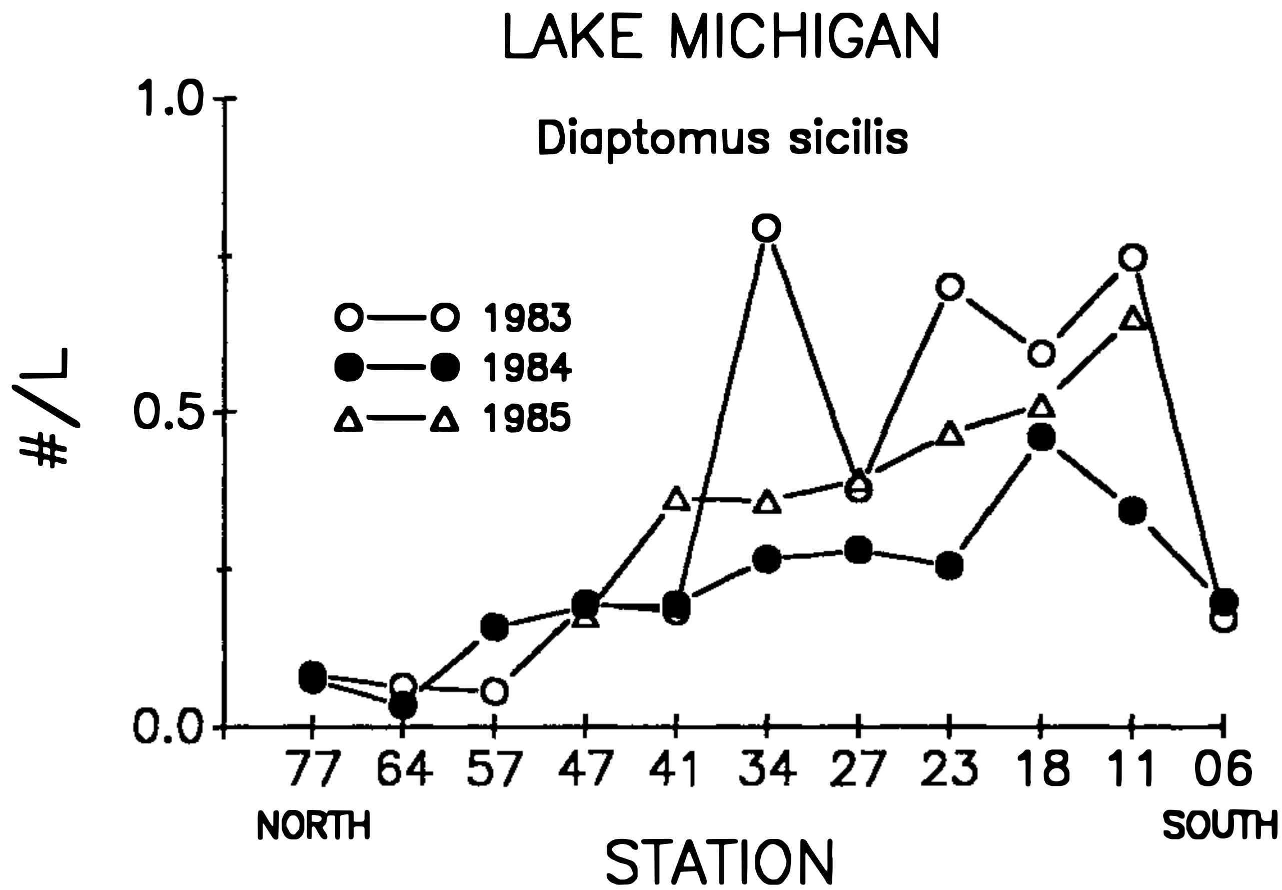


Figure 17. Geographical distribution of *Diaptomus sicilis* in Lake Michigan, 1985.

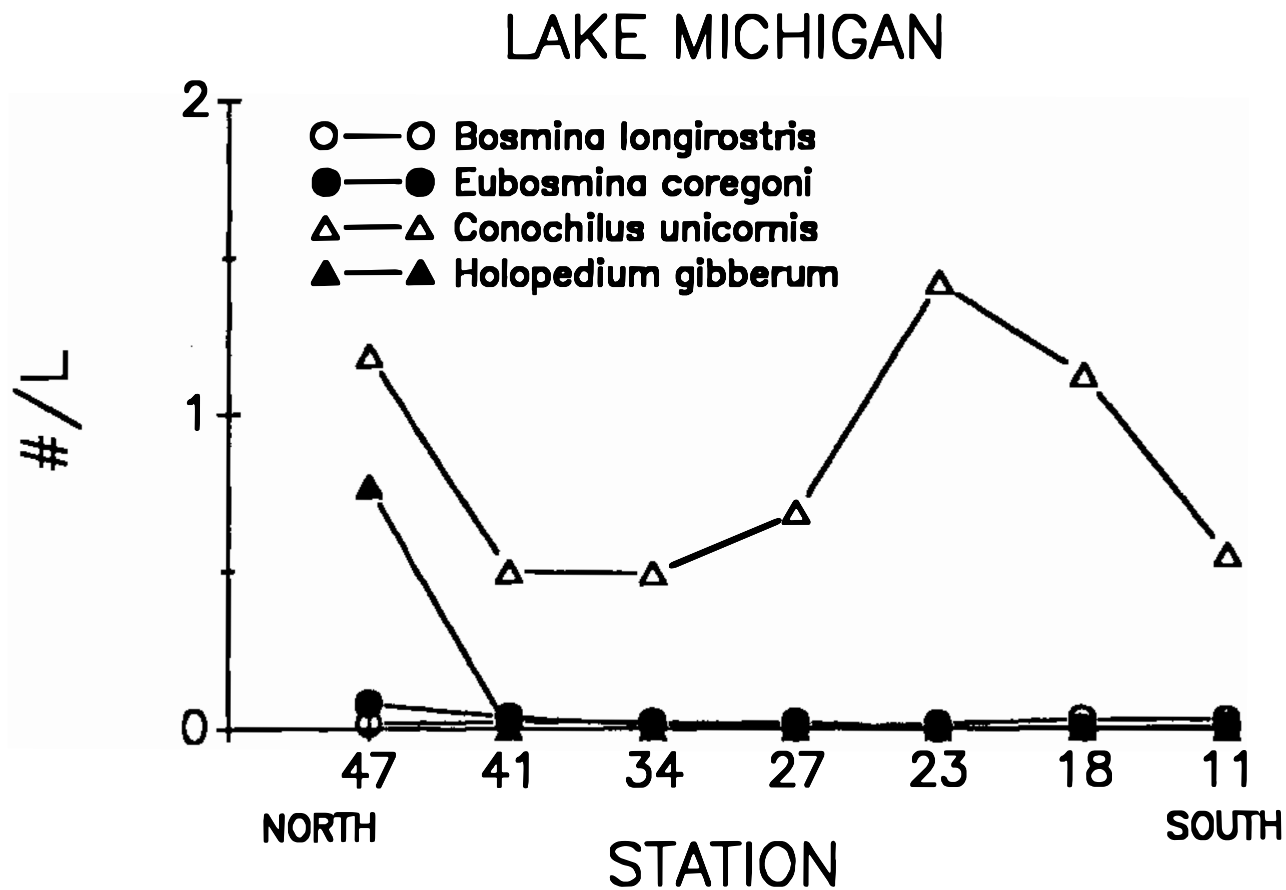


Figure 18. Geographical distribution of selected zooplankton in Lake Michigan, 1985.

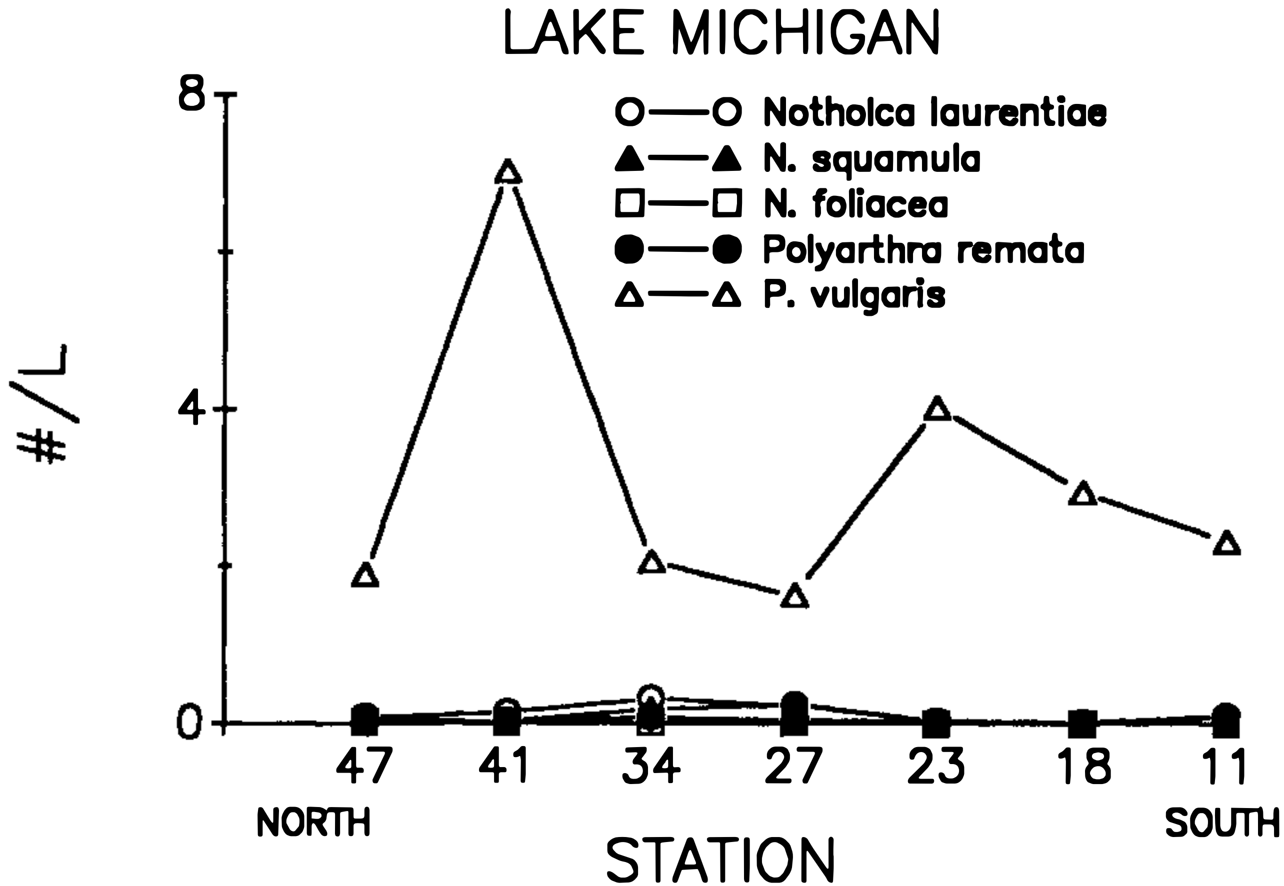


Figure 19. Geographical distribution of selected zooplankton in Lake Michigan, 1985.

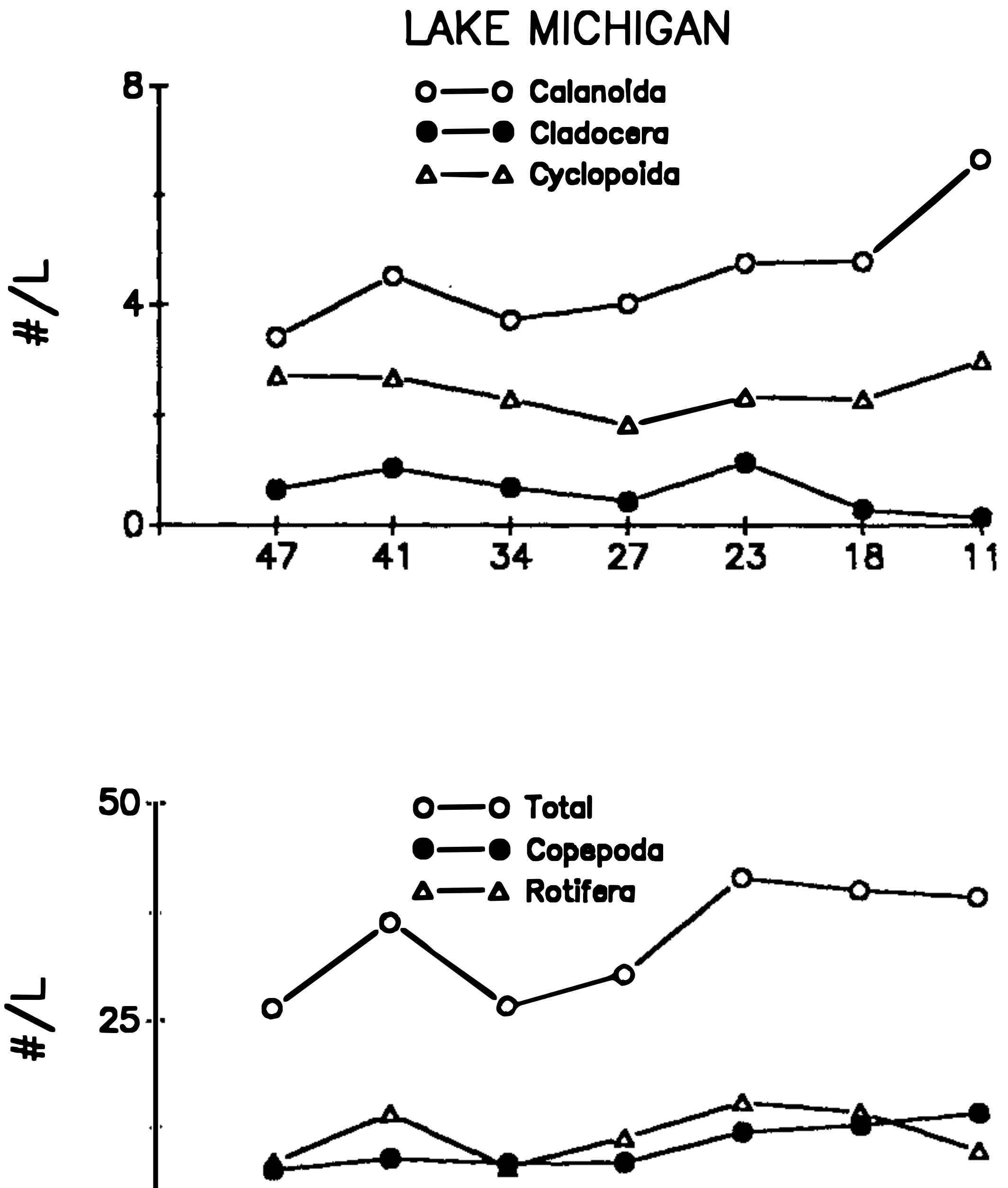


Figure 20. Geographical distribution (numerical) of major zooplankton groups in Lake Michigan, 1985. Copepoda - Copepoda nauplius.

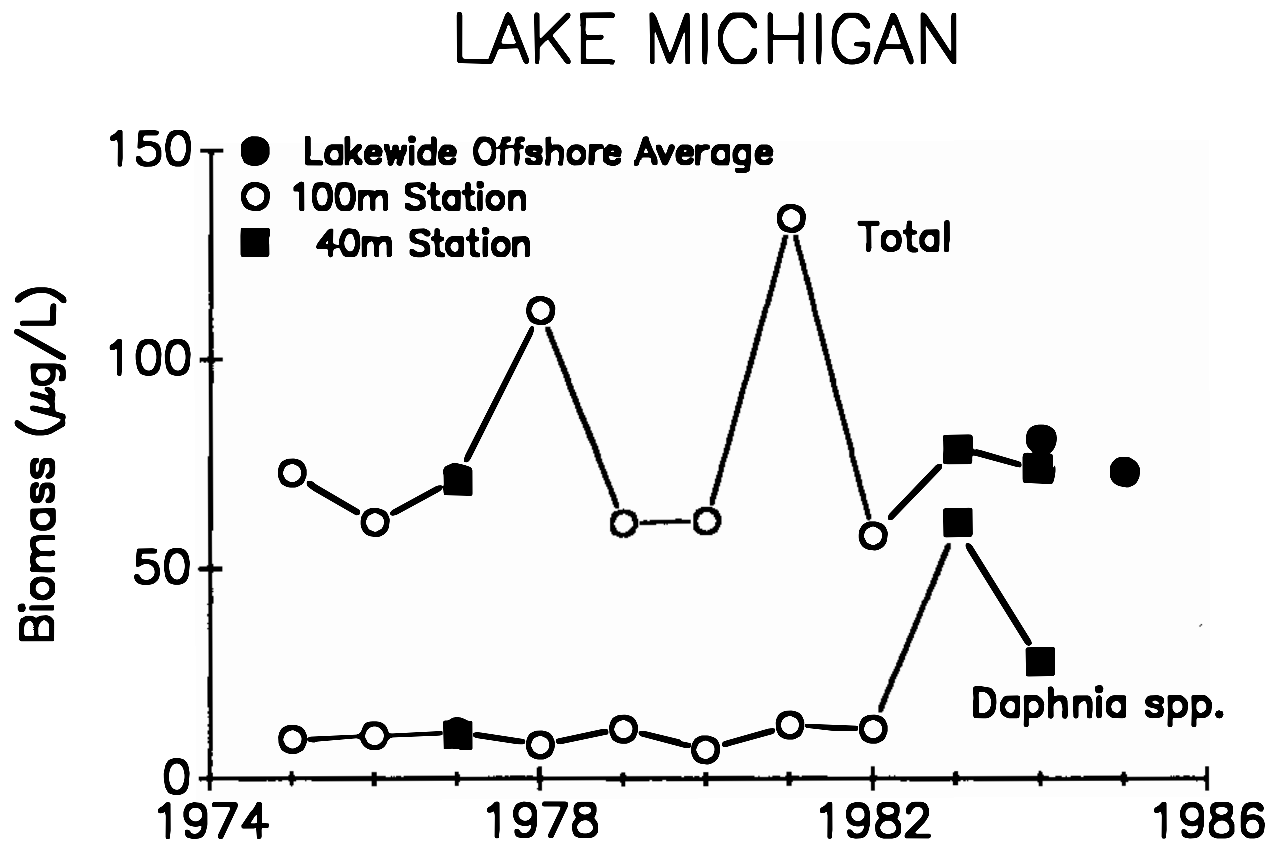


Figure 21. Historical trends in zooplankton biomass during July and August, Lake Michigan. The 1984 and 1985 data (Makarewicz 1988, This Study) are the mean of all offshore stations. Modified from Scavia *et al* (1986).

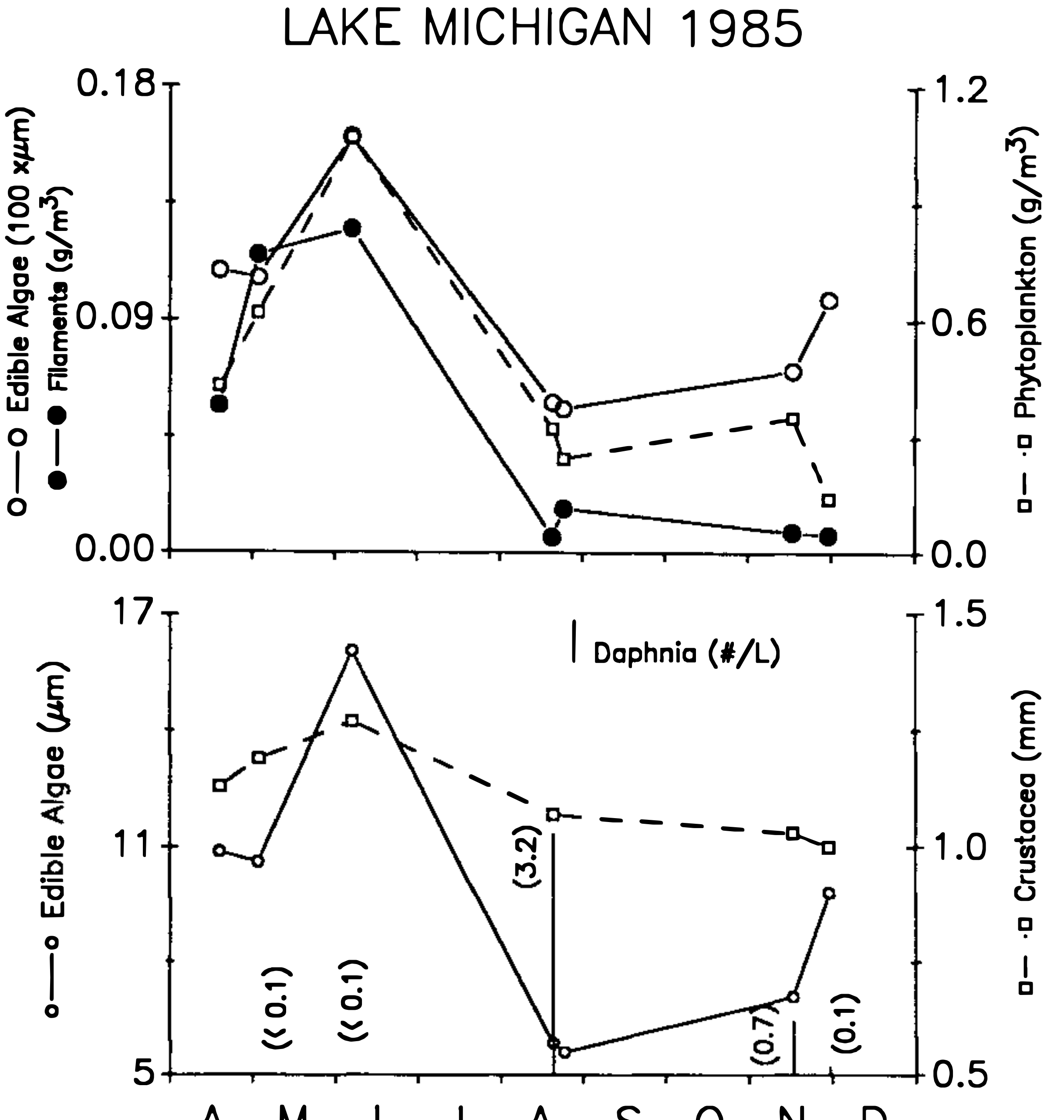


Figure 22. (A) Seasonal total algal and filamentous algal biomass and mean weighted edible algal size in 1985; (B) The seasonal mean crustacean size and Daphnia spp. and adult Calanoida abundance, 1985, Lake Michigan.

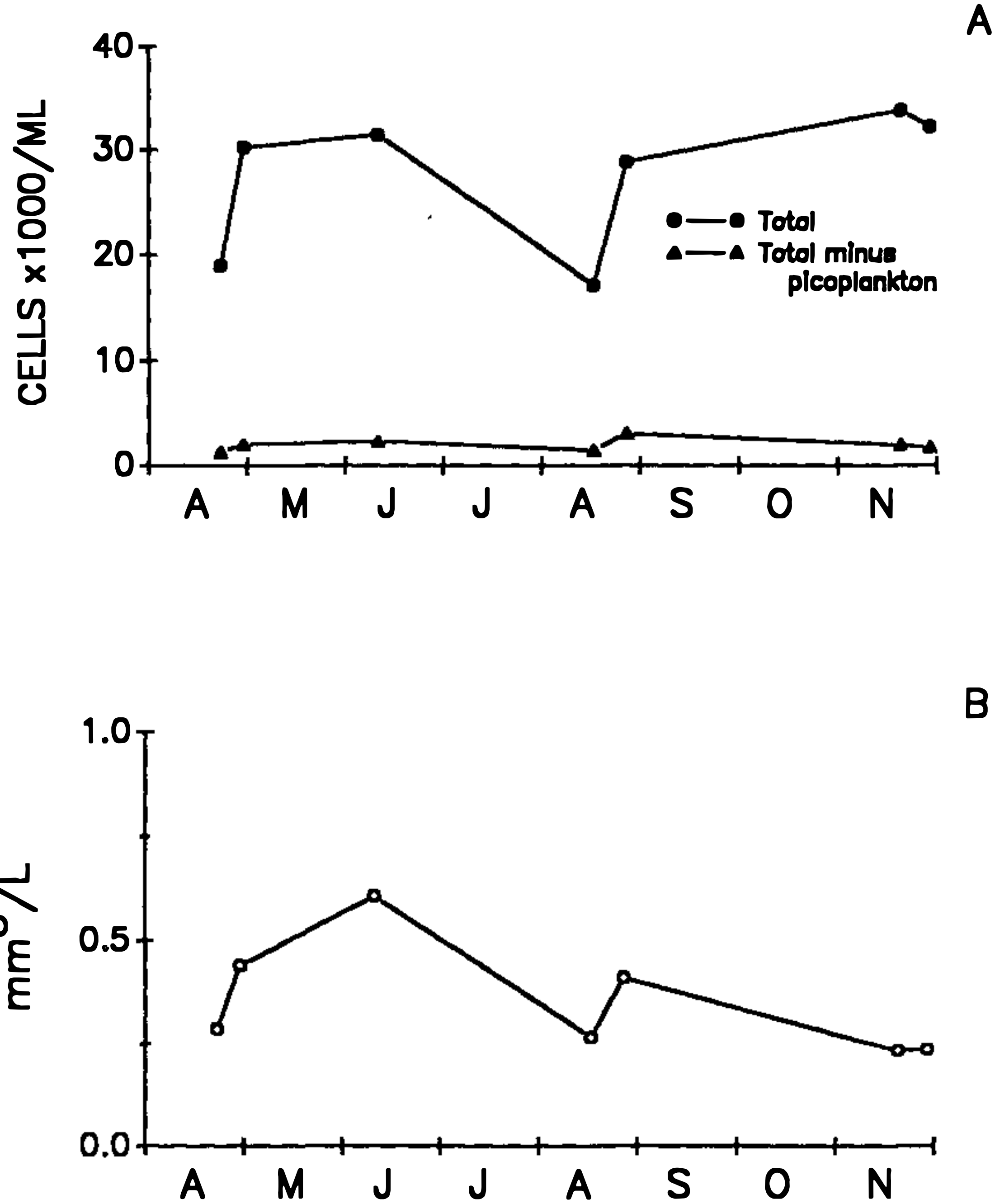


Figure 23. Seasonal phytoplankton biovolume and abundance trends in Lake Huron, 1985.

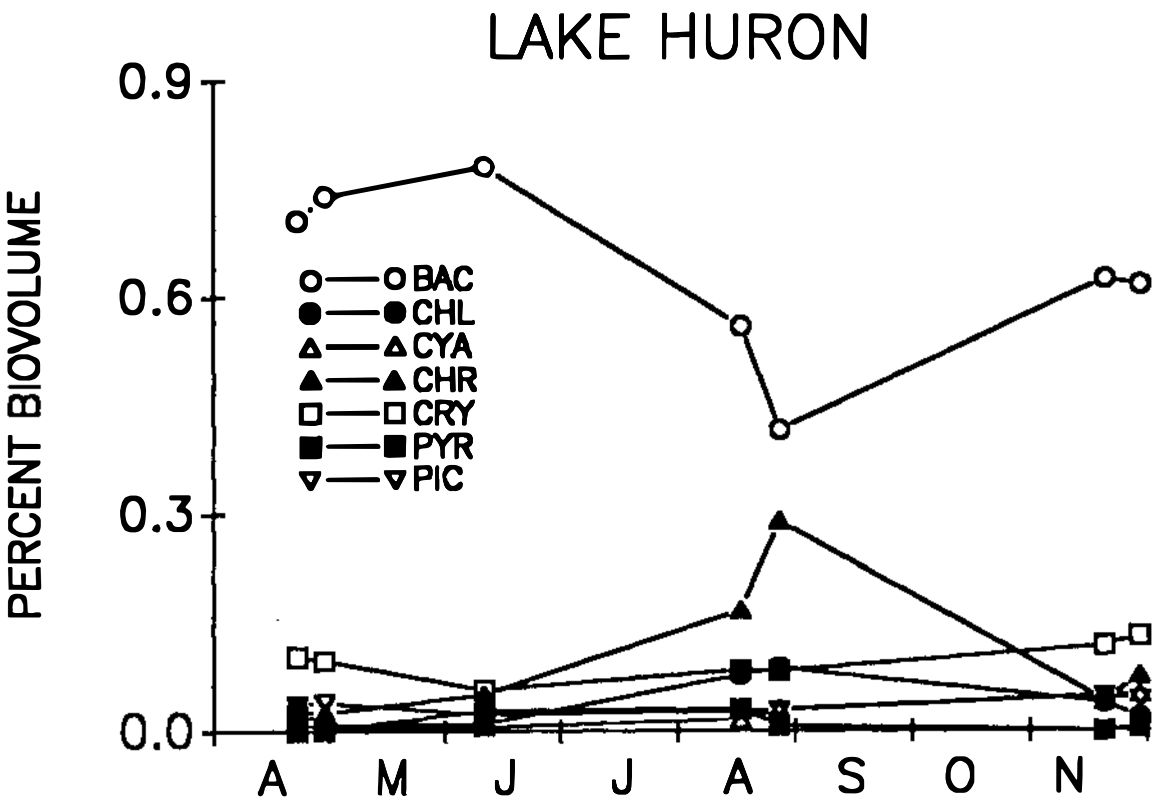


Figure 24. Seasonal distribution of algal (% biovolume) divisions in Lake Huron, 1985. Bac-Bacillariophyta, Chl-Chlorophyta, Chr-Chrysophyta, Cry-Cryptophyta, Cya-Cyanophyta, Pic-Picoplankton, Pyr-Pyrrophyta.

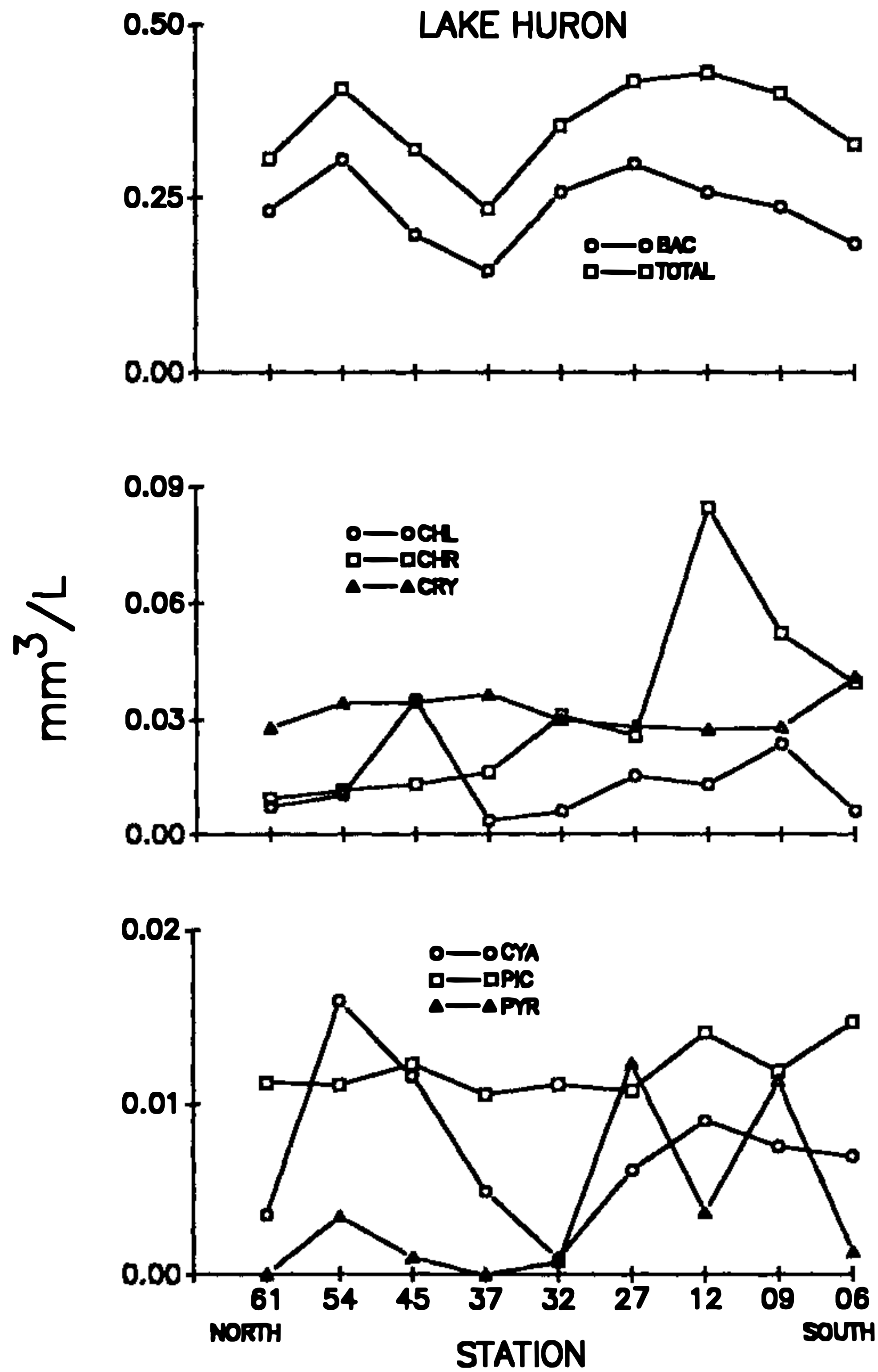


Figure 25. Annual geographical distribution of major algal divisions in Lake Huron, 1985.

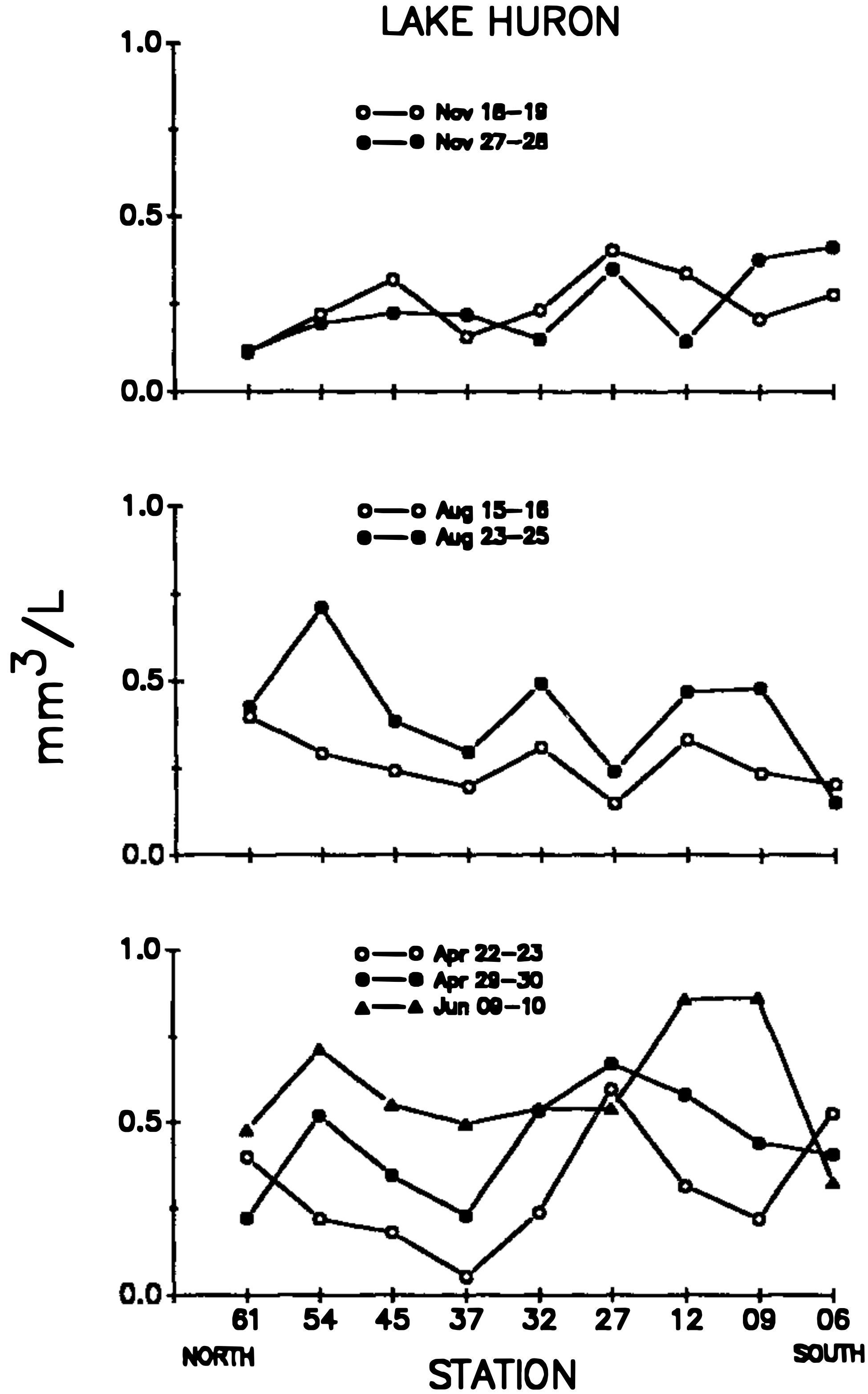


Figure 26. Seasonal geographical distribution of phytoplankton biomass, Lake Huron, 1985. Bac-Bacillariophyta, Chl-Chlorophyta, Chr-Chrysophyta, Cry-Cryptophyta, Cya-Cyanophyta, Pic-Picoplankton, Pyr-Pyrrophyta.

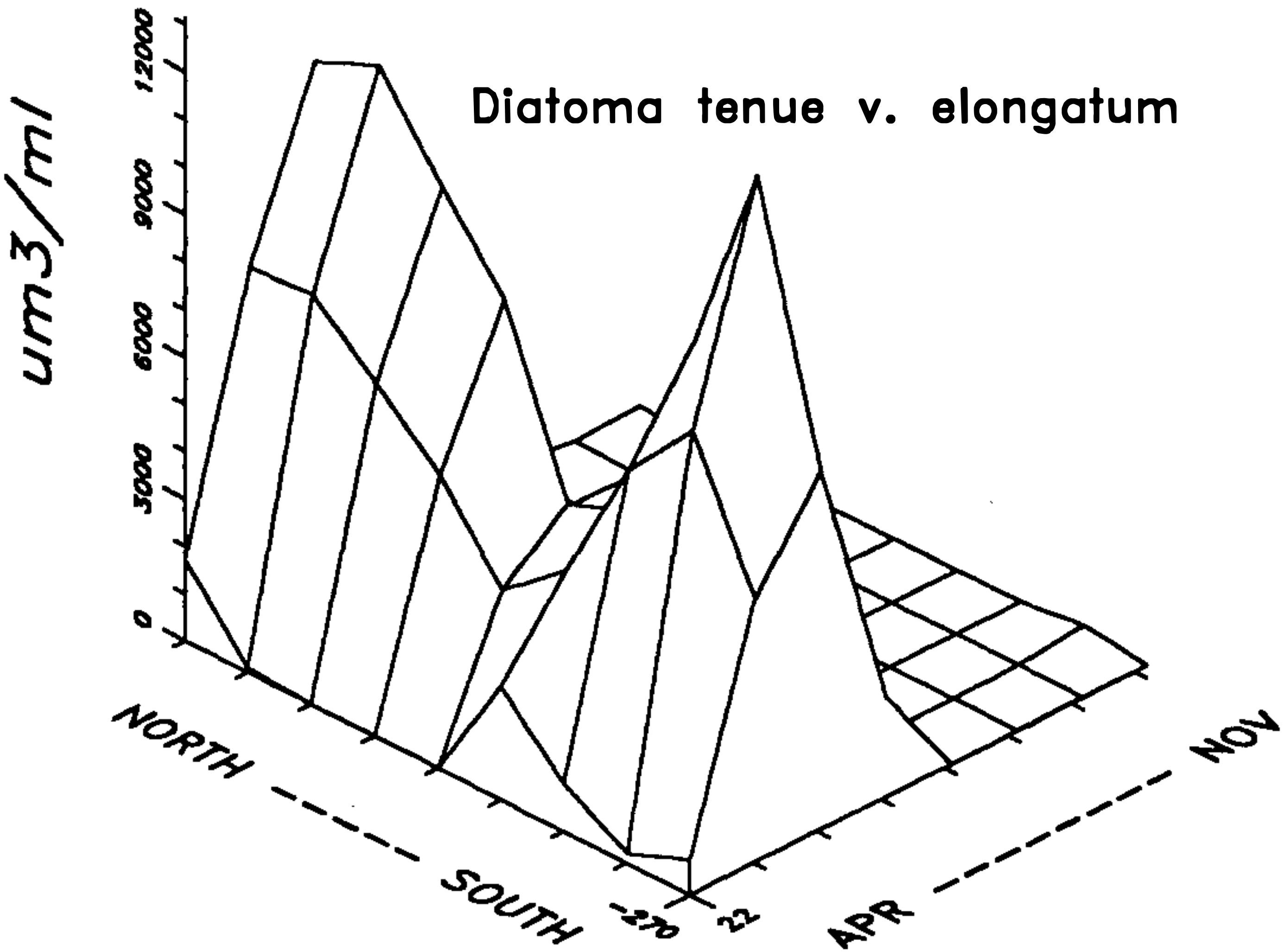


Figure 27. Geographical and seasonal distribution of *Diatoma tenue* var. *elongatum*, Lake Huron.

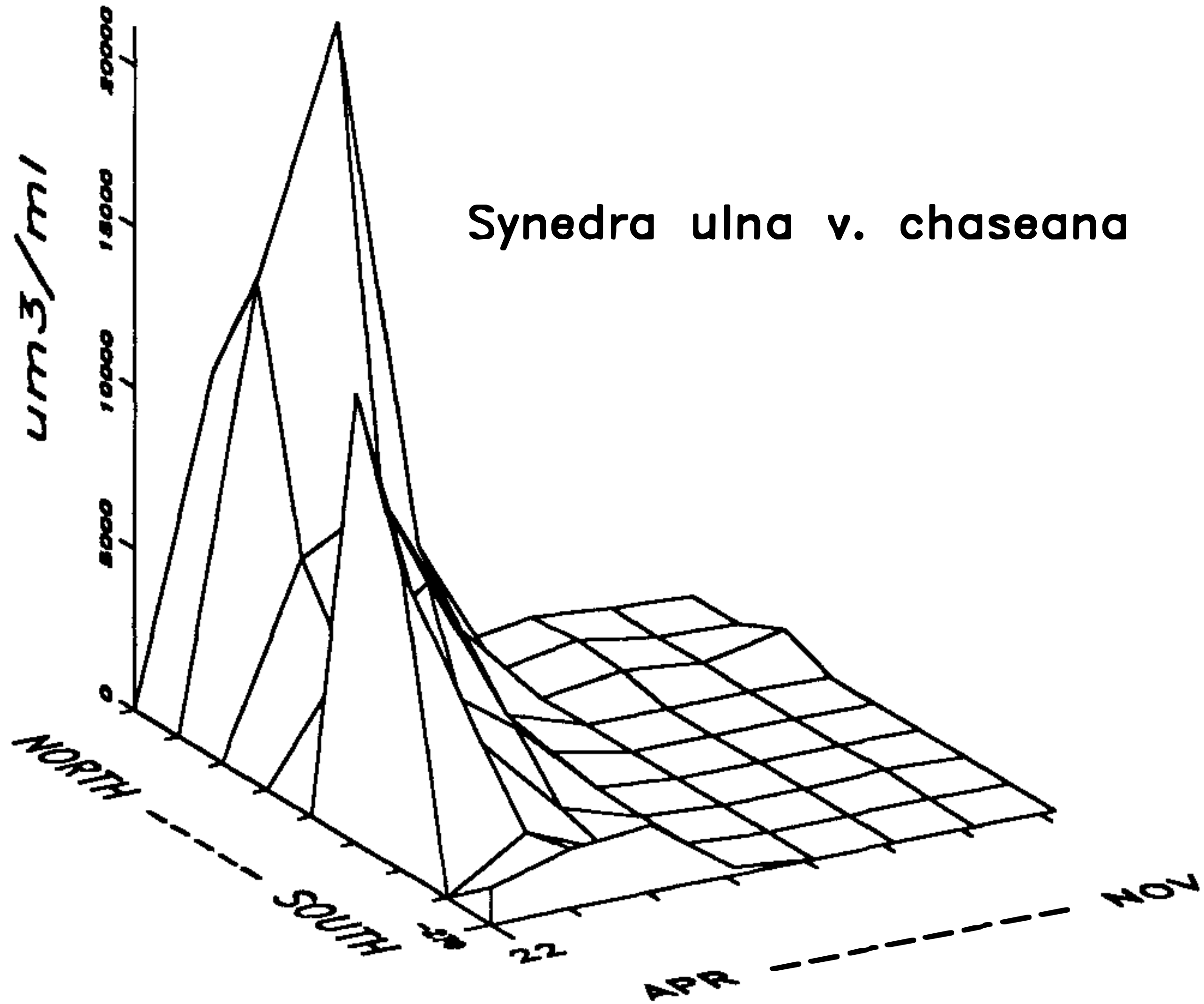


Figure 28. Geographical and seasonal distribution of *Synedra ulna* var. *chaseana*, Lake Huron.

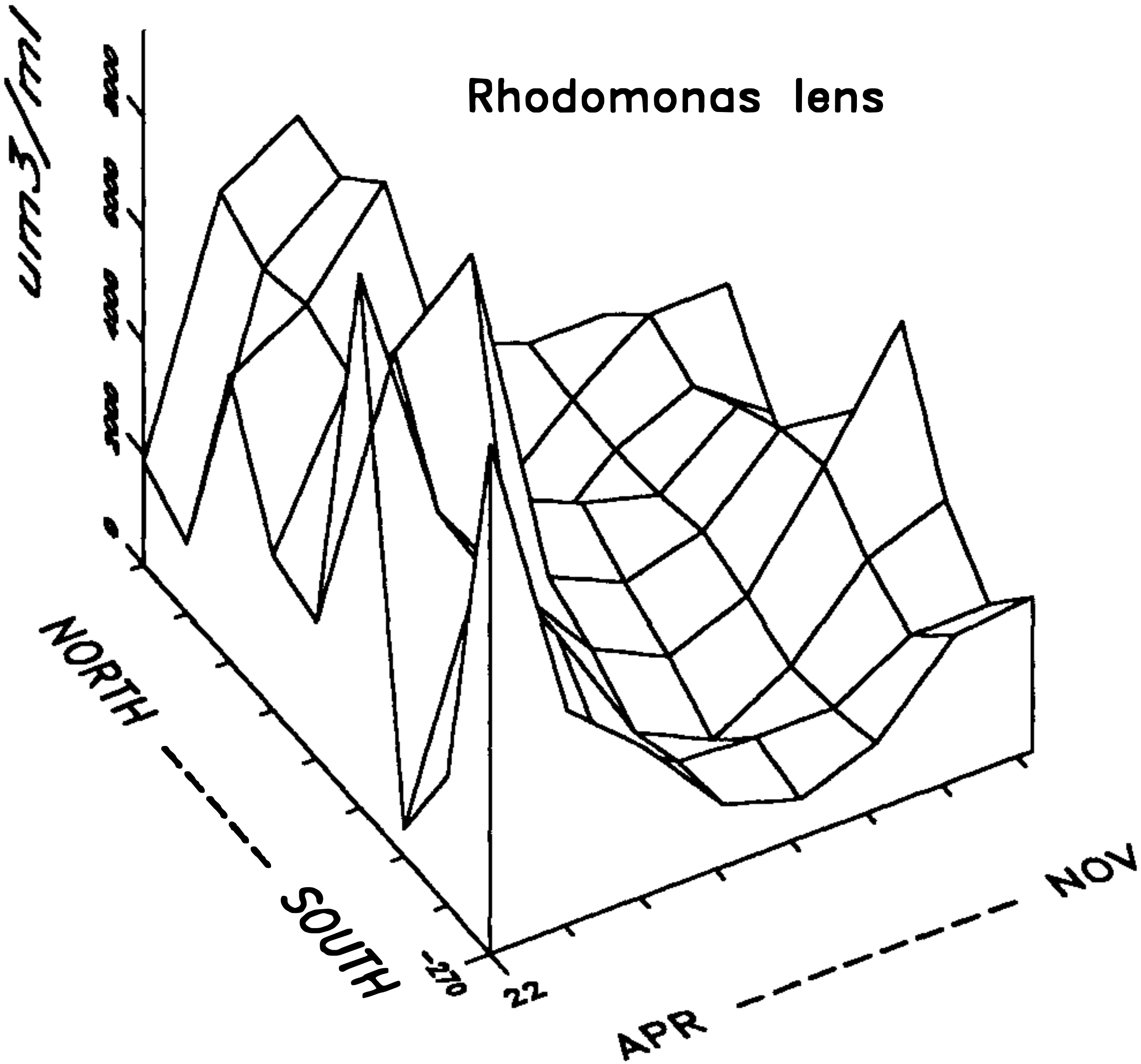


Figure 29. Geographical and seasonal distribution of *Rhodomonas lens*, Lake Huron.

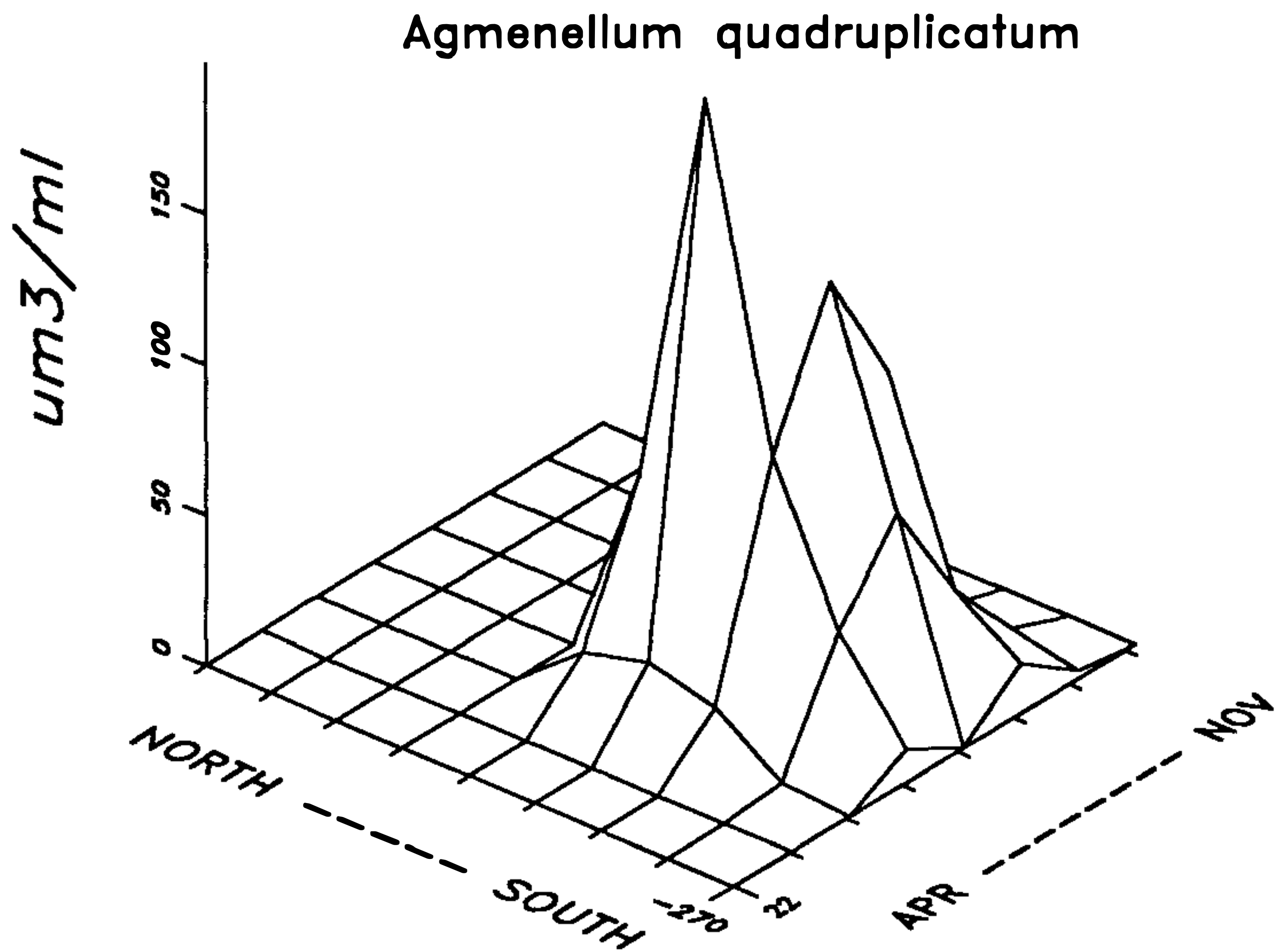


Figure 30. Geographical and seasonal distribution of *Agmenellum quadruplicatum*, Lake Huron.

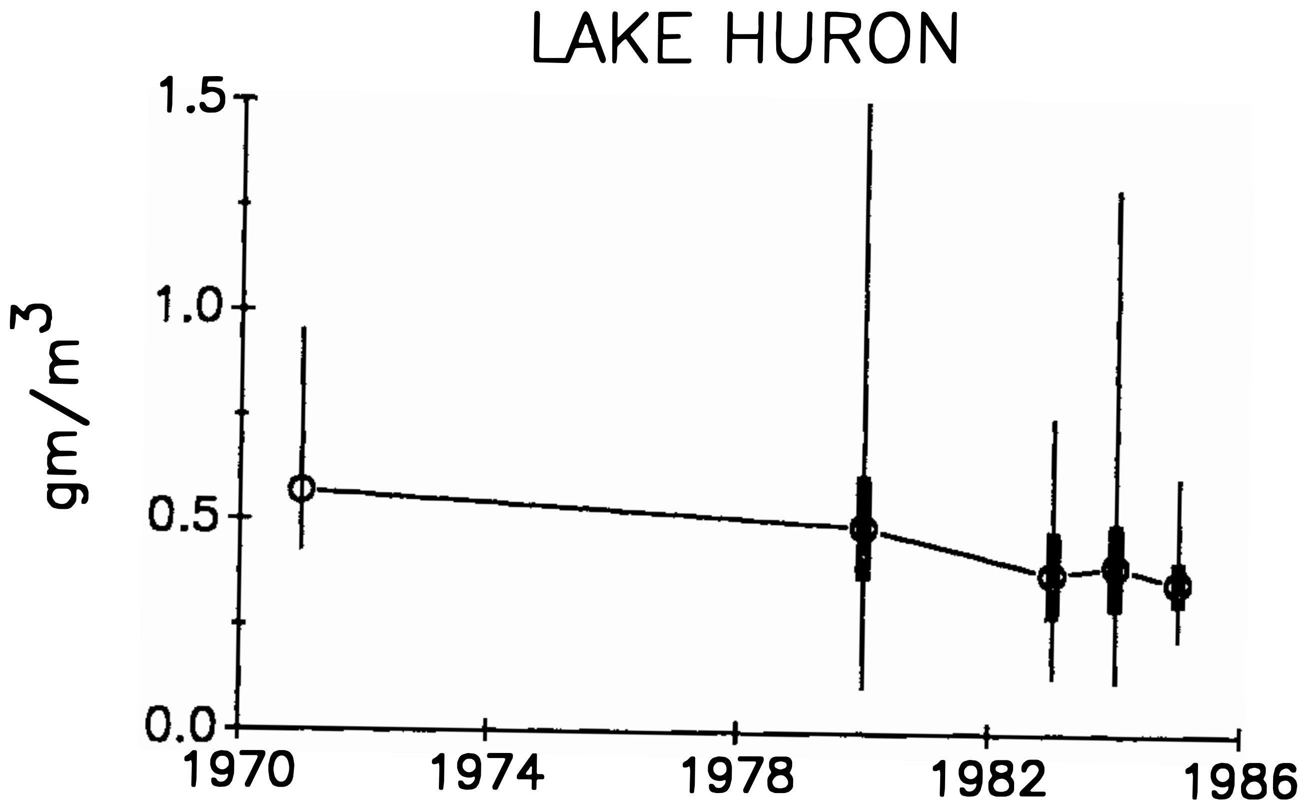


Figure 31. Historical offshore algal biomass trends in Lake Huron. Values are the mean±S.E. and the range. Data are from Munawar and Munawar (1979), Makarewicz (1987, 1988) and this study. 1980 data are modified froma GLNPO data base (1980).

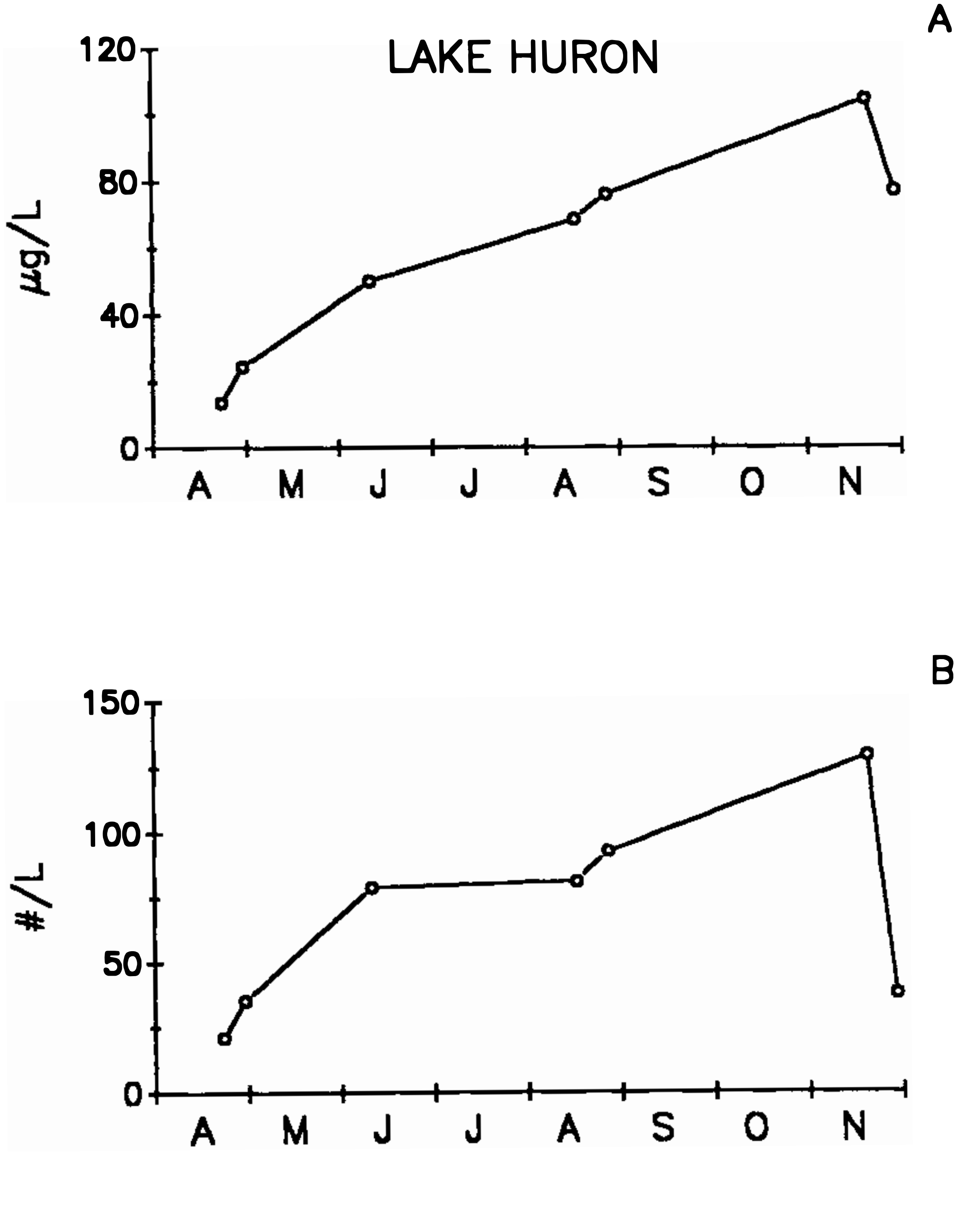
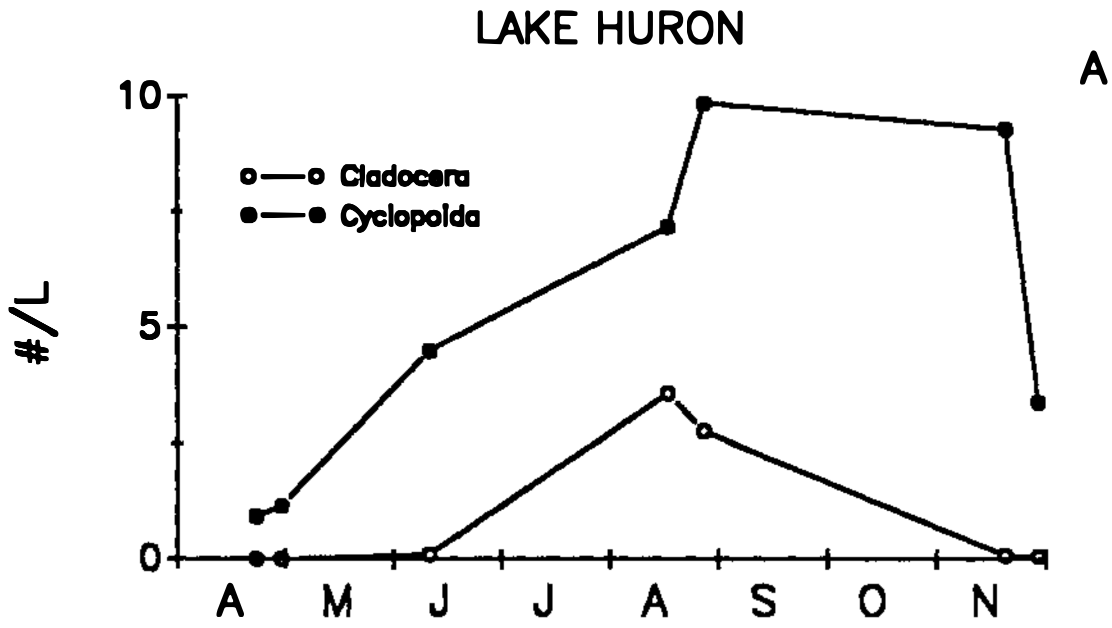


Figure 32. Seasonal zooplankton biomass (A) and abundance (B) in Lake Huron, 1985.



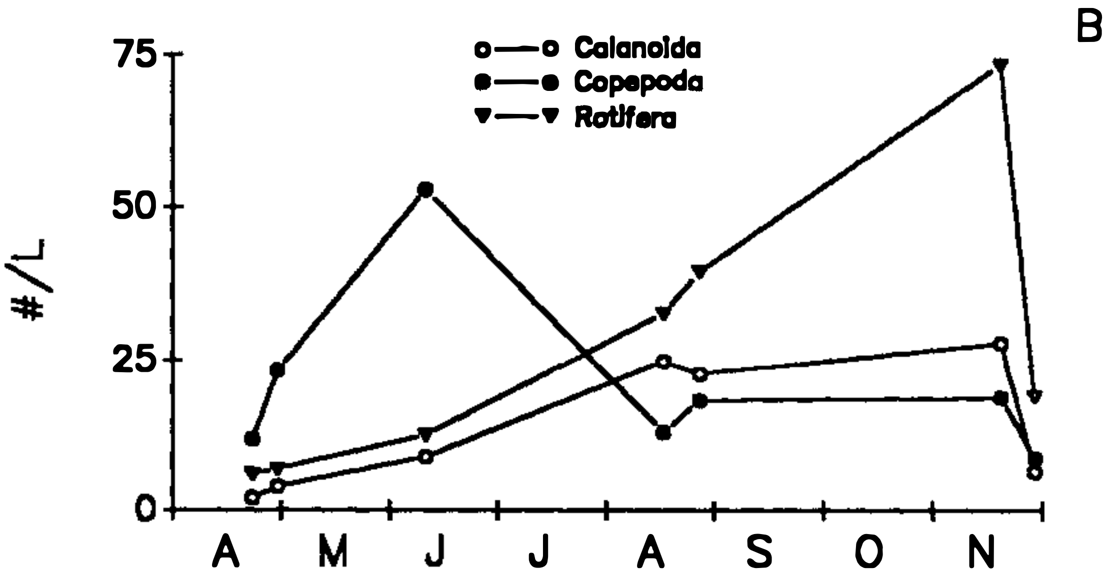


Figure 33. Seasonal fluctuation (numerical) of zooplankton groups in Lake Huron, 1985. Copepoda refer to the nauplius stage of the Copepoda.

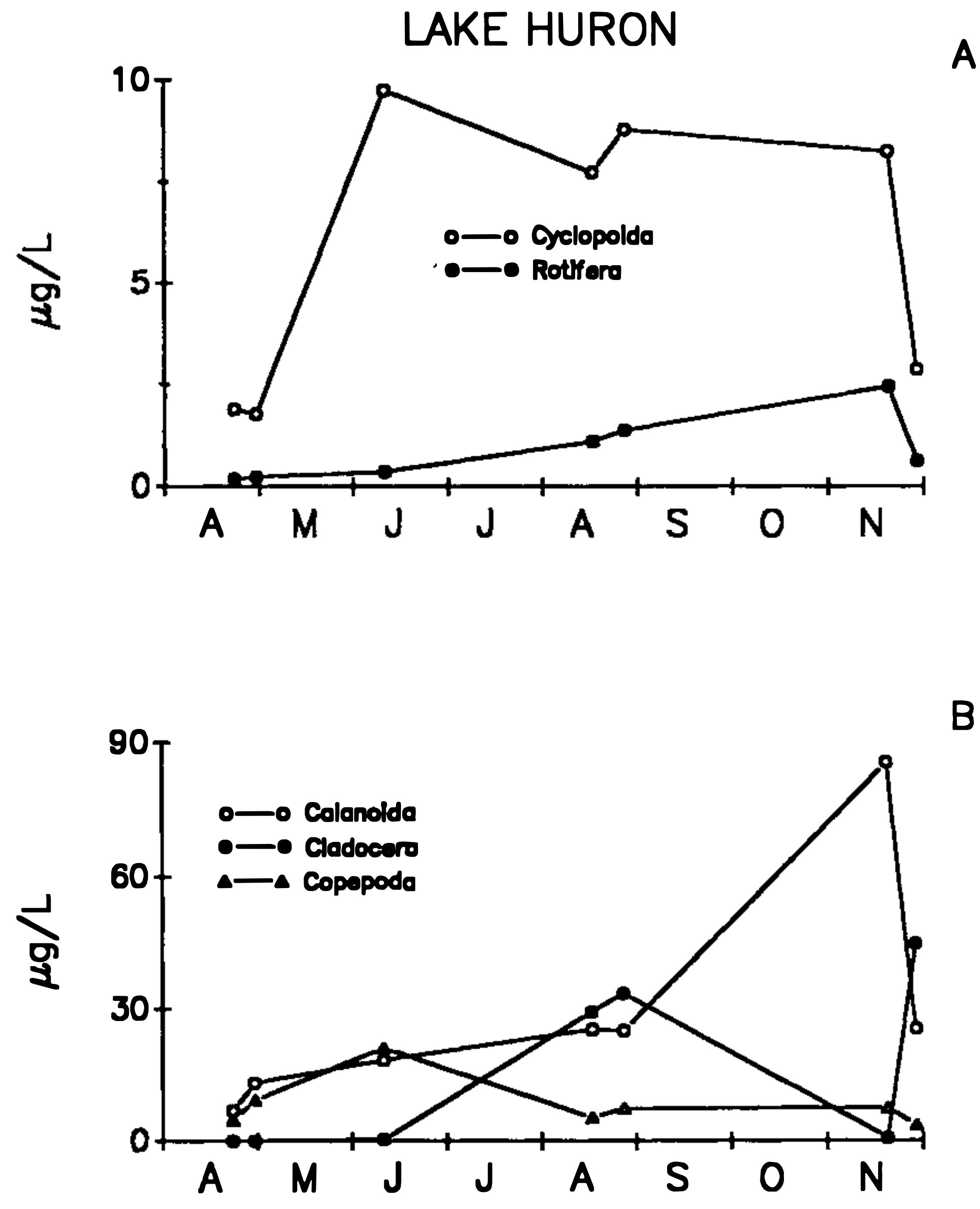


Figure 34. Seasonal flucuation (biomass) of zooplankton groups in Lake Huron, 1985. Copepoda refers to the nauplius stage of the Copepoda.

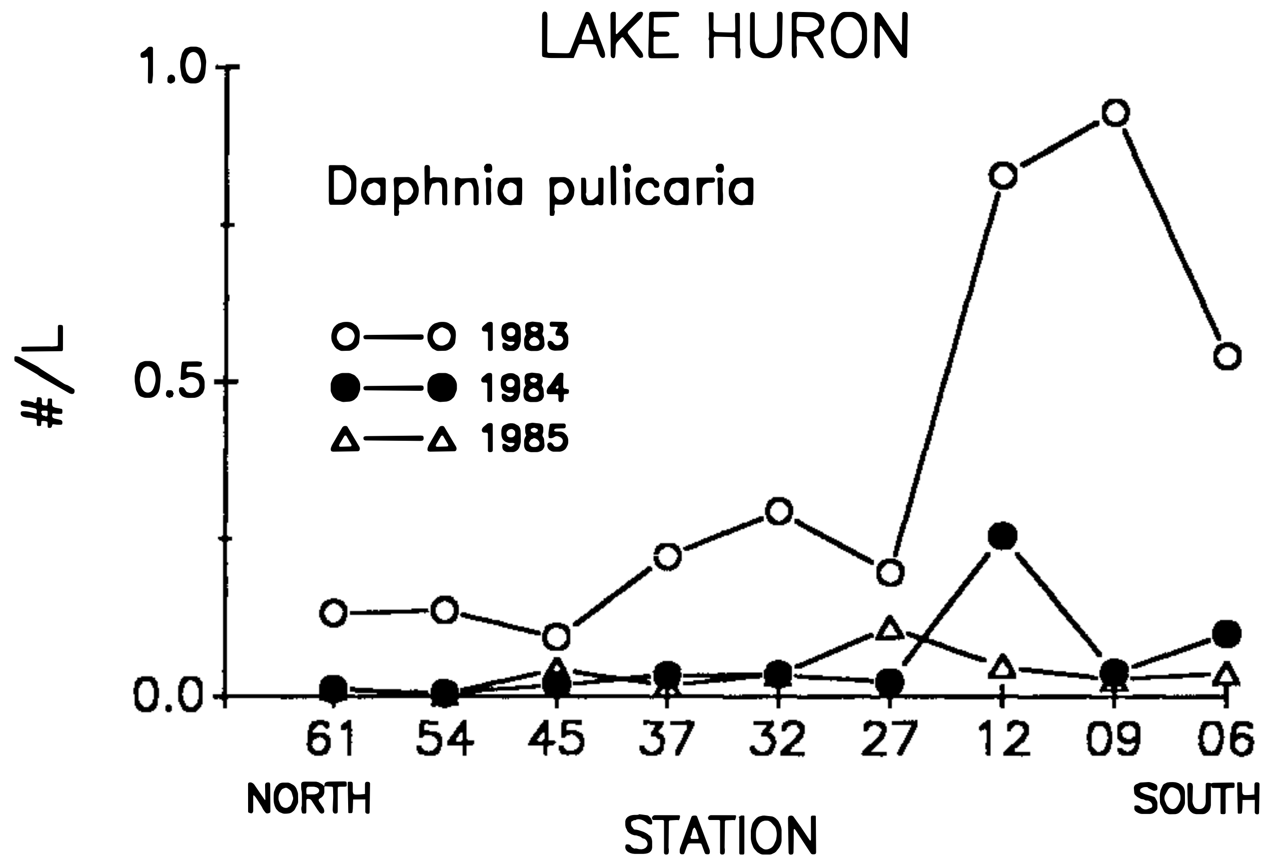


Figure 35. Geographical distribution of *Daphnia pulicaria* from 1983 to 1985, Lake Huron.

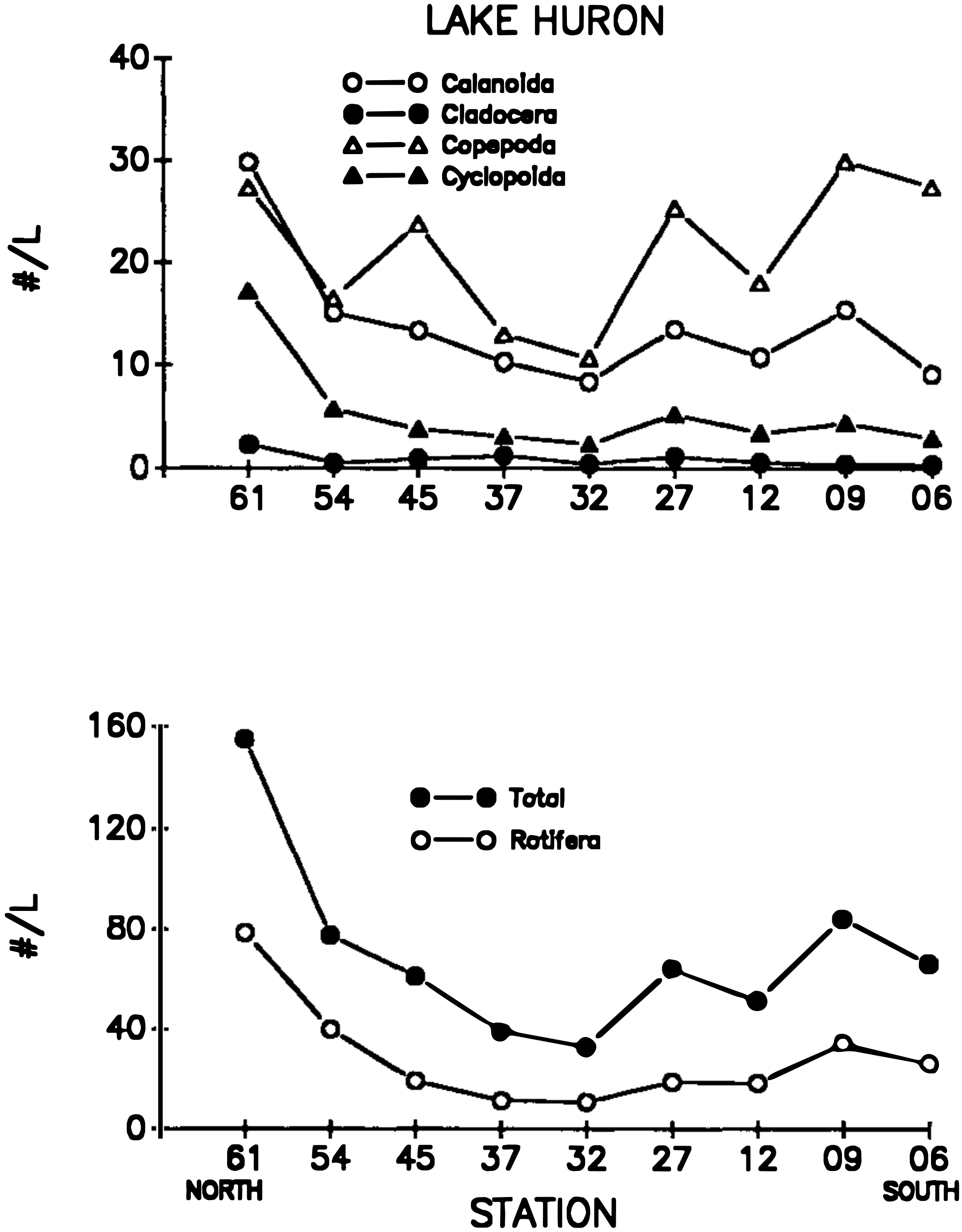


Figure 36. Geographical distribution (abundance) of major zooplankton groups in Lake Huron, 1985. Copepoda refers to the nauplius stage of the Copepoda.

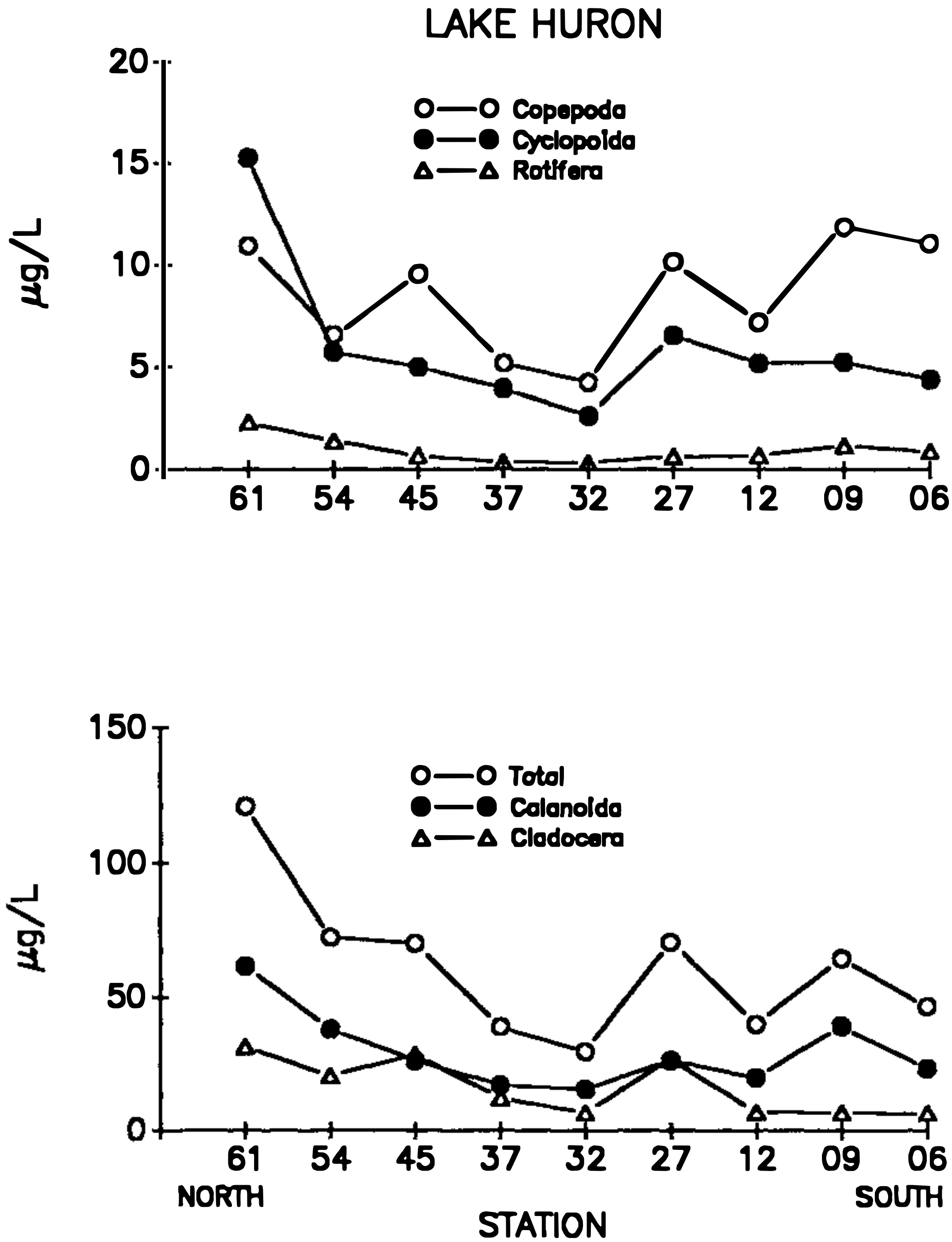


Figure **37**. Geographical distribution (biomass) of major zooplankton groups in Lake Huron, 1985. Copepoda refers to the nauplius stage of the Copepoda.

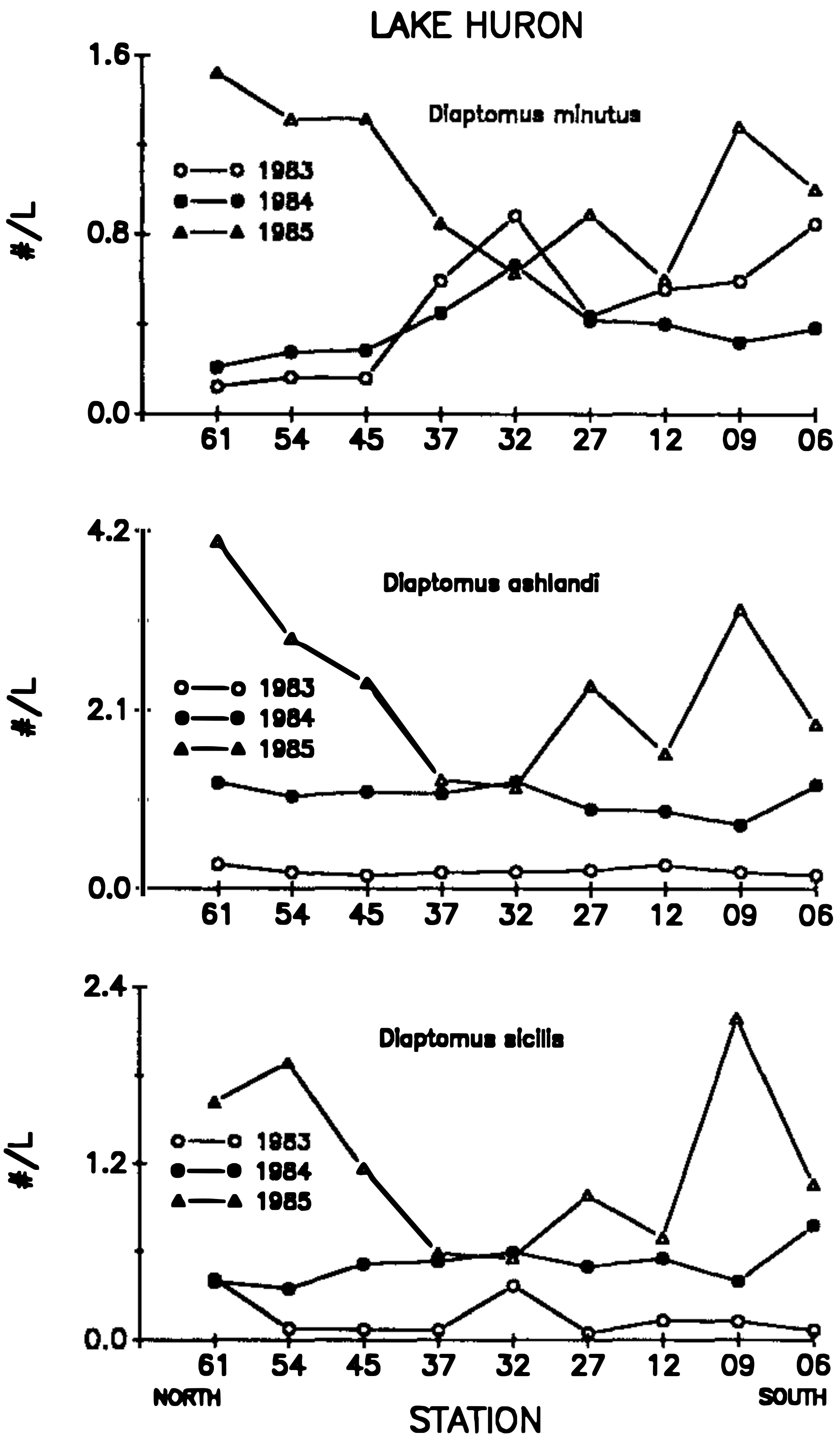


Figure 38. Geographical distribution of *Diaptomus minutus*, *D. ashlandi* and *D. sicilis* in 1983, 1984 and 1985. Data are from Makarewicz (1987, 1988) and this study.

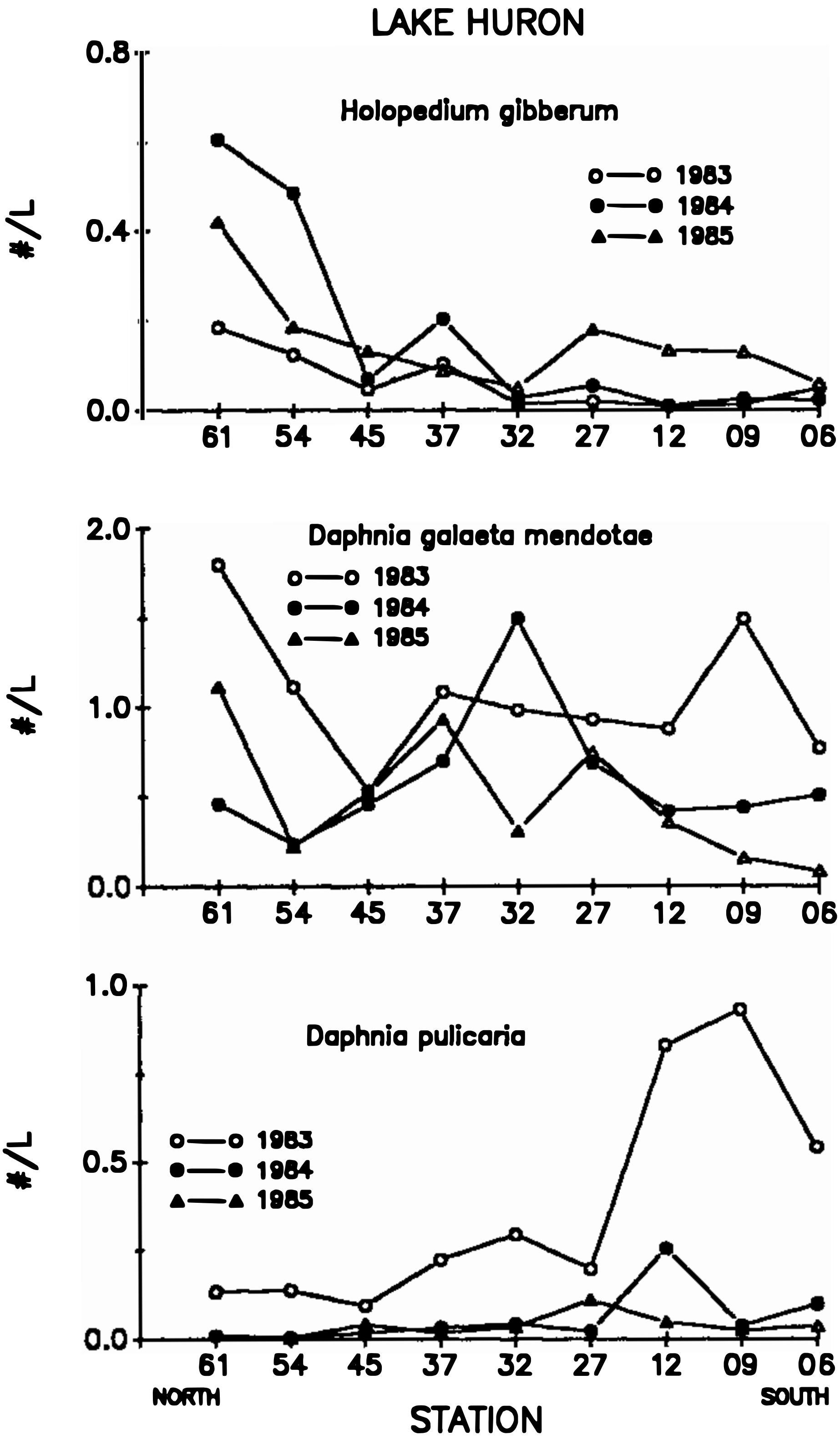


Figure 39. Geographical distribution of *Holopedium gibberum, Daphnia galaeta mendotae* and *Daphnia pulicaria* in 1983, 1984 and 1985. Data are from Makarewicz (1987, 1988) and this study.

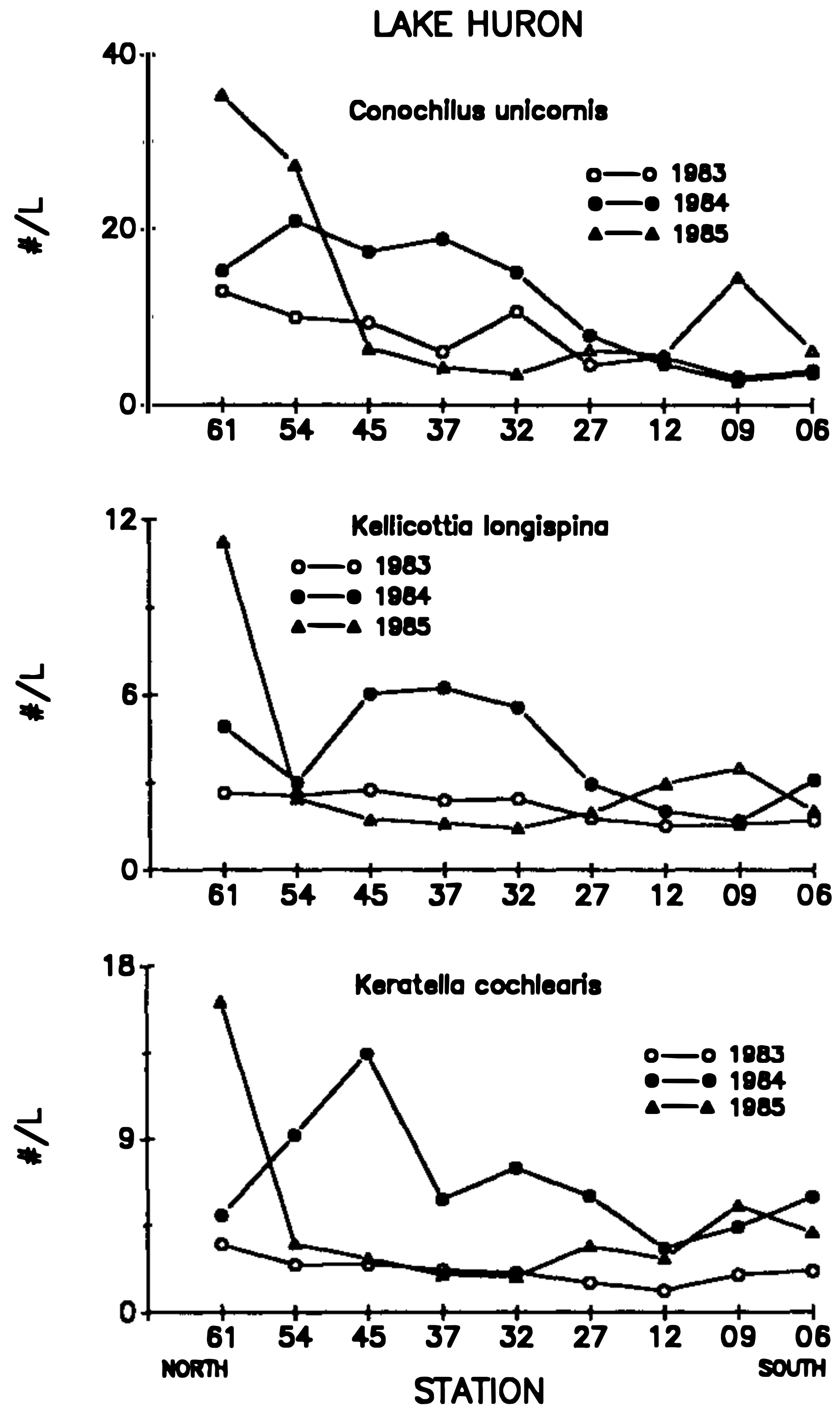


Figure 40. Geographical distribution of *Conochilus unicornis*, *Kellicottia longispina* and *Keratella cochlearis* in 1983, 1984 and 1985, Lake Huron. Data are from Makarewicz (1987, 1988) and this study.

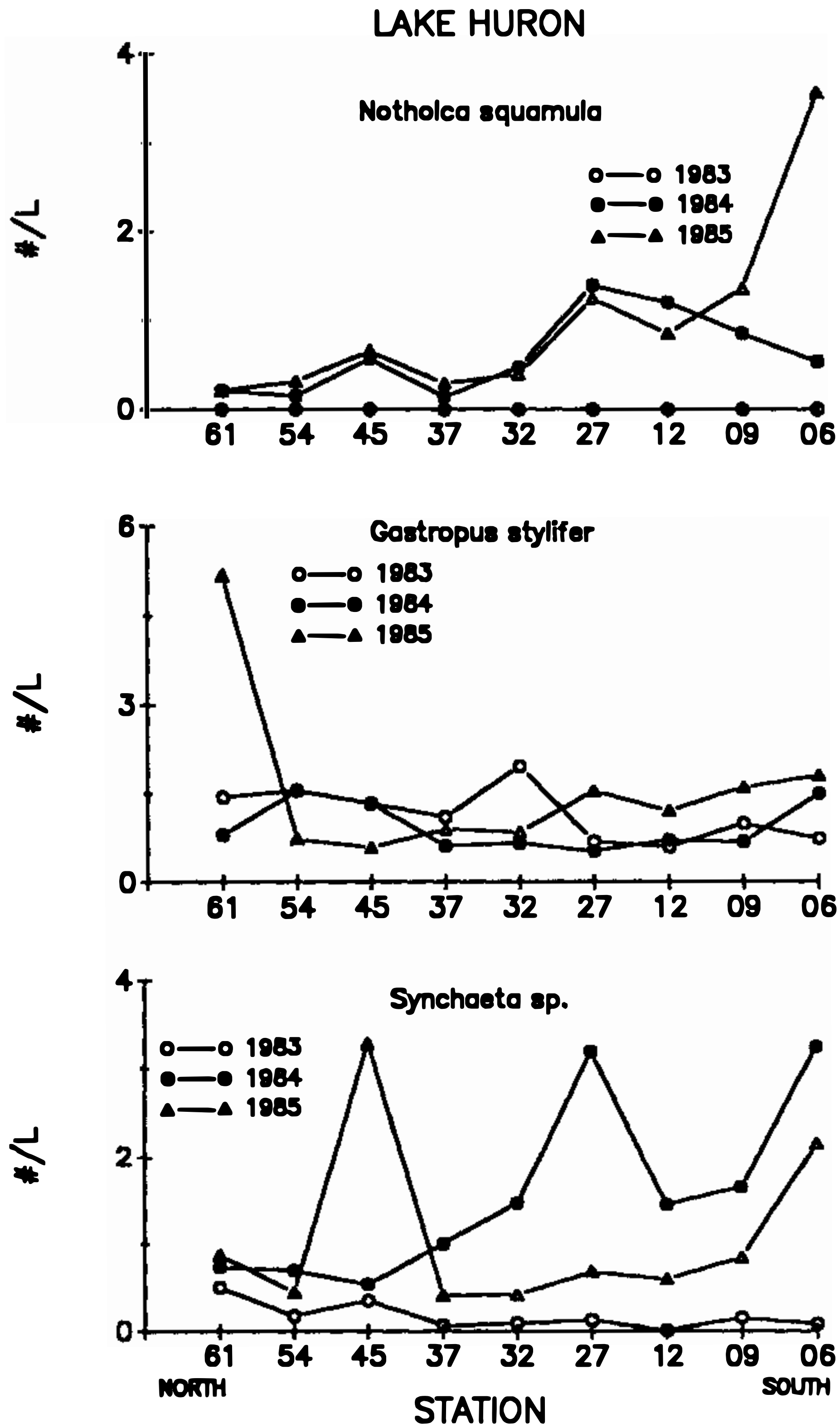


Figure 41. Geographical distribution of *Notholca squamula*, *Gastropus stylifer* and *Synchaeta* spp. in 1983, 1984 and 1985, Lake Huron. Data are from Makarewicz (1987, 1988) and this study.

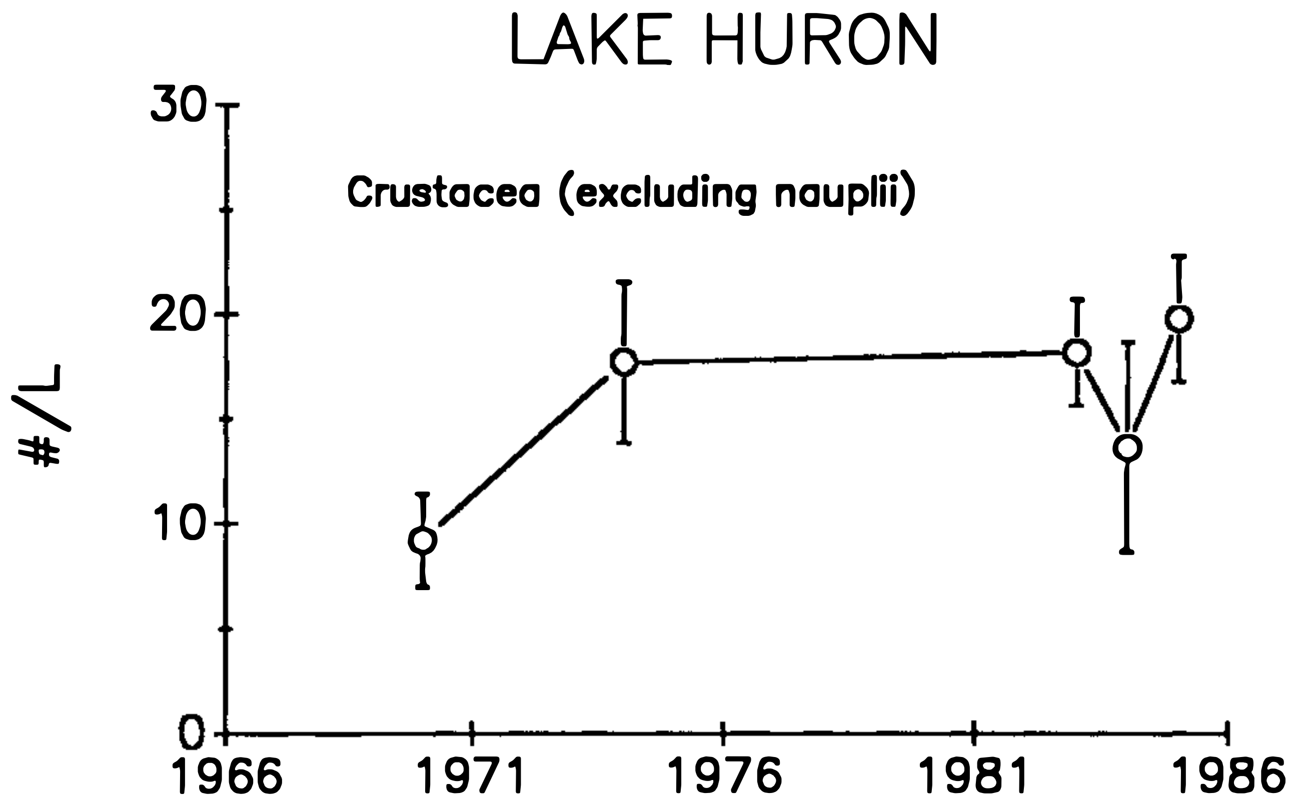


Figure **42**. Crustacean abundance (excluding nauplii) of Lake Huron, 1970-1985. Values are the mean ± S.E. Data are from Watson (1974), McNaught (1980), Makarewicz (1987, 1988). 1974 data represent oofshore sites only.

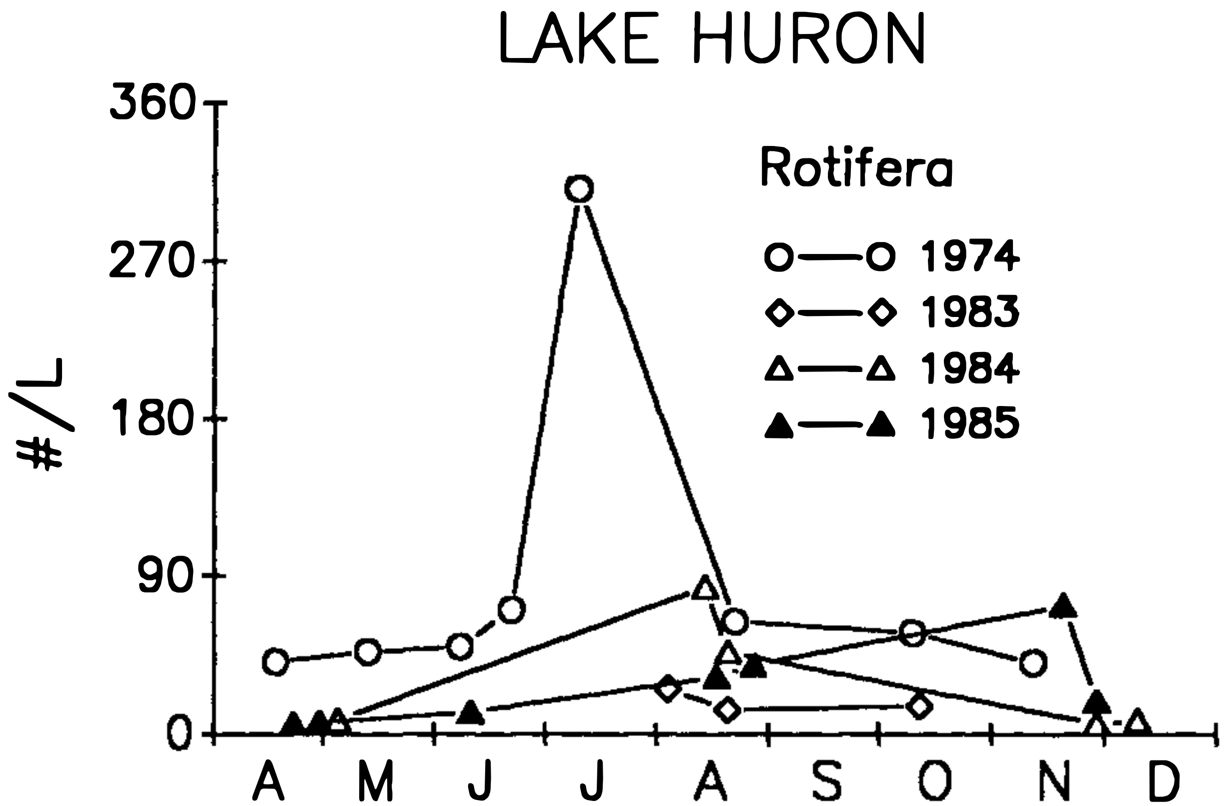


Figure **43**. Abundance of Rotifera in Lake Huron in 1974, 1983 1985 and 1985. 1974 data are from offshore stations only (Stemberger *et al* 1979).

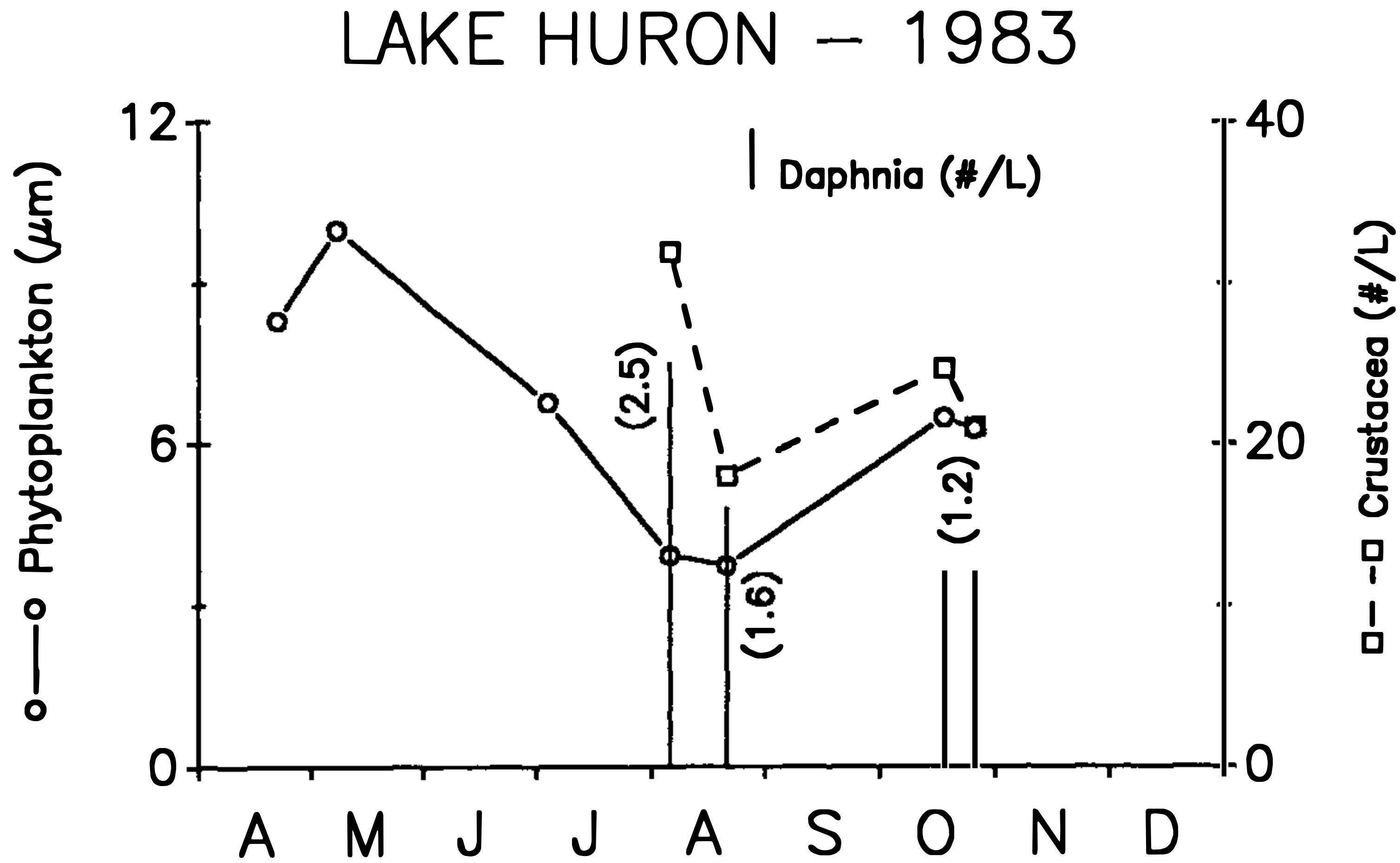


Figure **44**. Relationship between mean weighted edible phytoplankton size and Crustacea and *Daphnia* abundance, 1983. Vertical bars represent *Daphnia* abundance. Abundance values are the mean for a cruise. Picoplankton are not included. Edible phytoplankton are defined as all species minus colonial and filamentous forms.

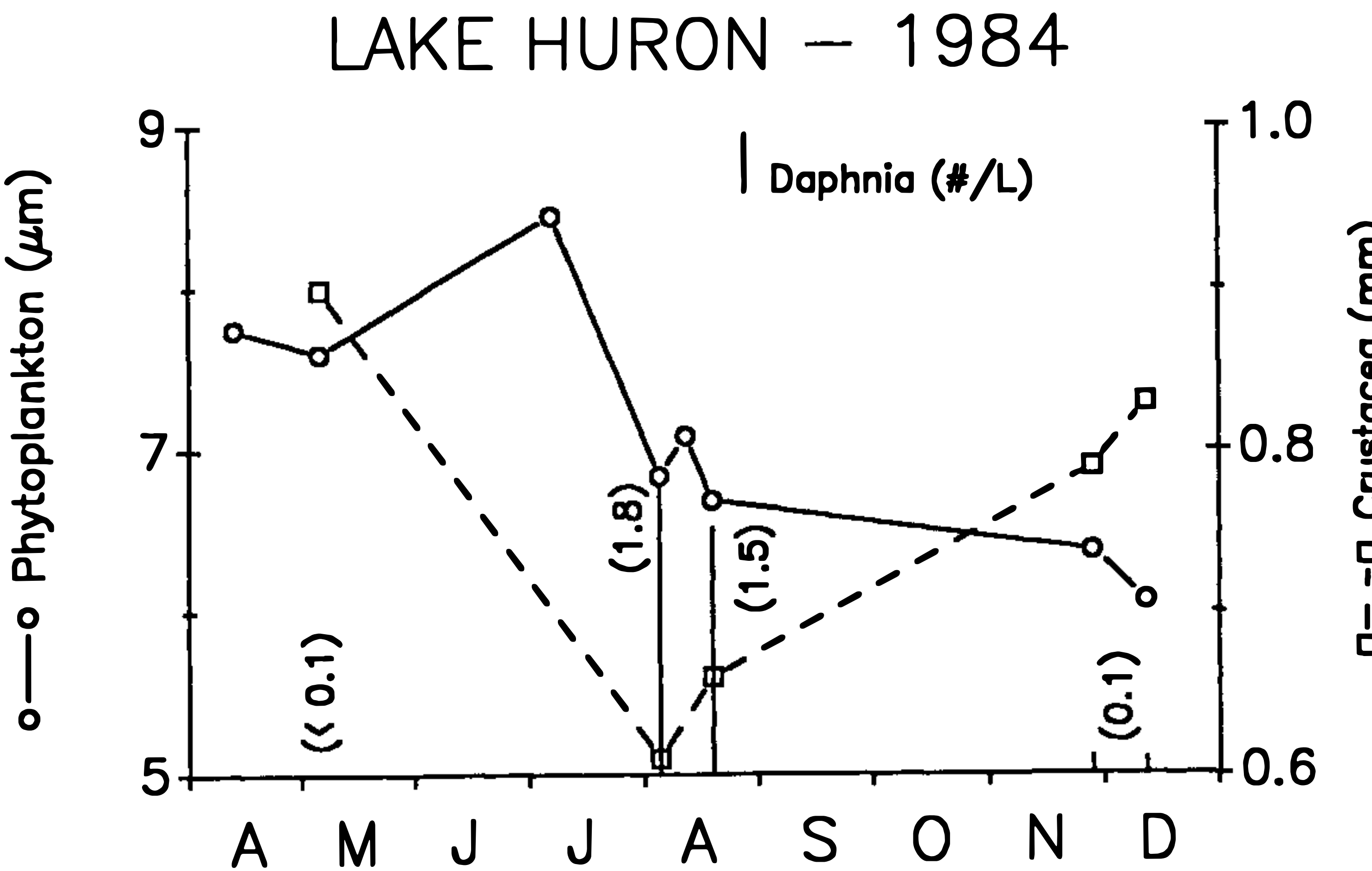


Figure 45. Relationship between mean weighted edible phytoplankton size, mean weighted Crustacea size and Crustacea and *Daphnia* abundance, 1984. Vertical bars represent *Daphnia* abundance. Abundance values are the mean for a cruise. Picoplankton are not included. Edible phytoplankton are defined as all species minus colonial and filamentous forms.

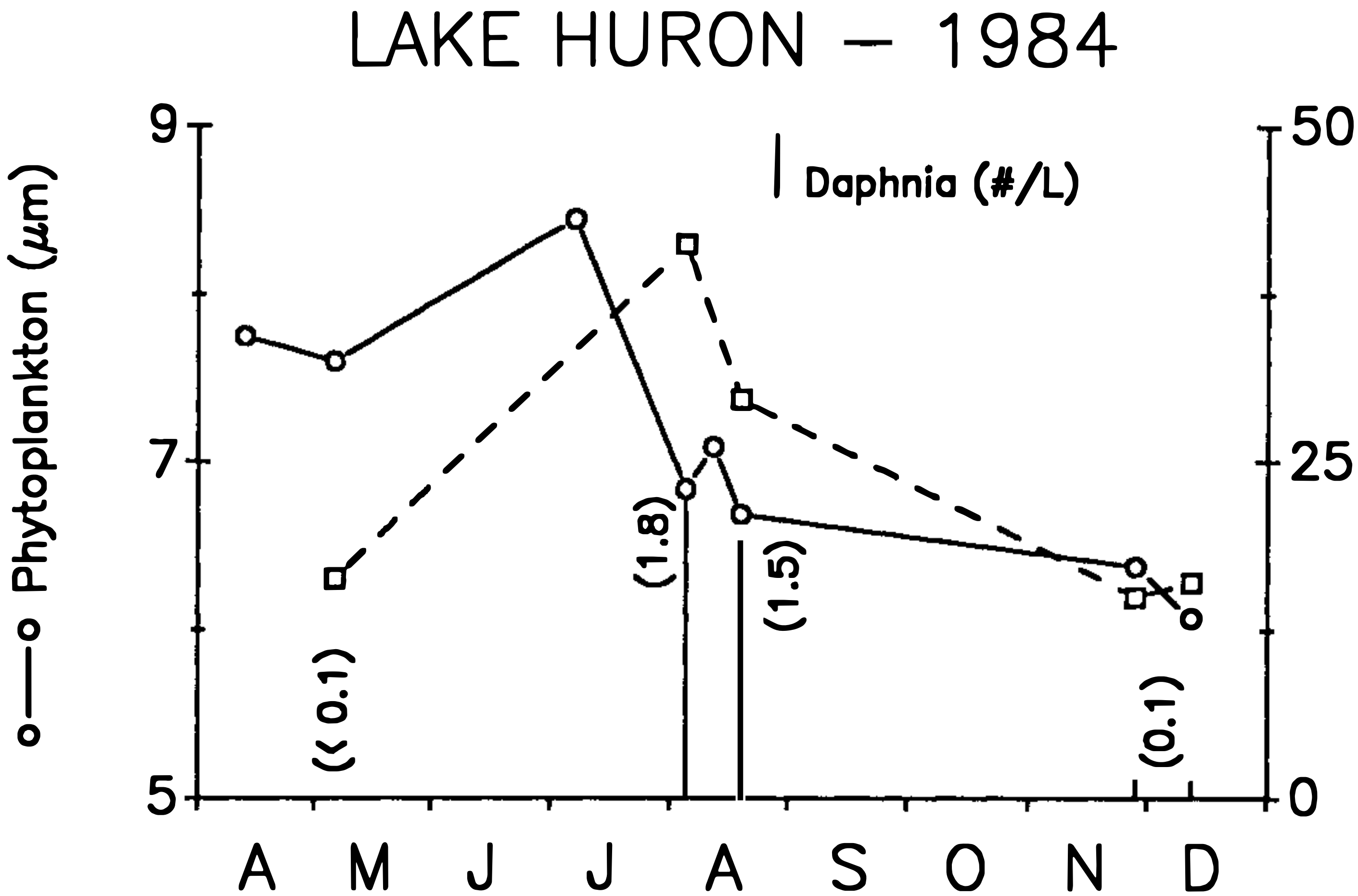


Figure 46. Relationship between mean weighted edible phytoplankton size and Crustacea and *Daphnia* abundance, 1984. Vertical bars represent *Daphnia* abundance. Abundance values are the mean for a cruise. Picoplankton are not included. Edible phytoplankton are defined as all species minus colonial and filamentous forms.

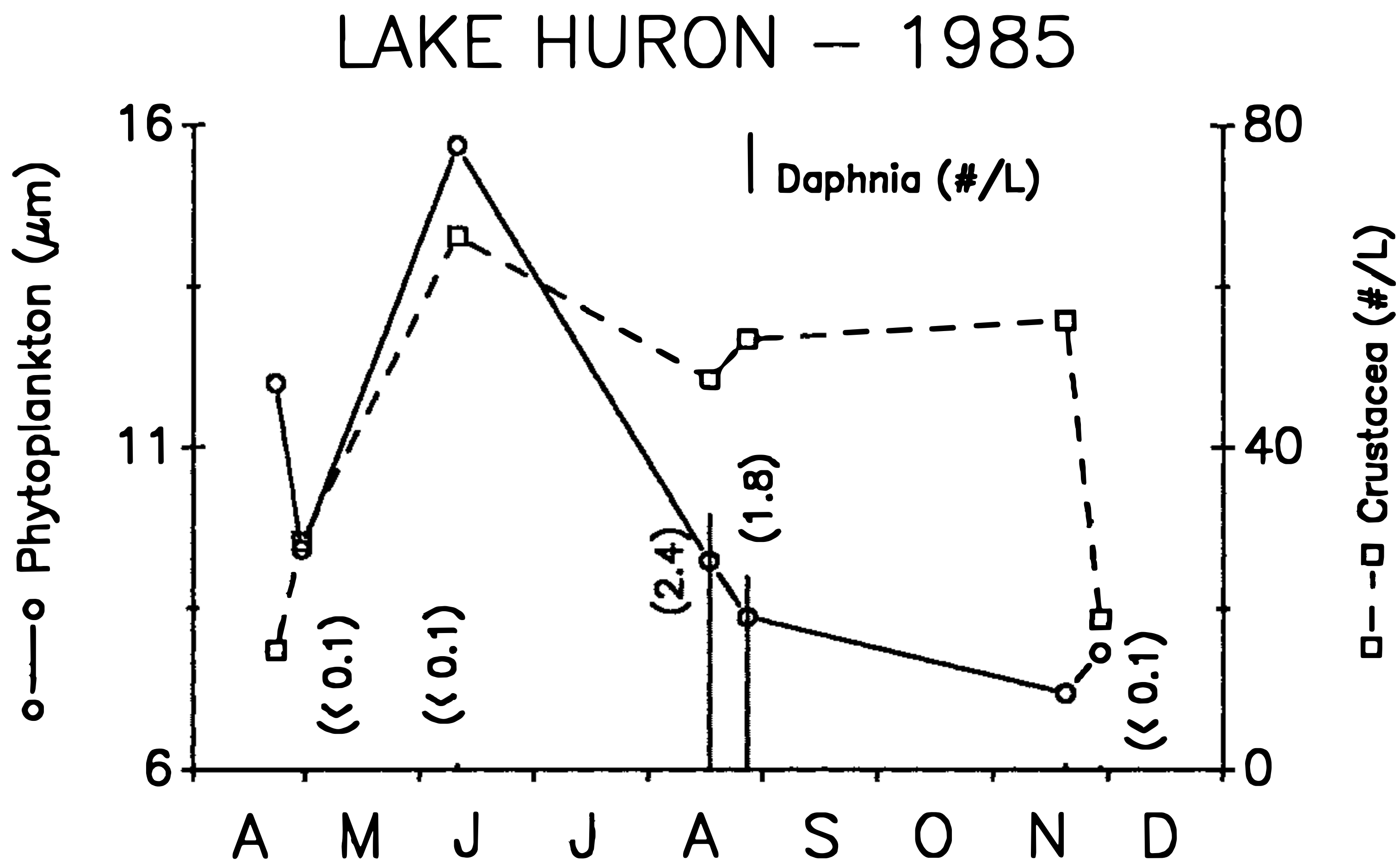


Figure 47. Relationship between mean weighted edible phytoplankton size, mean weighted Crustacea size and Crustacea and *Daphnia* abundance, 1985. Vertical bars represent *Daphnia* abundance. Abundance values are the mean for a cruise. Picoplankton are not included. Edible phytoplankton are defined as all species minus colonial and filamentous forms.

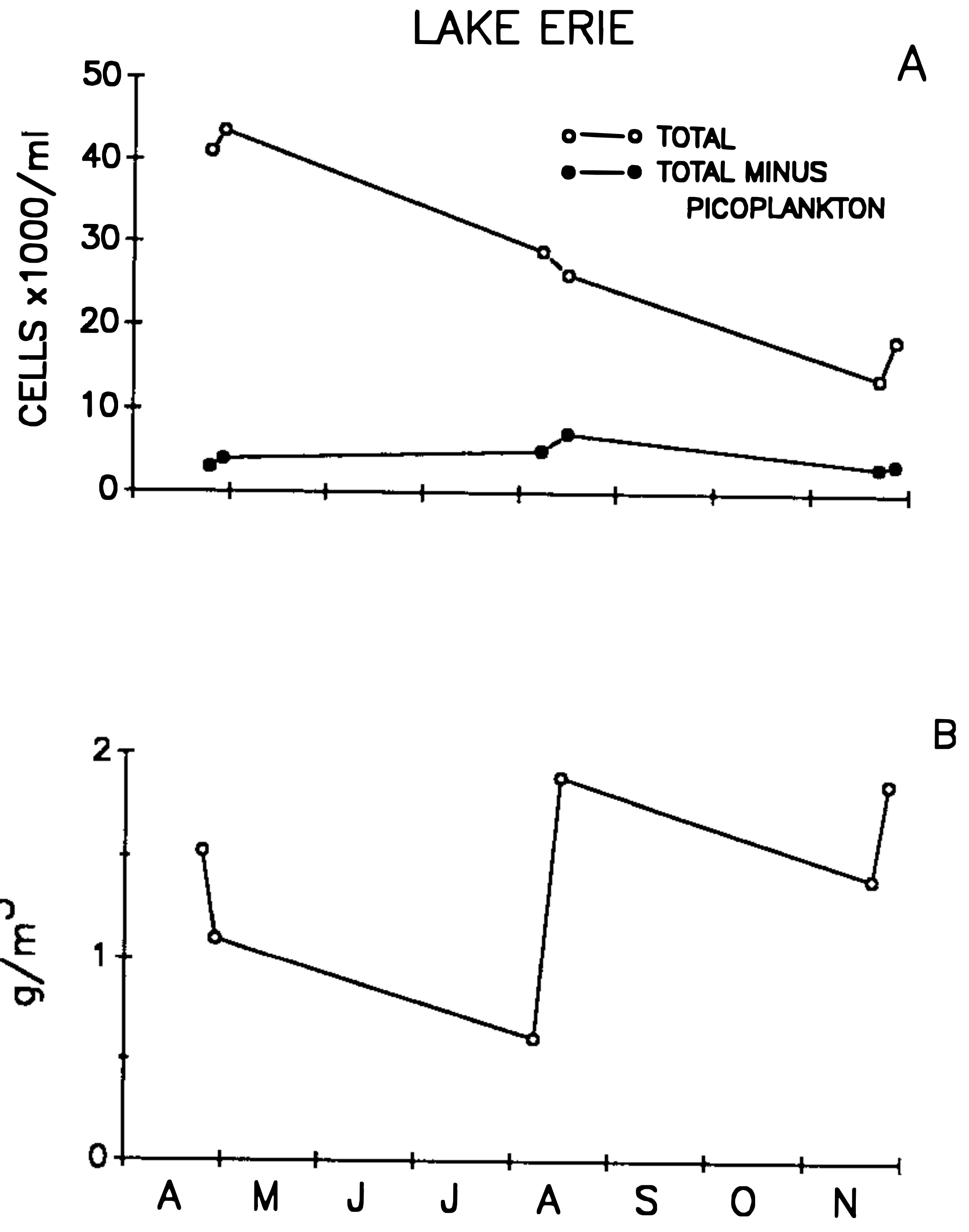


Figure 48. Seasonal phytoplankton abundance (A) and biomass (B) trends in Lake Erie, 1985. Plotted are the means of all stations (17) for a given cruise. Four samples were not completely counted due to high turbidity (Station 60, April 24 and November 21; Station 55, April 25; Station 57, November 21) and are not included.

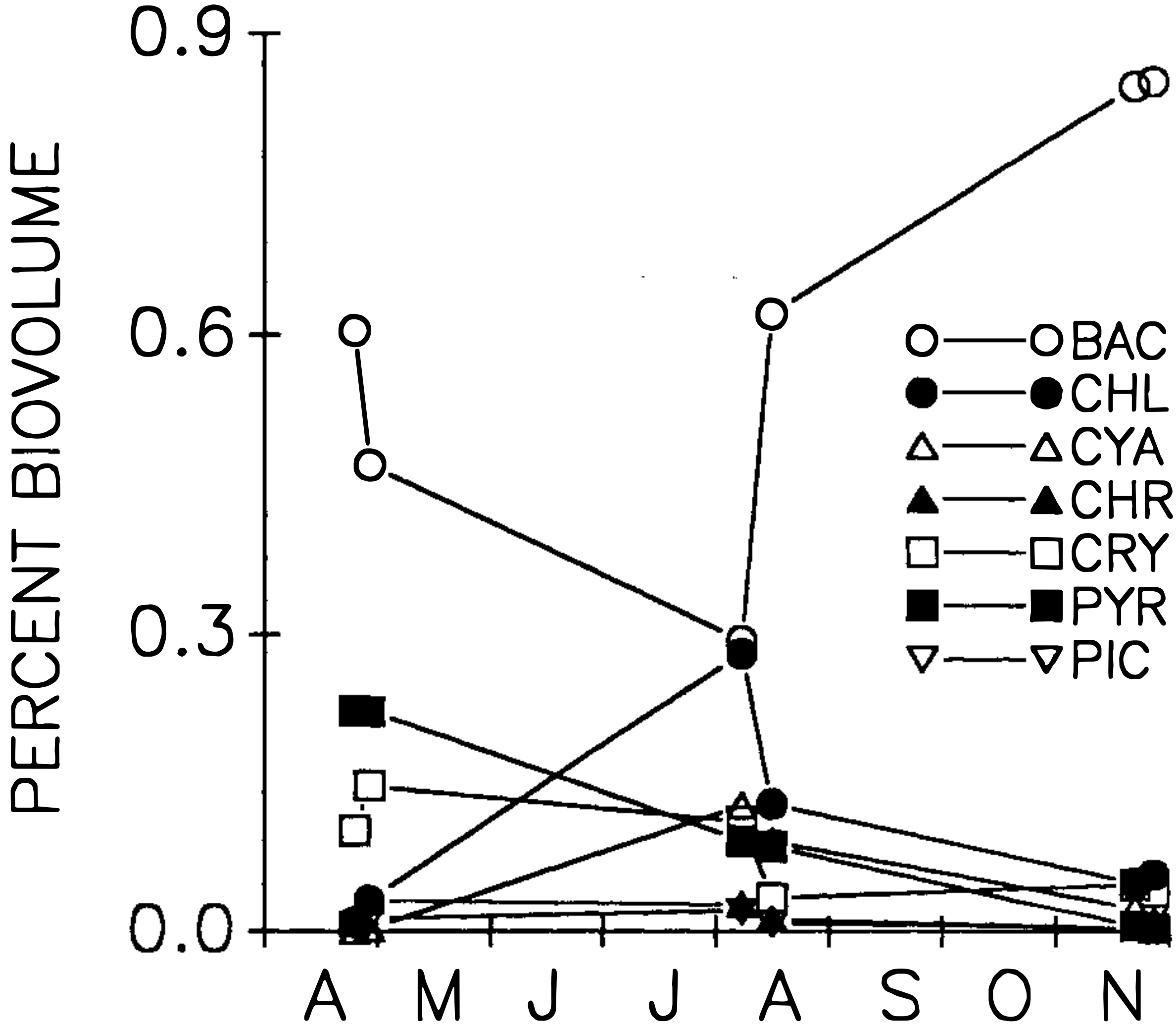


Figure 49. Seasonal distribution of algal divisions in Lake Erie, 1985. Bac = Bacillariophyta, Chl = Chlorophyta, Chr = Chrysophyta, Cry = Cryptophyta, Cya = Cyanophyta, Pic = Picoplankton, Pyr = Pyrrophyta.

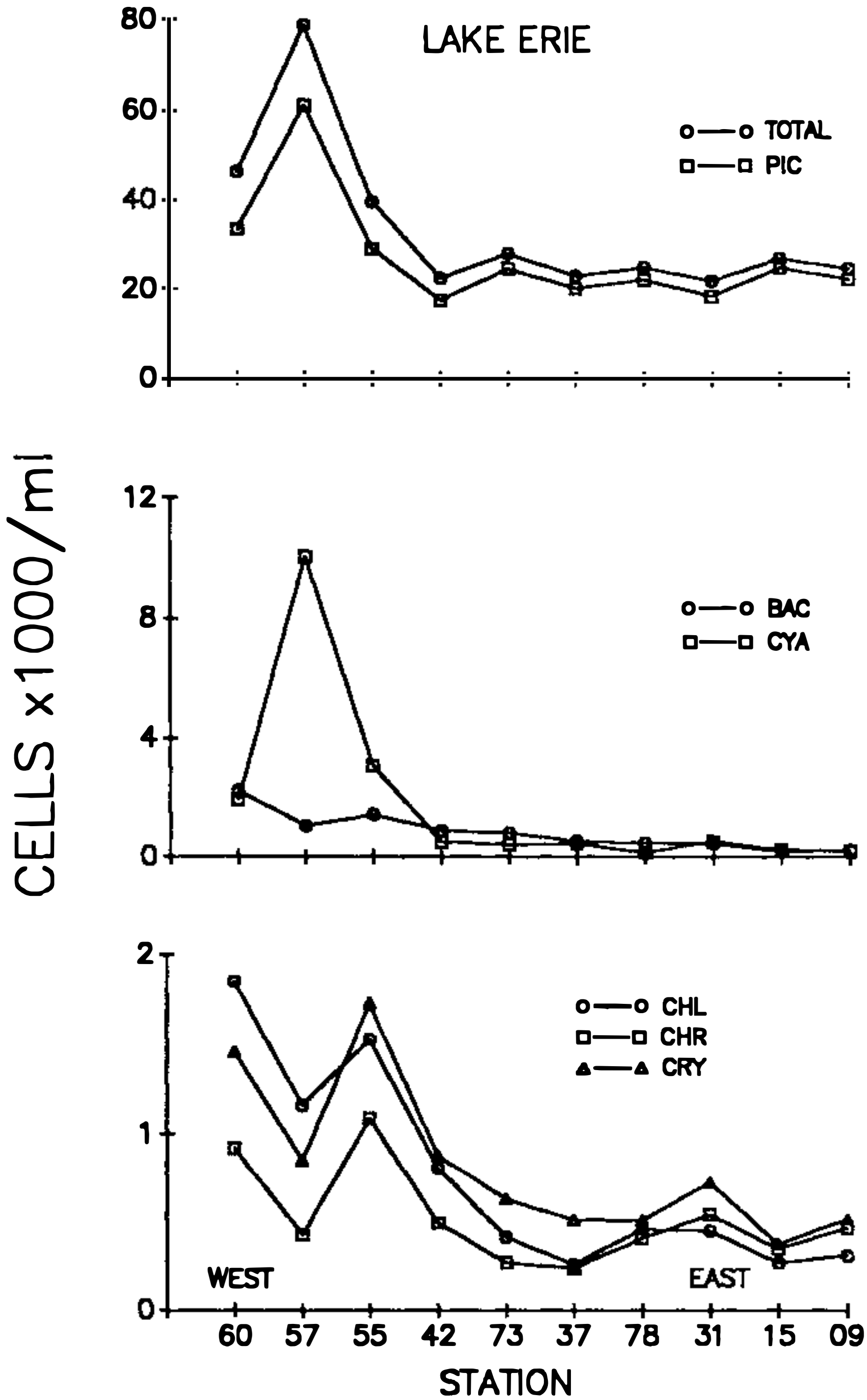


Figure 50. Annual geographic distribution of major algal divisions in Lake Erie, 1985. Plotted are the means of all seasonal samples for a given station. Station 42 is the mean of Stations 42 and 43. Station 37 is the mean of Stations 36, 37 and 38. Station 31 is the mean of Stations 30, 31 and 32. Station 15 is the mean of Stations 15 and 63 and Station 09 is the mean of Stations 09 and 10. Graph A data points were calculated without four samples that were not completely counted due to high turbidity (Station 60 on April 24 and November 21, Station 55 on April 25 and Station 57 on November 21). Graph C and the CYA line on Graph B were calculated without two samples that were not completely counted due to high turbidity (Station 60 and Station 57 on November 21). Bac - Bacillariophyta, Chl - Chlorophyta, Chr - Chrysophyta, Cry - Cryptophyta, Cya - Cyanophyta, Pic - Picoplankton.

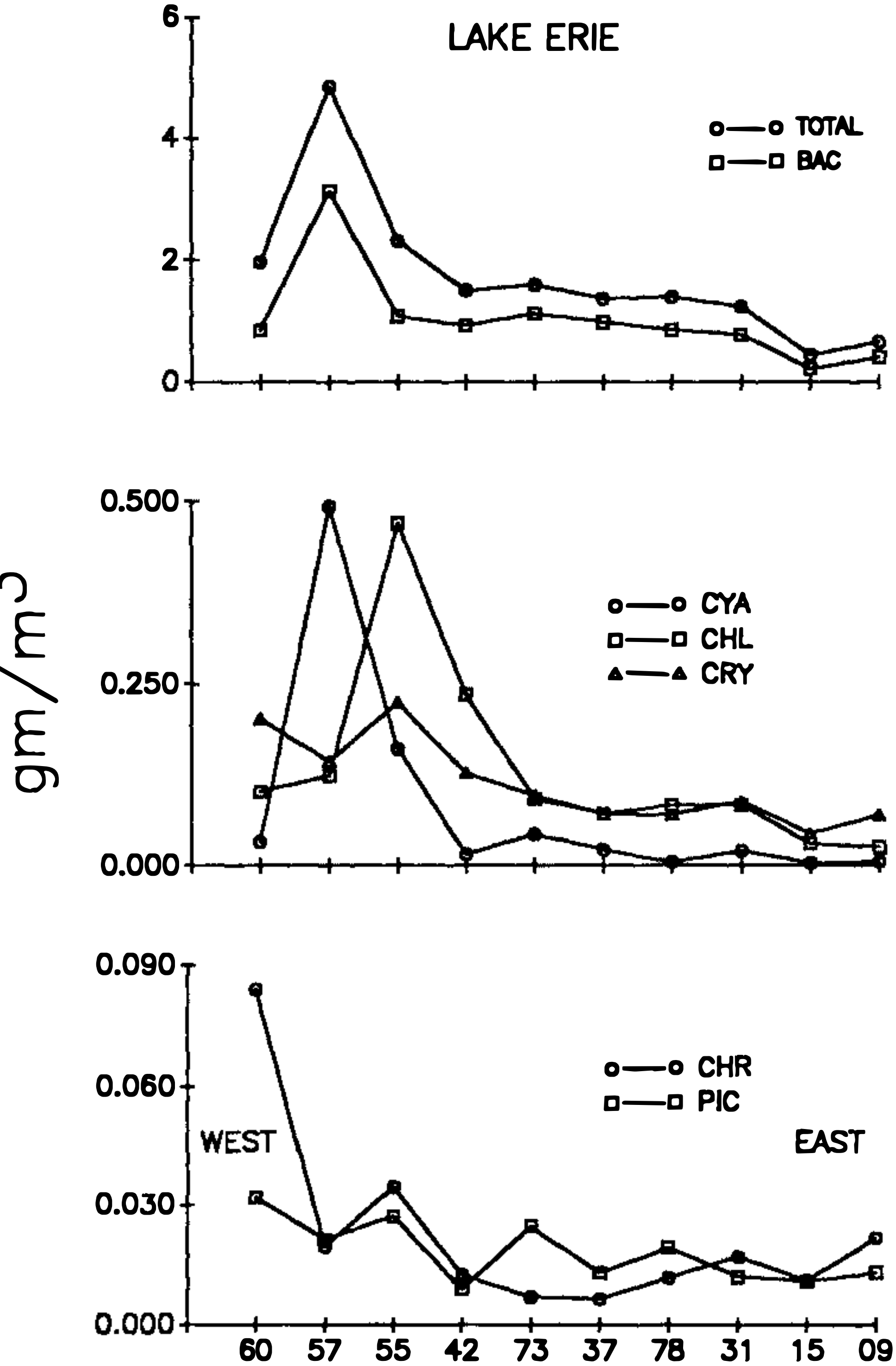


Figure 51. Annual geographical distribution (biomass) of major algal divisions in Lake Erie, 1985.

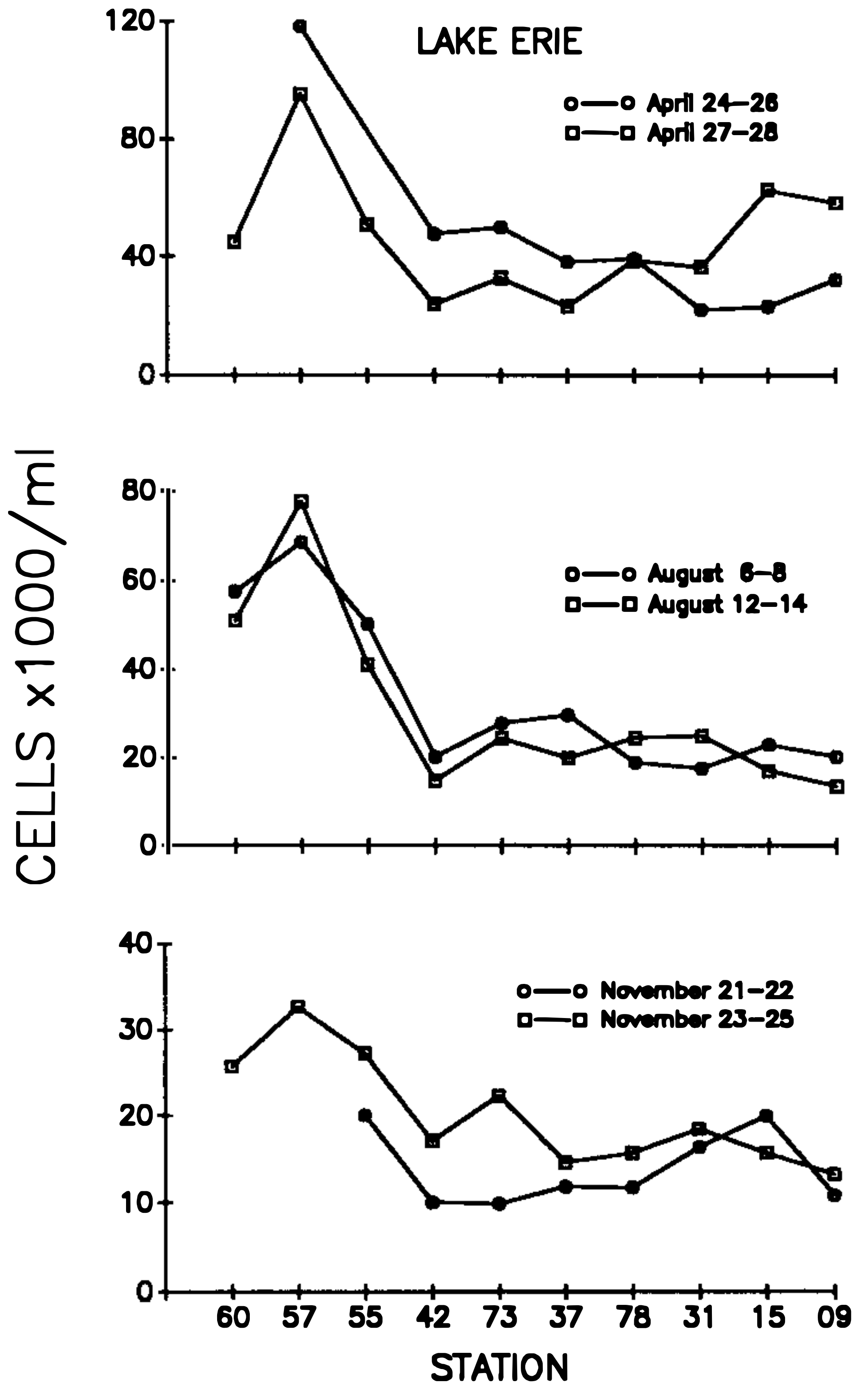


Figure 52. Geographical distribution of phytoplankton abundance, Lake Erie, 1985. Station 42 is the mean of Stations 42 and 43. Station 37 is the mean of Stations 36, 37 and 38. Station 31 is the mean of Stations 30, 31 and 32. Station 15 is the mean of Stations 15 and 63. Station 09 is the mean of Stations 09 and 10.

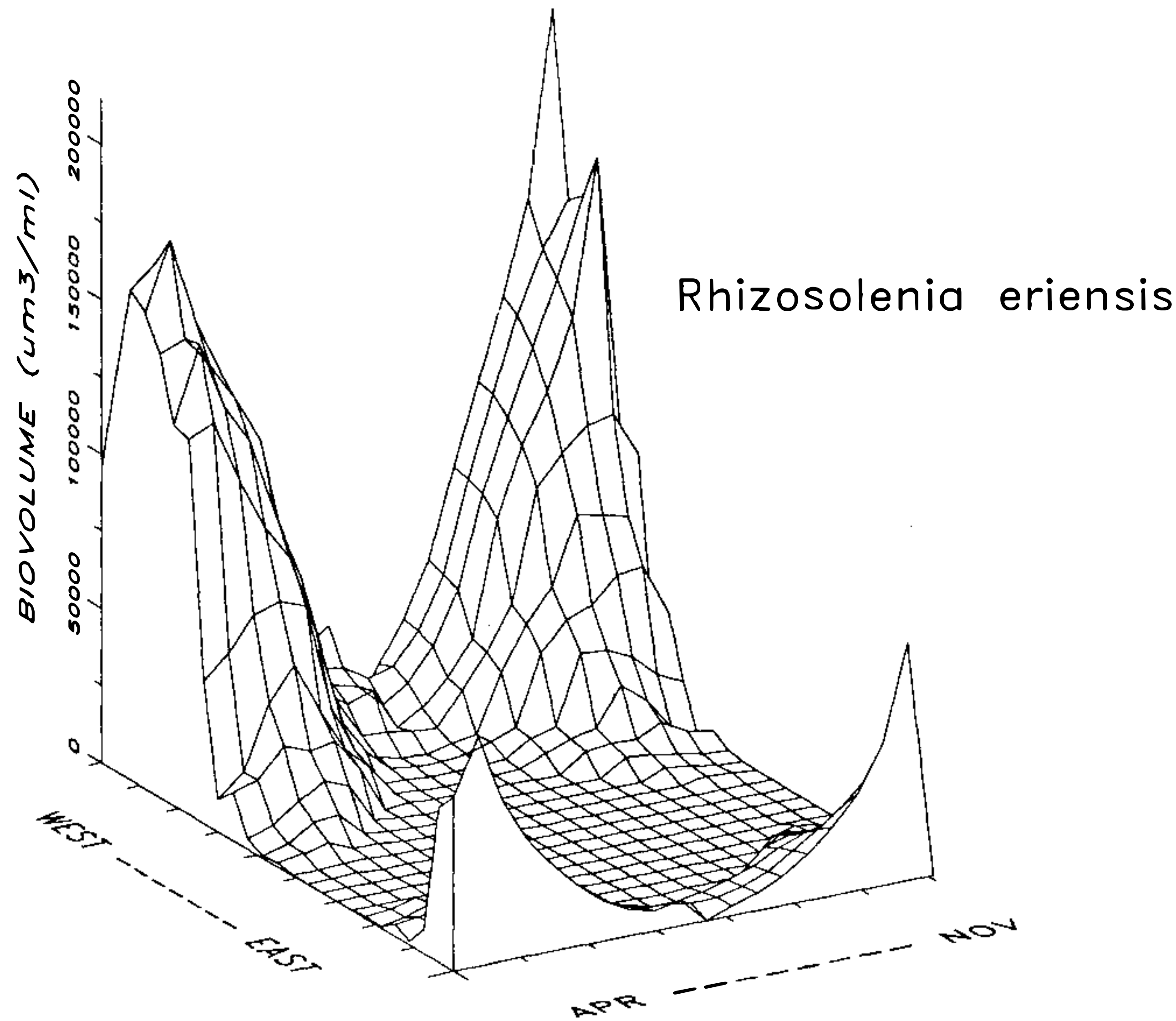


Figure 53. Geographical and seasonal distribition of *Rhizosolenia eriensis*, 1985.

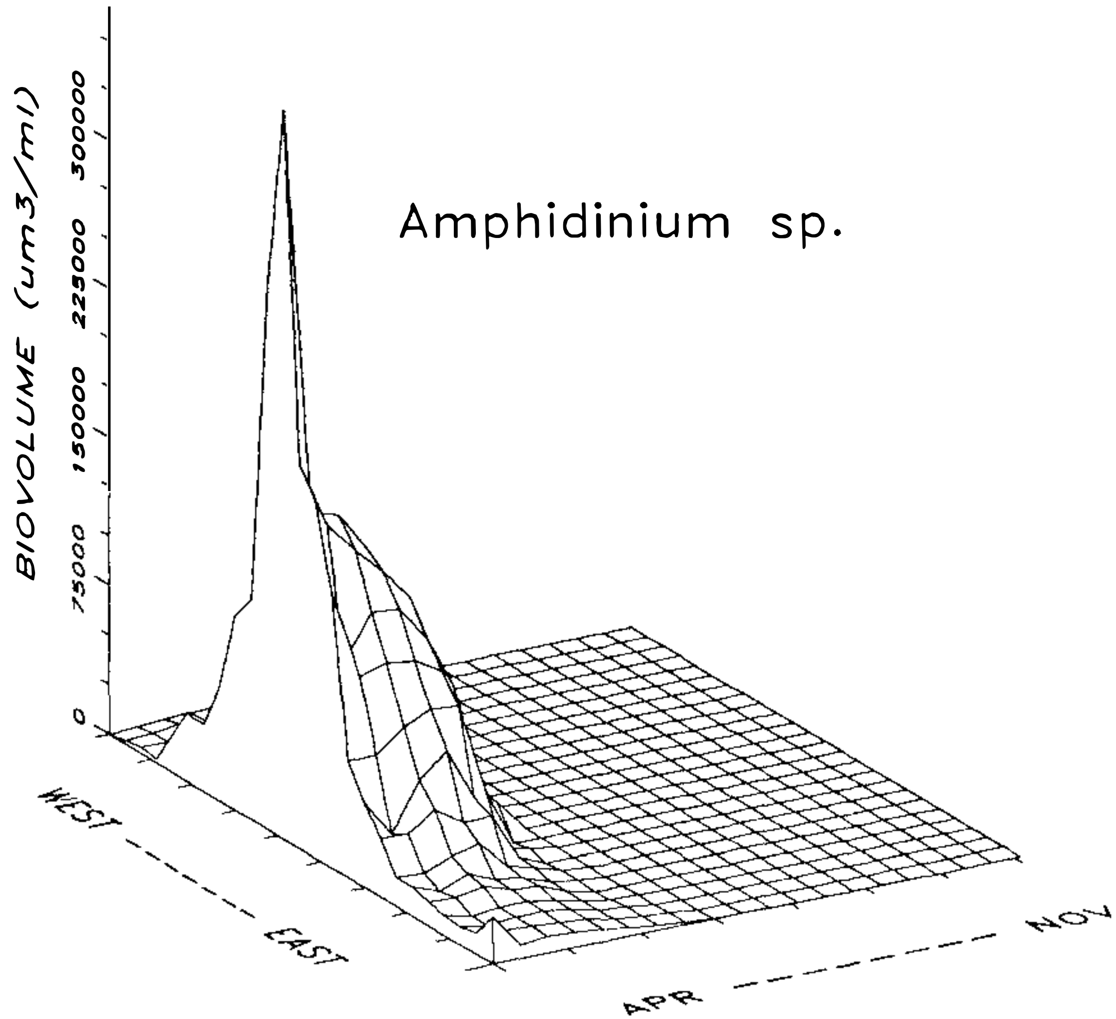


Figure 54. Geographical and seasonal distribibition of *Amphidinium* sp., 1985.

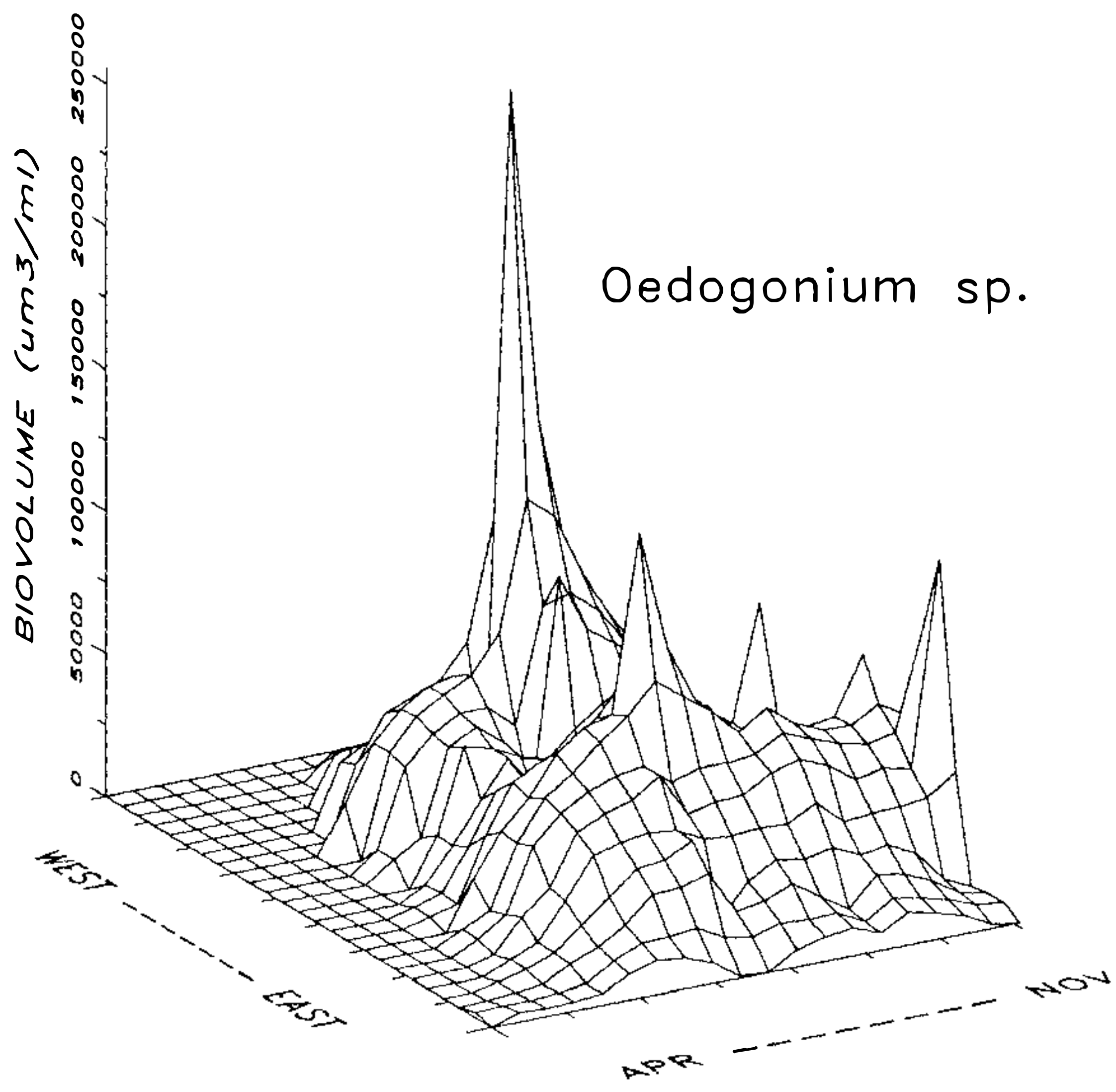


Figure 55. Geographical and seasonal distribition of *Oedogonium* sp., 1985.

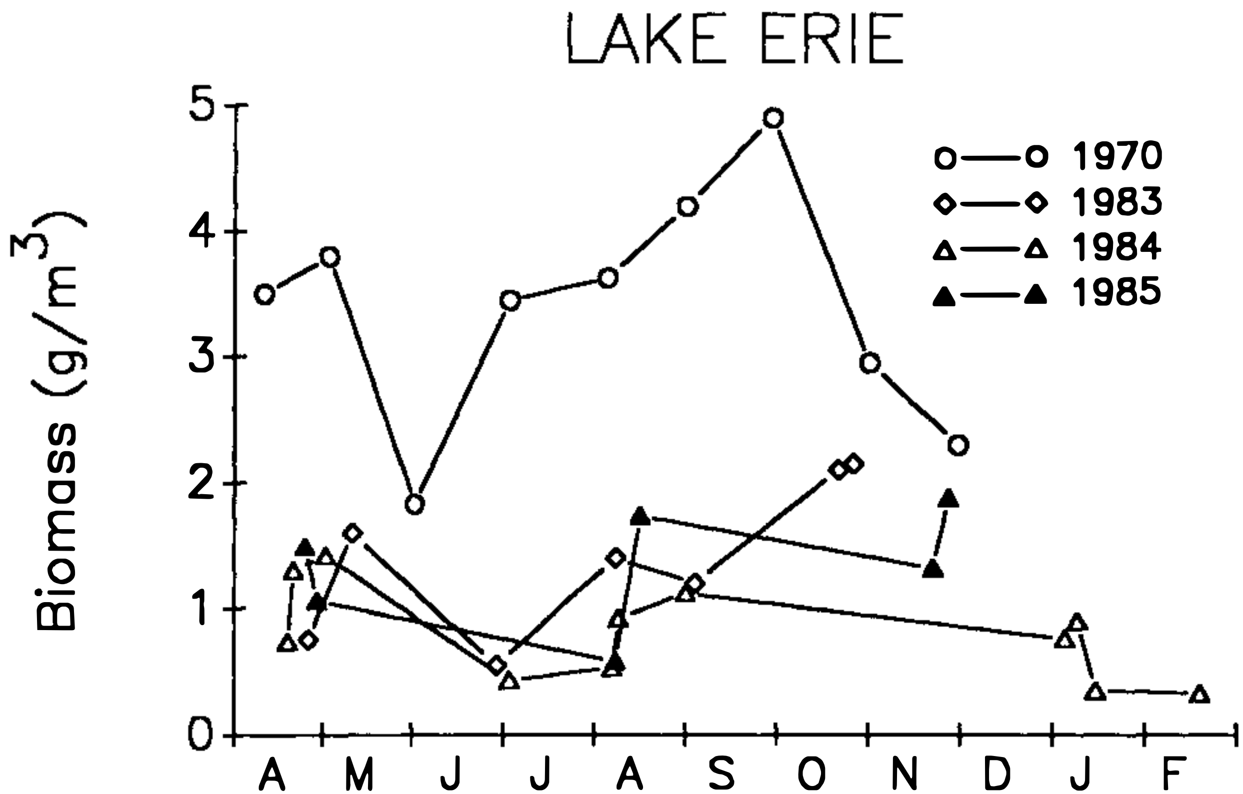


Figure 56. Seasonal flucuation of weighted mean phytoplankton biomass in 1970, 1983, 1984 and 1985, Lake Erie. 1970 data modified from Munawar and Munawar (1976). 1983 and 1984 data from Makarewicz (1988, 1989). Values are corrected by using the weighting factors of 15.6%, 59.6% and 24.6% for the western, central and eastern basins (after Munawar and Munawar 1976).

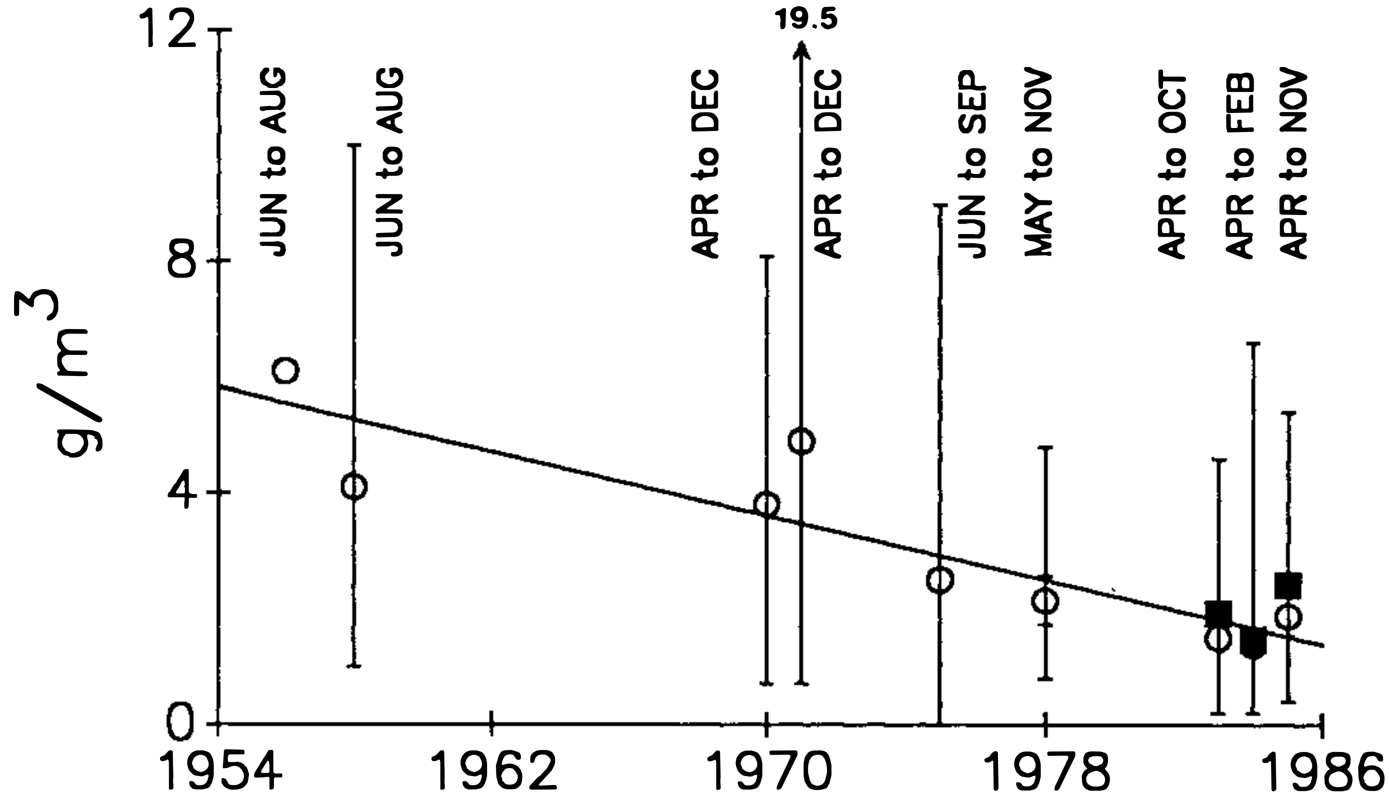


Figure 57. Regression (r^2-80.5) of phytoplankton biomass versus time in western Lake Erie. Modified from Gladish and Munawar (1980). 1956-58 data are from the Bass Island region. 1970 data from Point Pelee and near the mouth of Detroit River. 1975-76 data are from northern portions of the western basin. 1978 data are from similar geographic areas as 1970 (Devault and Rockwell 1986). 1979 data are not included because of a reduced sampling regime and other technical difficulties (Devault and Rockwell 1986). 1983-85 data are from Stations 60, 57 and 55. Except for the 1956 and the 1957-58 data sets, all enumeration was by the Utermohl technique. In 1956 and 1957-58, a settling technique was used, but counts were not made on an inverted microscope. Thin vertical lines are the range. Wide vertical lines are the standard error.

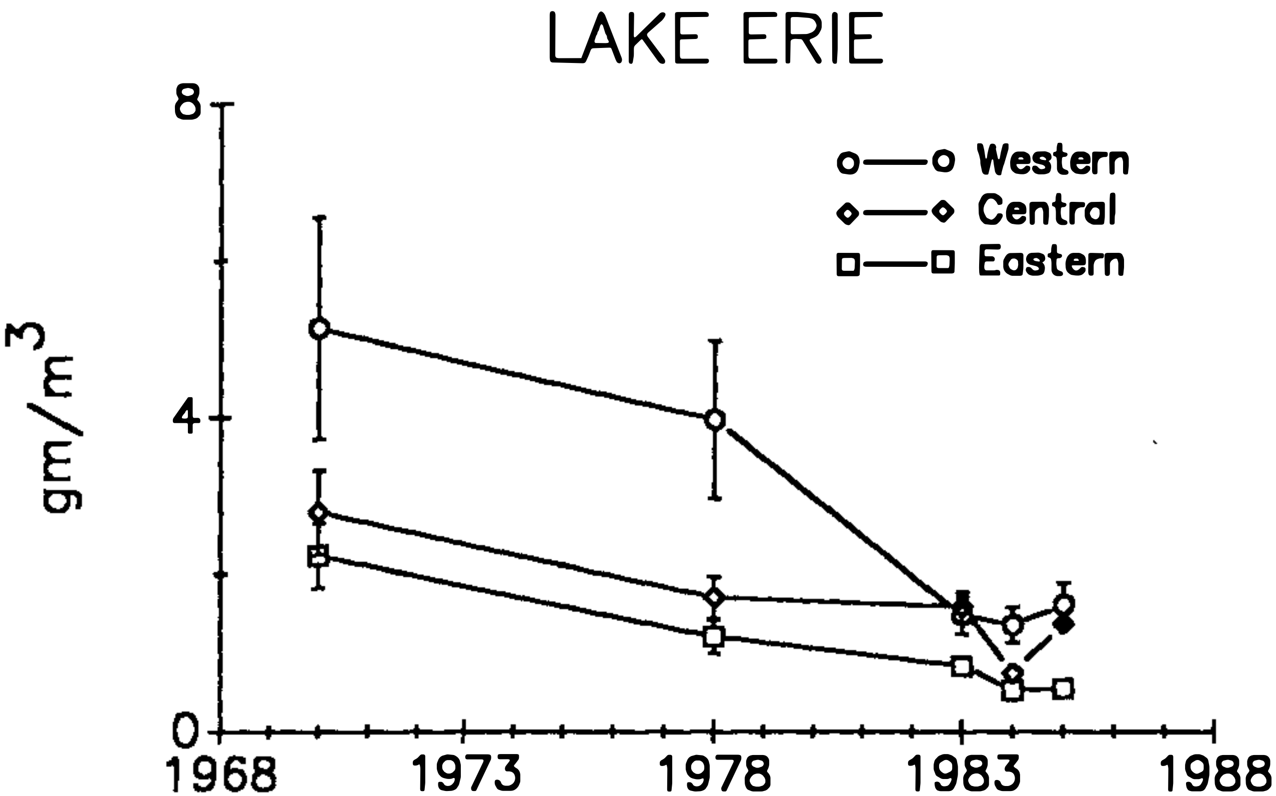


Figure 58. Phytoplankton biomass versus time for the Western, Central and Eastern Basins of Lake Erie. Data are from Munawar and Munawar (1976, graphical accuracy) and Devault and Rockwell (1986).

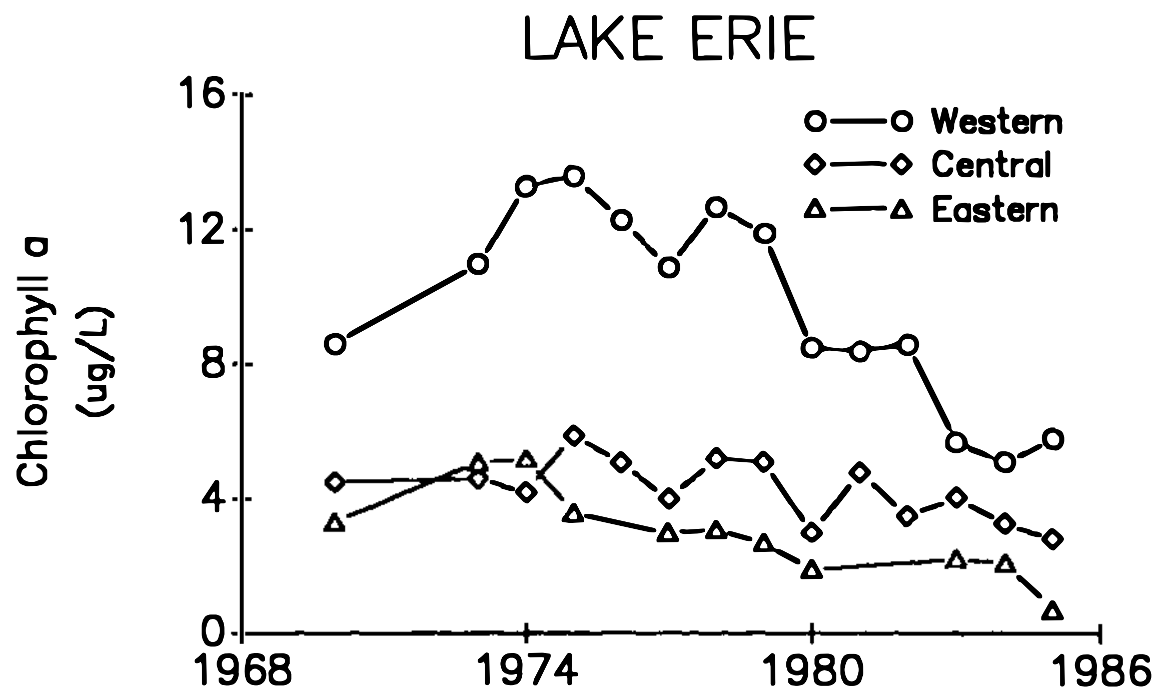


Figure 59. Time trend in annual cruise mean concentration of corrected chlorophyll *a* since 1970. Data from Rathke (1984) and Rockwell (1989).

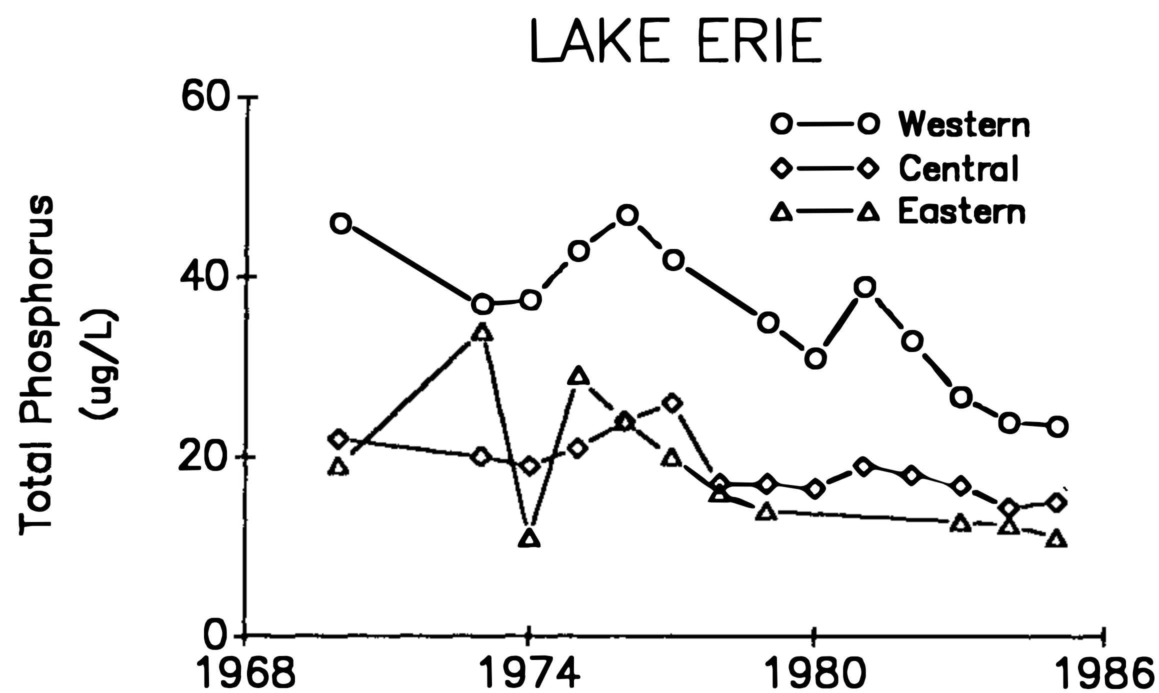


Figure 60. Time trend in annual cruise average of total phosphorus since 1970, Lake Erie. Data are from Depinto *et al* (1986) and Rockwell (1989).

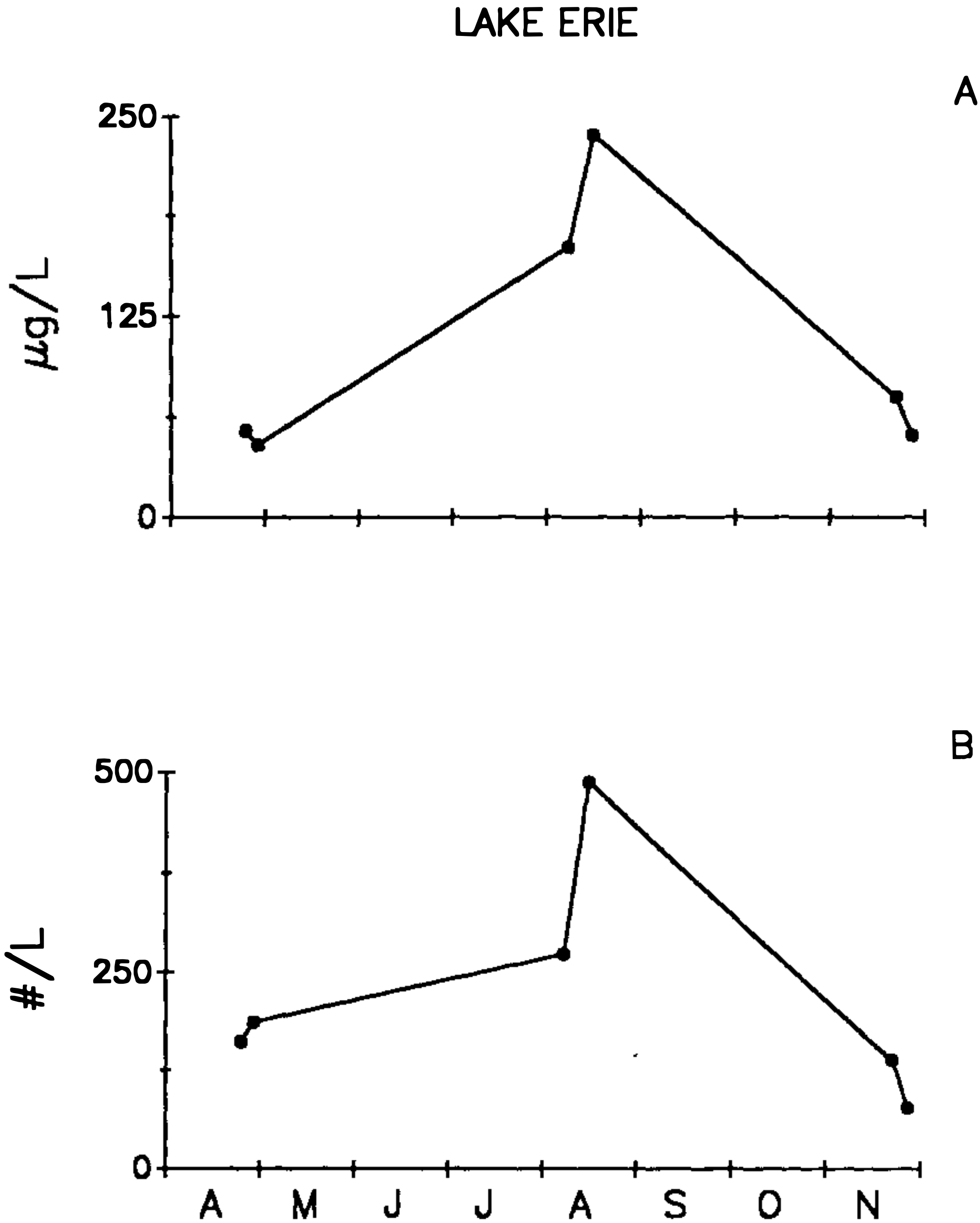


Figure 61. Seasonal zooplankton biomass (a) and abundance (b) in Lake Erie, 1985. Plotted are the means of all stations for a cruise date.

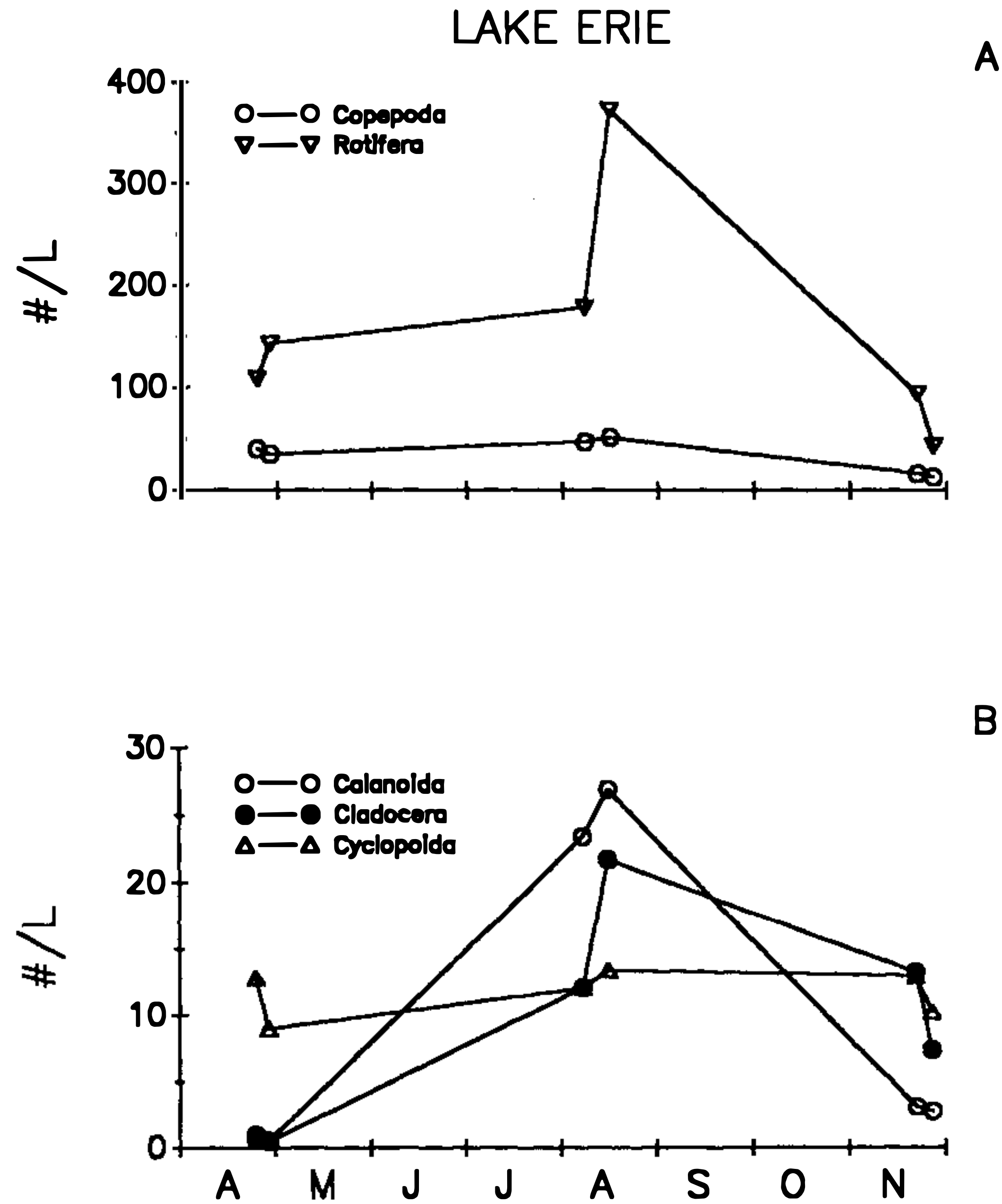
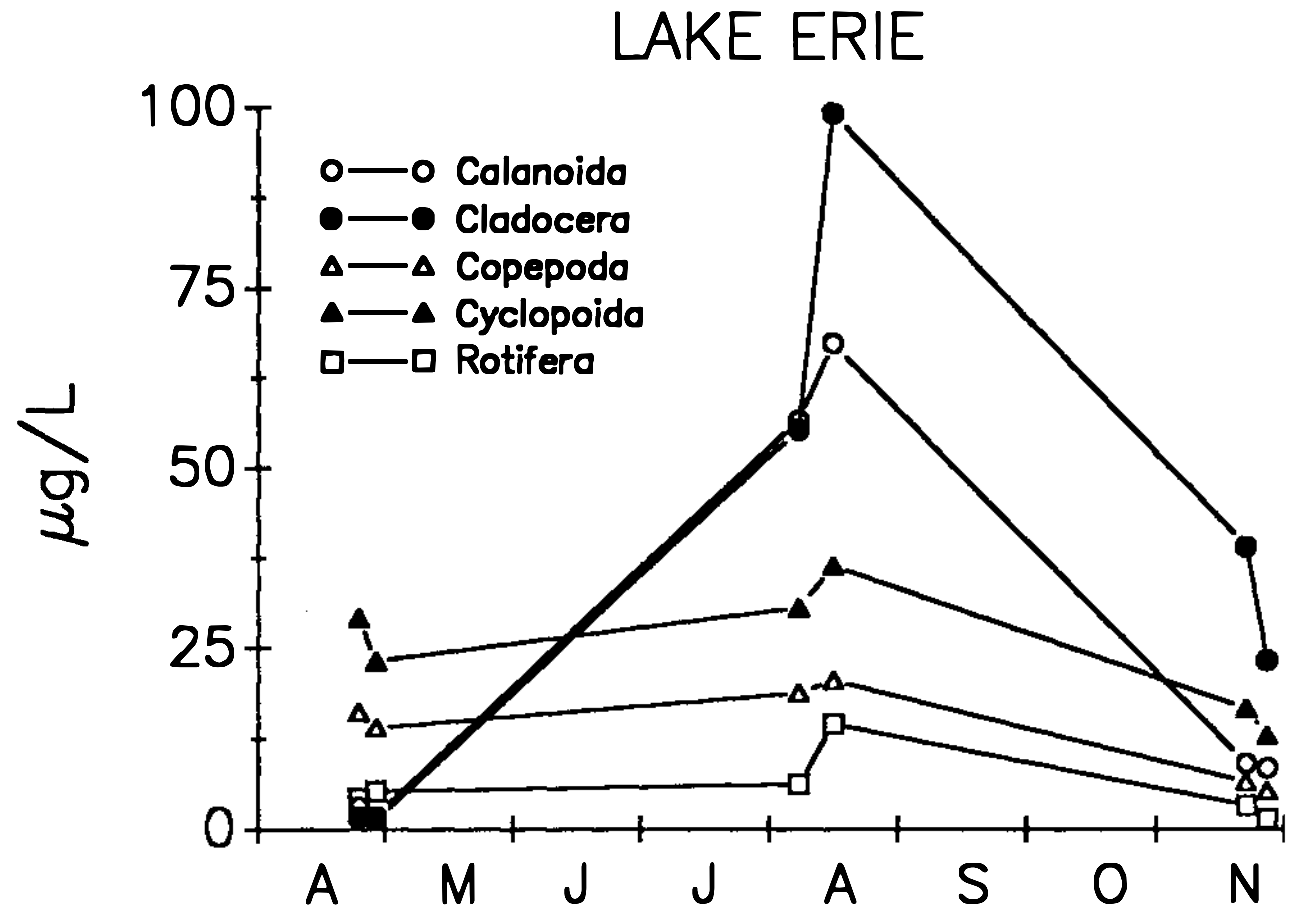


Figure 62. Seasonal abundance distribution of zooplankton groups in Lake Erie, 1985. Copepoda refers to the nauplius stage of the Copepoda.



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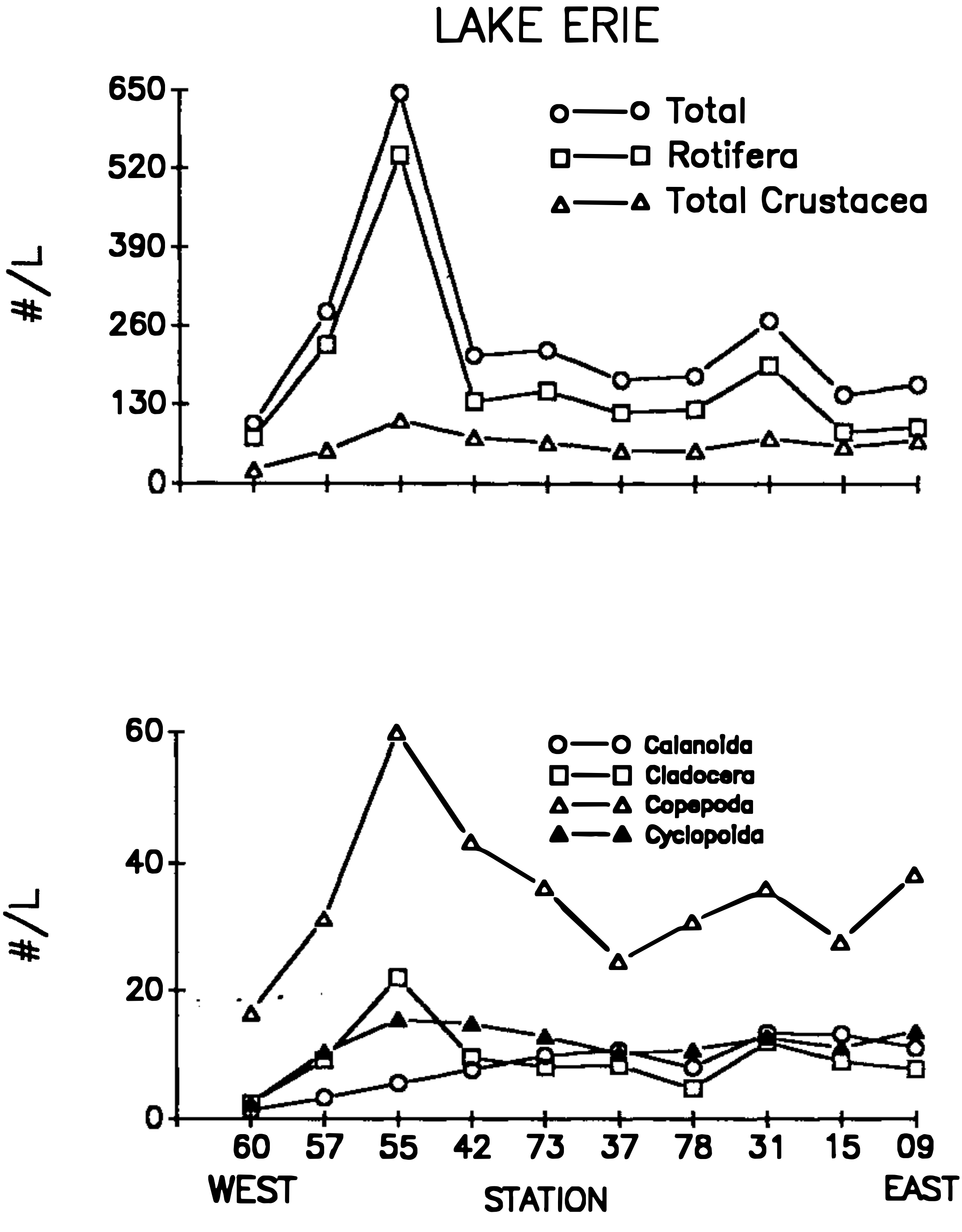


Figure 64. Geographical distribution (abundance) of zooplankton groups in Lake Erie, 1985. Copepoda refers to the nauplius stage of the Copepoda.

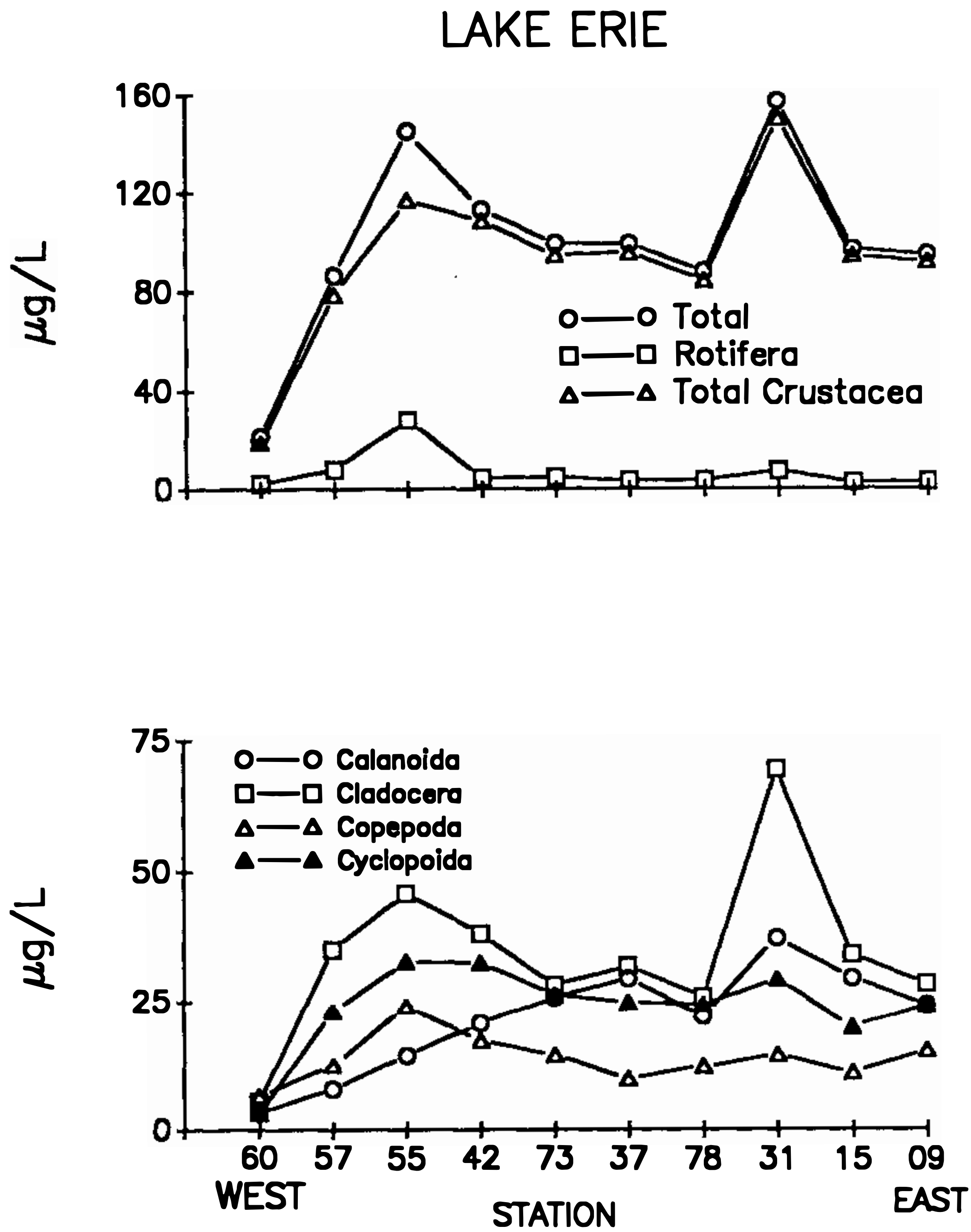


Figure 65. Geographical distribution (biomass) of zooplankton groups in Lake Erie, 1985. Copepoda refers to the nauplius stage of the Copepoda.

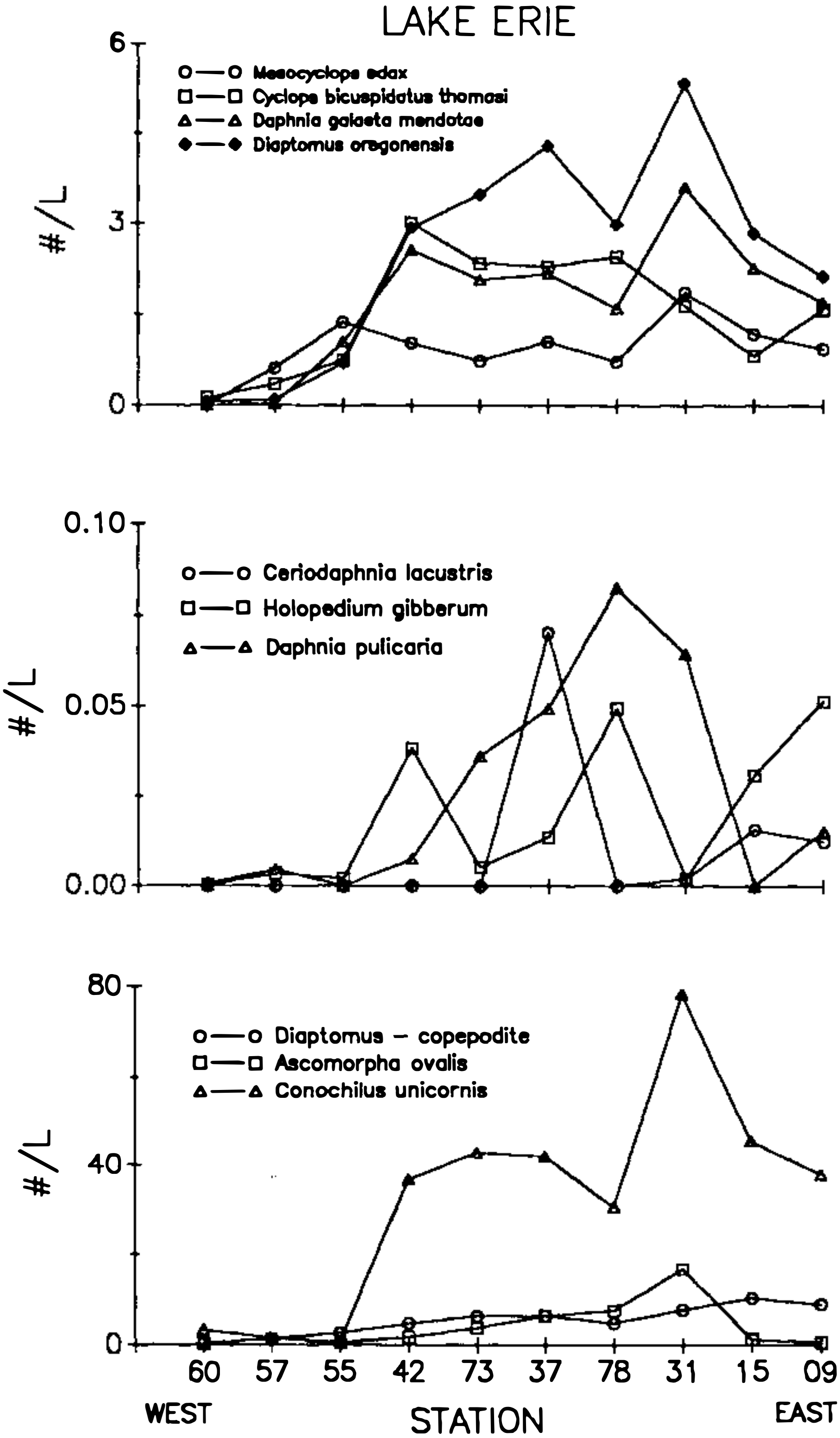
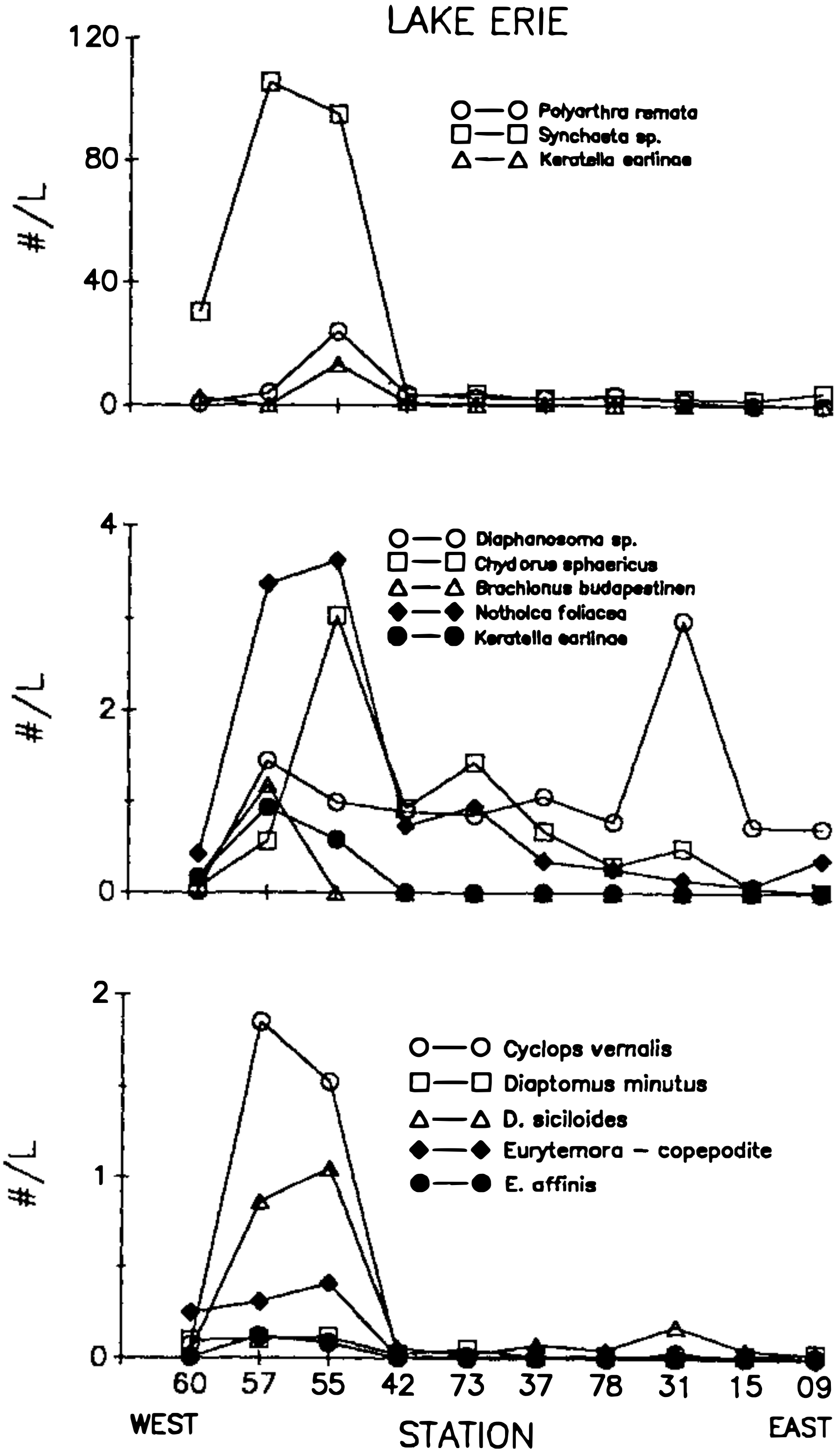


Figure 66. Geographical distribution of selected zooplankton species in Lake Erie, 1985. Station 42 is the mean of Stations 42 and 43. Station 37 is the mean of Stations 36, 37 and 38. Station 31 is the mean of Stations 30, 31 and 32. Station 15 is the mean of Stations 15 and 63. Station 09 is the mean of Stations 09 and 10.



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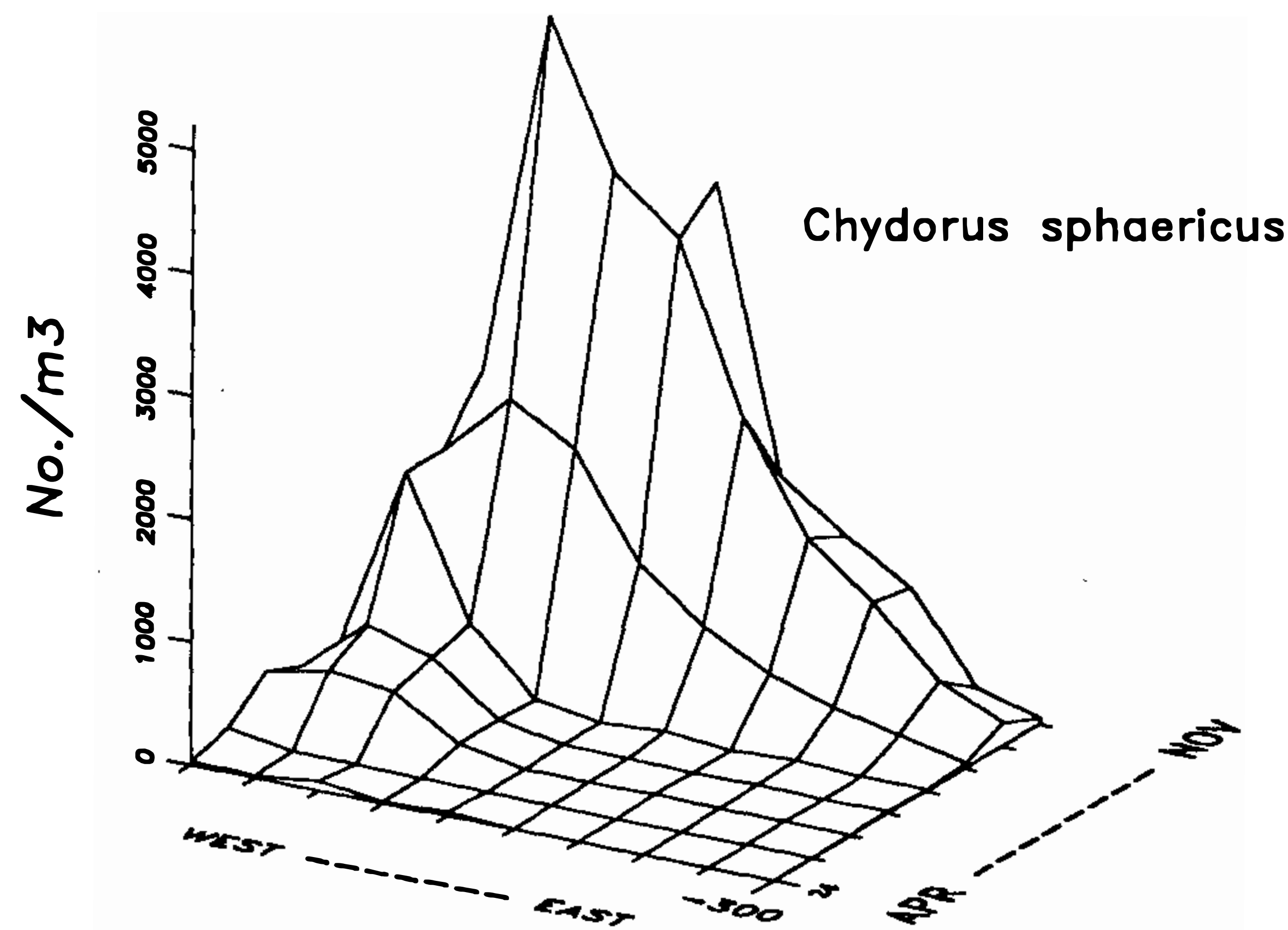

Figure 68. Geographical and seasonal distribibition of *Chydorus sphaericus*, 1985.

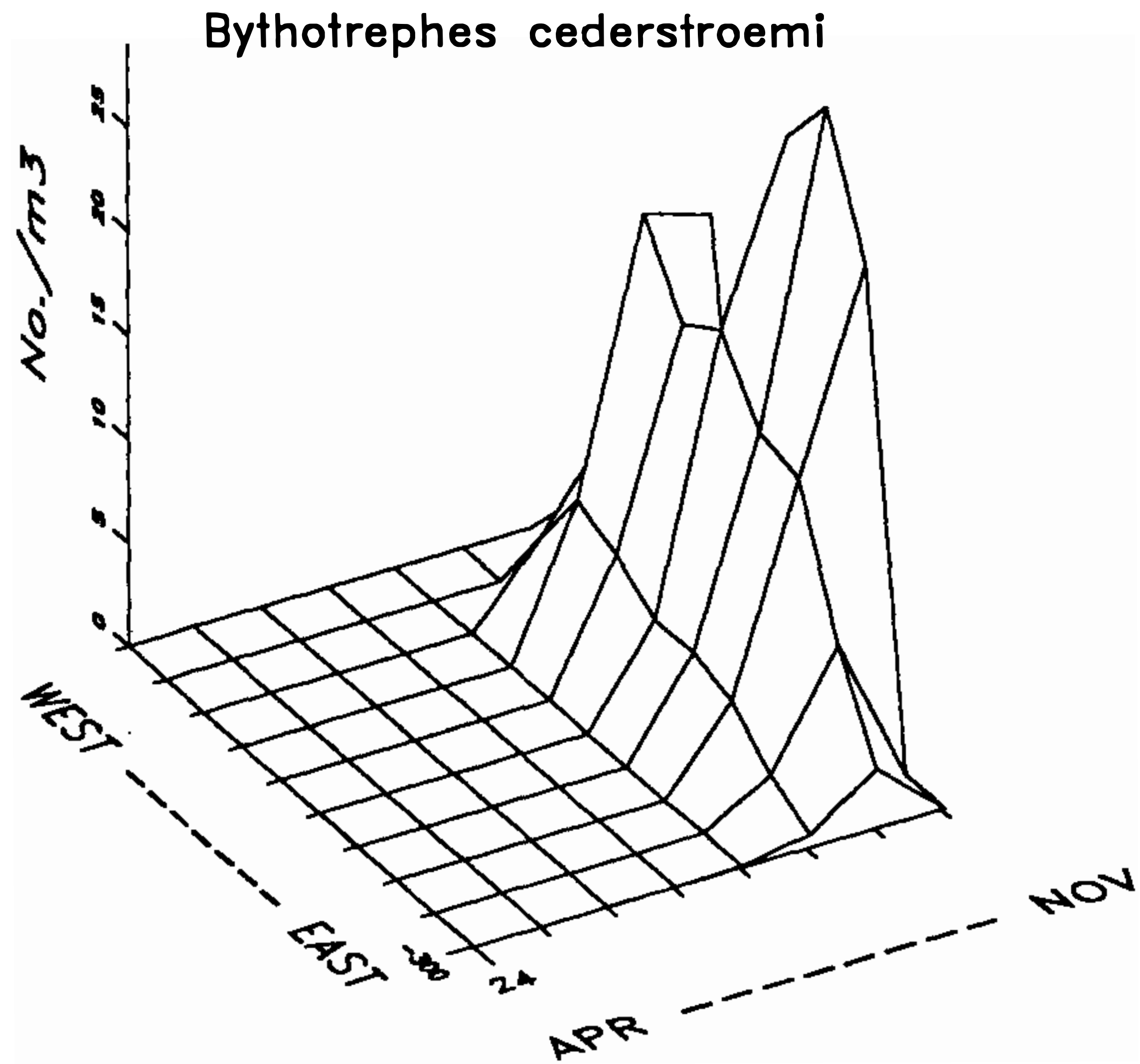

Figure 69. Geographical and seasonal distribition of *Bythotrephes cederstroemi*, 1985.

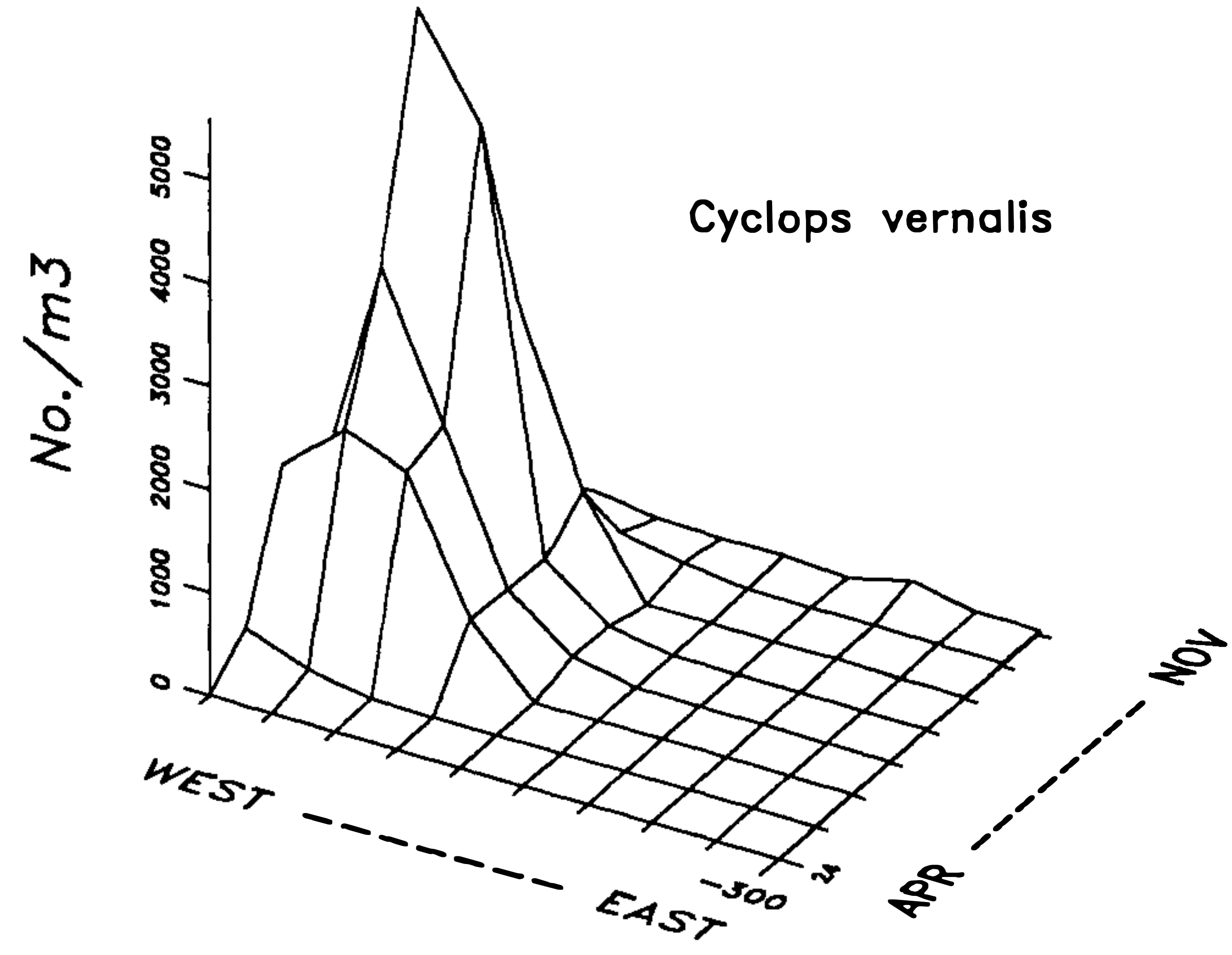

Figure 70. Geographical and seasonal distribition of *Cyclops vernalis*, 1985.

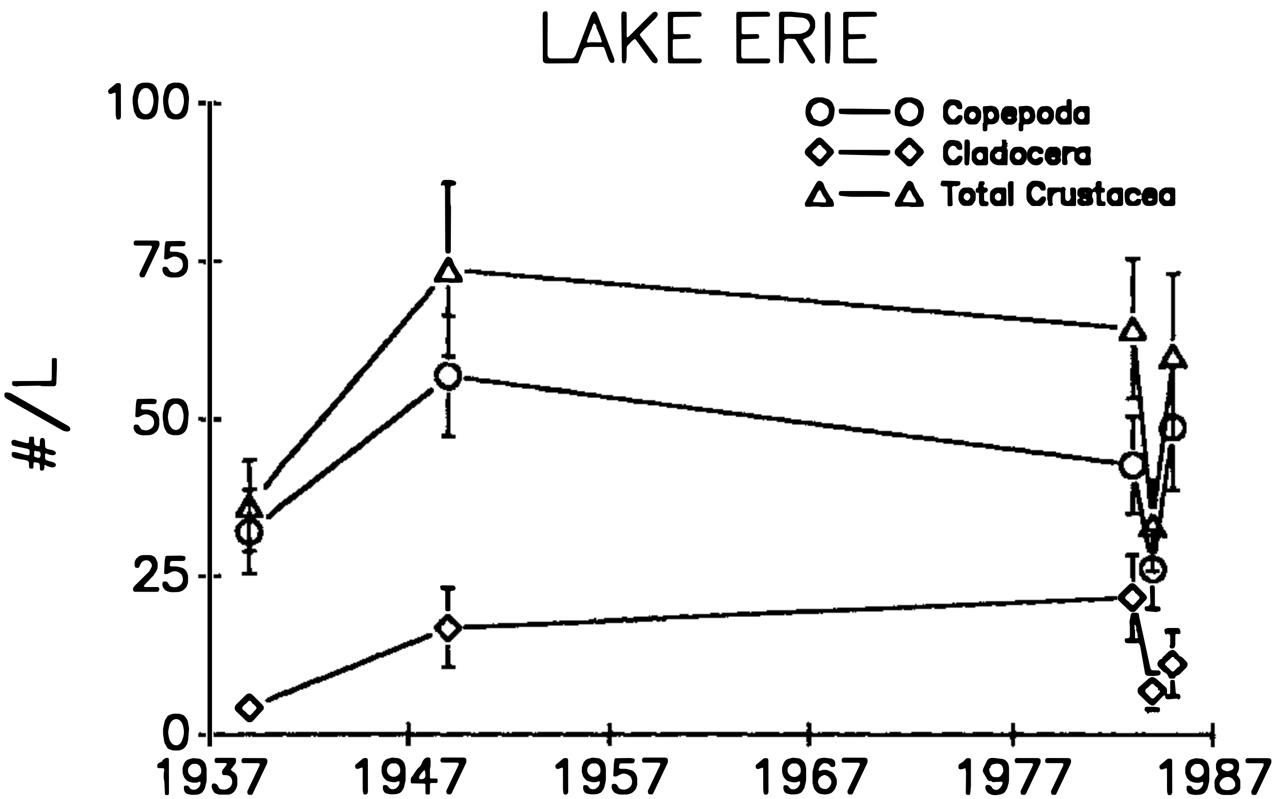

Figure 71. Crustacean zooplankton abundance since 1939 in the Western Basin of Lake Erie. Values are the mean ± Standard Error. 1939 data are from Chandler (1940; April-October). 1949 data are from Bradshaw (1964; April-October). 1983 (April-November) and 1984 (April-December) data are from Makarewicz (1987, 1988). 1985 (April-November) are from this study.

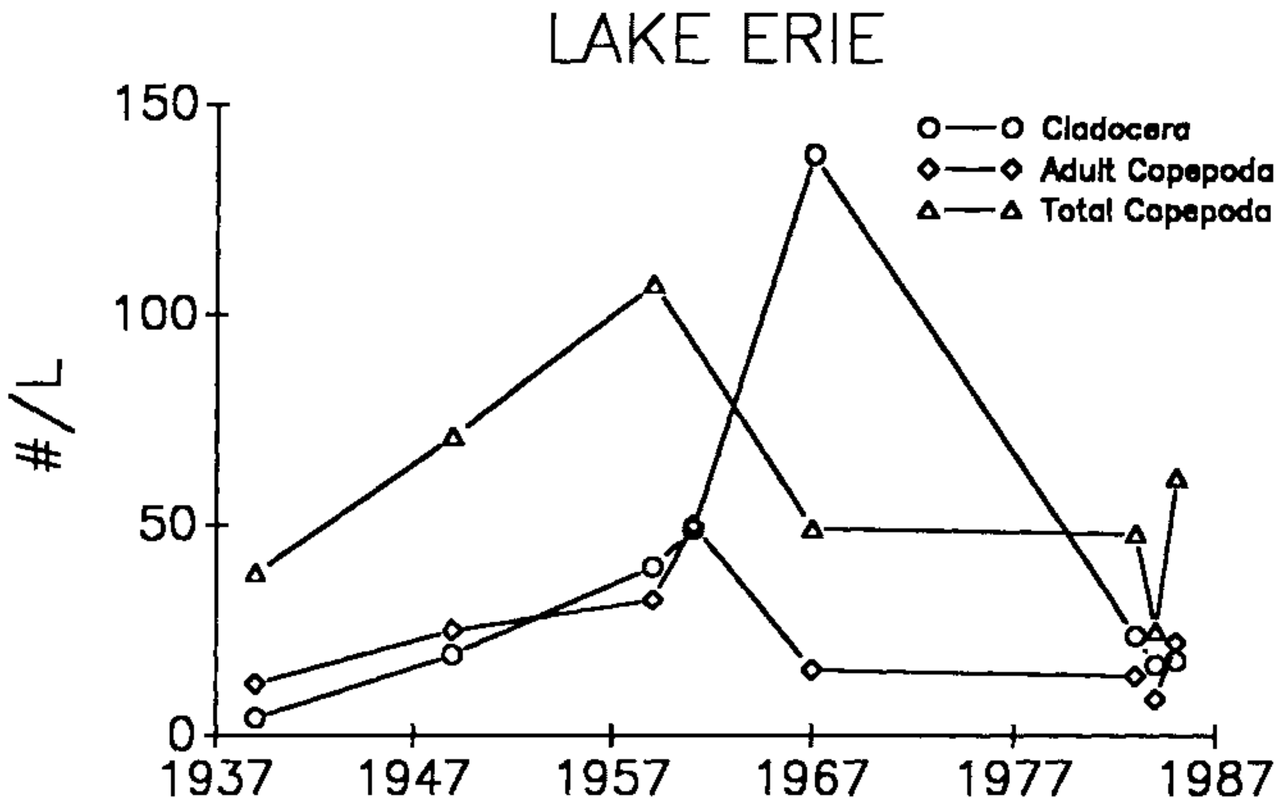

Figure 72. July and August abundance of Cladocera and Copepoda in the Western Basin of Lake Erie since 1939. Total Copepoda refers to adults plus the nauplius stage. Data are from Chandler (1940), Bradshaw (1964), Hubschman (1960), Britt *et al* (1973), Davis 1969a, Makarewicz (1987, 1988) and this study. The number of adults and total copepods in 1939 and 1959 follow Bradshaw's (1964) calculations.

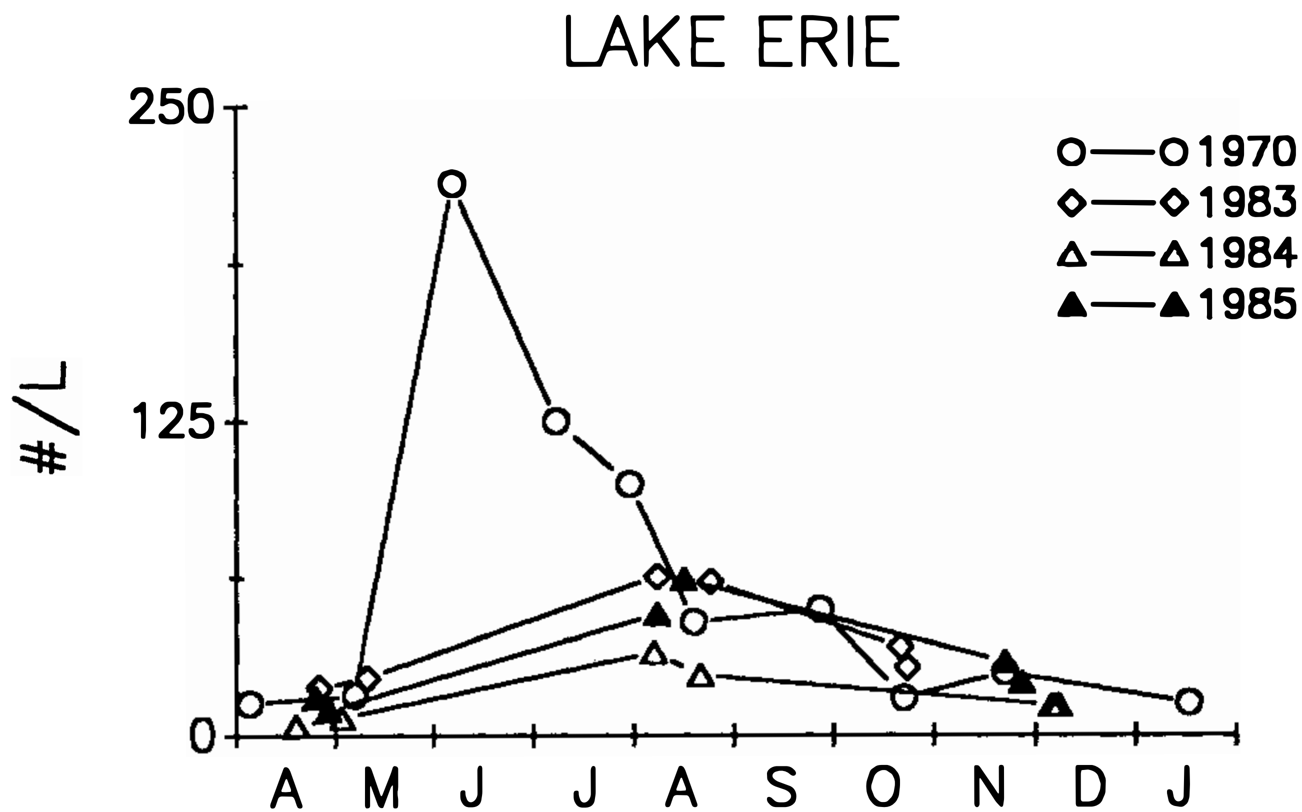

Figure 73. Seasonal flucuation of weighted mean Crustacea (nauplii excluded) abundance in 1970, 1983, 1984 and 1985, Lake Erie. 1970 data follow Watson and Carpenter (1974). 1983 and 1984 data are from Makarewicz (1987, 1988).

1983-1985 values are corrected using the weighting factors of 15.6%, 59.6% and24.6% for the Western Central and Eastern Basins (after Munawar and Munawar 1976).

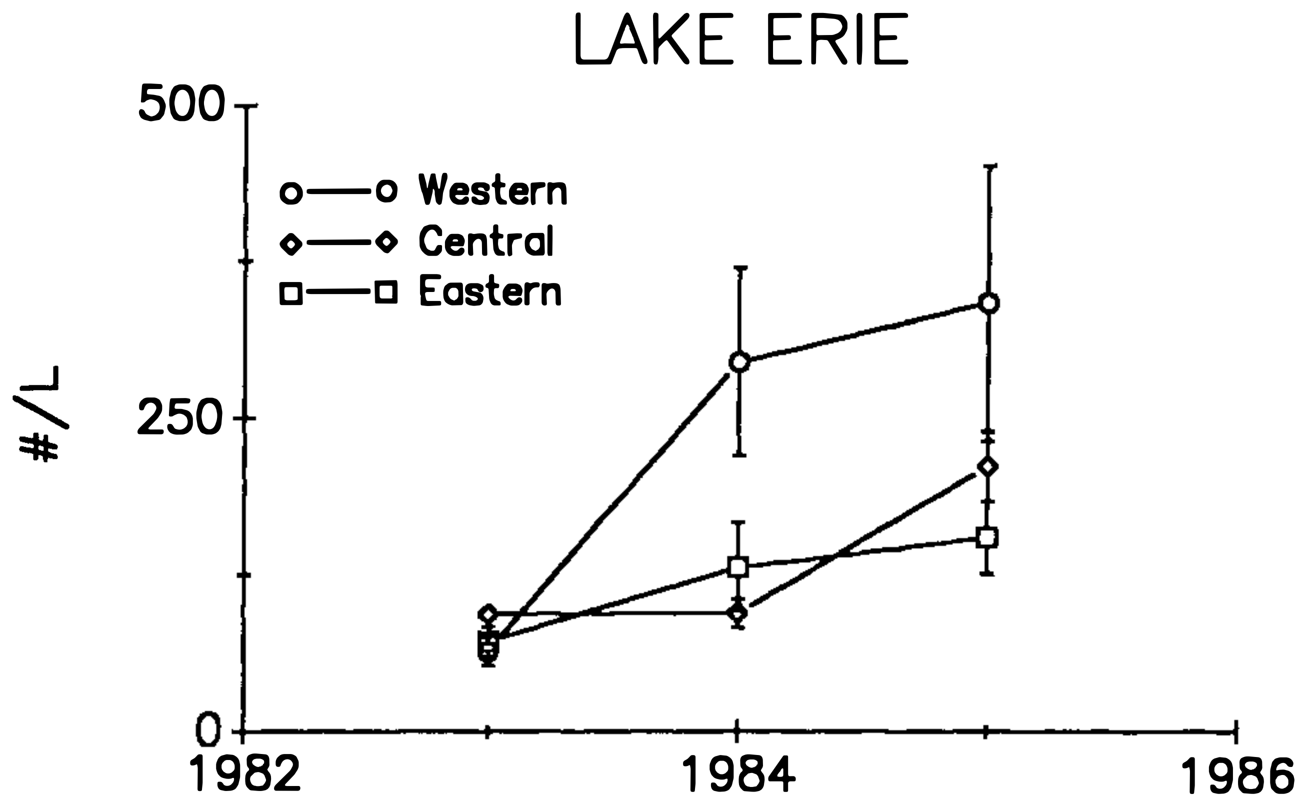

Figure 74. Zooplankton biomass versus time for the Western, Central and Eastern Basins of Lake Erie.

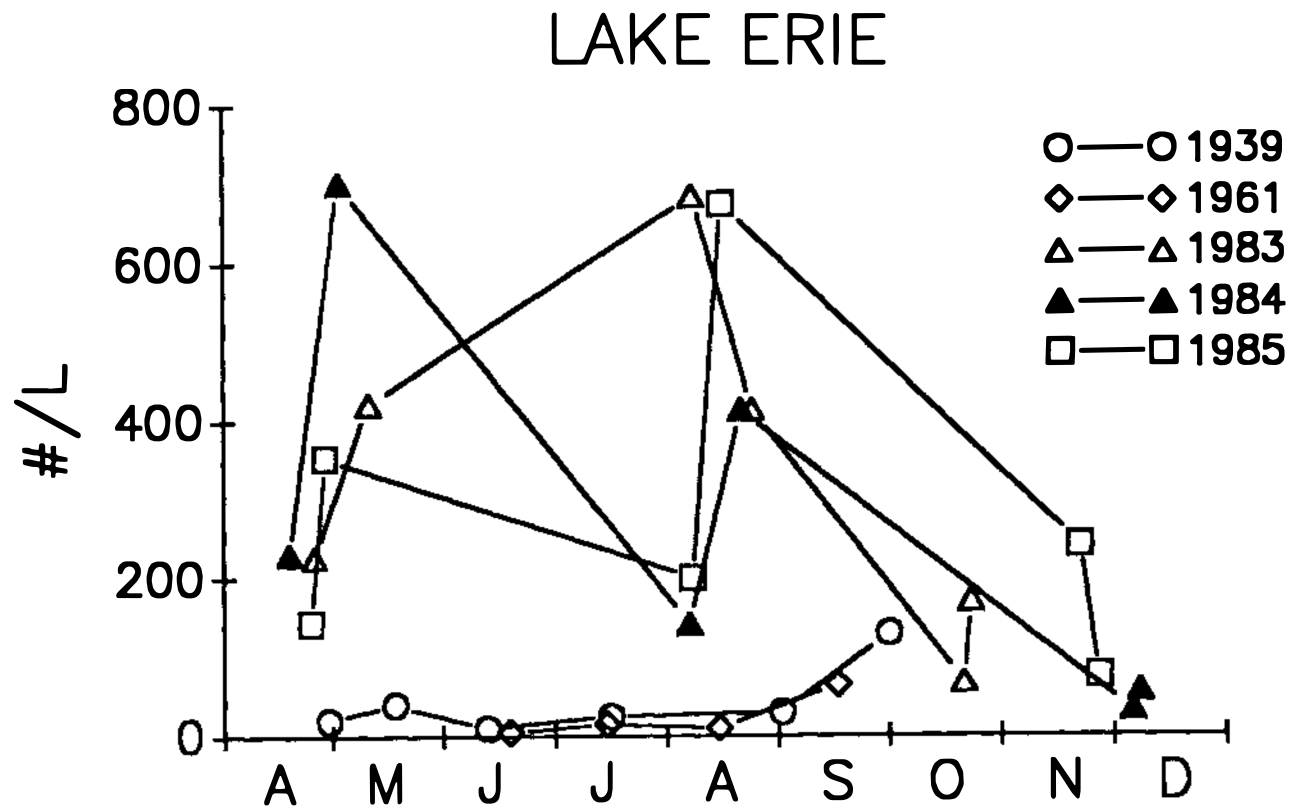

Figure 75. Seasonal fluctuation of Rotifera in the Western Basin of Lake Erie from 1939 - 1985. Sources: 1939 - Chandler (1940); 1961 - Britt *et al* (1973); 1983 and 1984 - Makarewicz (1987, 1988). The 1970 samples of Nalepa (1972) are not included because they are from the far western end of the basin and may not be representive of the entire basin.

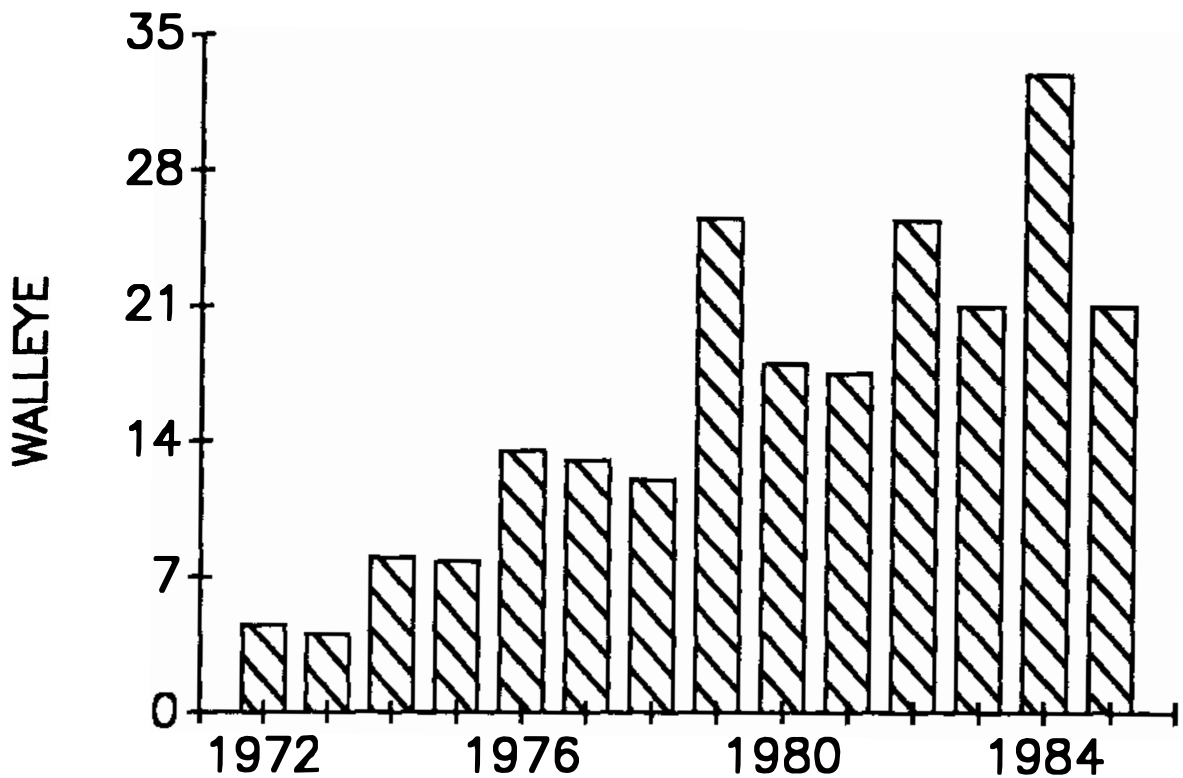

Figure 76. Projected abundance (millions of fish) of fishable walleye (age 2+) in western Lake Erie (Ohio waters). Data are from the Ohio Department of Natural Resources (1989).

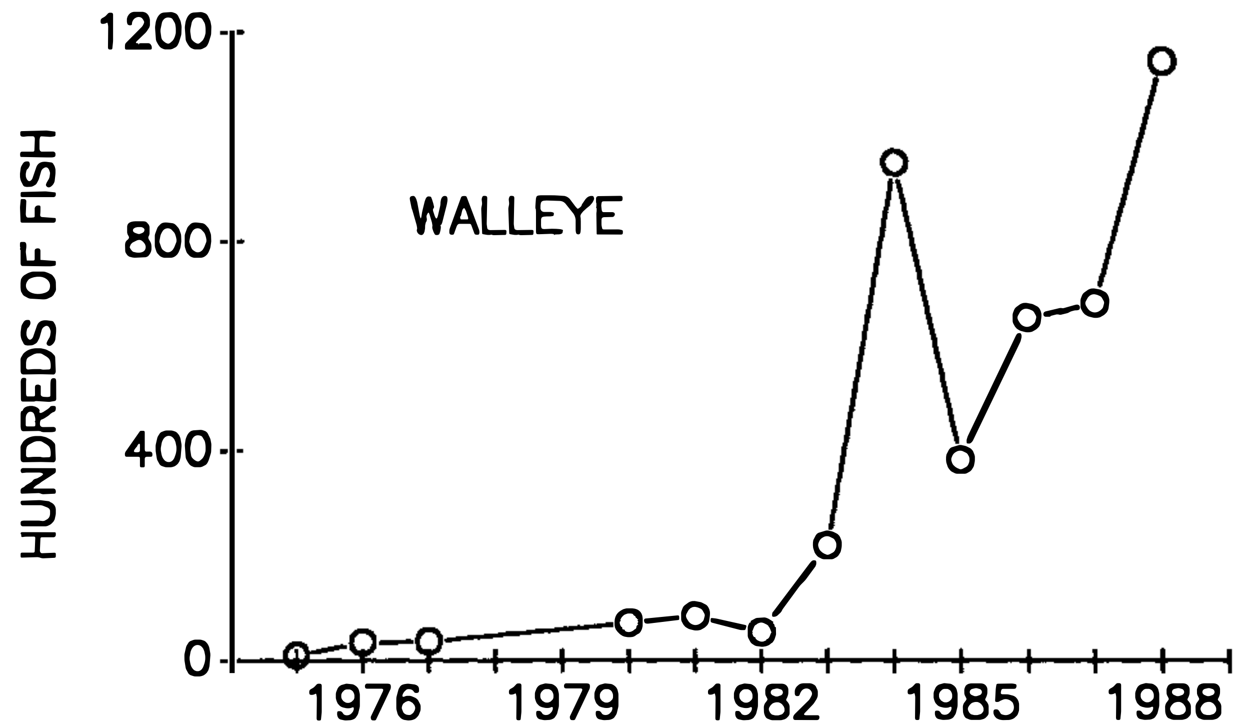

Figure 77. Sport angler harvest of walleye from the Central Basin (District II and III of the Ohio Department of Natural Resources) of Lake Erie. Data from the Ohio Department of Natural Resources (1989).

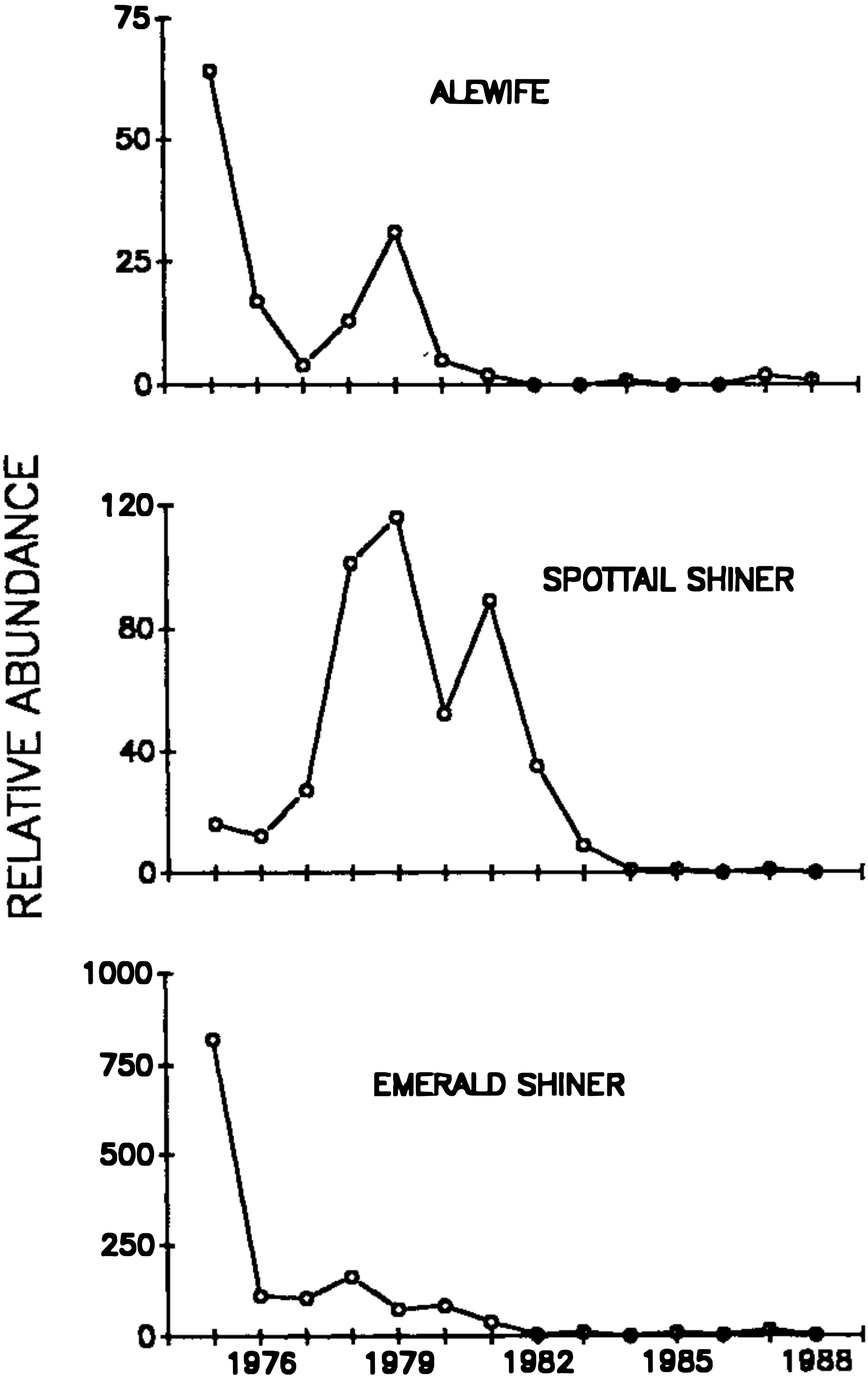

Figure 78. Time trend of autumn emerald and spottail shiner (age 1 and older) abundance in the Central Basin and alewife (young-of-the year) from the Western Basin of Lake Erie. Data from the Ohio Department of Natural Resources (1989). Data in 1986 and 1988 are from a limited number of stations due to inclimate weather. Values represent the geometric mean of catch per trawling hour. Abundance index values are different from Makarewicz (1988) due to revisions in calculations by the Ohio Departmentof Natural Resources.

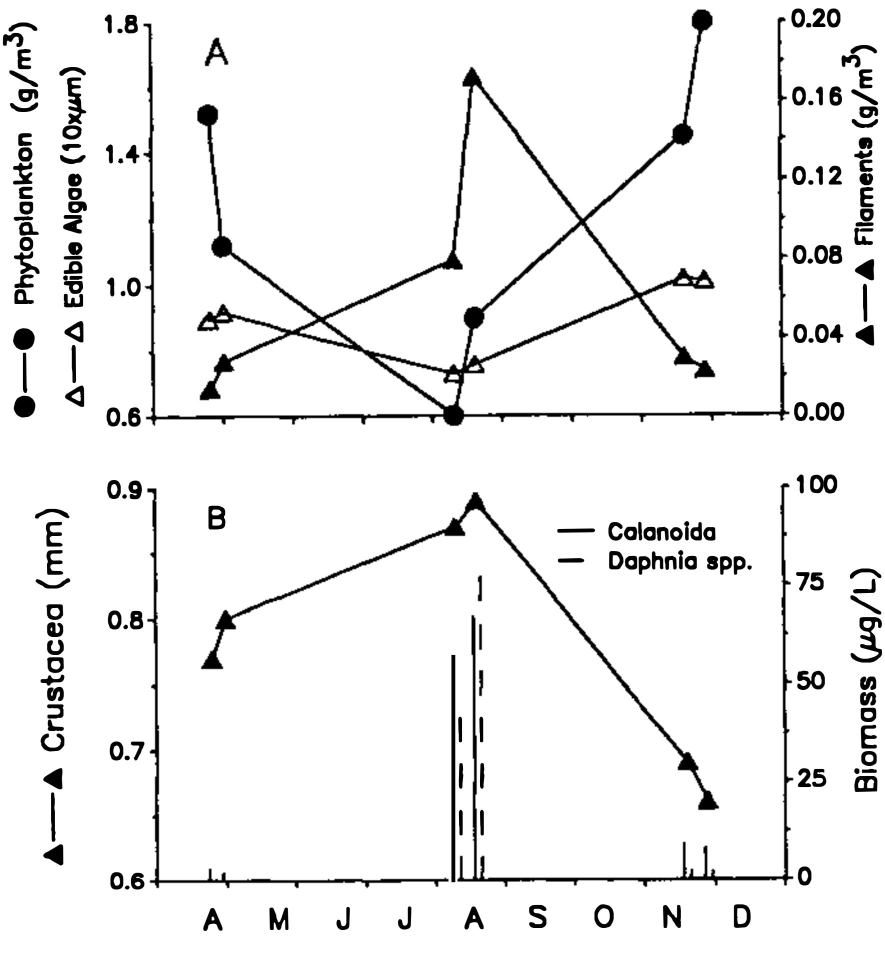

Figure 79. (A)Seasonal total algal and filamentous algal biomass and mean weighted edible algal size in 1985; (B) the seasonal mean crustacean size and *Daphnia* spp. and adult Calanoida abundance, 1985.

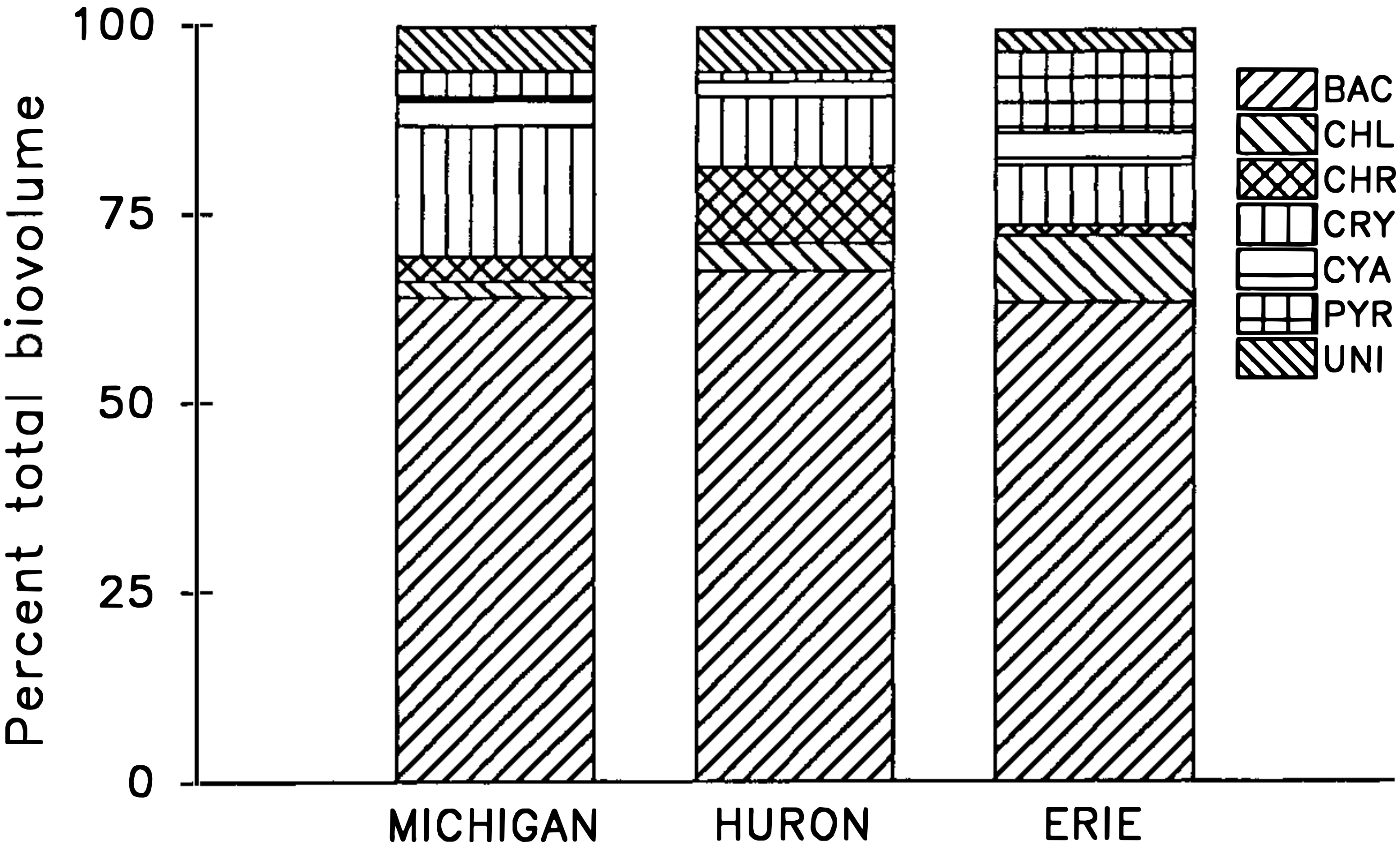

Figure 80. Comparison of the phytoplankton composition of Lakes Michigan, Huron and Erie, 1985. Bac - Bacillariophyta, Chl - Chlorophyta, Chr - Chrysophyta, Cry - Cryptophyta, Cya - Cyanophyta, Pyr - Pyrrophyta, Uni - Unidentified.

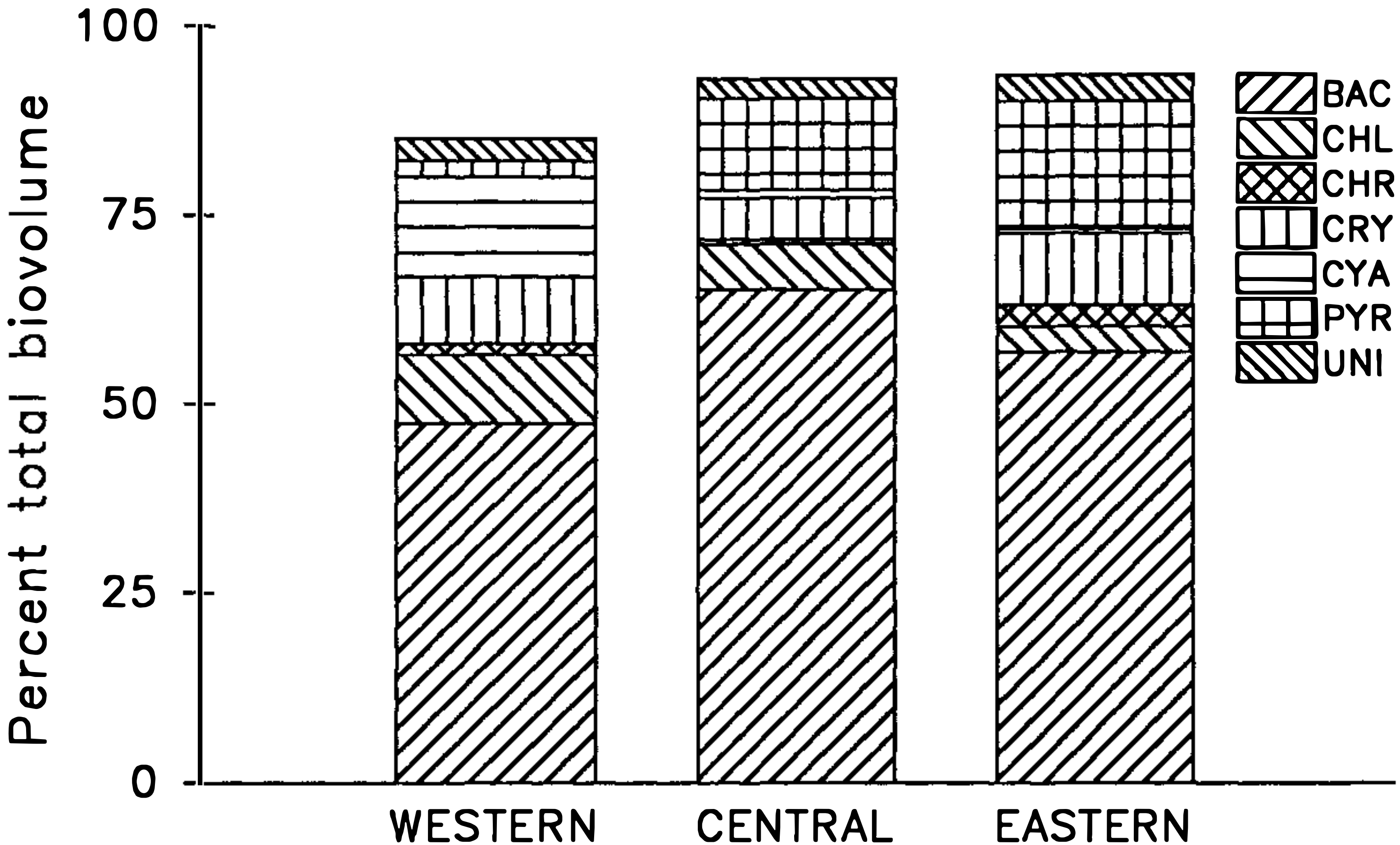

Figure 81. Comparison of the phytoplankton composition of the basins of Lake Erie, 1985. Bac = Bacillariophyta, Chl = Chlorophyta, Chr = Chrysophyta, Cry = Cryptophyta, Cya = Cyanophyta, Pyr = Pyrrophyta, Uni = Unidentified.

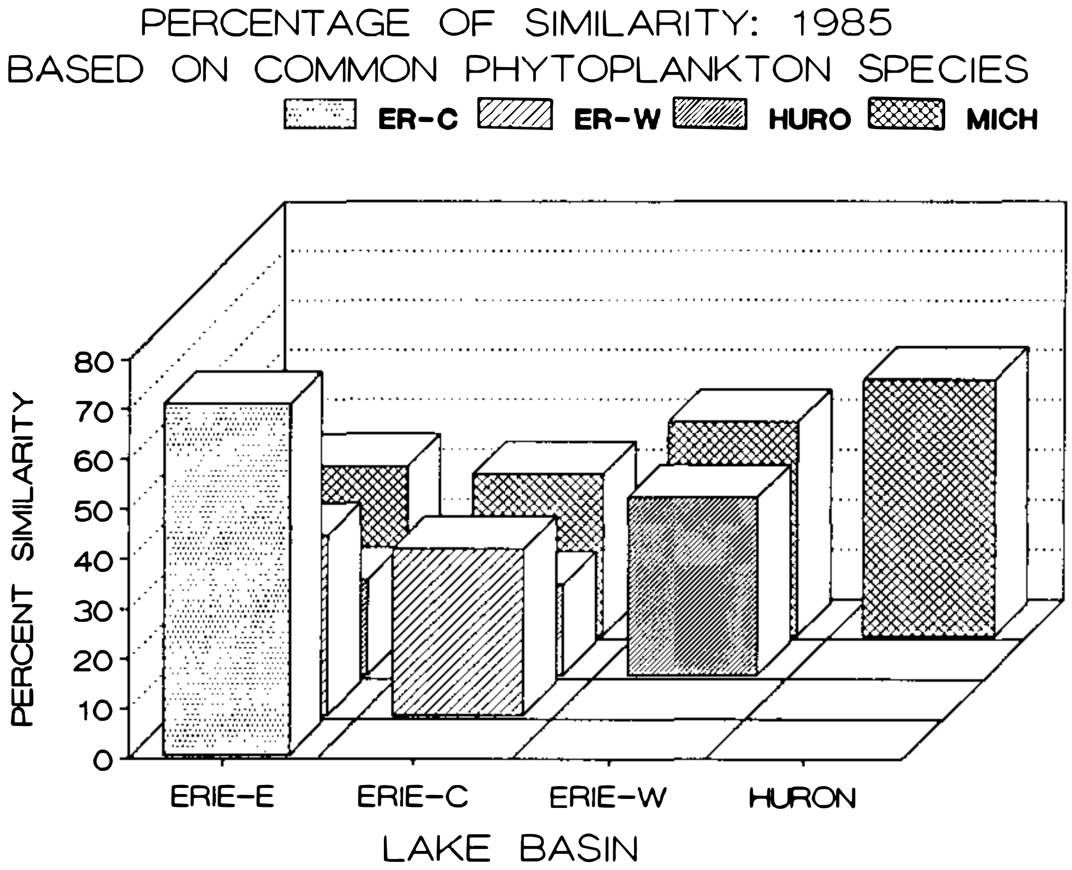

Figure 82. Percent similarity of common phytoplankton species, 1985.

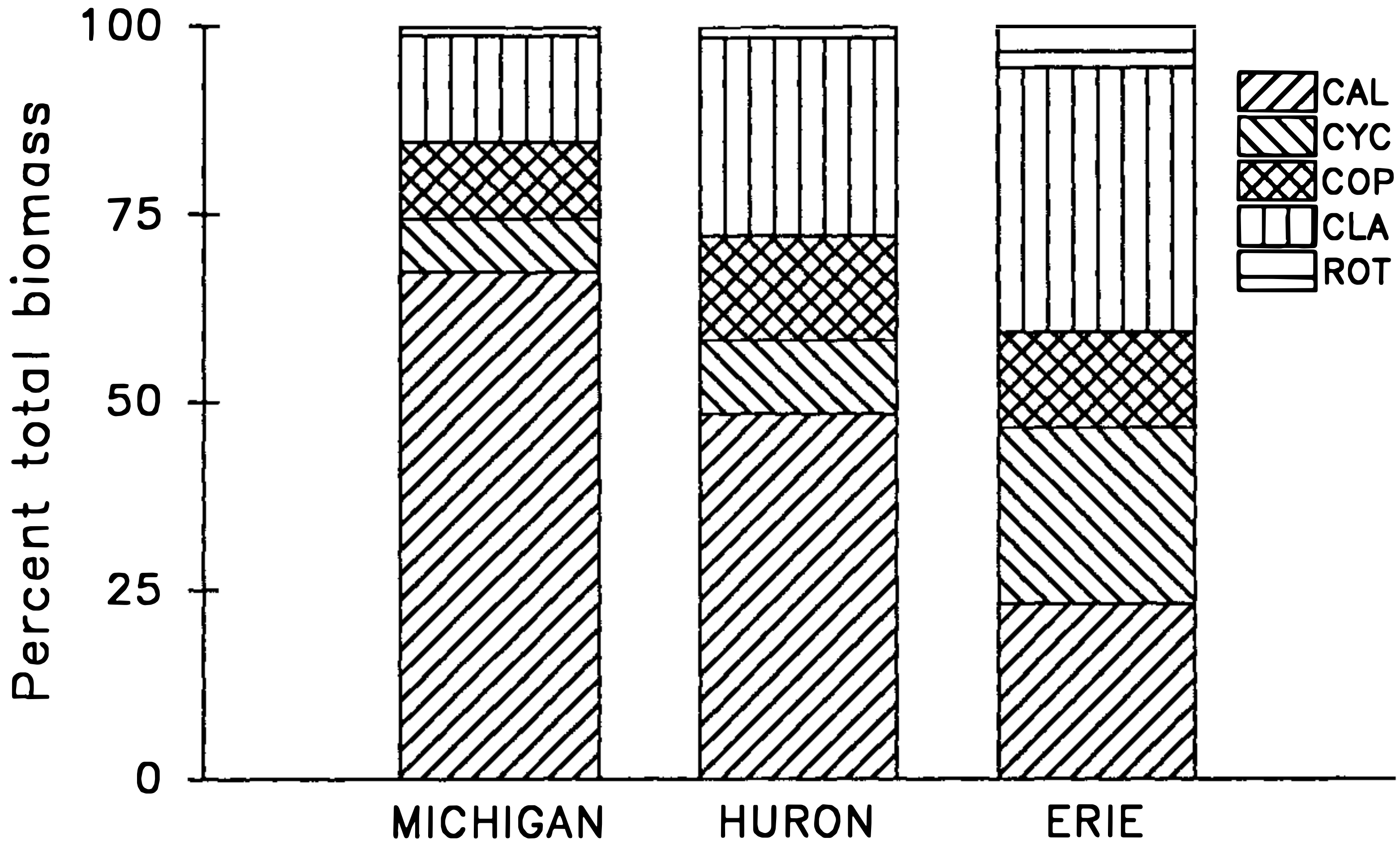

Figure 83. Comparison of the zooplankton composition of Lakes Michigan, Huron and Erie, 1985.

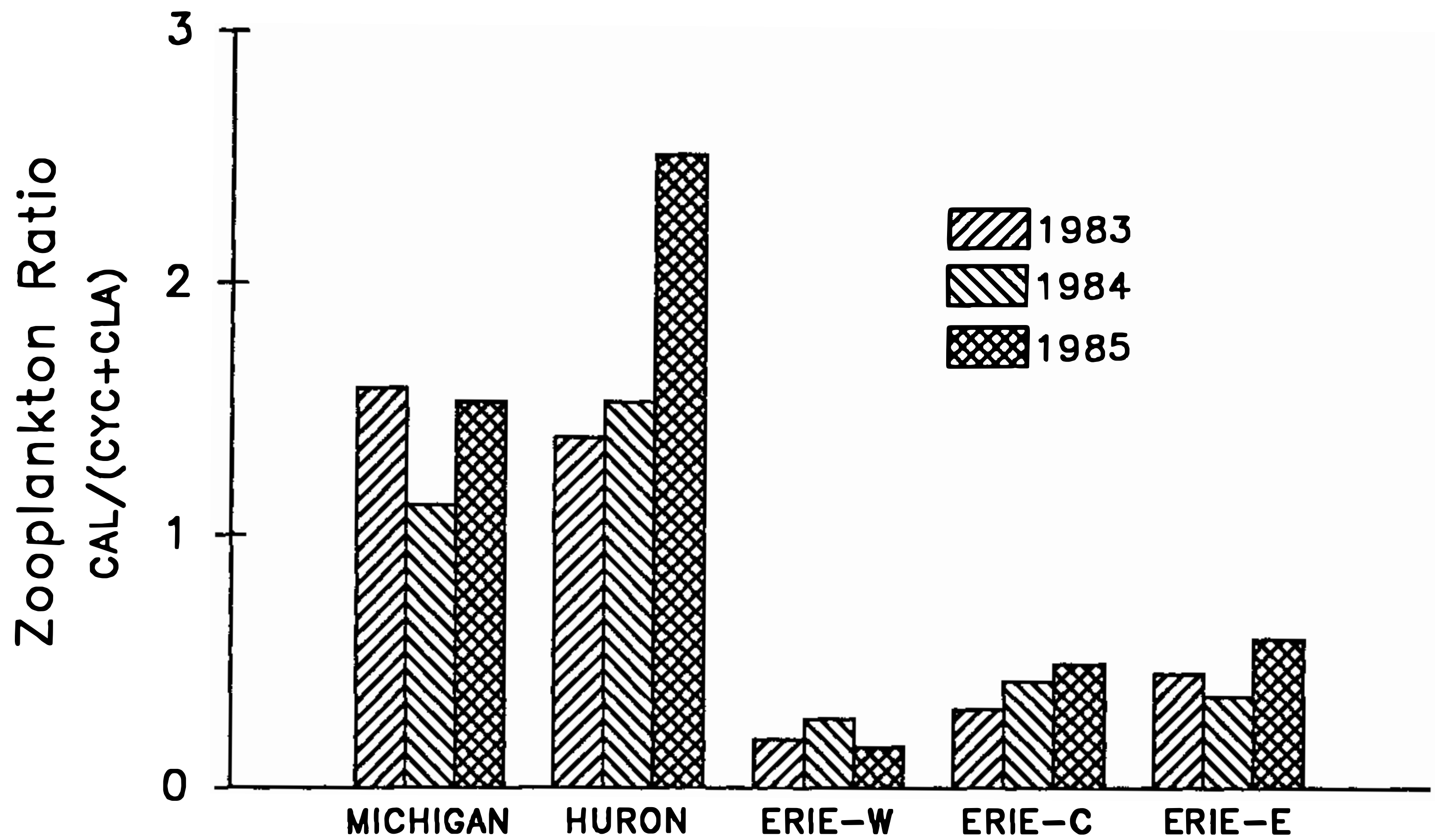

Figure 84. Comparison of annual zooplankton ratios in Lakes Michigan, Huron and Erie.

TECHNICAL REPORT DATA

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16. ABSTRACT

During the spring, summer and autumn of 1985, the structure of the phytoplankton and zooplankton communities in the offshore waters of Lake Michigan, Lake Huron and Lake Erie was monitored. In Lake Michigan, the presence of an oligotrophic rotifer association and the oligotrophic crustacean indicator species *Diaptomus sicilis* and *Limnocalanus macrurus*, the predominance of mesotrophic diatom species, and the abundance and biomass of plankton between that of Lake Huron and Lake Erie suggest that the offshore waters are currently in the oligotrophic-mesotrophic range. In Lake Huron, the presence of an oligotrophic rotifer assemblage, the domination of the calanoid copepods, the abundance of the oligotrophic *Diaptomus sicilis*, and relatively low zooplankton abundance suggest that the offshore waters continue to be oligotrophic. In Lake Erie, phytoplankton and zooplankton species composition and biomass suggest a more productive status than Lake Michigan and Lake Huron. Data support the classification of the Western Basin as meso-eutrophic, the Central Basin as mesotrophic and the Eastern Basin as oligo-mesotrophic. Significant changes in the composition of the zooplankton community with the appearance of the large cladoceran *Daphnia pulicaria* in Lake Erie are attributed to a change in planktivory. The planktivorous emerald and spottail shiners have dramatically declined in abundance, possibly due to a resurgence of the walleye and the salmonine stocking programs.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Great Lakes, Lake Michigan, Lake Huron, Lake Erie, Limnology, Eutrophication, Community Structure, Plankton, Phytoplankton, Zooplankton, Species		
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