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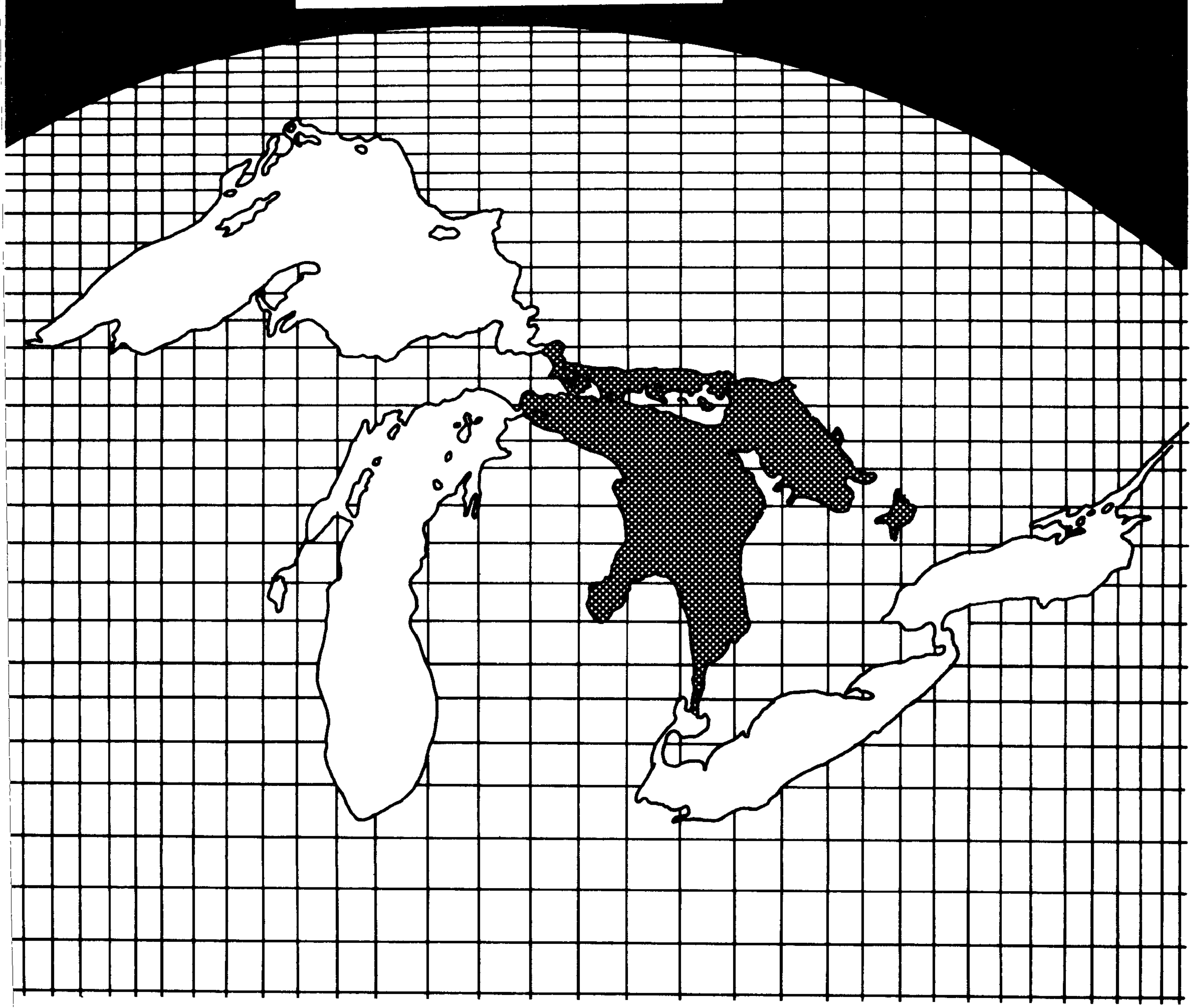
Phytoplankton Composition Abundance And Distribution In Lake Huron



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PHYTOPLANKTON - COMPOSITION, ABUNDANCE AND DISTRIBUTION IN LAKE HURON

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ABSTRACT

The phytoplankton of Lake Huron were studied to assess the water quality of this Great Lake. The phytoplankton species were counted in integrated and discretely collected water samples from all of Lake Huron except Saginaw Bay. Cell abundances and biovolumes of the algae were studied seasonally and spatially in the Lake.

Patterns of phytoplankton indicated that Lake Huron waters were generally oligotrophic. Diatoms with broad ecological ranges, Tabellaria flocculosa and Fragilaria crotonensis, dominated the phytoplankton year-round. Abundance and biovolume were not great during the spring bloom. Algal biovolumes were low during the summer. Small, coccoid blue-green algae were common, but heterocystis, nitrogen-fixing blue-greens were never abundant. Only a slight increase in phytoplankton abundance occurred during the fall.

Regional variation in water quality was indicated by the highest standing crops of phytoplankton commonly occurring in the nearshore regions of the southern basin and the lowest in the Georgian Bay. Slight enrichment along the western shore of Lake Huron and near Cheboygan was indicated by high and persistent standing crops of phytoplankton during spring.

Little evidence was observed that the water quality of Lake Huron had changed during the last decade. There were some signs that continued loading of nutrients to the southern basin was causing some degradation of those waters. But, low standing crops of algae near Saginaw Bay indicated that nutrient loading through Saginaw Bay had been reduced.

ACKNOWLEDGEMENTS

Completion of this study of Lake Huron would not have been possible without the assistance of many scientists. The staffs of Mar, Inc., Bionetics, and Great Lakes Research Division, who counted the algae, deserve recognition for their efforts in generating this data. I would also like to thank Joe Makarewicz for assembling the raw data into computer files. I would particularly like to thank Russ Moll and Russ Kreis for making available copies of drafts of their reports of Lake Huron water quality. Dr. Kreis was especially helpful in gathering background information about Lake Huron. A special note of appreciation is given to Dr. E. F. Stoermer, who encouraged me to do this project. Dr. Stoermer made materials in his library available to me and also helped me develop a perspective of conditions in the Lake.

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INTRODUCTION

Lake Huron is the main body of water connecting Lakes Superior and Michigan to Lake Erie in the chain of Laurentian Great Lakes. It is a valuable natural resource for the citizens of the United States and Canada. The waters of Lake Huron provide a source of water for most commercial and private activities for the millions of people that live along the eastern border of Michigan and the southwestern border of Ontario. Lake Huron is a shipping waterway, assimilates wastes from agricultural, municipal and industrial sources, and is a source of recreation for millions of Americans each year.

The water quality of Lake Huron varies from region to region. The greatest water quality problems in the lake have been associated with high nutrient concentrations which have caused large standing crops of phytoplankton and taste and odor problems in Saginaw Bay (Vollenweider et al. 1974, Smith et al. 1977, Stoermer et al. 1982), one of the two large embayments of Lake Huron. Low standing crops of phytoplankton in the waters of the Georgian Bay, the North Channel, and the north and central basins of Lake Huron indicate that they have been oligotrophic. Nutrient enrichment in the nearshore waters in regions of the Georgian Bay (Veal and Michalski 1977, Nicholls et al. 1977) and the central basin (Lowe 1976, and Ladewski et al. 1982) have been detected.

This study of the phytoplankton of Lake Huron was part of the Great Lakes surveillance program, during which the five Great Lakes are monitored on a rotational basis. In particular, this study was part of an intensive research program conducted during 1980 to survey the water quality of Lake Huron. Other parts of the intensive 1980 research program were: surveillance of nutrient chemistry and physicochemical characteristics of Lake Huron waters (Moll et al. in press), surveillance of zooplankton patterns (Evans 1983), and a detailed study of phytoplankton in the southern basin of Lake Huron (Kreis et al. in press). Whereas, the primary objectives of all three studies were to assess the water quality of Lake Huron and estimate changes in water quality that have occurred after implementation of measures to reduce phosphorus loading into the lake, each study focused on different aspects of the limnology and ecology of Lake Huron.

The ojectives of the study described in this report were:

1. to characterize phytoplankton standing crop and species composition in Lake Huron;
2. to characterize the water quality of regions of Lake Huron by studying the abundance and the autecology of phytoplankton;
3. to provide data with which future assessments of the changes in water quality of Lake Huron can be made;
4. to compare the phytoplankton communities of Lake Huron with those found in the past and to assess changes in water quality that have occurred during the period in which phytoplankton has been monitored.

CONCLUSIONS AND RECOMMENDATIONS

Patterns of phytoplankton indicated that the waters of Lake Huron were generally oligotrophic. The phytoplankton was dominated by the eurytopic diatoms year-round. Abundance and biovolume of algae was not large during the spring bloom. Algal biovolumes were low during the summer. Nitrogen-fixing blue-green algae were never abundant. Only a slight increase in phytoplankton abundance occurred during the fall.

Regional variation in water quality was indicated with relatively large standing crops of algae in the nearshore waters of the southern basin and with low standing crops in the Georgian Bay. Higher and more persistent standing crops of phytoplankton than in most regions of the Lake were also observed along the western shore of Lake Huron and near Cheboygan, which indicated that these waters were slightly enriched at different times of the year.

Little change in the water quality of Lake Huron waters was indicated by studying reports of algal abundances during the last 20 years. There were some signs that loading of nutrients to the southern basin was still causing some degradation of these waters. But, lower standing crops of algae near Saginaw Bay, than in the past, indicated that loading of nutrients had been reduced there.

Recommendations for future monitoring address the problems of identifying trends in the water quality of Lake Huron. It was difficult to assess long-term trends in water quality without knowing what annual variation in phytoplankton standing crops was. Seasonal sampling of nearshore and offshore waters would be desirable. Such studies have been done by studying algae at water intake stations and with seasonal cruises running transects through the Great Lakes. The spring bloom should be studied thoroughly by starting sampling earlier in the winter, rather than ending then. Patterns of algal biovolume by division, and abundances of algal species causing those patterns should be studied as complimentary information.

Interpretation of the significance of large standing crops of algae in nearshore areas of the Lake were difficult. The importance of entrainment of nutrients within a thermal bar area and then transport into offshore waters is poorly understood in Lake Huron. Intensive studies of nearshore waters in the southern basin and at discharges of several northern Michigan rivers is recommended to study the loading of nutrients in these regions.

The combination of data that was collected during the three 1980 studies of water chemistry, phytoplankton, and zooplankton was a particularly large and well integrated set of data on a lake that has not been thoroughly studied, but which is a very valuable resource. These data should be studied further as a synthesized data set so that we can learn more about the limnology and ecology of Lake Huron.

MATERIALS AND METHODS

Sampling

Phytoplankton samples were collected from Lake Huron aboard the CSS LIMNOS, R/V ROGER R. SIMONS, and USCGS BRAMBLE. Nine cruises were conducted, three 1891 "winter" cruises, when a skeleton of locations were sampled, and six other 1980 cruises when more thorough sampling occurred. The location and number of samples collected varied substantially from cruise to cruise. For example, no samples were collected with the CSS LIMNOS in the Georgian Bay during Cruise 5 and most of the samples of Cruise 6 were discrete depth samples from offshore locations in northern Lake Huron. Winter samples were collected aboard the USCGS Bramble, but only from the southern basin. Most sampling locations were located in the nearshore regions of the main body of Lake Huron (Fig. 1). The cruise dates and number and location of samples are listed in Table 1.

Two sampling methods were used. Integrated samples were collected with a 20 m integrating sampler at most nearshore sampling locations and sometimes at offshore locations. Discrete samples were collected with Niskin bottles and usually from 1, 5, 10, 15, 20, 25, 30, and 50 m and at larger intervals to the bottom of the Lake. Samples were fixed with 10 ml of Lugol's solution/l.

Sample Preparation and Algal Enumeration

Samples from different cruises were processed in different laboratories. Samples collected during Cruises 1 to 3 were prepared and counted by Mar, Inc. Samples collected during Cruises 4 to 6 and "winter" cruises were prepared and counted in the laboratories of Bionetics. A few of the samples collected during Cruise 6 were prepared and counted by Great Lakes Research Division at The University of Michigan.

Samples were prepared for observation with inverted microscopes by using the modified Utermohl method. At least 250 algae were counted from a sample. The number of live diatoms was determined from these enumerations, but the taxonomic composition of diatom phytoplankton was determined from a second set of counts of at least 500 frustules that had been acid cleaned and mounted in HYRAX on microscope slides. The number of algae of a species observed and the proportion of samples that were counted, were recorded on benchsheets. In addition, the dimensions of algae were recorded so that the biovolumes of algae could be determined.

Data Analyses

The cell volume of each species was computed by applying average dimensions to the geometrical shapes that most closely resembled the species form, such as: sphere, cylinder, prolate spheroid, etc. During enumeration, cell shape was determined and appropriate (e.g. length, width, depth, diameter) dimensions of at least 10 specimens of each species were measured. 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. With loricated forms, the protoplast was measured, while the individual cells of filaments and colonial forms were present.

Analyses of data treated integrated samples differently than discrete

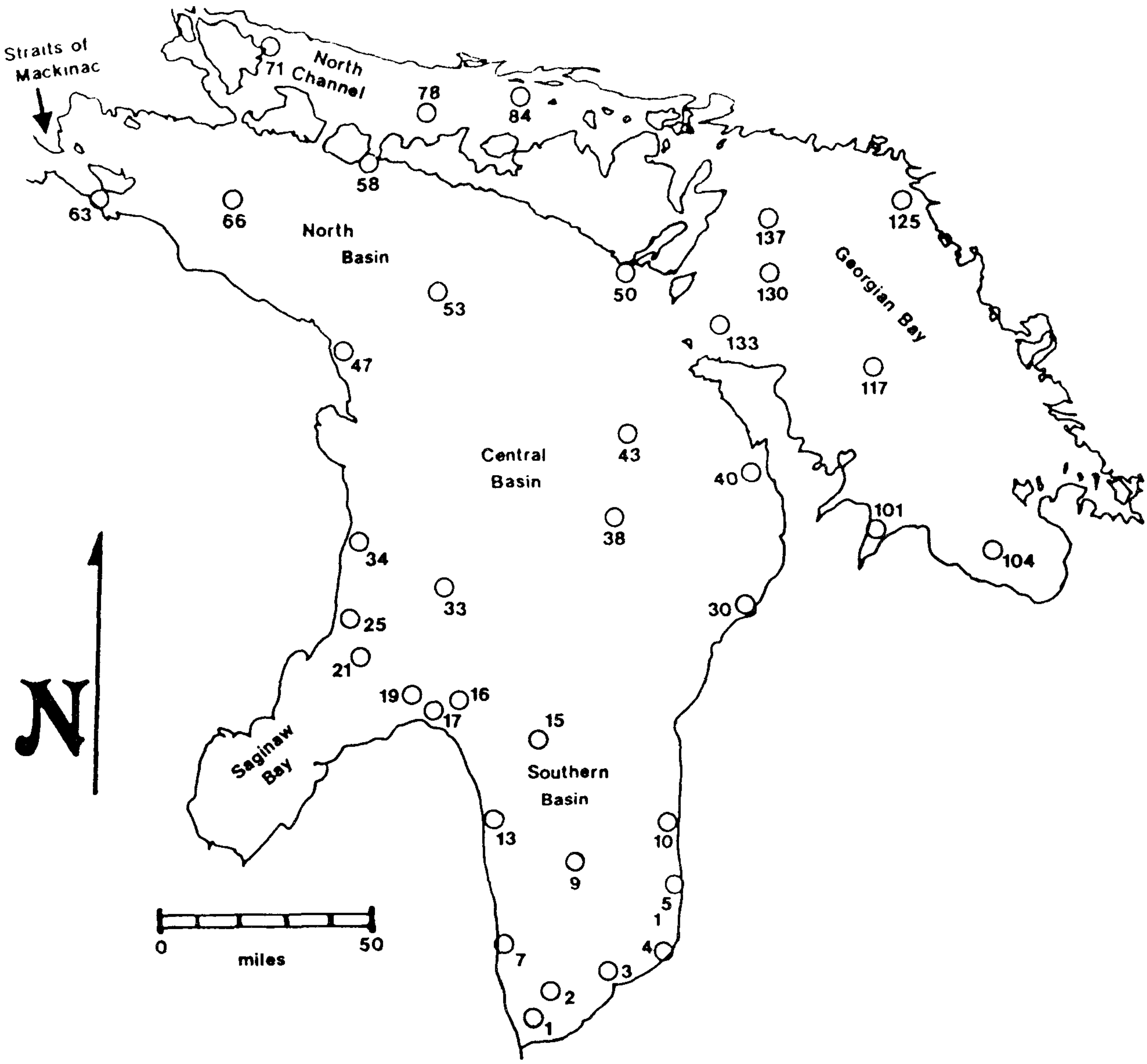

Fig. 1. Sampling locations in Lake Huron during April 1980 to March 1983 study.

Table 1. The cruise dates and types of samples collected at locations in Lake Huron. Integrated samples are indicated by a "0-?" notation, where ? is equal to the lower depth (m) of the depth range from which the sample was collected. Numbers separated by commas indicate the depth from which discrete samples were collected. "WC" stands for "winter" cruise and an "X" simply indicates that a sample was taken. "b2" stands for a sample collected 2 m from the bottom.

Location	Cruise 1	Cruise 2	Cruise 3	Cruise 4	Cruise 5	Cruise 6	WC 1	WC 2
1	0-20	0-20	0-20	0-20	0-9		x	x
3	0-20	0-20	0-20	0-20	0-20		x	x
4					0-20			
5	0-20	0-20	0-20	0-20	0-9			x
7	0-20	0-20	0-20	0-20	0-10		x	x
9	1,5,10, 15,20,30 50	1,5,10, 15,20,30 50,58	1,5,10, 15,20,30 50,57	1,5,10, 15,20,30 50	0-20 1,5,10, 20,25,30 40,59		9x	3x
10	0-20	0-20	0-20	0-20	0-10		x	
13	0-20	0-20	0-20	0-20	0-16		x	x
15							x	11x
16	0-20	0-20	0-20	0-20	0-20		x	x
17					0-20 1,5,10, 15,20,25 30,50,75	0-20 1,10,15, 20,25,30, 50,75		
19	0-20	0-20	0-20	0-20	0-20		x	x
21	5	0-20	0-20				x	x
25					0-15			
30					0-20			
33			0-20	1	0-20			
34	0-20	0-20	0-20	1	0-8			
38		0-20						
40	0-20	0-20	0-20	1,0-20	0-20			
43	1,5,10, 15,20,30 50,75, 100,142	1,5,10, 15,20,30 50,75, 100,B-2	0-20 1,5,10, 20,25,30 50,75, 100,150, 174	1,5,10, 15,20,30 50,75, 100,150, 160	0-20 1,5,10, 15,20,25 30,50,75 100,150, 180	0-20 1,5,10, 15,20,25 30,50,75 100,150, 180		
47	0-20	0-20	0-20	0-10	0-18			
50	0-20	0-20	0-20		0-20			
53	0-20	0-20	0-20					
58	0-20	0-20	0-20	0-20	0-13			
63	0-20	0-20	0-20	0-20	0-14	0-20		
66	1,5,10, 15,20,30 50,64	1,5,10, 15,20,30 50	0-20 1,5,10, 15,20,25 30,50,68	1,5,10, 15,20,26 30,50,b2	0-20 1,5,10, 15,20,25 30,50,68	0-20 1,5,10, 15,20,25 30,50,67		
71	0-20	0-20	0-20	0-20	0-20	0-20		
78		1,5,10, 15,20,30 b2	0-20 1,5,10, 15,20,25 30,43	1,5,10, 15,20,30 b2	0-20 1,5,10, 15,20,25 30,45	0-20 1,5,10, 15,20,25 30,44		
84		0-20	0-20	0-20				
101	0-20	0-20		0-20				
104	0-20	0-20 1,5,10, 15,20,30 50,b2	0-20	1,5,10, 15,20,30 50,b2				
117	1,5,10, 15,20,50 78	1,5,10, 15,20,30 50,75	0-20 5,10,15, 20,25,30 50,75	1,5,10, 15,20,30 50,b2				
125	0-20	0-20	0-13	0-20				
130	0-20	0-20	0-20	0-20				
133	0-20	0-20	0-20	0-20				
137		0-20						

samples. Patterns in algal division biovolume with depth were studied by plotting data from the stations where discrete samples were collected. In this analysis, algal biovolumes from all depths were studied. In most other analyses, the average of algal standing crops in discrete samples from the surface to 20 m was calculated and compared to algal standing crops in integrated samples.

The standing crop data of algae have been analyzed in a variety of different forms. Algal abundances (cells/ml) were studied when a more cellular interpretation of patterns of algal genetic diversity and cell numbers was the objective. Algal biovolumes (um3/ml) were studied when interpretation of patterns with respect to the ecology of algal biomass and sequestering of resources was more important. When competition between species of algae for resources was a priority or when parametric statistical analyses of data were performed, algal abundances and biovolumes were transformed with a natural logarithm function and were considered to be an indication of algal reproductive rates. When the standing crops of algae were not transformed, the objective of study was more in the context of how much or many were present. Of course, all analyses were not performed with all forms of the data that have just been listed, but the forms of data used in analyses have been selected in accordance with the above criteria.

Standing crops of phytoplankton divisions were the data studied from Cruises 1 to 6. Abundances and biovolumes of numerically or volumetrically dominant algal divisions in integrated samples from Cruises 1 to 6 have been plotted to analyze seasonal trends in standing crop and divisional composition of phytoplankton at selected locations. In addition, histograms of the abundances and biovolumes of dominant algal divisions were spatially plotted within an outline of Lake Huron to illustrate the spatial variation in algal standing crop within the lake. The statistical significance of spatial variation in standing crop of algal divisions in different segments of Lake Huron (segmentation scheme modified slightly from that of Moll et al., in press) was assessed by using two-factor analyses of variance with cruise and regions of the lake as factors. The number of replicates per region during each cruise varied and was equal to the number of locations in a region in which integrated samples were collected during a cruise.

Another spatial pattern in the seasonal standing crops of algal divisions that was studied was seasonal variation in algal biovolumes. Seasonal variation has been used in this report as an indicator of resource availability, probably nutrient availability, at various locations in the lake. The theory behind using seasonal variation in algal standing crop as an indicator of resource availability is: that abundances of opportunistic algae will vary more in locations where resources are abundant and they can reproduce rapidly, than in locations where resources are scarce and, consequently reproduction and turnover rates of algae are slower. The seasonal variation in phytoplankton was measured as the change in biovolumes of algal divisions from one sampling date to the next. The change in biovolume was calculated with the following Euclidean distance (difference) formula:

$$\left(\sum_{i=1}^{D} (B_{ij} - B_{ik})^2\right)^{1/2}$$

where, D is equal to the number of divisions, and B_{ij} and B_{ik} were the biovolumes of the i^{th} division on the j^{th} and k^{th} sampling dates. Of course, the seasonal variation in standing crop of phytoplankton may be the result of environmental factors other than resource availability, such as current patterns in the lake. This measure was studied because it could be an easily calculated and could be a valuable indicator of eutrophication.

The spatial variation in diatom assemblages around Lake Huron during Cruises 1 to 6 was studied to delineate water masses in the lake. Water masses were delineated by using cluster analyses to group locations where diatom reproduction rates were similar. The cluster analyses were computed using BMDP software on a DEC-10 computer at the University of Louisville. Log-transformed abundances of the dominant diatoms, those with an average abundance greater than 2% or a maximum abundance that was greater than 10% of the total diatom abundance at a location, were used as variables in the cluster analyses. In these analyses, clusters of locations were grouped based on the Euclidean difference in log-transformed diatom abundances between locations. Initially, each case is considered to be a cluster; and then the two clusters with the least difference (amalgamation distance) between them are grouped. This process continued until all cases were combined into one cluster by using an algorithm called average distance or average linkage.

Results of cluster analyses were used to assess the spatial integrity of regions of the Lake that were discussed in this report. The location of water masses with similar diatom communities will be compared to several nearshore regions around the Lake and offshore regions in the North Channel, the Georgian Bay, and the north, central, and southern basins. Since the Euclidean difference between assemblages was calculated with log-transformed abundances of diatoms, it was an integrated estimate of the similarity of net reproductive rate of the dominant diatoms in two assemblages (assuming grazing and sinking rates were the same in the two assemblages). Thus, low distance, i.e. high similarity, between diatom assemblages indicated similar physicochemistry and similar water qualities at the two locations.

The species that characterized a water mass were determined by studying tables of the species' averages within clusters. The tables were part of the output generated by the BMDP-1M program.

The correlations between physicochemical conditions of the Lake and algal division biovolumes plus abundances of the many common diatoms were studied with water chemistry data from Moll et al. (submitted). The average of log-transformed algal division biovolumes and of log-transformed diatom species' abundances were calculated for each region during each cruise. The segmentation scheme (Fig. 2) used to calculate average water chemistry of a region by Moll et al. (submitted) and average phytoplankton characteristics in this analysis closely corresponded to the 1974 segmentation scheme of the IJC (1976a, 1976b). The identification number of stations that were located in each segment are listed in Appendix I. Water chemistry and average algal statistics in eight segments of Lake Huron during the six cruises were correlated using Pearson correlation and partial correlation procedures (SPSS software). Partial correlations between water chemistry and algae were studied while accounting for the variation in algae that was due to seasonal changes. The seasonal time variable used was simply cruise number (determining the exact time of collection of each sample was impractical). Since seasonal changes in algae are usually not linear, partial correlation, while holding time and time-squared constant, was used so that non-linear changes in algae with season could be accounted for.

RESULTS

One thousand forty-nine algal taxa, grouped into nine divisions and two categories of unidentified taxa, were recorded from Lake Huron samples. More than half, 540, of those taxa were forms, varieties, and species of diatoms. Most of the unidentified taxa were small phytoflagellates. A list of these taxa is available from the author or project officer.

Seasonal Variation in Algal Division Biovolumes

Algal biovolume was usually greatest during the late spring (Fig. 3), even though cell numbers were usually lowest then (Fig. 4). Most of the phytoplankton biomass in Lake Huron was diatoms. With few exceptions, diatoms comprised the greatest proportion of algal biovolume at stations around the lake and during all seasons (Fig. 3). Biovolumes of dinoflagellates and green algae were occasionally great. Blue-green algae were numerically most common during most of the year at most locations, but the cells were generally so small that they seldom represented important proportions of the biovolume.

The seasonal pattern in algal biovolumes varied around the Lake (Fig. 5). Large biovolumes of diatoms occurred during the spring, greater than 1.0 x 106 um3/ml in the Lake Huron proper (region 1), but less than those near the St. Mary's River, in the North Channel, and in the Georgian Bay (regions 3, 4, & 2; Fig. 6). The patterns in total algal biovolume were very similar to patterns in diatom biovolume (Figs. 3, 5, & 6). In general, diatom biovolume decreased from spring through early summer highs to summer and fall lows. This pattern was observed in all areas of the lake except near the St. Mary's River in the North Channel (region 3; Fig. 6) where diatom biovolumes were low and variable throughout the field season, and near the Straits of Mackinac (region 7) where a second, fall peak was observed. The greatest diatom biovolumes during the spring-early summer peak period were along the western shore of southern Lake Huron (region 6). The large diatoms responsible for most of the biovolume peaks were <u>Tabellaria</u> <u>fenestrata</u> and <u>T</u>. <u>flocculosa</u>.

In addition to biovolumes of algae, the length of time that the large standing crops of spring persisted into summer seemed to be related to suspected nutrient loading (Fig. 5). The bloom period was shortest in the North Channel and Georgian Bay (regions 2 & 4). Biovolumes of algae did not decrease to below 500.0×10^3 um^3/ml until July or September in the nearshore and offshore regions of the central and southern basins of Lake Huron (regions 1, 5, 6, & 8; Fig. 5).

Substantial seasonal variation was observed in the biovolumes of the other, non-diatom algae, although their biovolumes usually peaked later than diatoms during June, July, and/or September. Green algae (Fig. 7) in offshore waters of the central basin of Lake Huron (region 1) and Georgian Bay (region 2) increased throughout the latter part of the field season, often because of an increase in chlorococcalean algae, such as <u>Oocystis</u>. A similar pattern was indicated in the offshore waters of the southern basin, except that a very high July maximum was followed by a decrease in green algal biovolumes; however, the July maximum was an artifact of observing one large <u>Staurastrum</u> cell. High green algal biovolumes, mostly unidentified coccoid forms, were observed during April along the western shore of the southern basin. The April peak near the Straits of Mackinac may have been overestimated because of the observation of a

Fig. 2. Regions of Lake Huron from which phytoplankton and water chemistry averages were calculated. These regions were similar to the regions delineated in the 1974 segmentation scheme by IJC (1976a, 1976b).

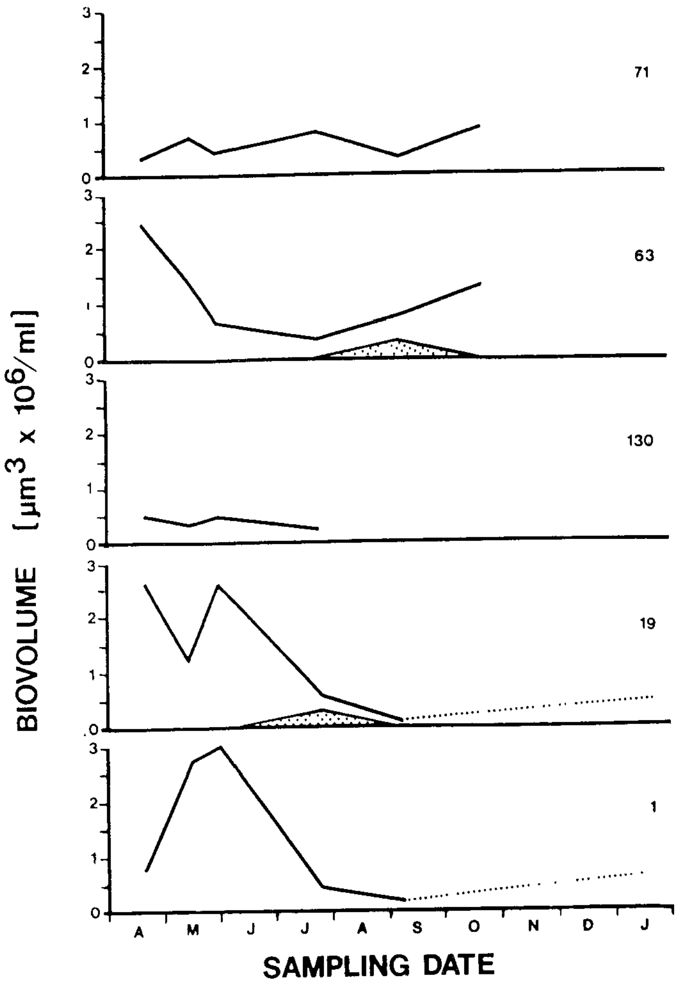

Fig. 3. Seasonal patterns in phytoplankton biovolume at selected locations (numbered at right edge of each figure) around the Lake. Unmarked area under curve indicated diatom biovolume and dotted area indicated dinoflagellate biovolume. Biovolumes of other algal divisions could not be distinguished graphically.

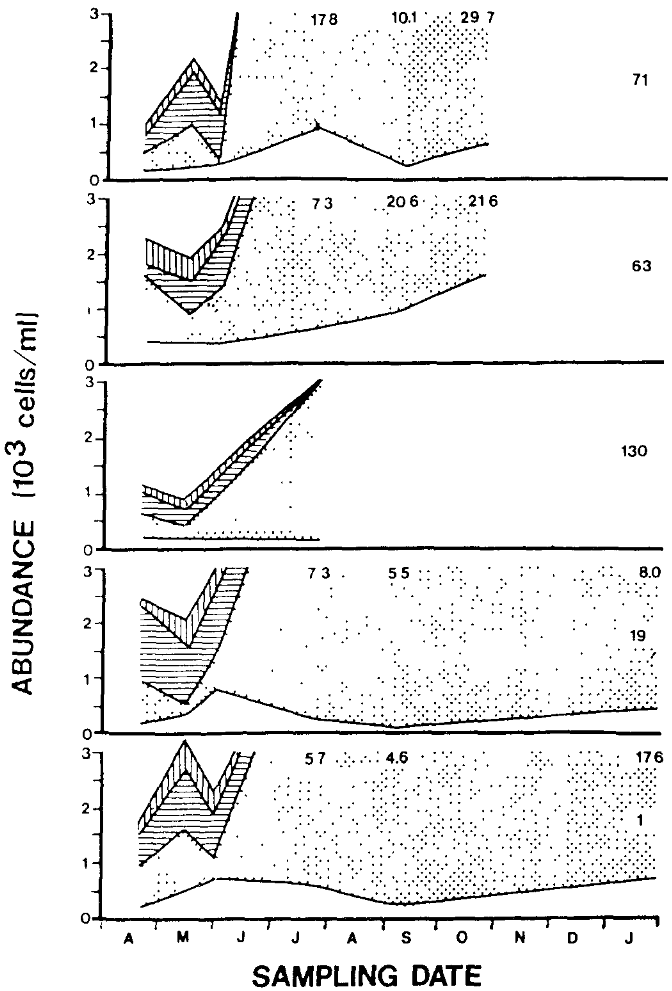

Fig. 4. Seasonal patterns in phytoplankton abundance at selected locations (numbered at right edge of each figure) around the Lake. Unmarked area under curve indicated diatom abundance; dotted area indicated blue-green algal abundance; area marked by horizontal lines indicated microflagellate abundance; and area marked by vertical lines indicated chrysophyte abundance.

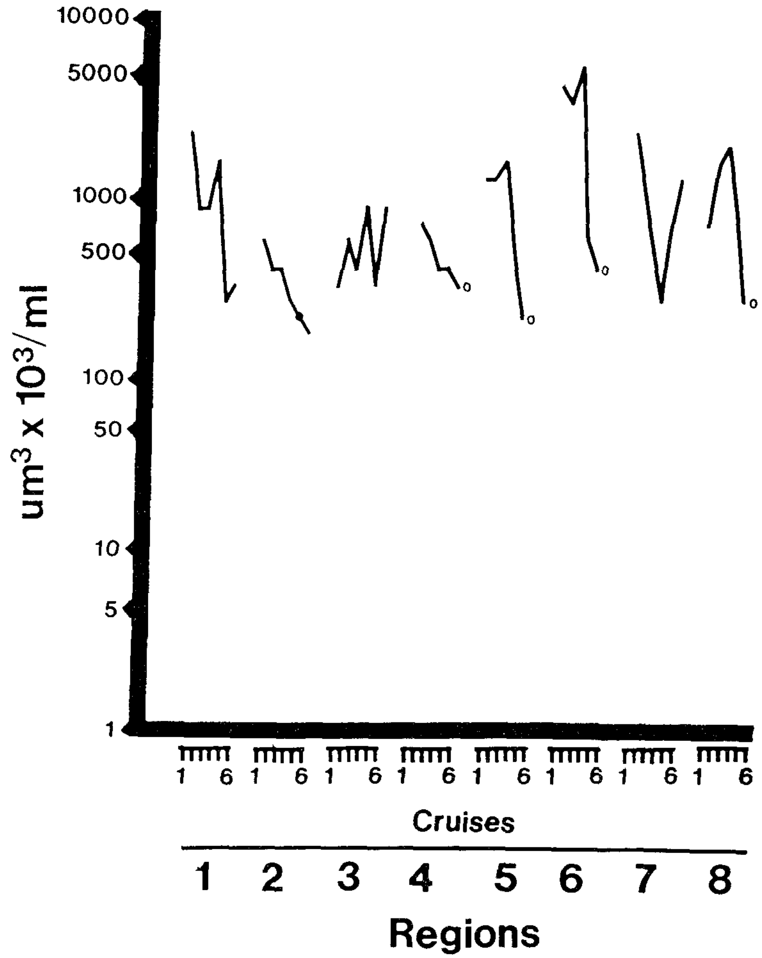

Fig. 5. Seasonal biovolume patterns of all algae in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

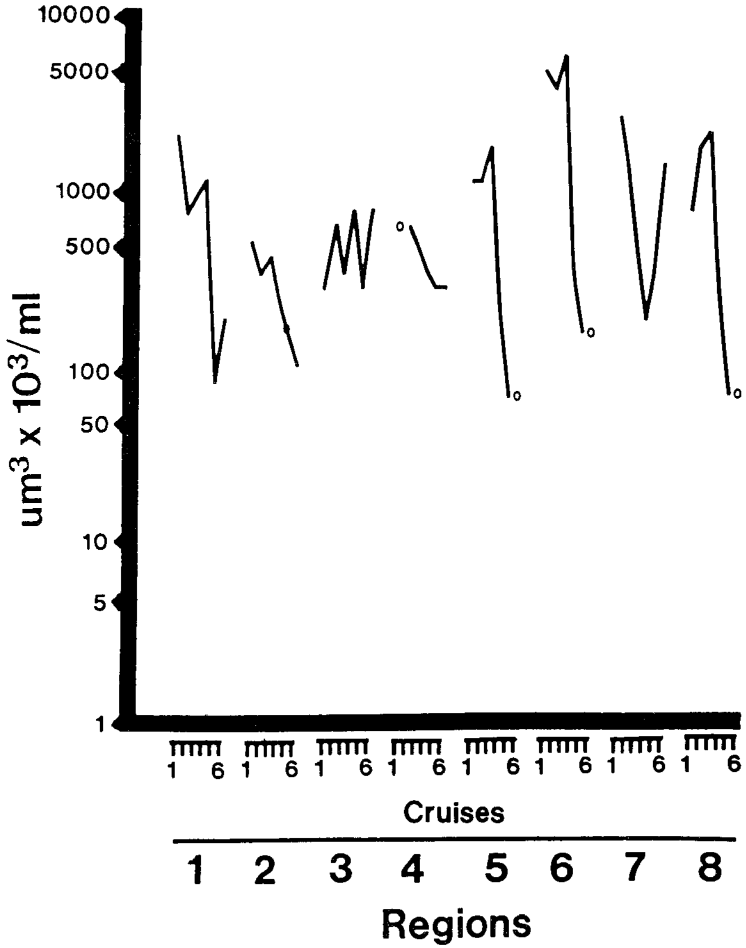

Fig. 6. Seasonal biovolume patterns of diatoms in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

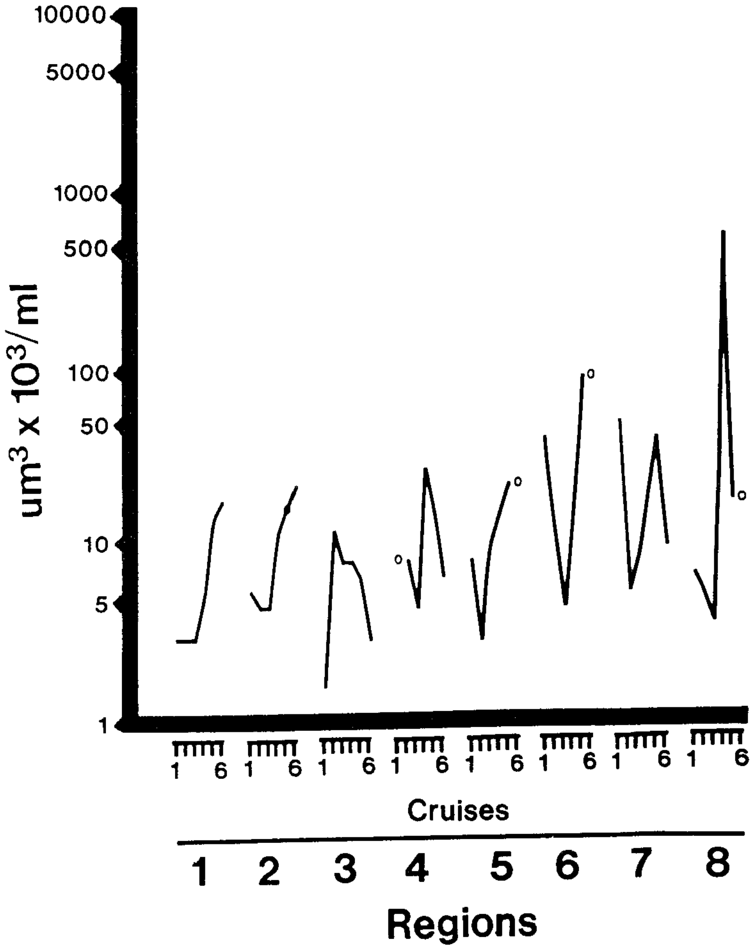

Fig. 7. Seasonal biovolume patterns of green algae in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

large Pediastrum colony. The only area where a May or June minimum was not found was near the St. Mary's River. So there is an indication that diatoms outcompete green algae for inorganic nutrients supplied by spring turnover, except in areas where enough nutrients may be entrained that green algae can also bloom.

Blue-green algal biovolume was lowest in all regions of the Lake during June (Fig. 8). Again, high spring biovolumes were followed by late summer-fall maxima in areas where substantial nutrient loading would be suspected, near the mouth of Saginaw Bay (region 5) and the western nearshore and offshore regions of the southern basin (regions 6 and 8). Chroococcalean algae, small coccoid forms, comprised much of the spring and fall peak.

Chrysophyte biovolumes peaked during July in all regions of the Lake except the North Channel (Fig. 9). A steady increase in chrysophyte biovolume through July was only observed in the Georgian Bay region. June lows were observed in many parts of the main body of Lake Huron. Dinobryon statospores and D. sertularia typically comprised most of the biovolume during April-May periods, whereas other Dinobryon spp., Chrysosphaerella longispina, and Ochromonas spp. comprised the July-September chrysophyte assemblage.

Dinoflagellate biovolumes were variable seasonally, as were biovolumes of cryptomonads and unidentified flagellates. Their biovolumes were generally less than 1.0×10^4 um^3/ml. The only regularities observed in seasonal patterns of these algae were the July minima in unidentified flagellate biovolumes.

Cell numbers of diatoms, on the other hand, were relatively constant from cruise to cruise (Fig. 4), while being as high as 1500 cells/ml, but usually between 100 and 500 cells/ml. Unidentified flagellates were most abundant during the spring (Fig. 4) and blue-green algae were most abundant during the summer, fall, and winter. Blue-green algal abundances were commonly 5000 cells/ml and as great as 20,000 cells/ml during these seasons, whereas peak abundances of unidentified flagellates were between 500 and 1000 cells/ml.

Spatial Patterns in Phytoplankton -- April

Diatoms comprised such a large proportion (> 90%) of the algal biovolume during the first three cruises that illustrations of algal biovolume and diatom biovolume look the same (Figs. 10 & 11). During the April cruise algal biovolume commonly exceeded 1.0×10^6 um^3/ml in the western nearshore regions of Lake Huron. High algal biovolumes were also observed in the north basin (S 53) and along the eastern shore of Lake Huron at S 40. Tabellaria, primarily T. fenestrata, comprised most of the biovolume along the western shore of Lake Huron, whereas Melosira islandica was also an important species, if not the dominant (> 40%) species of the phytoplankton communities in other parts of the lake. The greatest abundances of blue-green algae and unidentified flagellates were in nearshore regions of the southern basin and along the western shore of Lake Huron in April (Figs. 12 & 13). Algal standing crops were generally lowest in the Georgian Bay and North Channel. The greatest biovolumes and abundances of algae were at S 7 along the western shore of the southern basin, where diatom abundances were also the highest (Fig. 14).

The April differences in phytoplankton from the Georgian Bay, S 7, and most of the rest of Lake Huron were also evident in the patterns of similarity in diatom assemblage composition (Fig. 15). Sixteen species of diatoms with

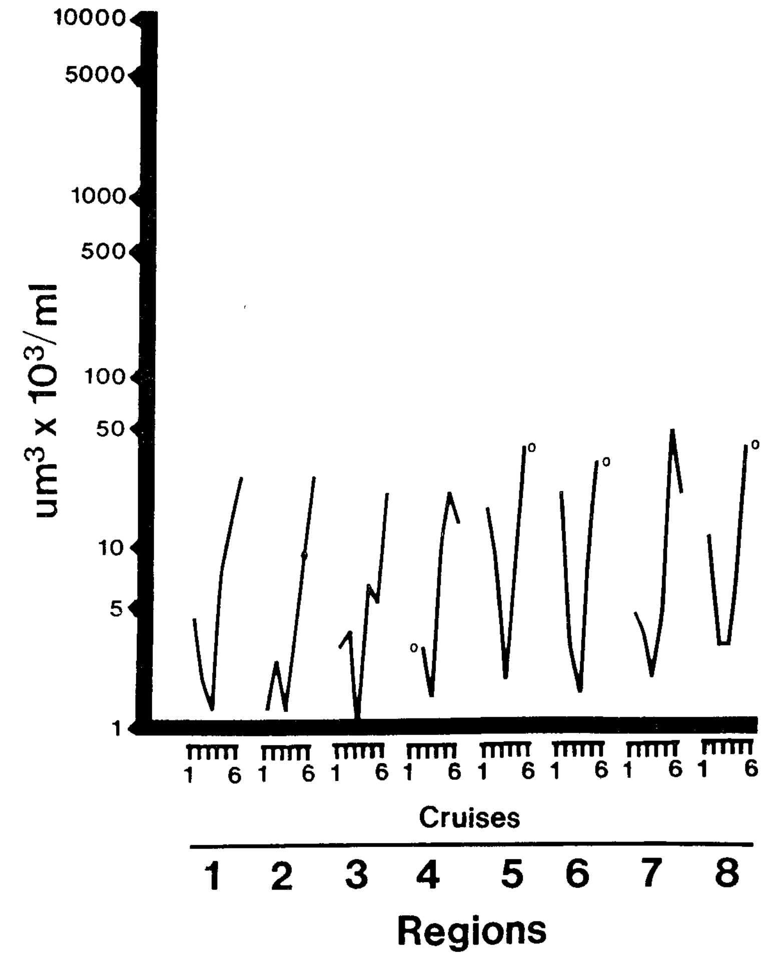

Fig. 8. Seasonal biovolume patterns of blue-green algae in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

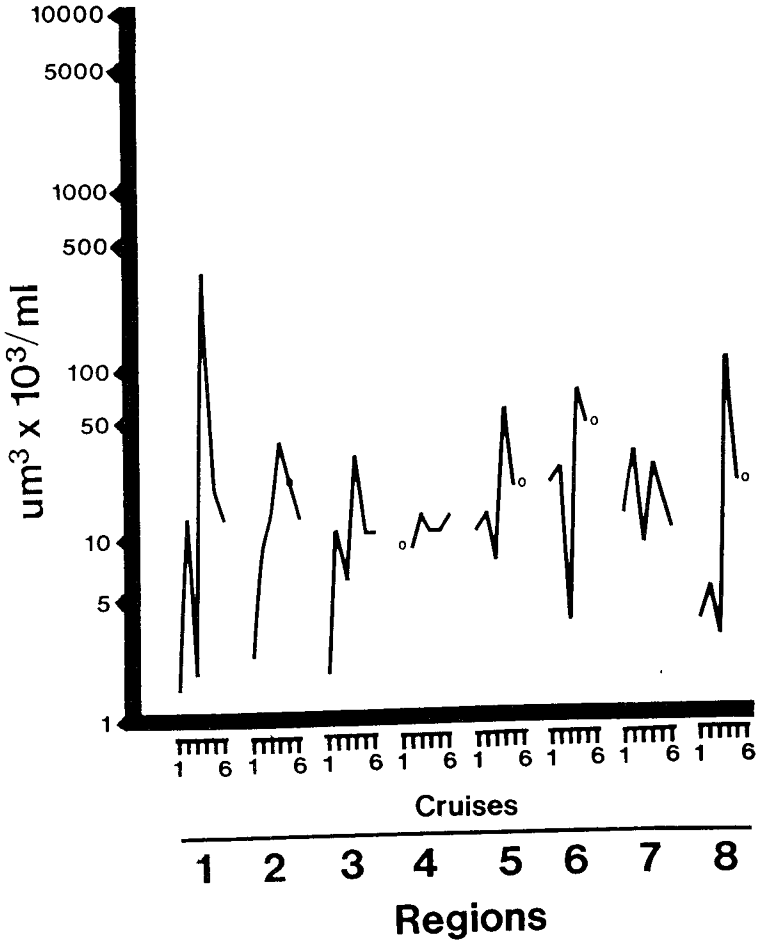

Fig. 9. Seasonal biovolume patterns of chrysophytes in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

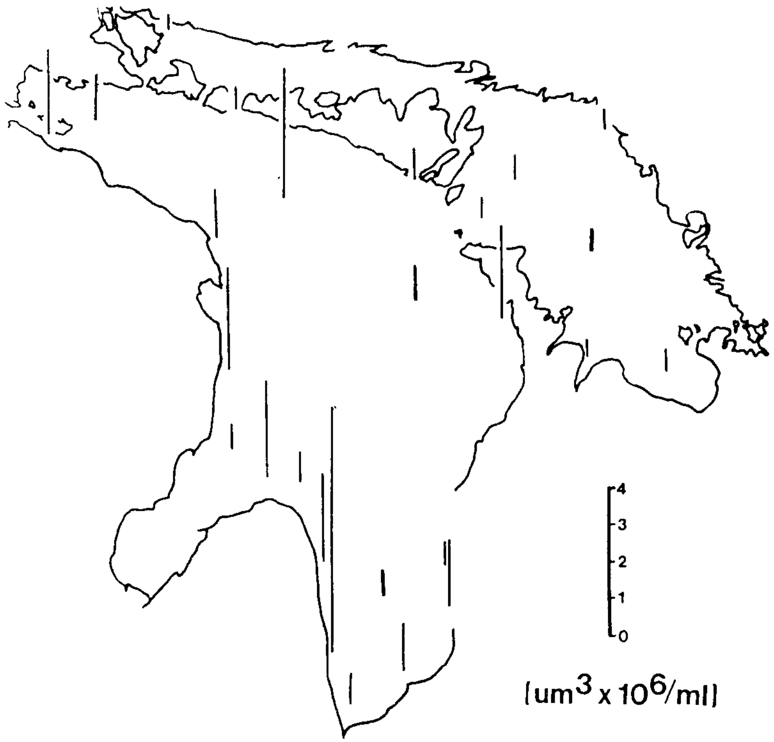

Fig. 10. April spatial pattern of total algal biovolume.

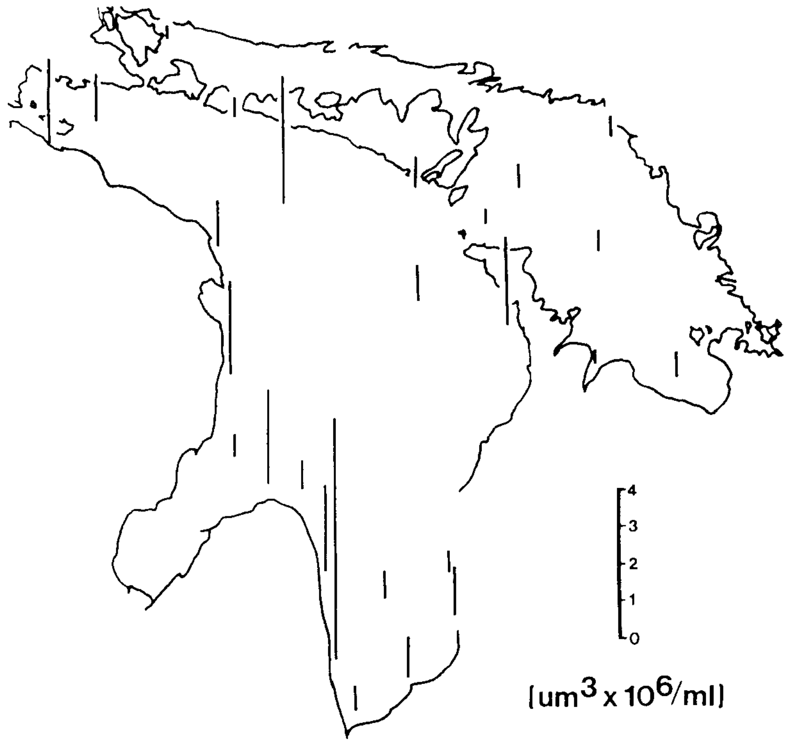

Fig. 11. April spatial pattern of diatom biovolume.

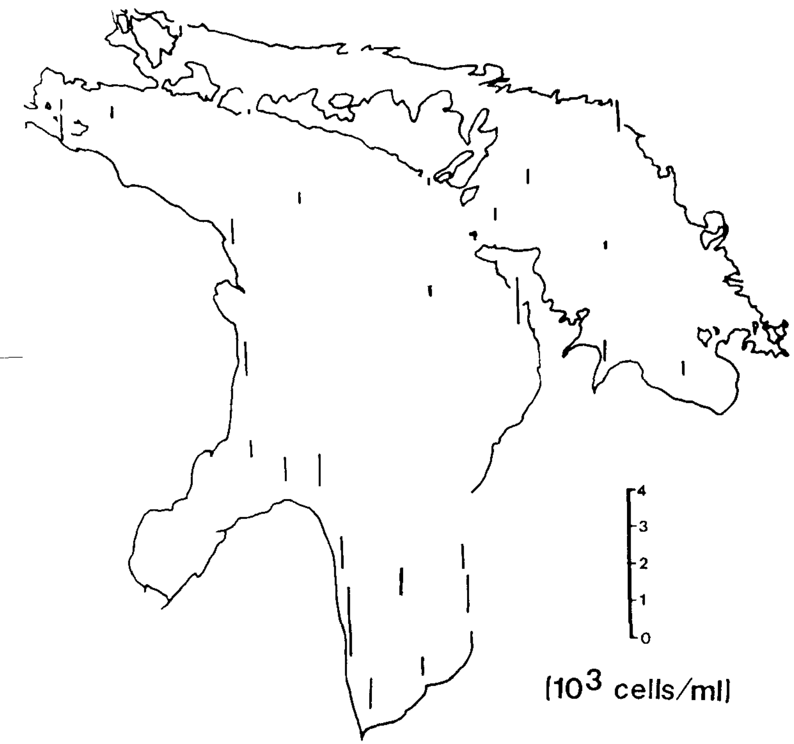

Fig. 12. April spatial pattern of blue-green algal abundances.

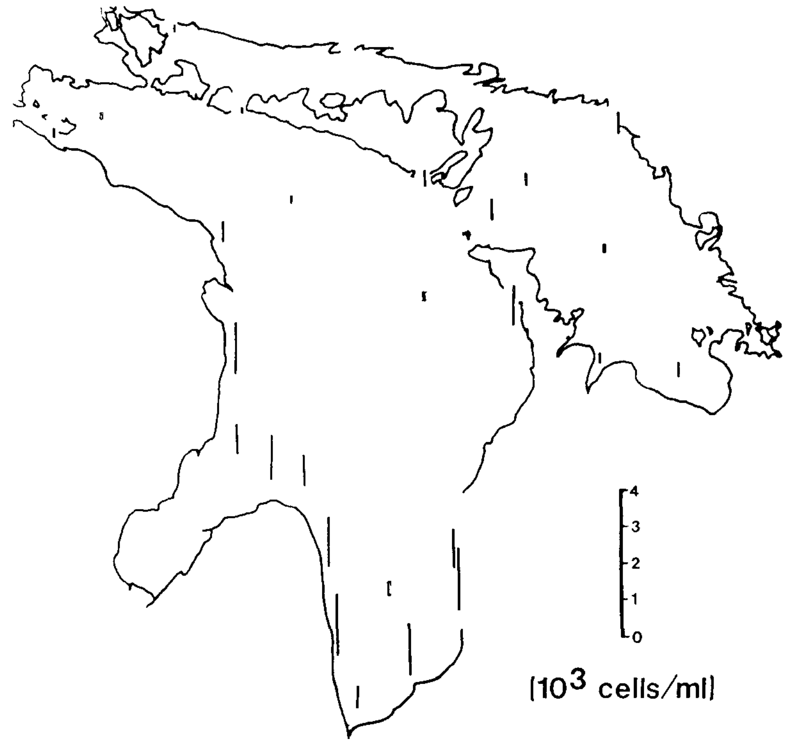

Fig. 13. April spatial pattern of unidentified flagellate abundances.

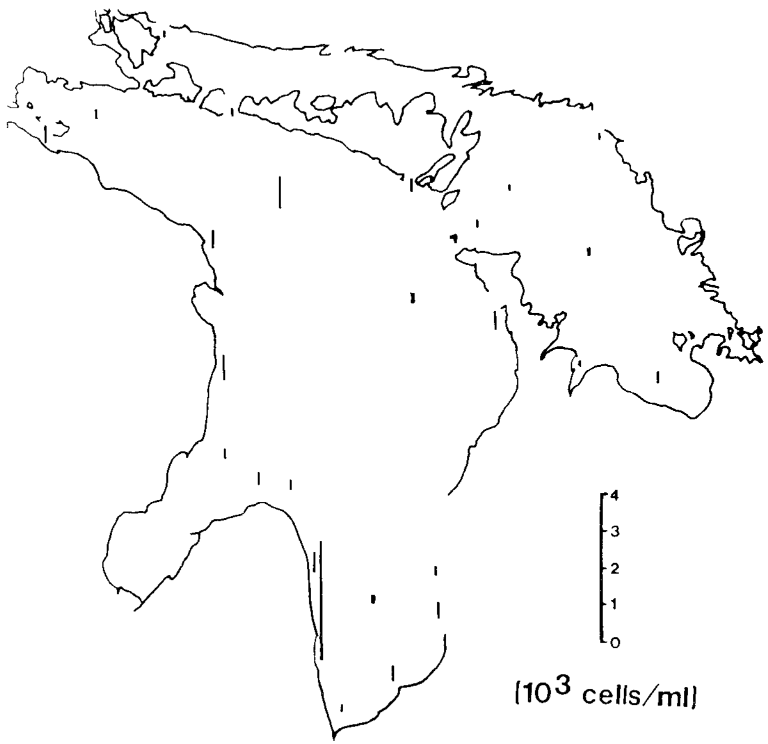

Fig. 14. April spatial pattern of diatom abundances.

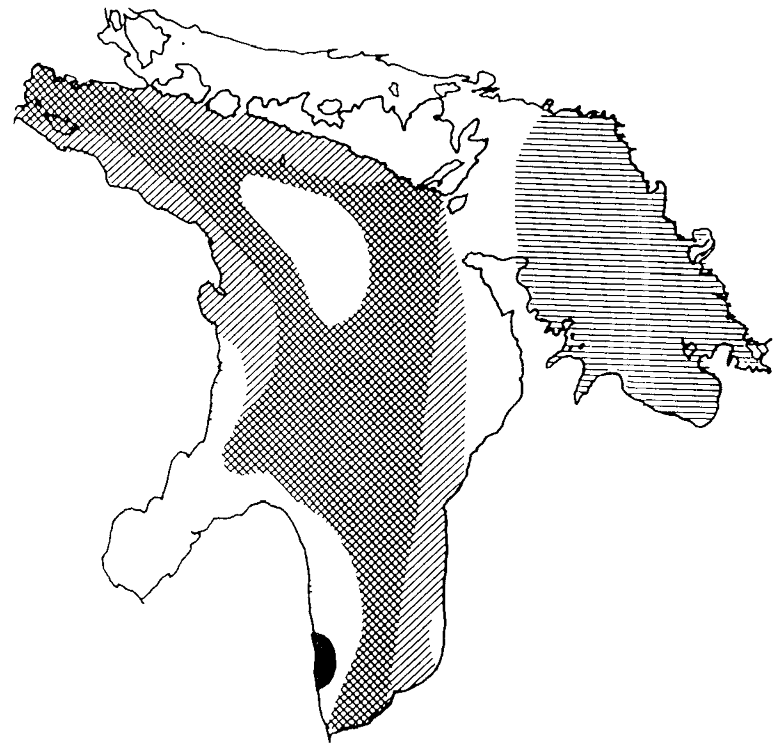

Fig. 15. April clusters of similar planktonic diatom assemblages.

relative abundances greater than 10 percent or averaging greater that 2 percent were used in the cluster analysis of April diatom assemblages (Table 2). Fragilaria crotonensis and Tabellaria fenestrata were the most common with average relative abundances of 18.0 and 16.8 percent, respectively (Table 3). Asterionella formosa and two Cyclotella spp., C. glomerata and C. ocellata had relative abundances averaging about 6 percent. A fourth subdominant species, Melosira islandica, had an average relative abundance of 5 percent during April. Regions of the lake with similar diatoms were delineated when the amalgamated Euclidean difference within a cluster was between 2.5 and 4.0, or when an assemblage at an individiual station was distinctly different from those in the rest of the lake (distance greater than 9.0).

Except for the assemblage at S 53 in the north basin, offshore diatom assemblages in Lake Huron in April were quite similar. The offshore assemblage was characterized by higher abundances of an unidentified centric diatom and Stephanodiscus subtilis (which may have actually been Stephanodiscus parvus; see Stoermer and Hakansson 1984) and with lower abundances of Nitzschia palea and F. crotonensis than elsewhere. By increasing the amalgamation distance from 2.5 to 3.5, many northern and eastern nearshore assemblages were included in the big Lake Huron cluster. Nearshore assemblages, generally, had more Fragilaria pinnata and N. palea and fewer centric diatoms than offshore stations.

High abundances of C. glomerata and C. ocellata and few M. islandica and S. subtilis characterized diatom assemblages in the Georgian Bay.

If the April amalgamation distance was 3.6, the diatom assemblages of the large Lake Huron and Georgian Bay clusters were grouped. Cyclotella glomerata and Cyclotella michiganiana were more abundant in the Georgian Bay cluster than in the large Lake Huron cluster; whereas, Fragilaria capucina and T. fenestrata were more abundant in the Lake Huron cluster. The remaining assemblages were different than this large cluster because they generally had higher diatom abundances, but in particular, lower abundances of the unidentified centric (known as #1).

Diatom abundances were low in water from the St. Mary's River also. In particular, abundances of C. michiganiana, S. subtilis, and T. fenestrata were lower and abundance of Diatoma elongatum was higher at S 71 than in the rest of the Lake.

Two unusual diatom assemblages occurred in offshore waters at S 53 and S 133. Low diatom abundances, about 200 cells/ml, at S 133 in the Georgian Bay were dominated by N. palea. Higher than average abundances, about 800 cells/ml, were observed at S 53 in the north basin where spring plankton diatoms were most common. Unusually, a typically benthic diatom, Gomphonema parvulum var. micropus, was uniquely most abundant at both stations S 53 and S 133.

With 3400 cells/ml, the diatom assemblage at S 7 along the southwestern shore was more abundant than anyplace else in the Lake. Log-transformed abundances of F. pinnata, F. capucina, D. elongatum, and A. formosa increased more rapidly from Lake to S 7 than other species. Even though abundances of diatoms in general were greatest at S 7, abundances of Tabellaria flocculosa and the unidentified centric were less abundant at S 7. Despite the high abundances of diatoms at S 7, species diversity was relatively high (H'>4.0) there (Fig. 16). In general, species diversities of diatom assemblages were highest in April, ranging from 3.0 to 5.0.

Table 2. Common diatom species that were used in cluster analysis of planktonic diatom assemblages during each cruise. Use of a species was indicated with an "X". "1-2" and "2-2" indicate the first and second species of two that were added together and used as one species.

Species	Cruise 1	2	3	4	5
Achnanthes minutissima					X
Asterionella formosa	X	X	X	X	
Cyclotella comensis				1-2	1-2
Cyclotella comta				X	X
Cyclotella glomerata	X	X	X		
Cyclotella michiganiana	X	X	X	2-2	2-2
Cyclotella ocellata	X	X	X	X	X
Cyclotella stelligera	X	X	X	X	
Diatoma elongatum	X				
Fragilaria capucina	X	X	X		
Fragilaria crotonensis	X	X	X	X	X
Fragilaria pinnata	X	X			
Gomphonema parvulum var. *micropus*	X				
Melosira islandica	X	X	X		
Melosira italica		X			
Nitzschia palea	X				
Rhizosolenia eriensis				X	
Rhizosolenia longiseta				X	
Stephanodiscus subtilis	X				
Synedra radians			X	X	
Tabellaria fenestrata	X	X	X	X	X
Tabellaria flocculosa	X	X	X	X	X
Unidentified centric #01	X				

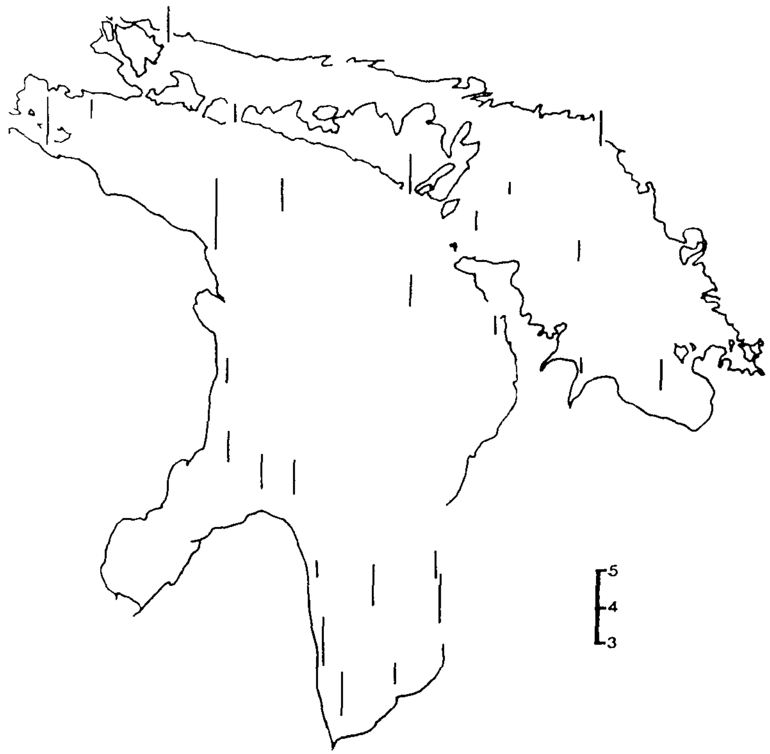

Fig. 16. April spatial pattern of diatom diversity.

Table 3. Average relative abundance of common diatoms in Lake Huron during each cruise. Relative abundance was calculated as the percent of the diatoms observed in a sample that was represented by one of the common species.

Species	Cruise					
	1	2	3	4	5	6
Asterionella formosa	6.5	6.2	7.5	8.8	1.2	10.1
Cyclotella comensis	-	-	1.6	11.6	14.6	11.0
Cyclotella glomerata	5.7	10.5	6.3	-	-	-
Cyclotella michiganiana	2.1	2.2	4.8	32.9	12.0	1.2
Cyclotella ocellata	5.9	7.1	4.6	4.5	2.1	7.2
Cyclotella stelligera	2.0	3.0	2.2	5.1	1.8	0.6
Fragilaria capucina	3.3	3.3	2.2	0.6	0.6	0.4
Fragilaria crotonensis	16.8	13.1	11.7	11.1	17.0	43.2
Melosira islandica	4.9	4.4	3.2	0.5	0.2	1.2
Tabellaria fenestrata	18.0	21.5	38.5	5.4	1.8	3.7
Tabellaria flocculosa	3.1	4.4	4.0	3.2	0.3	5.2

Spatial Patterns in Phytoplankton -- May

During the May cruise algal standing crops were again greater along the western shore of Lake Huron and eastern shore of the southern basin than along the North Channel and in Georgian Bay (Fig. 17). Algal biovolumes commonly exceeded 3.0 x 106 um3/ml in the nearshore regions of the southern basin. Most of that biovolume was still due to T. fenestrata with substantial quantities of M. islandica at S 5. Again abundances of diatoms were highly correlated to algal biovolumes (Fig. 18). In addition, locally high abundances of blue-green algae along the eastern shore of the southern basin contributed to high algal biovolumes there (Fig. 19). Cryptomonads and unidentified flagellates were also abundant along the eastern shore of the southern basin (Figs. 20 & 21).

Patterns in the similarity of diatom assemblages in Lake Huron were large mosaics in the North Channel, Georgian Bay, and north and central basins of Lake Huron (Fig. 22). The southern basin was a spatially finer mosaic than in the rest of the Lake. Twelve species of diatoms with relative abundances greater than 10 percent or averaging greater than 2 percent were used in the cluster analysis of May diatom assemblages (Table 2). Tabellaria fenestrata and Fragilaria crotonensis were again most common while averaging 21.5 and 13.1 percent, respectively, of the diatoms in samples (Table 3). The same subdominant species as in April were again subdominant during May. Regions of the Lake with similar diatoms were delineated when the amalgamated Euclidean distance was less than 3.0, except for the offshore assemblages in the north and central basins which had a distance of less than 1.3 between them.

The diatom assemblages at offshore stations in the north and central basins of Lake Huron were characterized by low abundances. Fewer Cyclotella spp. and more Melosira islandica distinguished diatom assemblages in this cluster from assemblages in the rest of the Lake. The assemblage at S 38 was very different than at S 43, S 53, and S 66 or elsewhere in the Lake because: 1) it was the only assemblage without Asterionella formosa and 2) more Cyclotella stelligera occurred at this site than at any other site.

Actually, diatom assemblages throughout most of the northern, central, and southern basins were very similar during May. High abundances of Tabellaria spp. (both T. fenestrata and T. flocculosa), A. formosa, and M. islandica and a low abundance of Cyclotella michiganiana characterized the diatom assemblages of most of Lake Huron.

There were three clusters of diatom assemblages in the Georgian Bay and North Channel. One near the St. Mary's River (S 71) and at S 125 was characterized by low abundances of C. stelligera. North Channel assemblages were notable because of low abundances of Tabellaria spp.and high abundances of Melosira italica. Georgian Bay assemblages were characterized by their higher than average abundances of Cyclotella spp. and lower than average abundances of other species.

The fine-scale mosaic in the southern basin was the result of great dissimilarity between diatom assemblages at S 3, S 5, and S 7. The amalgamated distance within the cluster containing all three assemblages would have to be greater than 4.5 to include them. Assemblages at S 5 and S 7 had less C. michiganiana and C. stelligera and higher abundances of other species, particularly Fragilaria pinnata. When considering all algae, algal assemblages at S 5 were distinguished from S 7 by having more of the cryptomonad Rhodomonas minuta and unidentified flagellates and much more chroococcalean blue-green

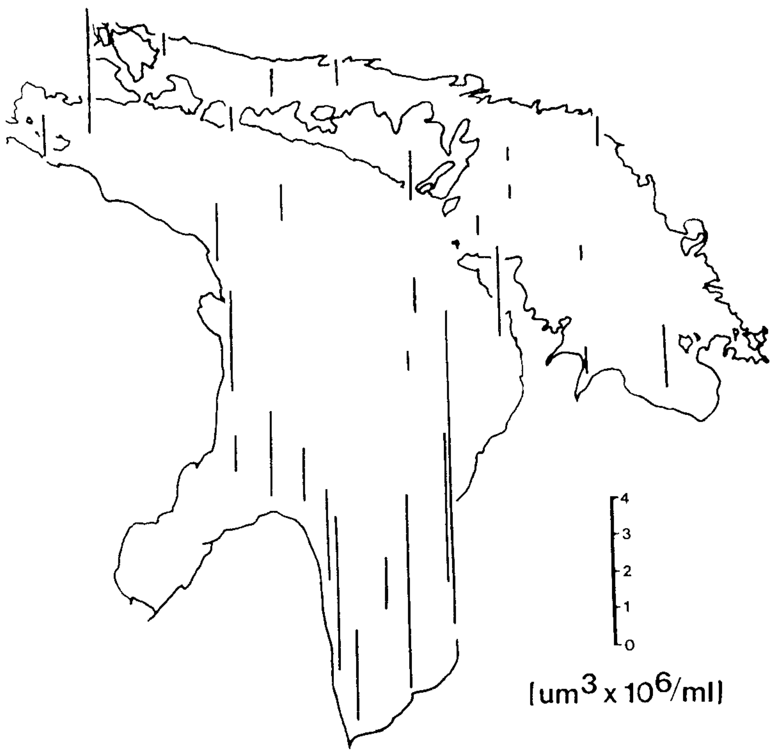

Fig. 17. May spatial pattern of total algal biovolume.

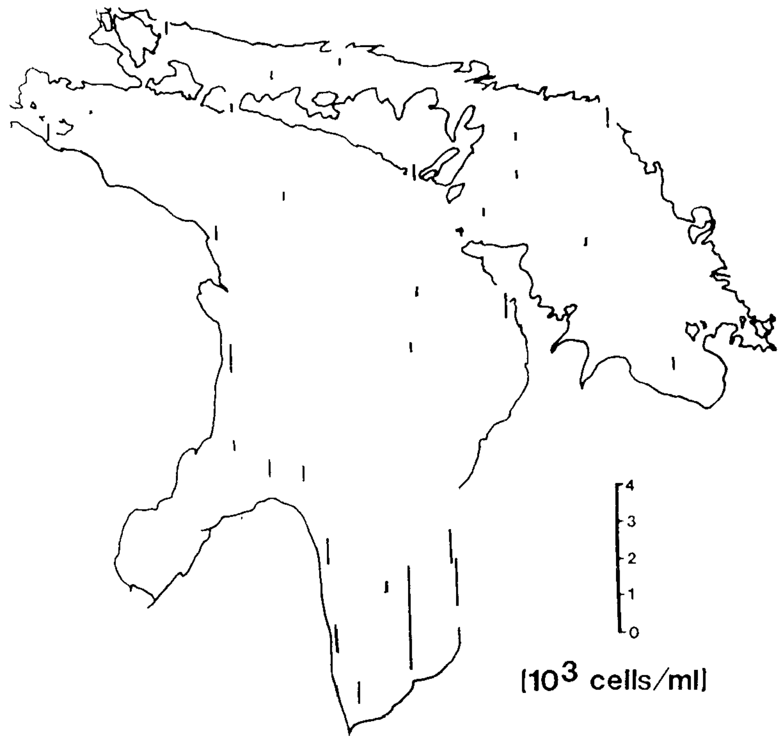

Fig. 18. May spatial pattern of diatom abundances.

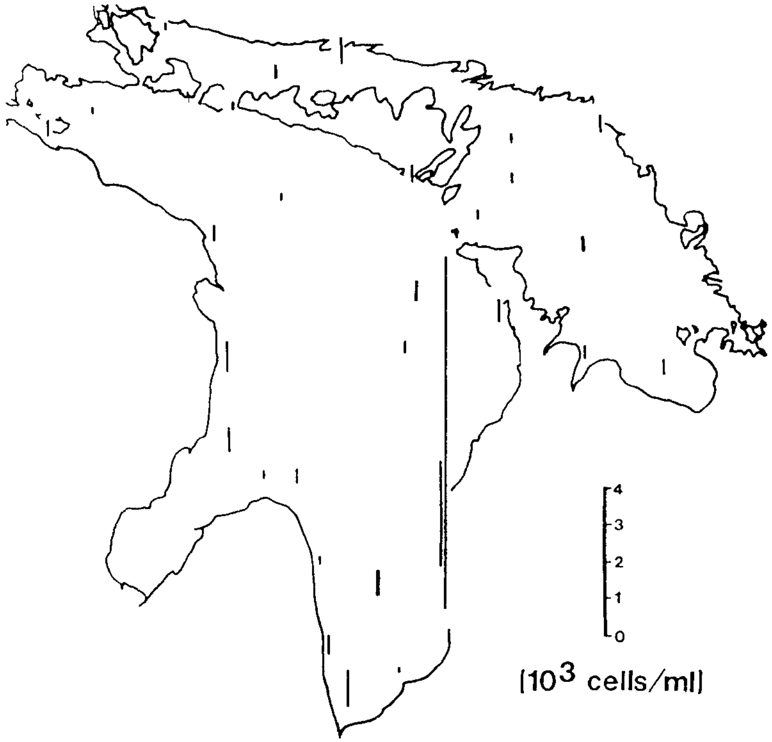

Fig. 19. May spatial pattern of blue-green algal abundances.

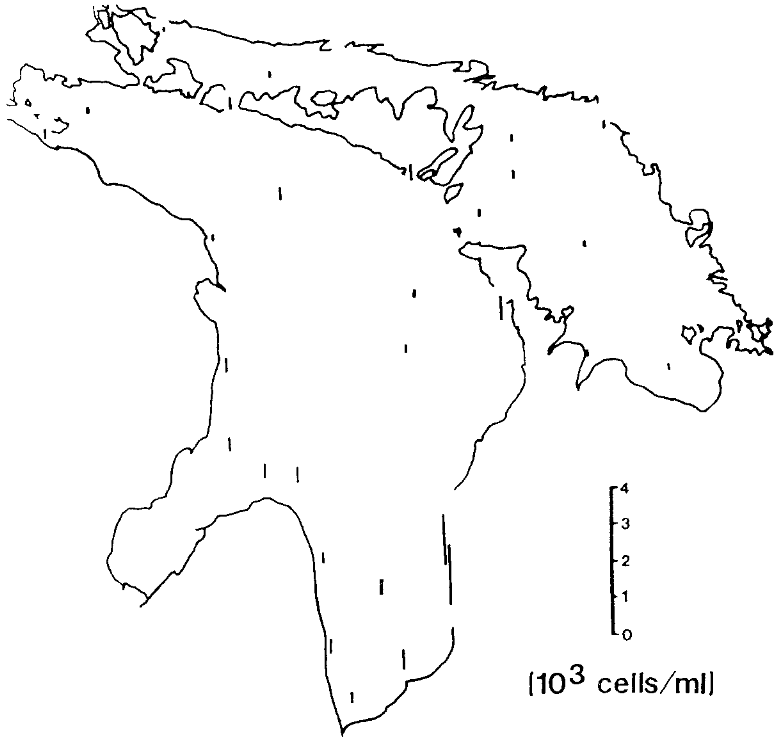

Fig. 20. May spatial pattern of cryptomonad abundances.

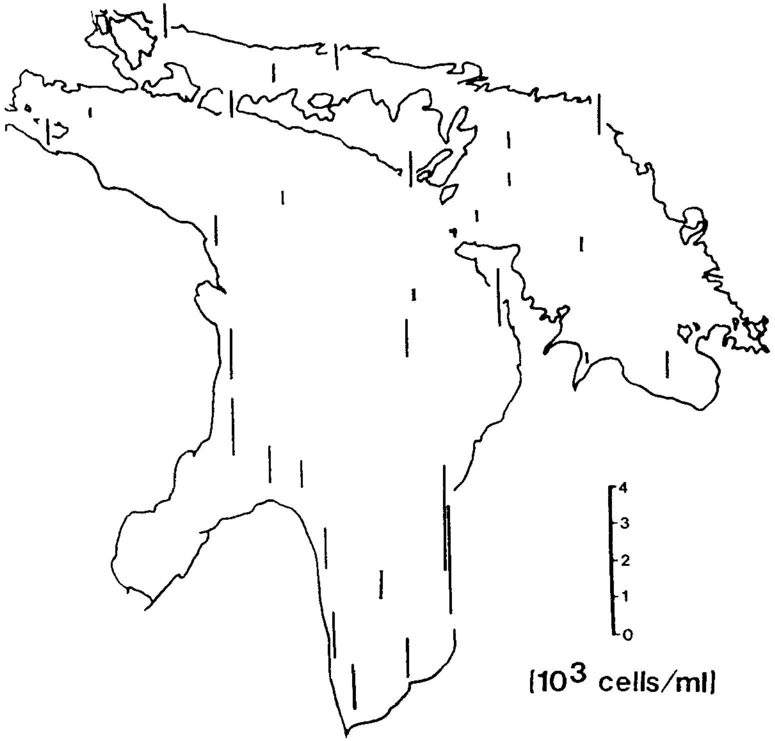

Fig. 21. May spatial pattern of unidentified flagellate abundances.

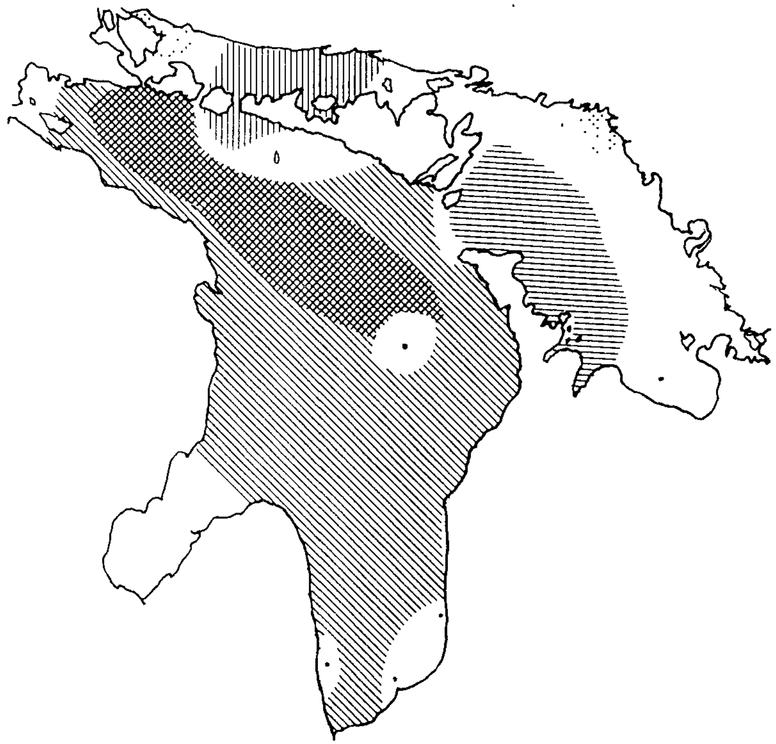

Fig. 22. May clusters of similar planktonic diatom assemblages.

algae (Figs. 19, 20, & 21). The greatest abundance of diatoms occurred at S 3. With an amalgamated distance of 7.0, the S 3 assemblage with particularly high abundances of C. ocellata and F. pinnata clustered with the rest of the assemblages observed in May.

Diatom diversity was as high in May as in April (Fig. 23), ranging from 3.0 to 5.0. Diatom species diversity was high in low abundance assemblages of the North Channel and Georgian Bay as well as in the assemblages of the nearshore of the southern basin. The greatest diversity was found at S 3, where the highest diatom abundance was also observed.

Spatial Patterns of Phytoplankton -- June

During June, when diatom biovolume still comprised most of the algal biovolume in the lake, diatom biovolume was again high, usually greater than 3.0 x 106 um3/ml in the southern basin. But unlike earlier in the spring, algal biovolumes were also shown to be higher in the central basin of the lake (Fig. 24). Diatom biovolume, as well as total algal biovolume was again low in the North Channel and Georgian Bay. As far as the biovolume of algae was concerned, Tabellaria fenestrata was more exclusively dominant around the lake during June than earlier in the spring. Abundances of diatoms and unidentified flagellates were generally greater in the nearshore areas of the southern basin (Figs. 25 & 26), whereas blue-greens were again concentrated along the eastern shore of the southern basin (Fig. 27). As in May, diatom biovolumes were greater at S 7 than elsewhere in the Lake; and as throughout the spring cruises, diatom biovolumes were consistently greater at S 7 than S 13, and greater at S 5 than S 10 along the two shores of the southern basin. Diatom diversity was low in this region in June (Fig. 29).

Again, the diatom assemblage at S 7 along the west shore of the southern basin was very different from other assemblages in the lake. Diatom assemblages along the northwest shore, in the north and central basins, and in most nearshore regions of the southern basin were were similar (Fig. 28). Diatom assemblages in most of the North Channel and Georgian Bay were similar and shared that similarity with assemblages across the Lake and north of Saginaw Bay. Diatom assemblages east of Saginaw Bay were similar to the assemblage at S 1, in the southern tip of the Lake. The diatom assemblages at the four stations at the interface of Georgian Bay and central basin and along the north shore of the north basin were somewhat different from one another, but were even more different from the assemblages in the rest of the lake. Ten and eleven species of diatoms were used in two cluster analyses to study patterns in diatom assemblages in June (Table 2). Tabellaria fenestrata and Fragilaria crotonensis were again the dominant two taxa, with relative abundances that averaged 38.5 and 11.7 percent, respectively (Table 3). During the spring, relative abundances of these taxa grew farther apart. The same subdominant taxa as in April and May were still averaging between 3 and 7 percent relative abundances in June. Regions in the lake were again separated from one another if the difference between assemblages in a cluster exceeded 3.0, and assemblages at individual stations were again distinguished if the difference between them and other assemblages exceeded 4.0.

The diatom assemblage at the mouth of the St. Mary's River, S 71, was very similar to the cluster of assemblages in north and central basins when the eleventh species, Synedra radians was not included in the cluster

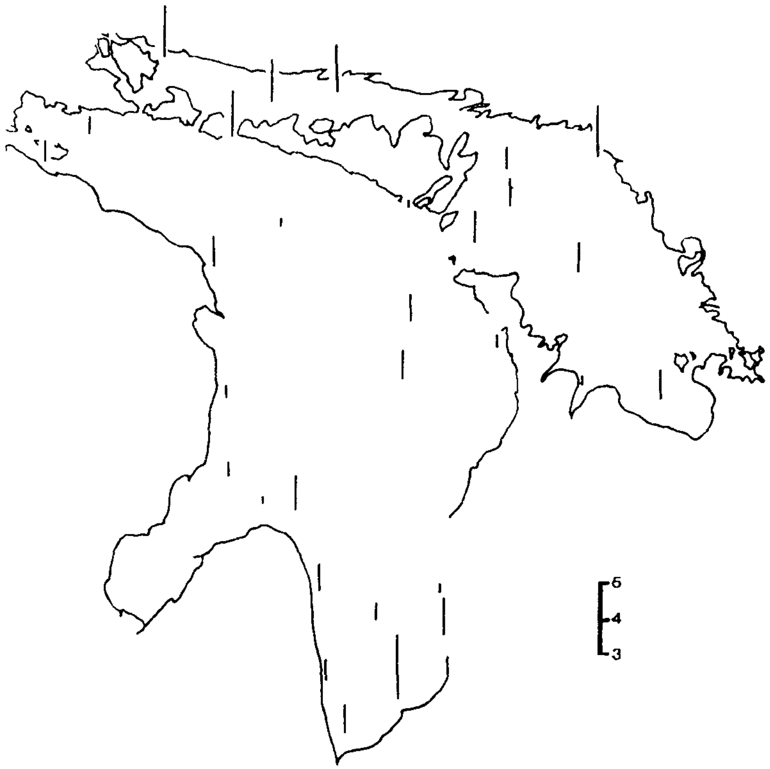

Fig. 23. May spatial pattern of diatom diversity.

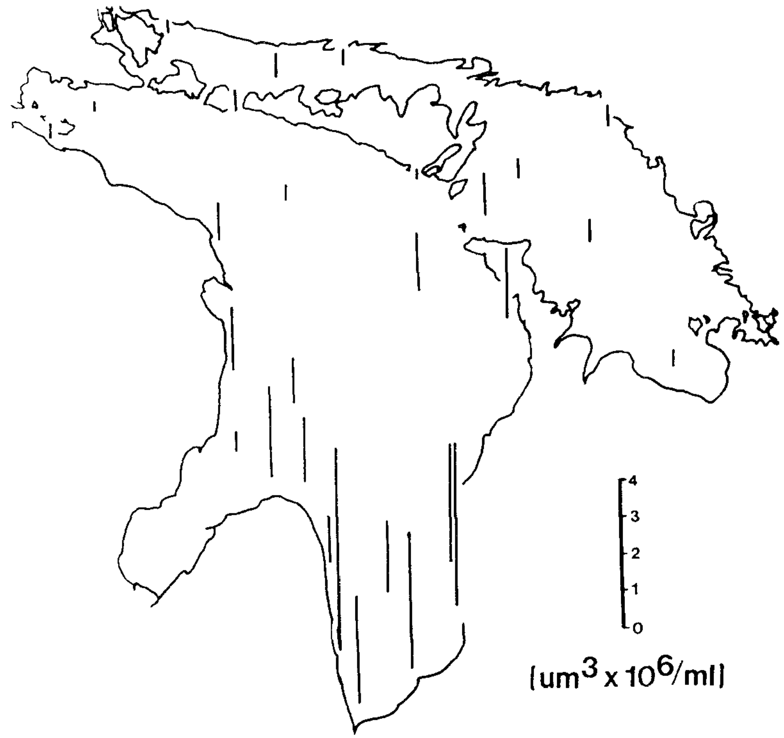

Fig. 24. June spatial pattern of total algal biovolume.

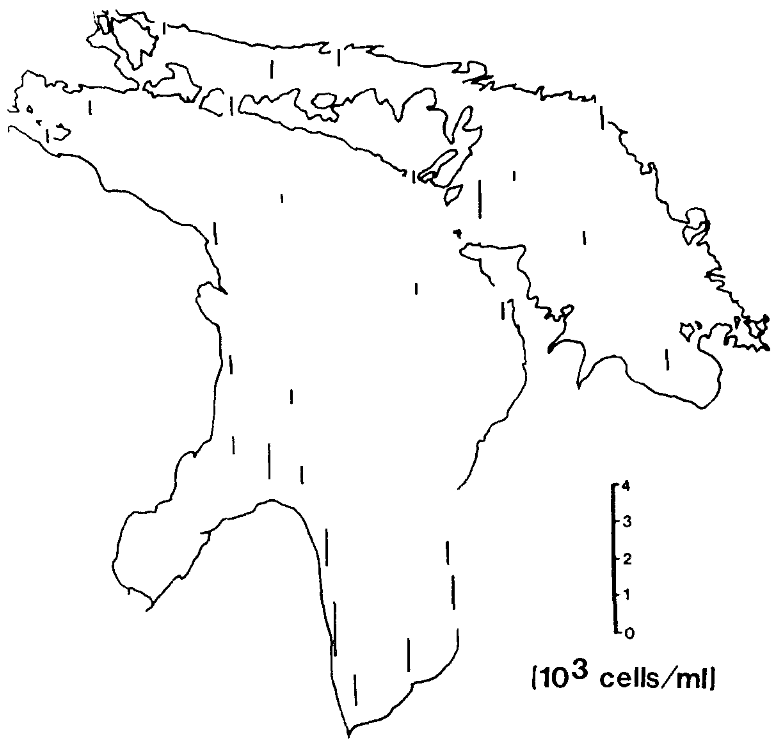

Fig. 25. June spatial pattern of diatom abundances.

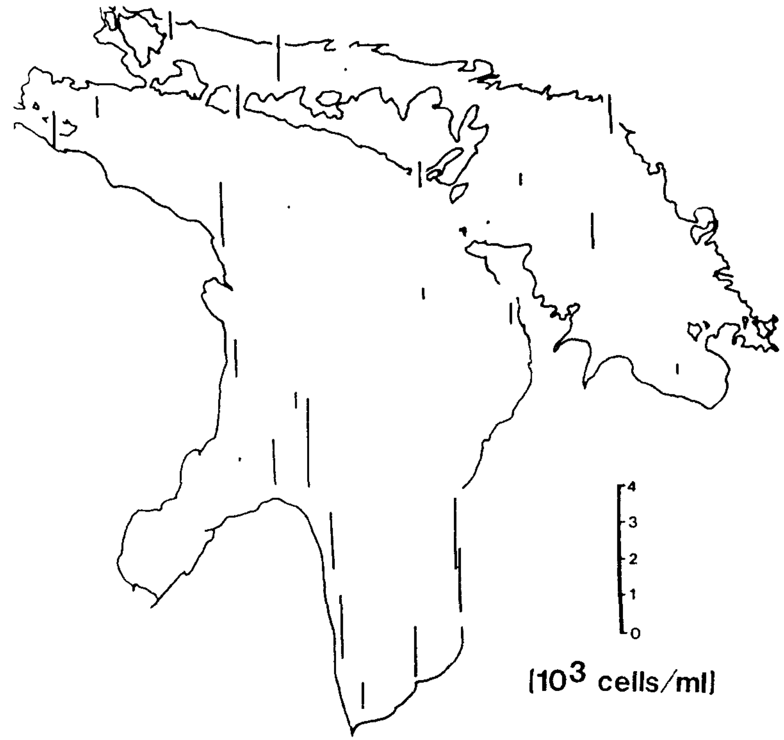

Fig. 26. June spatial pattern of unidentified flagellate abundances.

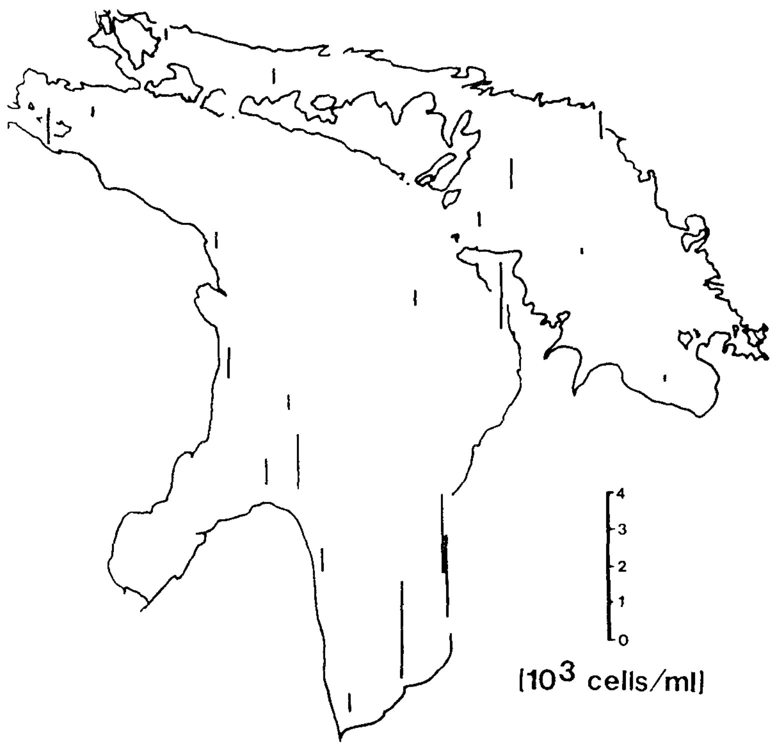

Fig. 27. June spatial pattern of blue-green algal abundances.

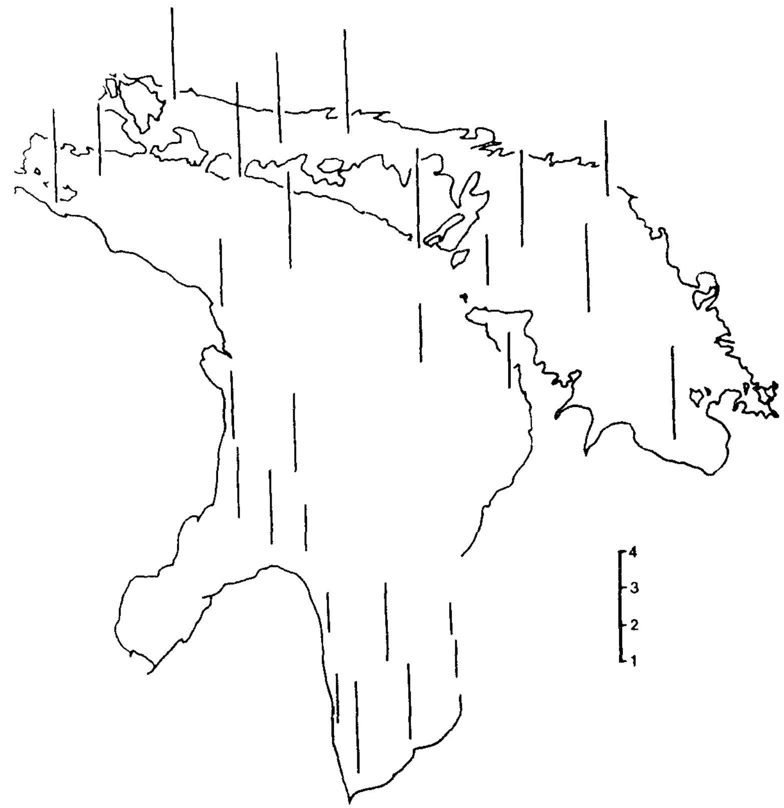

Fig. 28. June spatial pattern of diatom diversity.

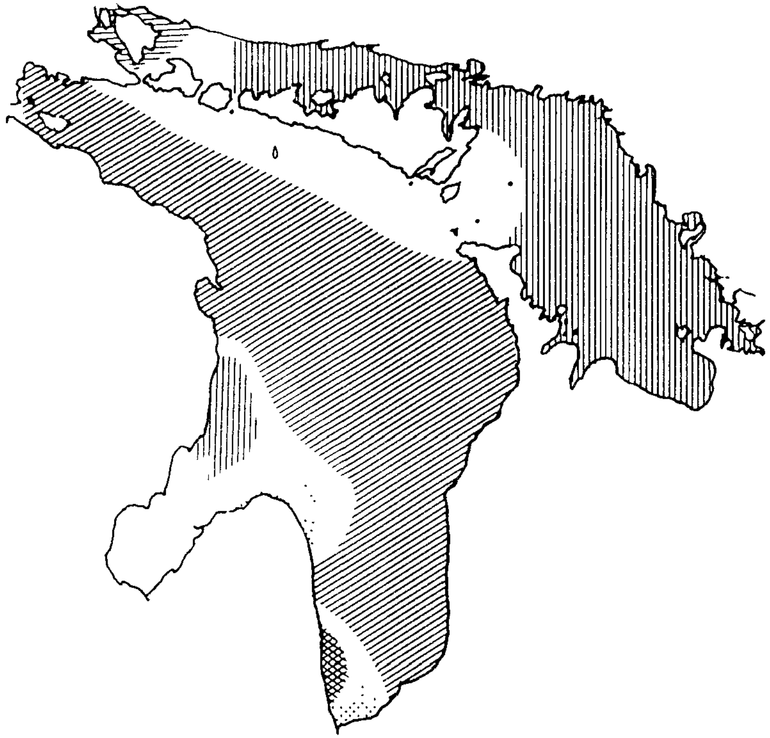

Fig. 29. June clusters of similar planktonic diatom assemblages.

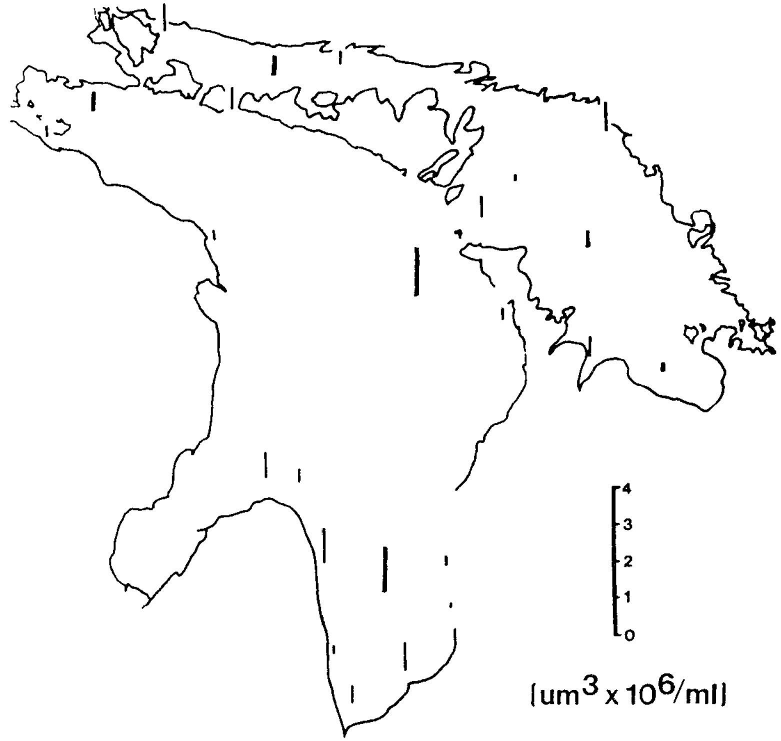

Fig. 30. July spatial pattern of total algal biovolume.

analysis. Synedra radians was only abundant at S 71, and was the reason that the region around the mouth of the St. Mary's River was separated from others.

The diatom assemblage in the central basin and most of the northern and southern basin during June was characterized by having more Asterionella formosa and Melosira islandica and less Cyclotella spp., particularly C. glomerata and C. michiganiana, than other assemblages.

The Georgian Bay - North Channel diatom assemblage had more Cyclotella spp. and less Fragilaria capucina, M. islandica, and Tabellaria spp. (both species) than other clusters of diatom assemblages.

Assemblages east of Saginaw Bay were characterized by having high abundances of F. capucina.

Diatoms were again most abundant at S 7 along the western shore of the southern basin, and most different from other assemblages as well. High abundances of T. fenestrata and C. glomerata and low abundances of Cyclotella stelligera and M. islandica characterized the assemblage at S 7.

As far as miscellaneous assemblages around the Lake were concerned, again more C. stelligera occurred at S 125 than other localities in the Lake. Low abundances of F. crotonensis and A. formosa occurred at S 50 and S 58 along the north shore.

Spatial Patterns in Phytoplankton -- July

Spatial patterns in standing crop of algal divisions were not clearly evident during the rest of the cruises. Two reasons seemed to be responsible for this. First, it is probable that no patterns existed during the July cruise. Second, the Georgian Bay was not sampled during the September cruise, 5, few nearshore stations were sampled during cruise 6, and only stations in the southern basin of Lake Huron were sampled during the winter cruises.

During July, algal biovolumes in the nearshore regions of the southern basin were substantially lower than in the spring and were not very different from the biovolumes of algae that were in the other parts of the Lake (Fig. 30). Algal biovolumes in the North Channel and Georgian Bay were similar to spring biovolumes. Algal biovolume seldom exceeded 1.0 x 106 um3/ml and was usually less than 0.5 x 106 um3/ml. Algal biovolumes were again highly correlated to diatom abundances (Fig. 31), which were generally 500 cells/ml or less. The correlation between algal biovolumes and diatom abundances was maintained despite the fact that blue-green algal abundances were starting to increase from previous dates (Fig. 32). Blue-green abundance, most of which was Anacystis marina, exceeded 1.0 x 104 cells/ml at S 71 in the North Channel and at several stations in the nearshore regions of the southern basin.

The composition of July diatom assemblages was similar in the Georgian Bay and many areas of Lake Huron, but small offshore and regional nearshore differences were evident (Fig. 33). Eleven species of diatoms with relative abundances greater than 10 percent or averaging greater than 2 percent were used in the cluster analysis of diatoms assemblages in July (Table 2). The relative abundances of Cyclotella michiganiana increased from 4 to 33 percent from June to July (Table 3). The sudden increase in C. michiganiana was probably the result of different personnel identifying algae in June and July. Fragilaria crotonensis and Cyclotella comensis were subdominant taxa with 11 and 12 percent relative abundances, respectively. Relative abundance of

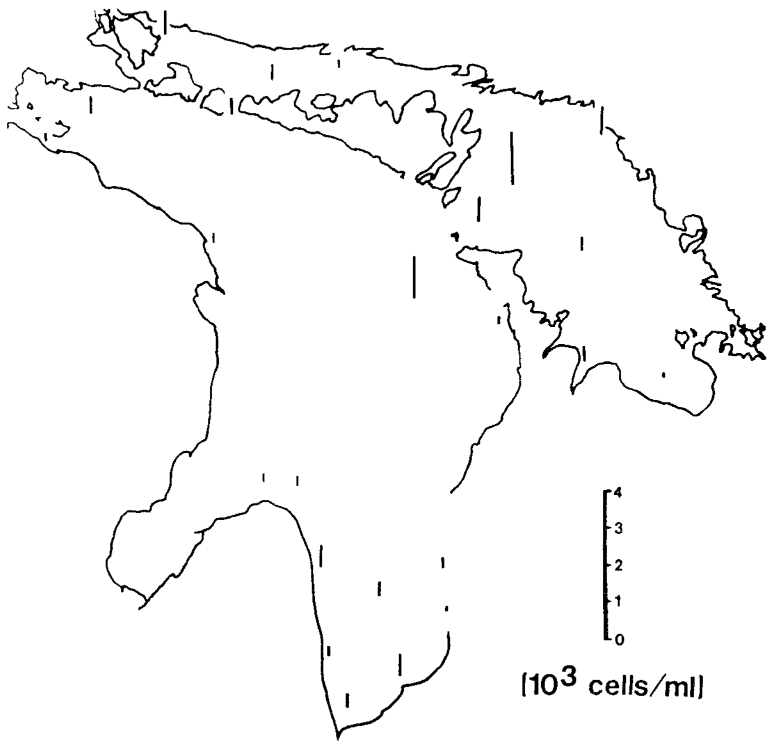

Fig. 31. July spatial pattern of diatom abundances.

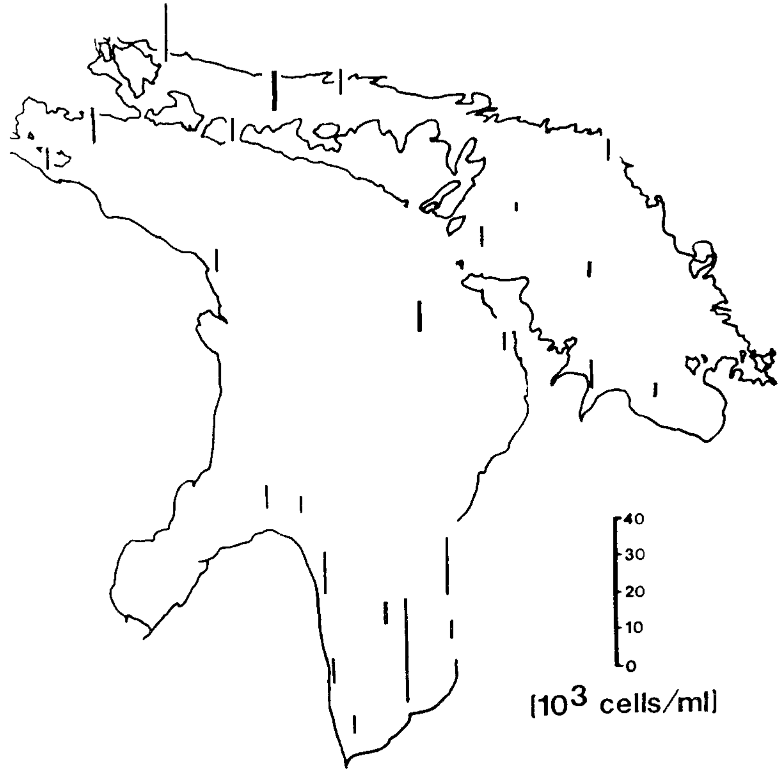

Fig. 32. July spatial pattern of blue-green algal abundances.

Fig. 33. July clusters of similar planktonic diatom assemblages.

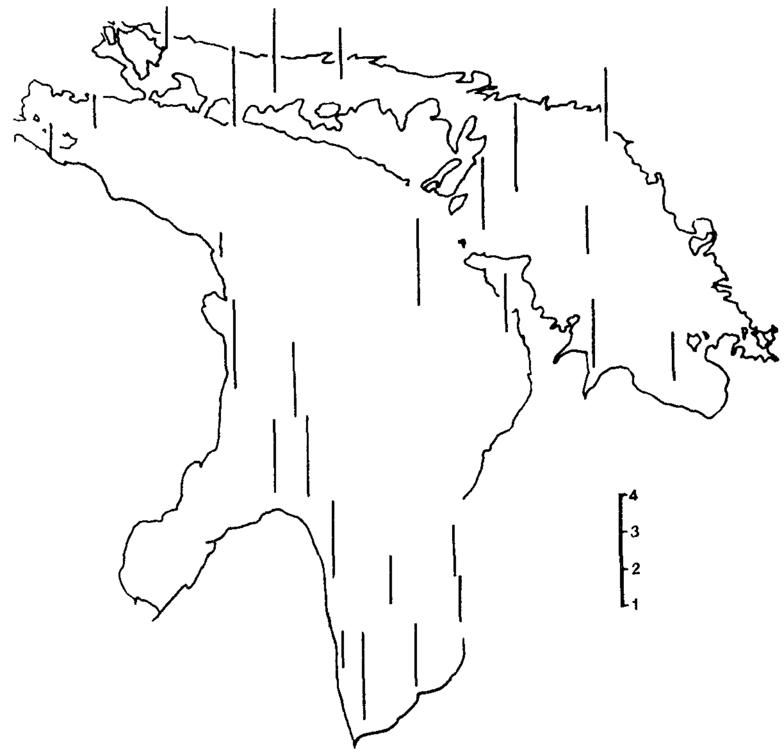

Fig. 34. July spatial pattern of diatom diversity.

Tabellaria fenestrata had decreased to an average of 5.4. The amalgamated Euclidean distances among assemblages in the clusters discussed were no greater than 3.0.

The large assemblage in the Georgian Bay and many nearshore areas of the Lake were characterized with less Synedra radians and more Tabellaria flocculosa and Cyclotella spp., particularly C. comta, C. ocellata, and C. stelligera, than in the rest of the lake. When amalgamation distance was increased from 2.8 to 3.0, the offshore assemblage in the central basin clustered with the Georgian Bay and the nearshore regions of most of Lake Huron. The offshore region had less C. comta and more C. ocellata, Rhizosolenia eriensis, Rhizosolenia longiseta, and T. fenestrata than most other assemblages.

The most different assemblage, clustering with the rest of the Lake with an amalgamation distance of 6.4, was at S 71 near the St. Mary's River. This assemblage was unusually rich in S. radians, T. flocculosa, and Asterionella formosa. Less T. fenestrata was observed here than elsewhere.

Species diversity of diatoms was lower than usual, ranging from 1.0 to 4.0 (Fig. 34).

Spatial Patterns in Phytoplankton -- September

During September algal biovolume was usually less than 0.5 x 10^6 um3/ml, but a couple of curiously high biovolumes occurred at S 50 along the north shore of the central basin and at S 2 in the southern basin (Fig. 35). Abundances of 10 cells/ml of the dinoflagellate Ceratium hirundinella were responsible for the peak in the southern basin, whereas a single observation of a frustule of the large diatom, Cymbella lanceolata, was responsible for the peak at S 50. Diatom abundances were again usually 500 cells/ml or less (Fig. 36), as were unidentified flagellate abundances (Fig. 37). Higher than average diatom abundances were again observed at S 7. Unidentified flagellates were also common at S 7, but also at other locations in the southern basin. Alternatively, high abundances of blue-green algae were more widespread during September than during July (Fig. 38). Although blue-green abundances greater than 2.0 x 10^4 cells/ml were most common in the southern basin, high abundances also occurred in other areas of the lake. Coccochloris peniocystis, as well as Anacystis marina, were the numerically dominant blue-green algae.

Diatom assemblages were very similar throughout the Lake during September, perhaps because abundances were so low. Only seven taxa of diatoms were considered to be numerically dominant forms for use in the cluster analyses of September diatom assemblages (Table 2). Regions of the Lake with diatom assemblages having differences between them of less than 2.0 were delineated, and an assemblage at a station with a difference greater than 3.0 was distinguished from other assemblages (Fig. 39). Three cluster analyses were computed to study regions with similar diatom assemblages because some taxonomic difficulties were encountered with three of the dominant taxa that were small species of Cyclotella. In these analyses, Cyclotella comensis, C. michiganiana, and C. comensis var. #1 were combined in different ways. Irregardless of which clustering scheme was studied, similar regions were delineated.

Cyclotella comensis (with var. #1) accounted for an average of 40 percent of the diatoms observed in samples (Table 3). Cyclotella michiganiana and

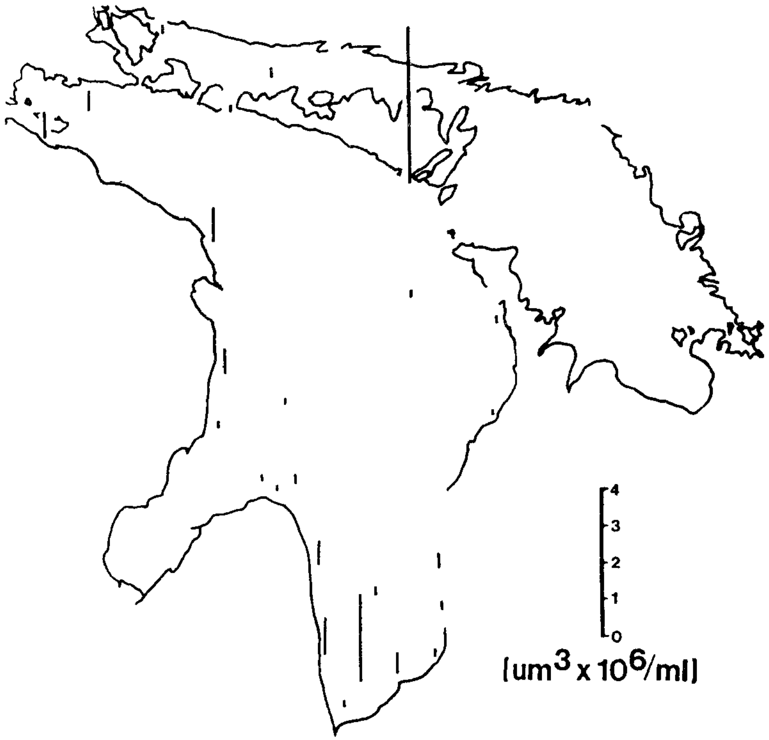

Fig. 35. September spatial pattern in total algal biovolume.

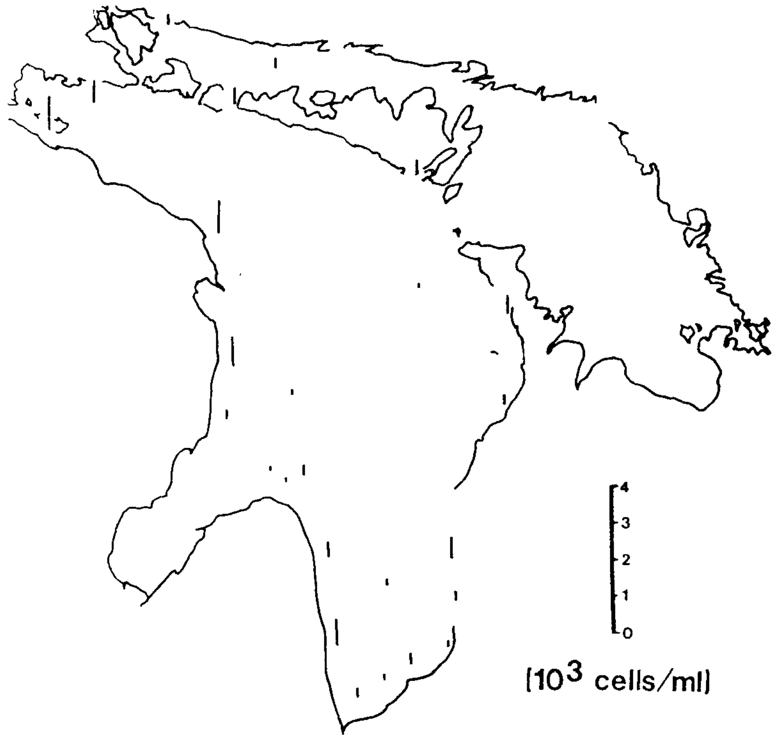

Fig. 36. September spatial pattern in diatom abundances.

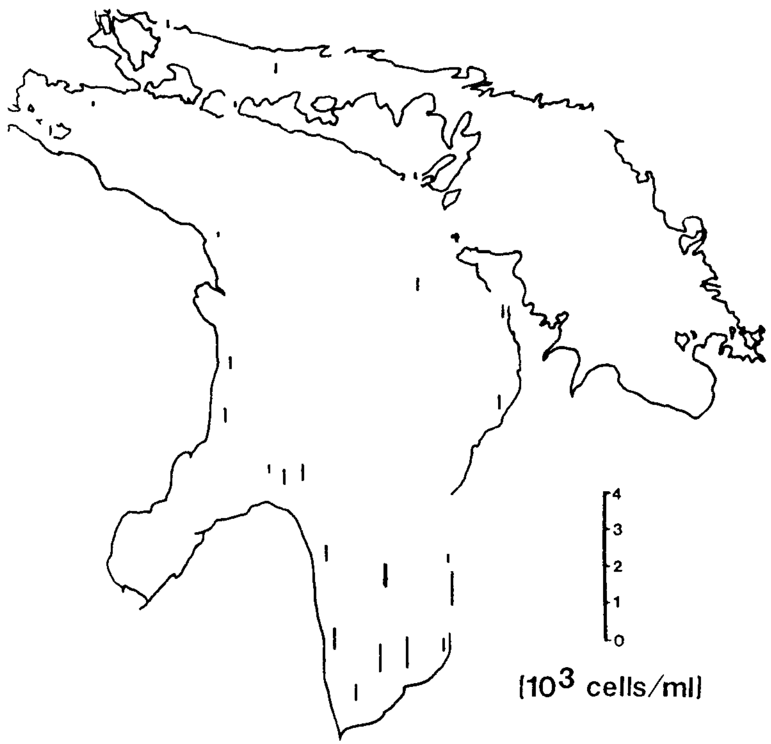

Fig. 37. September spatial pattern in unidentified flagellate abundances.

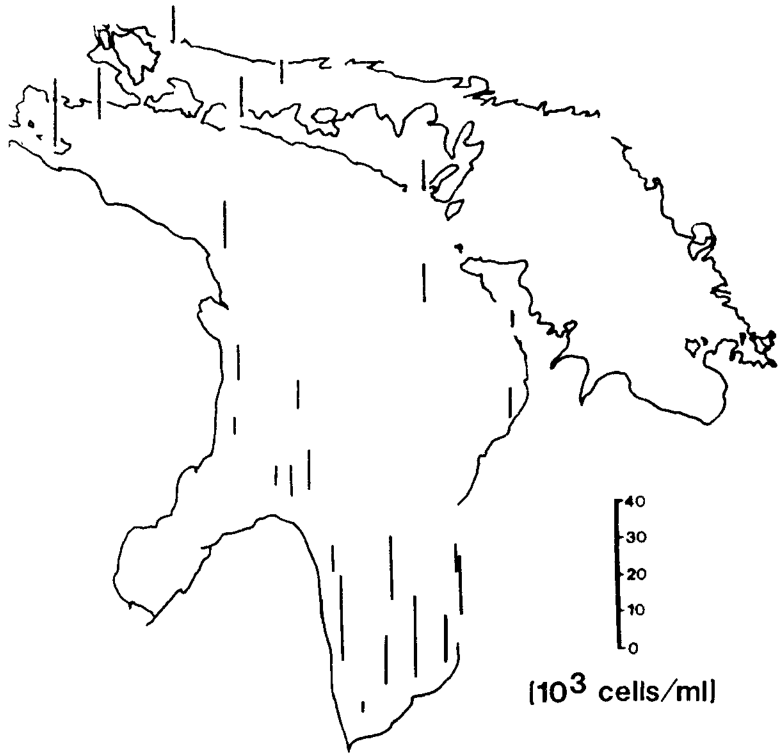

Fig. 38. September spatial pattern in blue-green algal abundances.

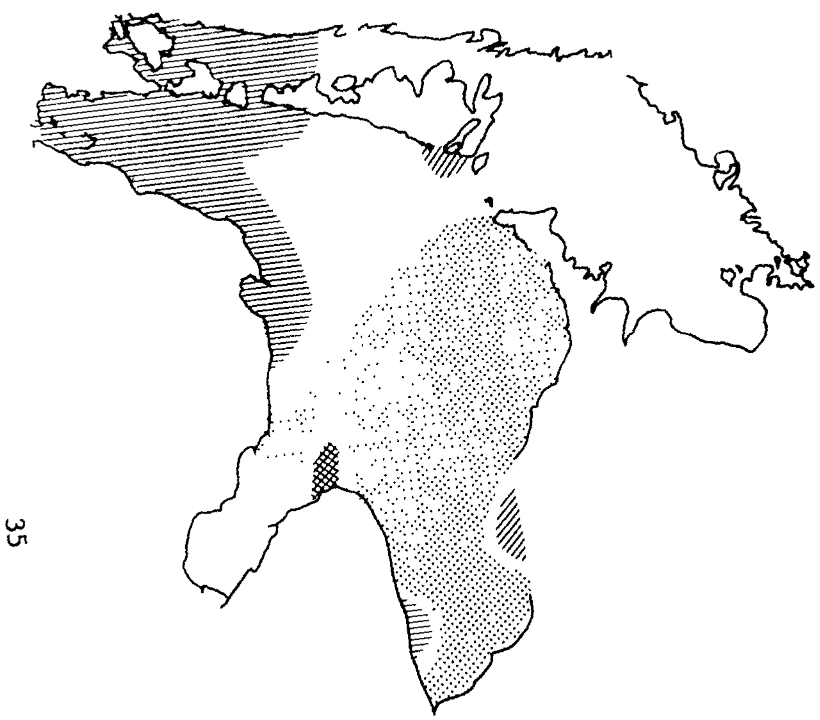

Fig. 39. September clusters of similar planktonic diatom assemblages.

Fig. 40. September spatial pattern in diatom diversity.

Fragilaria crotonensis remained subdominants with 12 and 17 percent relative abundance averages, respectively.

Diatom assemblages in the central basin and most of the southern basin were very similar. Assemblages in this region formed a cluster with an amalgamated distance less than 2.3. Diatom abundances in this region were lower than average. Cyclotella comensis (and related morphotypes) were unusually sparse here.

Diatom assemblages in the North Channel, near the Straits of Mackinac, and the nearshore regions of the north basin were also similar. The diatom assemblage at S 7 was again different from others in the southern basin, but during September was similar to assemblages in the northern end of the lake. With a 2.34 distance, abundances of Achnanthes minutissima were lower and abundances of Cyclotella comta were greater in this cluster than in most other assemblages.

Diatom assemblages with high abundances of A. minutissima at S 10, along the eastern side of the southern basin, and at S 50, in the nearshore region near the Georgian Bay, were very similar to one another, and different from assemblages in the rest of the lake.

The diatom assemblage at S 19, at the eastern end of Saginaw Bay, was the most different from other assemblages in the lake. It was grouped with the rest of the assemblages in the Lake if amalgamated distance of the cluster was 4.0. This assemblage was characterized by lower abundances of A. minutissima, and in particular, higher abundances of F. crotonensis than elsewhere.

Diatom diversities were again in the range of 1.0 to 4.0 during September (Fig. 40). No spatial pattern in diversities was evident.

Spatial Pattern of Phytoplankton -- October through February

Few integrated samples were collected during the late October cruise. Standing crops of algae at the stations that were sampled were not different than those observed in July and September cruises (Fig. 41). Fragilaria crotonensis accounted for 43 percent and Asterionella formosa accounted for 10 percent of the diatoms in samples from the northern regions of the Lake during October and November. No cluster analyses of diatom assemblages were studied. Diatom diversity again ranged from 1.0 to 4.0 (Fig. 42).

During the first winter cruise in January 1981, algal biovolume was nearly the same as during the July and September cruises, about 0.5 x 106 um3/ml, in the nearshore regions and less than that in the offshore regions of the southern basin (Fig. 43). Diatom abundance, about 500 cells/ml, was again responsible for algal biovolume (Fig. 44). Similar species of diatoms were common during January as were common during the rest of the year. Blue-green algae were quite abundant, commonly exceeding 1.5 x 104 cells/ml (Fig. 45). Diatom and especially blue-green algal abundances were generally lower near Saginaw Bay than elsewhere in the southern basin.

During the second winter cruise in February 1985, algal biovolume was generally the same in the southern basin as during January, but unusually high quantities of biovolume were observed at S 7 and 1 (Fig. 46). The high peaks at S 7 and 1 were due to observation of a few cells of an unidentified species of the desmid Staurastrum. Diatom cell abundances were again about 500 cells/ml (Fig. 47). Similar species of diatoms were common during February as were common during the rest of the year. A bloom of Anacystis marina was evident in blue-green algal abundances at S 5 (Fig. 48). Again,

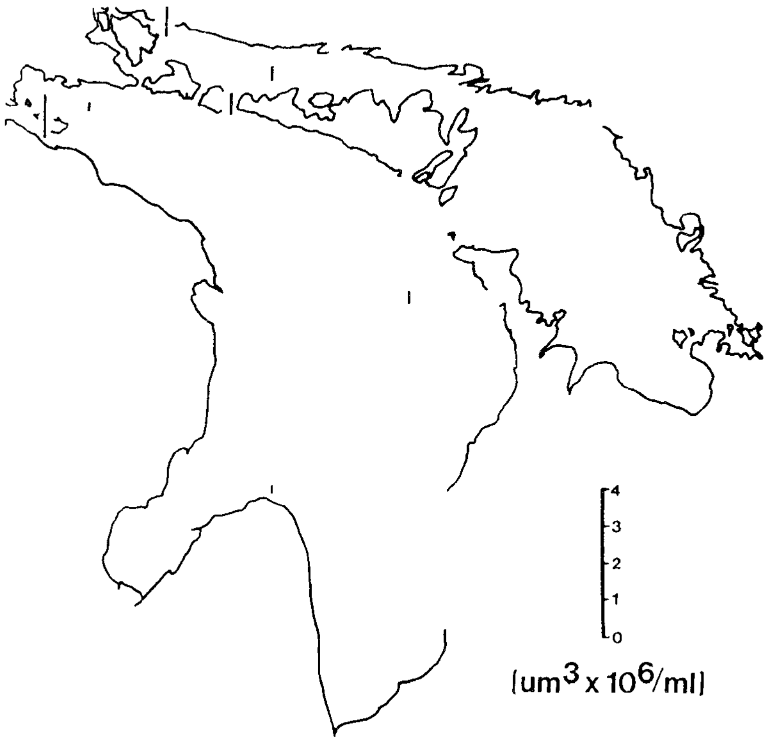

Fig. 41. October-November spatial pattern in total algal biovolume.

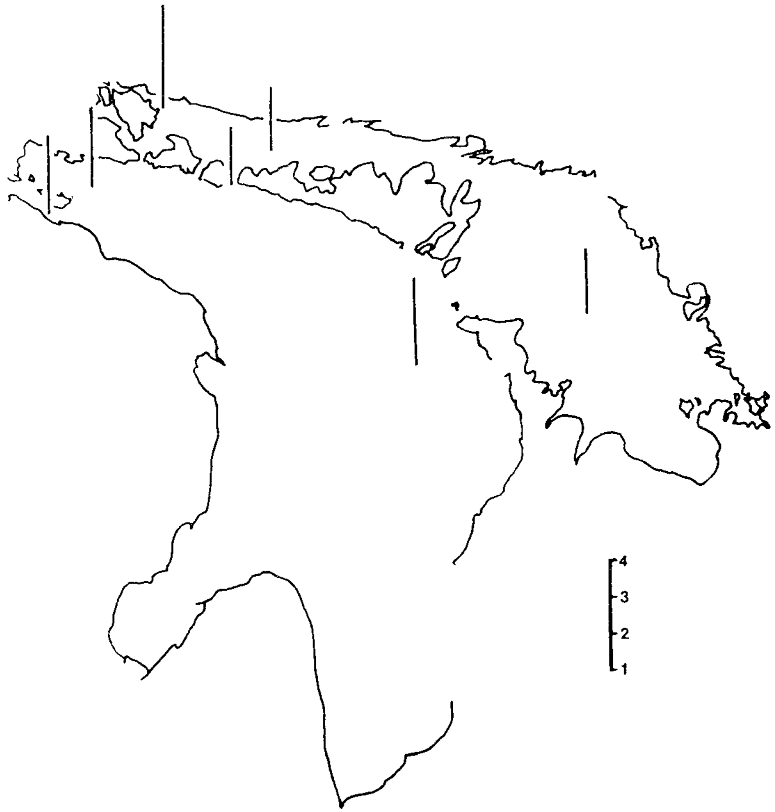

Fig. 42. October-November spatial pattern in diatom diversity.

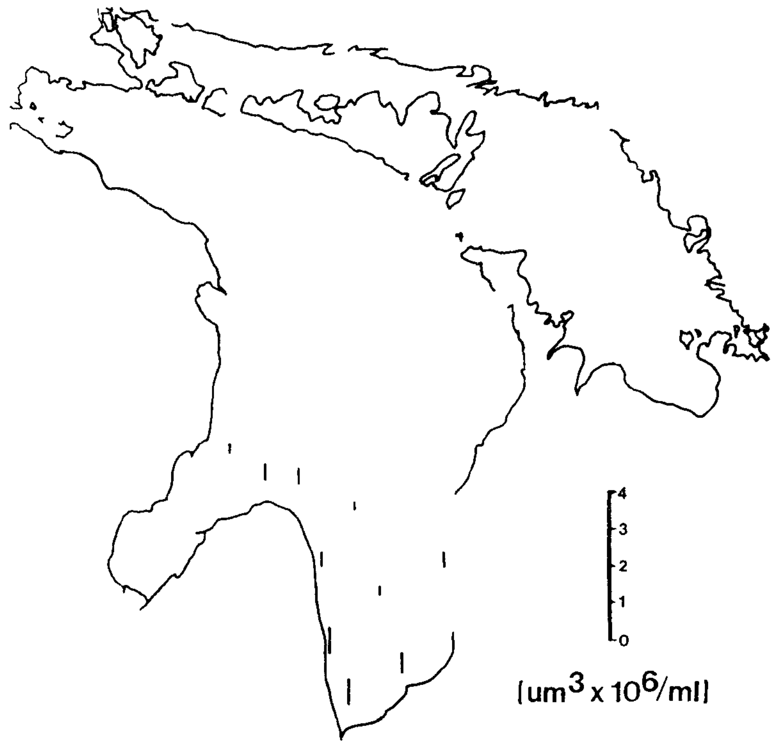

Fig. 43. January 1981 spatial pattern in total algal biovolume.

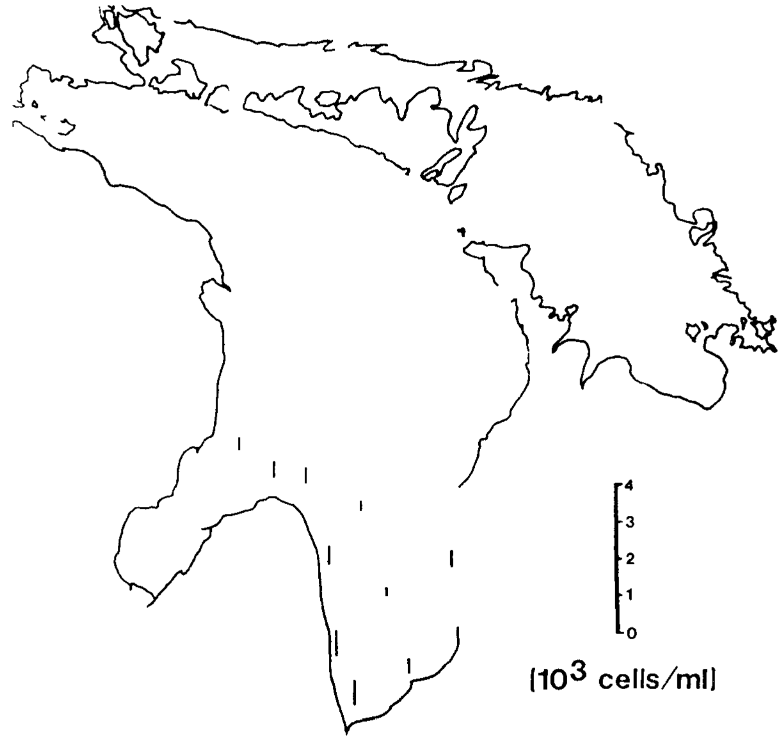

Fig. 44. January 1981 spatial pattern in diatom abundance.

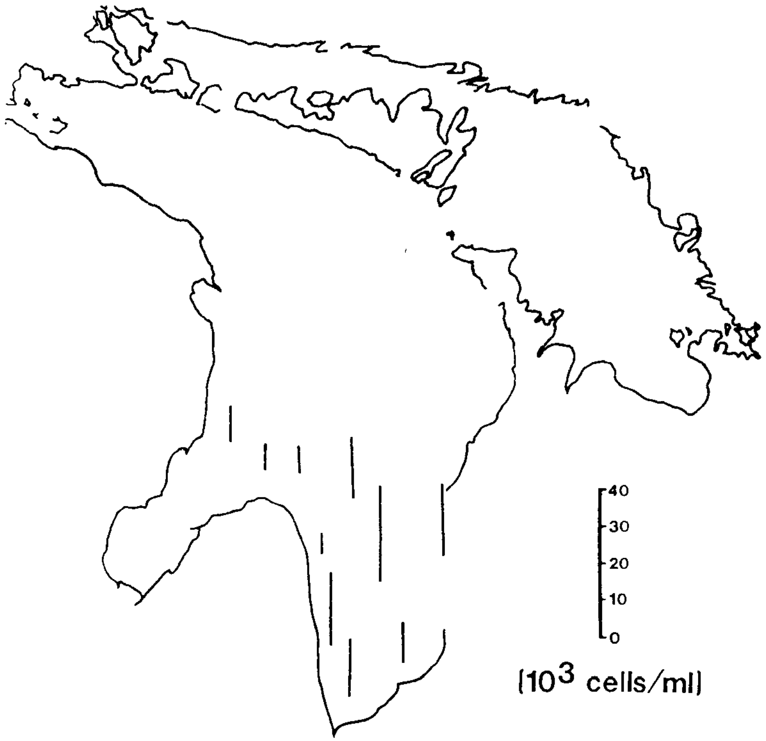

Fig. 45. January 1981 spatial pattern in blue-green algal abundance.

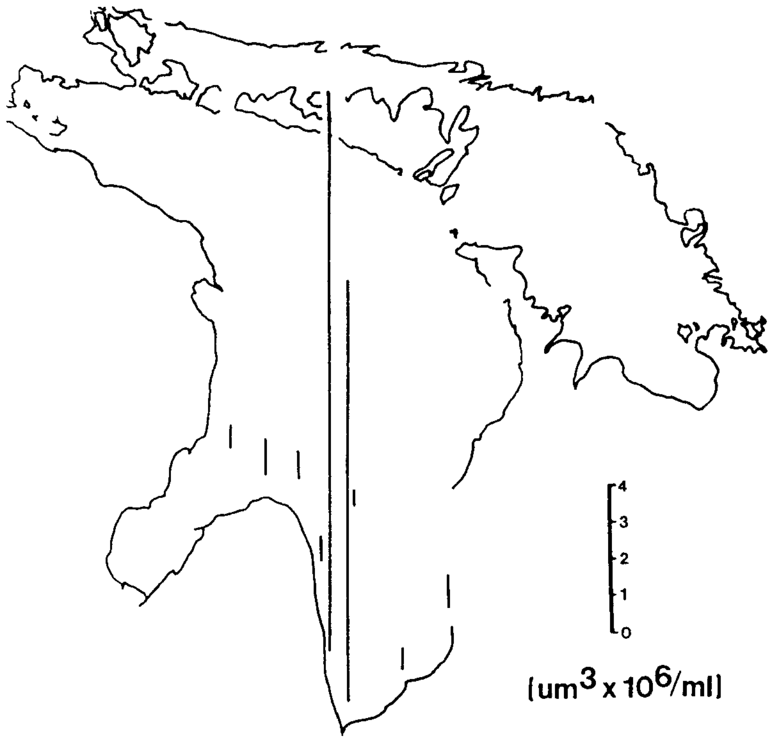

Fig. 46. February 1981 spatial pattern in total algal biovolume.

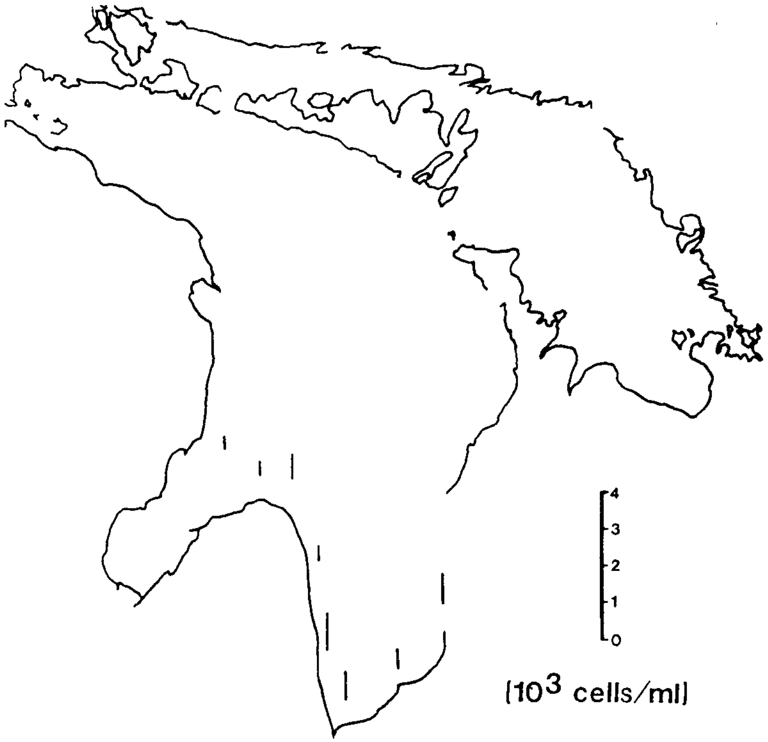

Fig. 47. February 1981 spatial pattern in diatom abundance.

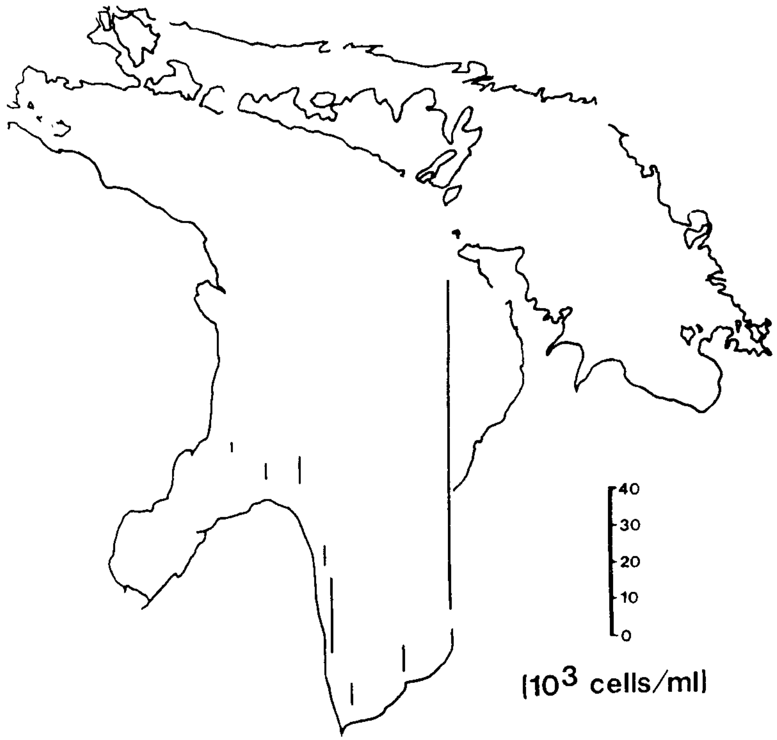

Fig. 48. February 1981 spatial pattern in blue-green algal abundance.

diatom and blue-green algal abundances were not as high as average near Saginaw Bay. During January and February, abundances of diatoms were greatest at S 7, and blue-green algal abundances were greater at S7 than S13.

Statistical Summary of Seasonal and Spatial Patterns

Algae at S 7 were also distinguished by the fact that changes in algal division biovolume from cruise to cruise were greatest there (Fig. 49). Generally, changes in algal division abundances between successive cruises were greatest in the nearshore regions of the southern basin. Unusually high changes were observed at S 21 near Saginaw Bay and S 84 in the North Channel. These great changes were probably related to the irregular sampling schedule at these stations such that times between successive samples were greater. The results of the analysis of regional variation in algal biovolumes were highly significant. Statistically significant ($P<0.001$) differences in total algal biovolume and diatom, chlorophyte, chrysophyte, cyanophyte, and unidentified flagellate biovolume occurred between cruises and between segments of the lake. The regions of the lake that were used in this analysis were modified from those outlined in the EPA segmentation scheme from the 1980 Lake Huron study by Moll et al. (submitted for publication) and are illustrated in Fig. 50. The segmentation scheme was modified to examine differences in algal biovolumes in nearshore regions along the western shore of the southern basin and along the eastern coast of the lake. The nearshore region along the western shore was divided between S 16 and S 13 so that changes in algal abundance due to effects of waters from Saginaw Bay could be separated from effects of water quality degradation that could be occurring along the southwest shore of the lake. The nearshore region along the eastern shore of the lake was divided between S 30 and S 10 for a similar reason, so that changes in water quality along the southeastern shore of the lake could be distinguished from conditions farther north. Interactive effects between season and region were also statistically significant, and probably biologically significant as well, so detailed comparisons of differences between regions would not have been appropriate. In addition, the number of samples collected during each cruise within a region varied from cruise to cruise. The following discussion, then, is based upon the most pronounced differences between segments.

Offshore biovolumes of all algae in the north and central basin, segment 8, and in the Georgian Bay, segment 7, were generally the lowest in the lake (Table 4). Highest algal biovolumes were found in either the nearshore region on the eastern side, western side, or southern end of the southern basin. Biovolumes of all algal divisions were higher in segment 10 than segment 3, farther north along the eastern shore of the lake. Biovolumes of all algae except blue-greens were higher in segment 11, on the western shore of the southern basin than east of Saginaw Bay in segment 2. The highest total, diatom, and green algal biovolumes were found along the western shore of the southern basin in segment 11. Biovolumes of diatoms and green algae were also high in segment 5, along the western shore of the north basin and near the Straits of Mackinac.

Vertical Patterns in Algae

The seasonal pattern of high algal biovolumes during the spring and

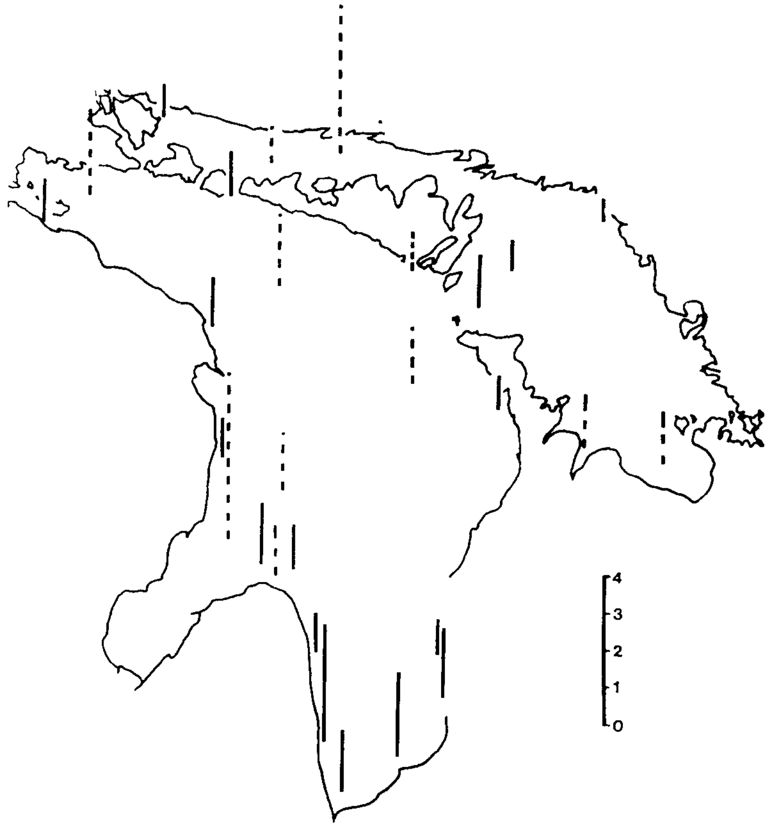

Fig. 49. Spatial pattern in seasonal variation of algal division biovolumes. Dotted lines were used at stations where integrated samples were not collected during one or more of the first four cruises.

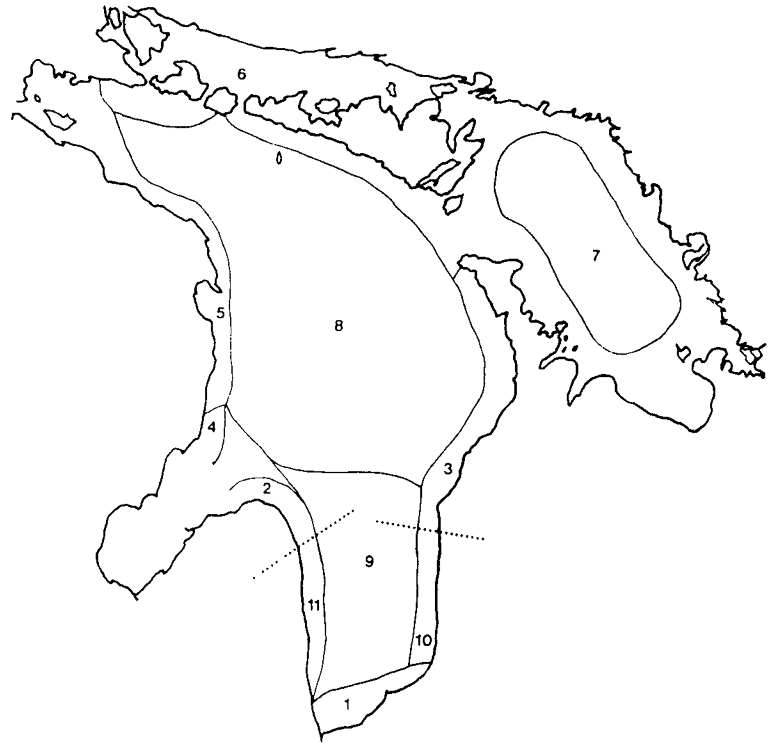

Fig. 50. Regions of Lake Huron that were used to study differences in algal division biovolumes with analysis of variance procedures.

Table 4. Ranks of the biovolumes of algae in segments of Lake Huron. The lowest is 1 and 10 is the highest.

Segment	Total Algae	Diatoms	Green Algae	Blue-Green Algae	Chryso-phytes	Unident. flag.
1	9	7	7	10	9	8
2	7	4	6	8	7	7
3	6	6	3	6	6	5
4	2	2	5	4	2	3
5	5	8	9	5	5	6
6	3	5	4	3	3	4
7	4	1	2	2	4	1
8	1	3	1	1	1	1
9	*	*	*	*	*	*
10	10	9	8	9	10	10
11	8	10	10	7	8	9

* Only one integrated sample collected in region 9.

early summer was also evident in plots of depth profiles of algal biovolume at stations 9, 43, 66, 78, 104, and 117 (Figs. 51 to 56). Algal biovolume in surface waters was lowest during July, September, and October; however, great biovolumes of diatoms were observed at deeper depths during July. The great predominance of algal biovolume by diatoms was again evident throughout the year.

The regional pattern in algal biovolume was also evident. Algal biovolume was generally greatest in the southern basin at S 9, and was regularly lowest in the North Channel and Georgian Bay at S 78, S 104, and S 117. Of course, this pattern was particularly evident when algal biovolumes were seasonally higher during April, May, and June (Figs. 51, 52, & 53) than during July, September, and October-November cruises (Figs. 54, 55, & 56).

It was also noted that peaks in algal biovolume occurred between 25 and 30 m at station 9 (Figs. 51 to 55), whereas unusually high algal biovolumes at significant depths were not clearly evident at other locations except during July. Some evidence for diatom blooms at 20 m was apparent near the Straits of Mackinac (S 66) in April, but diatom biovolumes were also high at 5 m (Fig. 51).

The deep-water peaks in algal biovolume were the result of many different species. Unidentified flagellates were responsible for the deep-water peak in the southern basin during April. The September peak in the southern basin at S 9 was due to observation of a couple cells of the green alga Staurastrum, as was also the case at 10 m at S 9 in July. The remaining deep-water peaks of algal biovolume in July were due to high abundances of the Rhizosolenia spp. Most of the 30 m peak in biovolume a S 9 in July was accounted for by R. longiseta, as was the small peak at S 78 in the North Channel. Deep-water peaks in the Georgian Bay were the result of high abundances of R. eriensis. Both species of Rhizosolenia were important in deep-water biovolume peaks at S 43 and S 66 in the central and northern basins of Lake Huron.

Correlations Between Lake Huron Water Chemistry Characteristics

Nutrient levels were generally poorly correlated to conservative ion concentrations and pH in the Lake Huron waters (Table 5; raw chemistry data from Moll et al. in press). Phosphorus, nitrogen, and silica concentrations were positively correlated to each other, and to ammonia and oxygen concentrations. Total and dissolved phosphorus concentrations were the most closely correlated nutrients ($r=.74$). Conductivity, chloride, and alkalinity were more closely related to each other ($.97>r>.57$) than to sulfate. The strongest negative correlations were between silicate and pH, conductivity, chloride, and alkalinity ($-.60>r>-.74$).

Nutrient concentrations decreased from spring to fall. Cruise number was negatively correlated to phosphorus concentrations and nitrate-nitrite, and silica concentrations. The strong negative correlation between cruise number and oxygen indicated the importance of the decrease in algal biovolume from spring to fall. However, little correlation was observed between conservative ion concentrations (conductivity, chloride, sulfate, and alkalinity) and cruise number.

Correlations Between Algal Division Biovolumes and Water Chemistry

Total algal biovolume was positively correlated to phosphorus and nitrogen

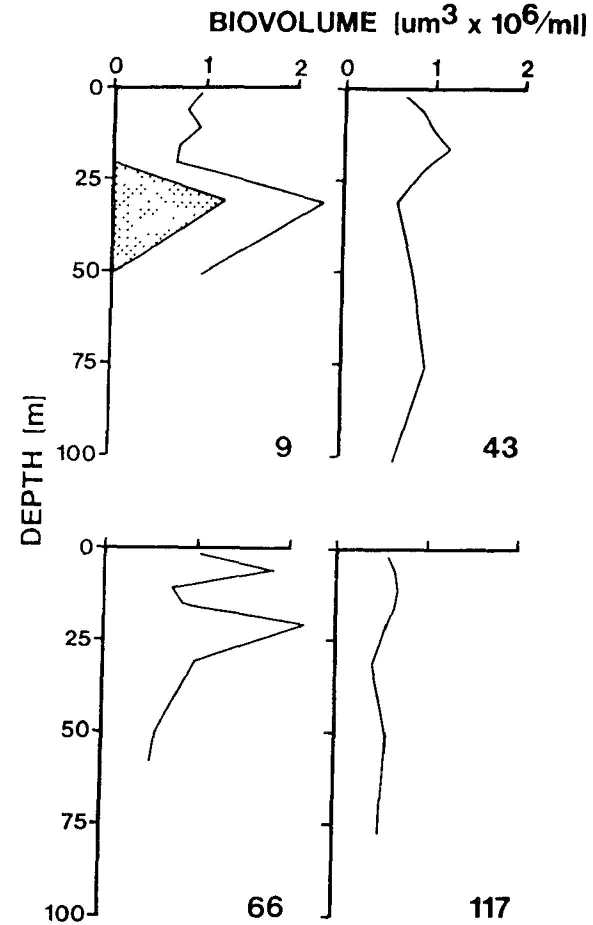

Fig. 51. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during April. Unmarked area indicated diatoms & the dotted area indicated dinoflagellates.

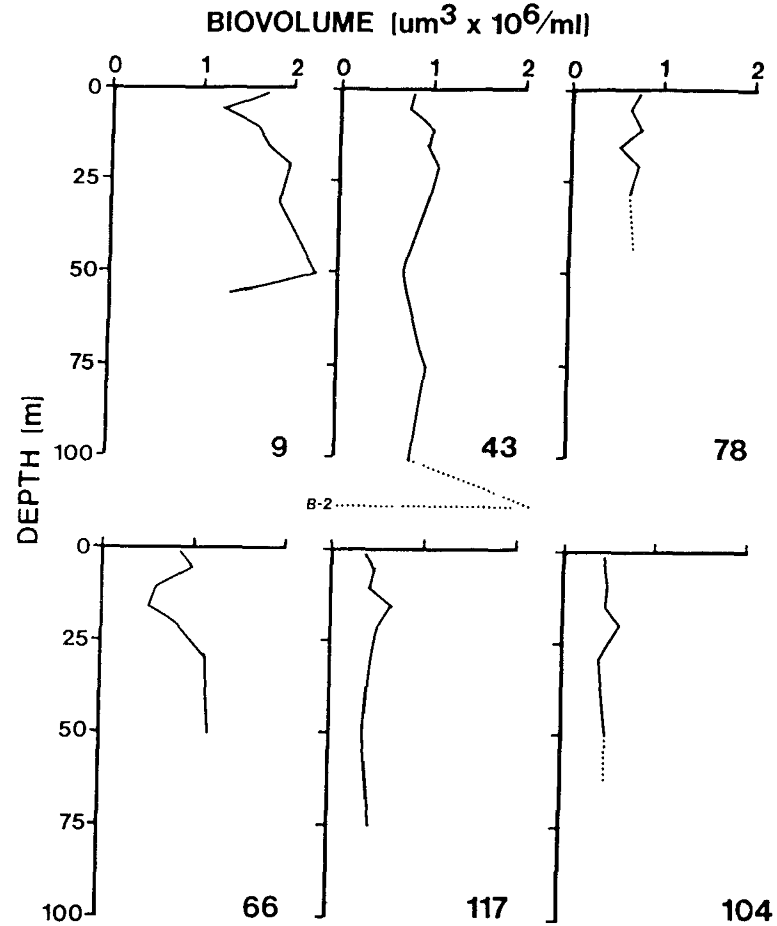

Fig. 52. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during May. Unmarked area indicated diatom biovolumes.

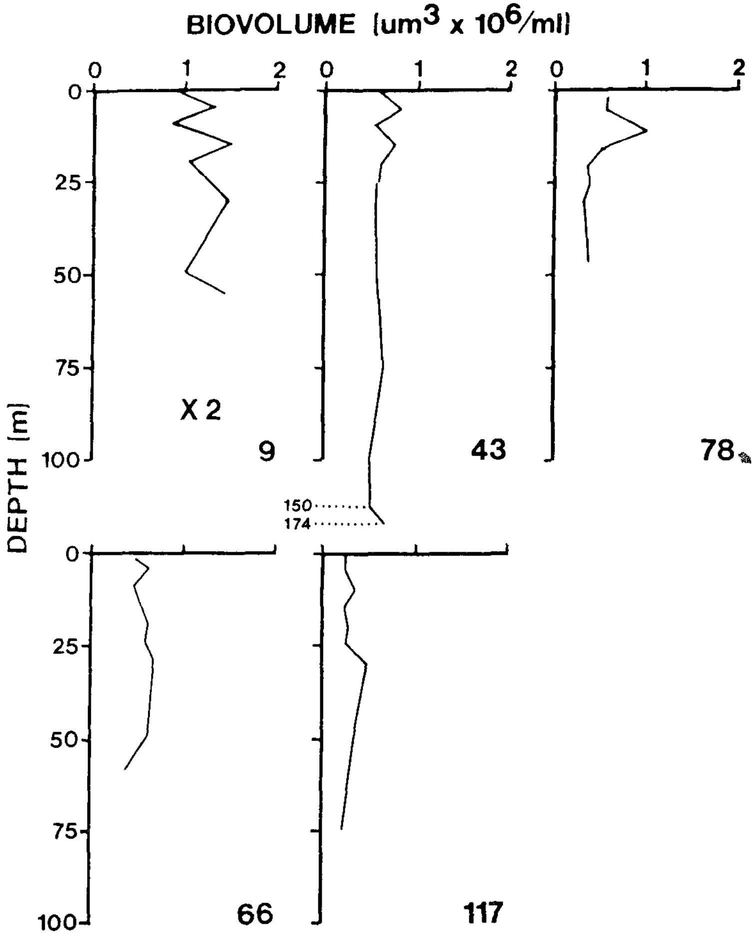

Fig. 53. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during June. Unmarked area indicated diatom biovolumes.

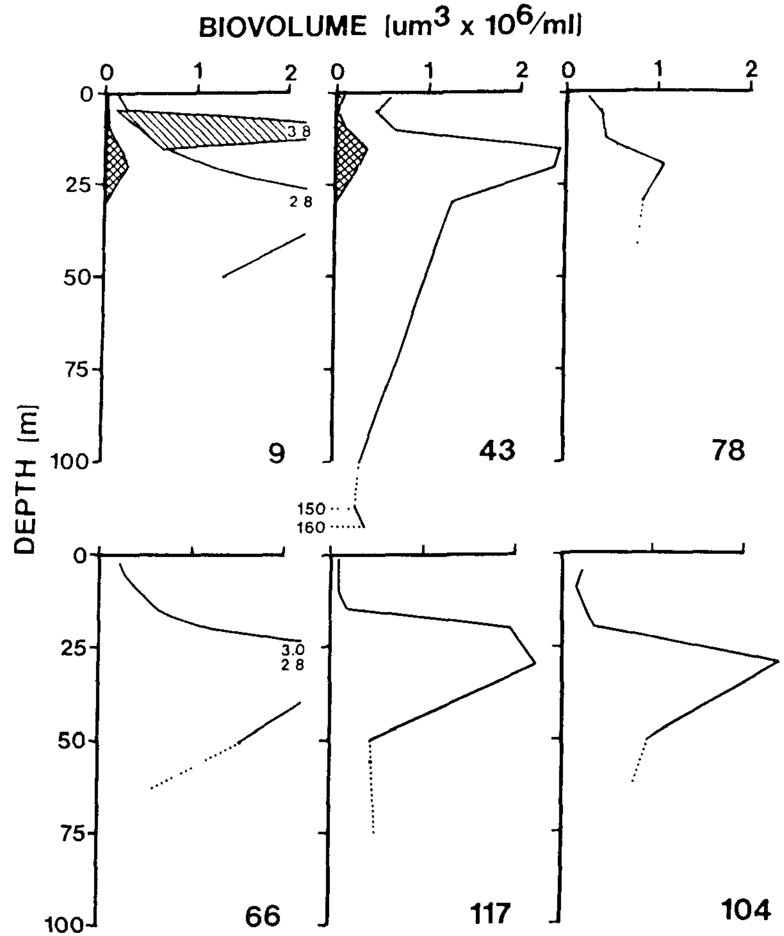

Fig. 54. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during July. Unmarked area indicated diatoms; area marked by cross hatching indicated chrysophytes; and the area marked by diagonal lines indicated green algae.

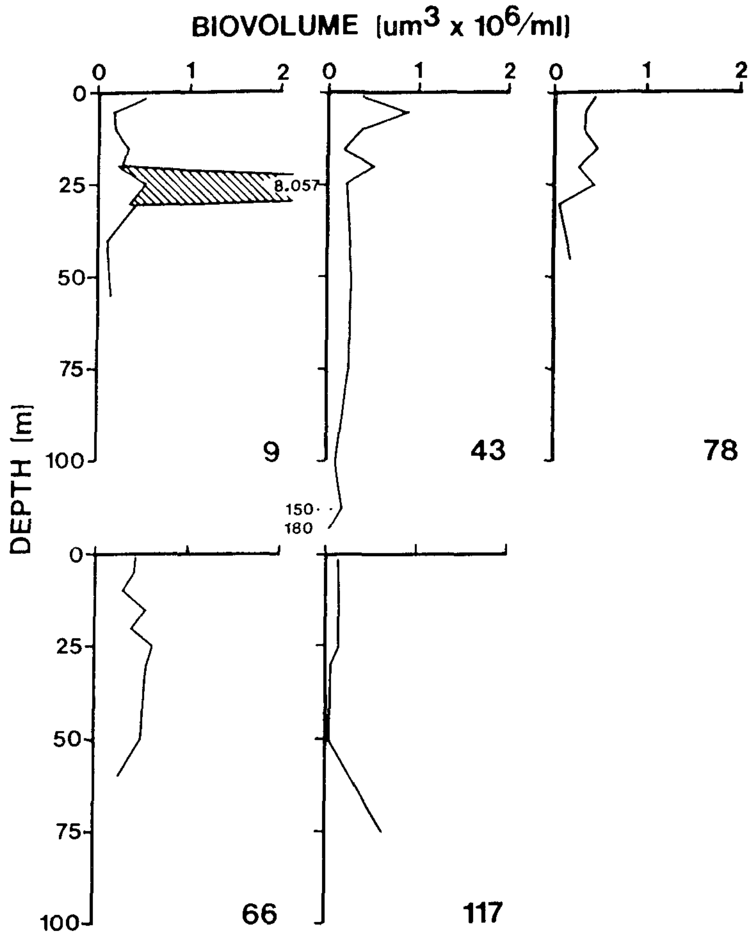

Fig. 55. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during September. Unmarked area indicated diatoms and the area marked by diagonal lines indicated green algae.

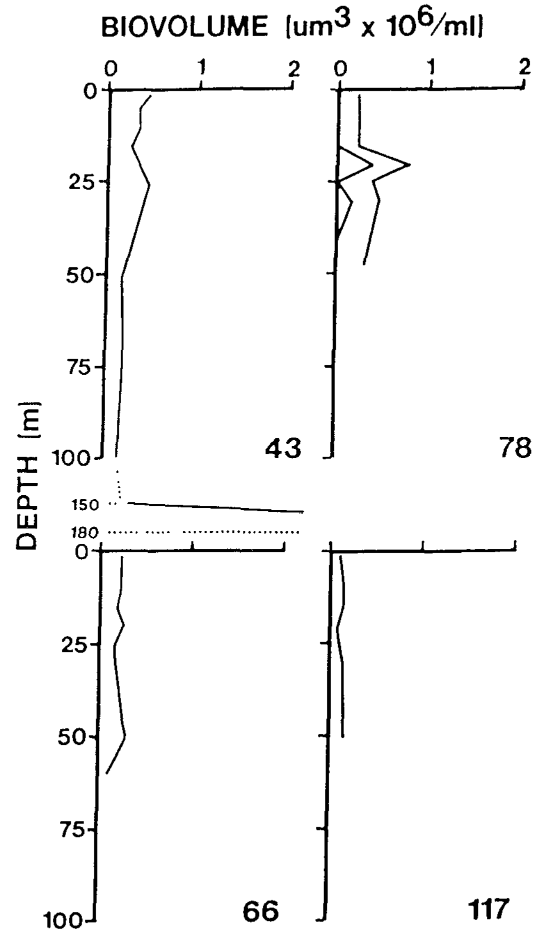

Fig. 56. Depth profiles of algal division biovolumes at various stations (numbered in lower right hand corner of figures) during October-November. Unmarked area indicated diatom biovolumes.

Table 5. Correlation coefficients between physicochemical conditions in Lake Huron. This data was reported by Moll _et_ _al_.(submitted). ($P<0.05$ if $-0.30>r>0.30$)

CHEMICAL PARAMETER	DP	OP	N23	NH3	SiO4	O2	PH	COND	CL	SO4	ALK
TP	.74	.53	.29	.36	.44	.37	-.37	-.23	-.26	-.06	-.24
DP		.53	.21	.36	.20	.52	-.35	-.03	.08	.18	-.03
OP			.35	.21	.30	.31	-.15	-.07	.13	-.34	-.08
N23				.21	.52	.63	-.42	-.24	-.24	-.12	-.39
NH3					.53	.22	-.33	-.53	-.36	.14	-.54
SiO4						.41	-.60	-.69	-.73	-.25	-.74
O2							-.42	.13	.06	.12	.00
PH								.57	.63	.13	.61
COND									.96	.19	.97
CL										.25	.93
SO4											.20

concentrations as well as conservative ion concentrations (Table 6). Total algal biovolume was also positively correlated to oxygen concentrations. Total algal biovolume was negatively correlated to ammonia and silicate concentrations.

Diatom biovolume was more closely correlated to total phosphorus and nitrate-nitrite concentrations than total algal biovolume, but was more poorly correlated to dissolved and ortho- phosphorus than total biovolume. Diatom biovolume was also more poorly correlated to conservative ion concentrations than total biovolume.

Green algal biovolume was negatively correlated to nutrient concentrations, especially nitrate-nitrite concentrations. Green algae were also negatively correlated to oxygen and positively correlated to pH, which was a pattern opposite the correlation pattern of diatoms.

Blue-green algal biovolume was also negatively or poorly correlated to nutrient concentrations as well as pH. Two reasons could explain the negative correlations between blue-green or green algal biovolume and nutrient levels. One was that these algae were most abundant during the summer, so that their negative correlations with nutrients could simply be an artifact of when they typically bloom. However, only the negative correlations between green, and to some extent, blue-green algae and dissolved and orthophosphorus can be accounted for if variation in biovolumes with cruise is accounted for. A stronger negative correlation between these algae and nitrate-nitrite developed if variation in biovolumes with cruise is accounted for in analyses of partial correlations. A second reason may have been that these algae were more efficient at sequestering phosphorus and nitrogen than diatoms when those nutrients were in low concentrations. They have been generally classified as facultative heterotrophs, so perhaps they could use organic sources of nitrogen. The latter reason more completely explained the strong negative correlation between green and blue-green algae and nutrient concentrations.

Chrysophyte and dinoflagellate biovolumes were also negatively correlated to orthophosphate, nitrate-nitrite, and silica concentrations, and oxygen concentrations. These correlations also became stronger when seasonal variation in chrysophyte concentrations were accounted for. Facultative heterotrophy was again indicated.

Autecologies of Common Species of Diatoms

--*Asterionella formosa*

Abundances of this species were generally greatest during the spring (Fig. 57) in most regions of the Lake. Lowest abundances regularly occurred during September, except near the Straits of Mackinac (region 7) where abundances increased from April to November. Increases during cruise 6, the fall, indicated that abundances again increased, although high abundances were not observed during the winter in the southern basin. Similar seasonal abundance patterns have been observed in Lake Ontario (Stoermer *et al*. 1974) and in studies of the southern basin of Lake Huron (Stoermer and Kreis 1980, Kreis *et al*. in press).

However, Stoermer and Yang (1970) reported the highest relative abundances of this species during the late summer and fall in Lake Michigan. Although August samples were not collected in this Lake Huron study, its relative abundance in Lake Huron was lowest in September (Table 3), when small *Cyclotella* were most abundant in samples. These discrepancies may have been

Table 6. Partial correlation coefficients* between divisional biovolumes and physicochemistry of waters in regions of Lake Huron while holding the variation in biovolume with time and time2 constant. Physicochemical data and section designations from Moll et al. (in press).

Division	Co-Var	TP	DP	OP	N23	NH3	Si04	02	PH	COND	CL	S04	ALK
Bacillariophyceae	-	.45	.40	.32	.47	-.13	.14	.71	-.04	.31	.21	-.03	.19
	t	.59	.46	.20	.36	-.21	-.00	.54	.21	.38	.36	.27	.22
	t2	.54	.39	.34	.28	-.24	-.12	.49	.46	.40	.41	.28	.27
Chlorophyta	-	-.19	-.02	-.31	-.40	-.15	-.44	-.50	.30	.19	.15	.07	.27
	t	-.28	.07	.09	-.53	.04	-.41	-.64	.11	.05	.16	.04	.18
	t2	-.21	.19	.02	-.50	.06	-.37	.67	-.01	.05	.14	.04	.17
Cyanophyta	-	-.07	-.05	-.15	-.33	-.25	-.27	-.44	.10	.12	.12	.06	.20
	t	-.17	.20	-.02	-.27	-.14	-.24	-.20	-.22	.11	.20	.24	.19
	t2	-.37	.07	.09	-.42	-.17	-.38	-.54	-.07	.12	.24	.26	.22
Chrysophyceae	-	-.19	-.21	-.56	-.48	-.15	-.40	-.49	.21	.13	.07	.27	.20
	t	-.00	.20	-.08	-.52	-.03	-.26	-.42	-.14	.07	.09	.12	.15
	t2	-.09	.14	-.02	-.63	-.05	-.34	-.71	-.06	.07	.10	.13	.17
Colorless Flag.	-	.58	.40	-.12	-.05	.16	.31	.18	-.24	-.23	-.35	-.15	-.18
	t	.62	-.12	-.03	.03	.20	.36	.21	-.06	-.07	-.23	-.36	-.06
	t2	.56	-.21	.11	-.26	.02	.20	-.31	-.05	-.10	-.20	-.36	-.01
Cryptomonads	-	.45	.23	.26	.25	-.03	.30	.28	-.14	-.07	-.11	-.23	-.12
	t	.47	.31	.16	.38	-.05	.21	.43	-.21	.02	.01	-.04	-.08
	t2	.32	.11	.41	.25	-.10	.05	.16	.09	.02	.07	-.03	-.03
Euglenoids	-	.39	-.21	.08	-.01	-.17	.35	-.20	-.13	-.35	-.27	-.29	-.44
	t	.25	-.13	-.14	.51	-.10	.36	.44	-.29	-.07	-.15	-.09	-.28
	t2	.12	-.29	.10	.43	-.23	.24	.34	-.15	-.02	-.06	-.04	-.22
Dinoflagellates	-	.00	-.07	-.02	-.27	.03	-.30	-.37	.20	.10	.23	.19	.17
	t	-.12	-.08	.27	-.35	-.13	-.32	-.53	.17	.09	.19	.11	.16
	t2	.17	.18	.14	-.20	-.11	-.17	-.33	-.17	.08	.14	.09	.11
Unideterm. Flag.	-	.16	.04	.45	.29	-.08	.01	.08	.16	.17	.27	-.02	.14
	t	.00	.18	.32	.08	.01	-.20	-.21	.28	.06	.24	.19	.05
	t2	-.01	.18	.35	.08	.01	-.23	-.30	.35	.06	.25	.19	.06
Total biovolume	-	.39	.39	.30	.39	-.19	-.02	.61	.10	.41	.36	-.02	.31
	t	.50	.52	.28	.25	-.28	-.21	.38	.33	.48	.52	.39	.35
	t2	.46	.48	.39	.19	-.30	-.31	.35	.55	.49	.55	.40	.38

* The probability that the correlation coefficient was equal to 0.00 was generally less than 0.05 if the correlation coefficient was greater than 0.25 or less than -0.25, however that varied somewhat depending upon sample size.

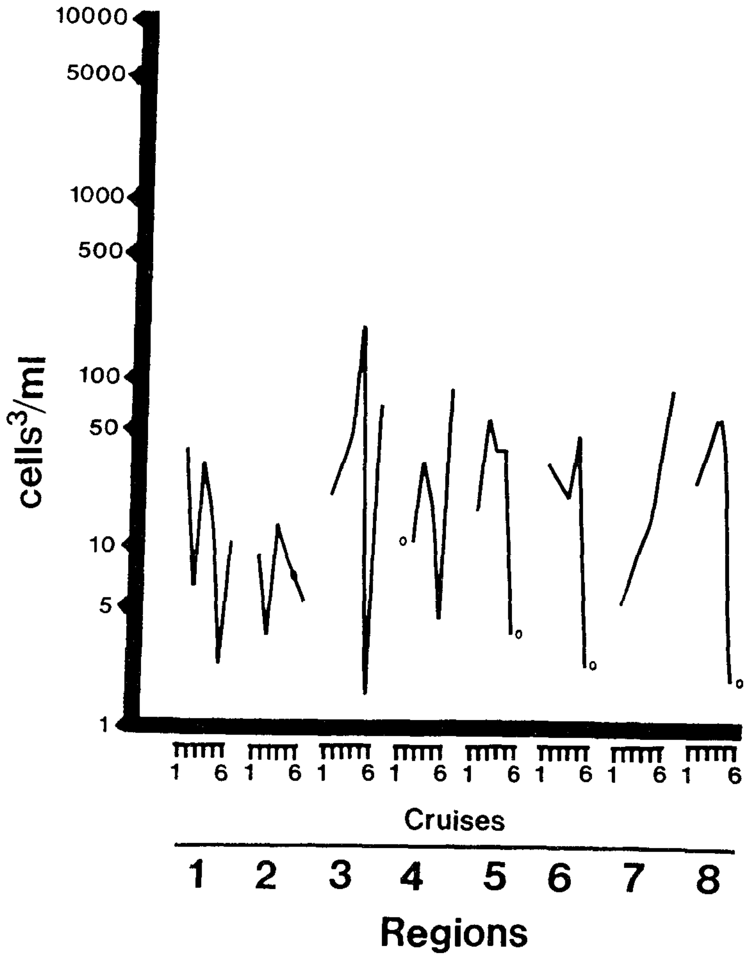

Fig. 57. Seasonal abundance patterns of Asterionella formosa in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

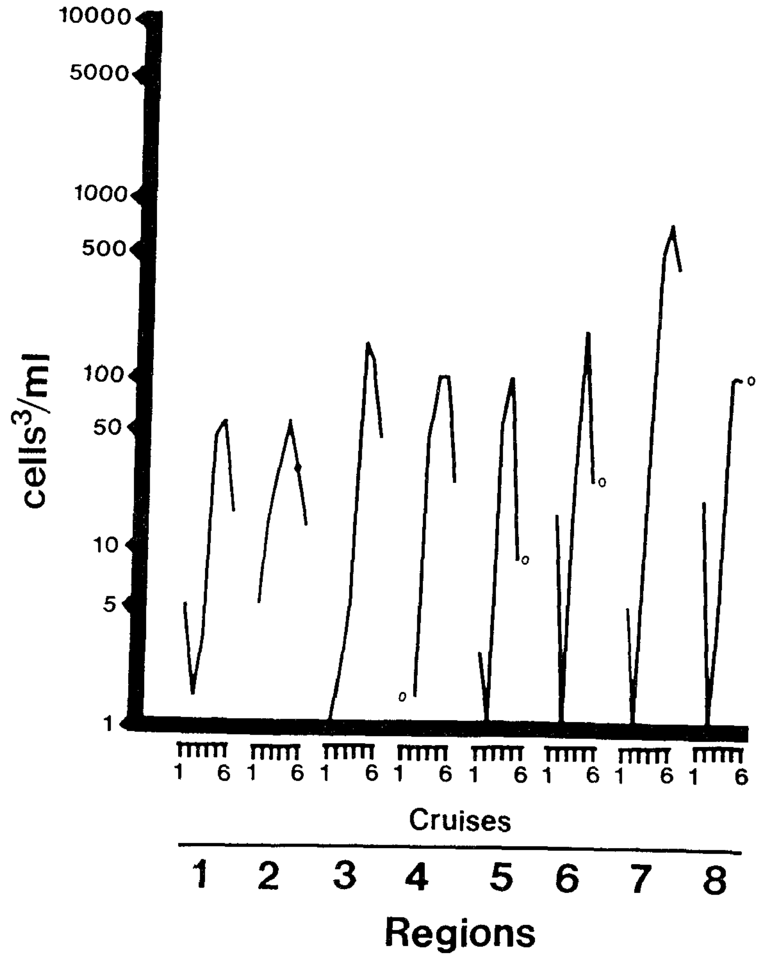

Fig. 58. Seasonal abundance patterns of Cyclotella comensis plus C. michiganiana in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

the result of unsuccessful competition for nutrients during low nutrient periods or predation (grazing) pressures which could be highly variable in different waters.

This species has been commonly referred to as a eurytopic species because of its widespread occurrence. To some extent that may be due to the great variablility in its seasonal occurrence between habitats (Fig. 57). However, correlations between its log-transformed abundance and nutrient concentrations suggested that it did well in transitional environments where most of the phosphorus had been sequestered by organisms, but nitrate-nitrite nitrogen and silica concentrations were higher than average (Table 7). This species, more than any of the common diatoms, had the strongest contrast in its positive correlation with total phosphorus and its negative contrast with orthophosphorus; which suggested that it was a good competitor for orthophosphorus as phosphorus was recycled from organic to inorganic form. Thus, the greatest abundances of this species would be expected at the end of the spring bloom, which was the case in many regions of Lake Huron. Cholnoky (1968) reported that lab studies indicated that A. formosa was a long-day species, which was not when it had been found abundant in small lakes. The periods of long days and cool water temperatures do not coincide in small lakes. Stoermer and Yang (1970) suggested that long-day characteristics and thermal inertia of the Great Lakes may allow this species to function near its optimum in the Great Lakes. The suggestion by correlation, that it was a good competitor for orthophosphorus when other nutrients were in abundance, may have also complimented the coincidence of light and temperature optima in the Great Lakes with nutrient optima.

--Cyclotella comensis & C. michiganiana

Since these Cyclotella spp. are small it can be difficult to distinguish between them. Cyclotella glomerata was probably also a problem taxon in this group. Counts from one lab to another exhibited marked discontinuites in the reports of abundances in these taxa. As many as four morphological entities of C. comensis were recorded in counts from one lab, whereas no C. glomerata were reported then. Relative abundances of all three taxa were listed in Table 3. At the time when data was accessible for correlation, the great abundance of C. glomerata and its role in taxonomic problems was not realized; thus, it was not studied further. The good data that were studied were C. comensis and C. michiganiana data. The combined abundances of these two taxa were illustrated in Fig. 58. Correlations between physicochemical conditions and abundances of each of the taxa and both together were presented in Table 7.

The reason that these taxa were studied, despite taxonomic problems, was because they were so abundant during the summer through fall period (Fig. 58), which was rather unique for the diatoms. Although, Stoermer and Yang (1970) reported that C. michiganiana was an ephemeral offshore species in Lake Michigan, both taxa were most common during the summer in Lake Huron (Table 3, Stoermer and Kreis 1980, Kreis et al. in press).

Although abundances of C. comensis and C. michiganiana were correlated, some niche separation was evident because of differences in correlations between physicochemical conditions. The strong negative correlations between log-transformed abundances of both taxa and nitrate-nitrite nitrogen indicated that they were both good competitors for nitrogen (Table 7). However, contrasts in whether the taxa were positively or negatively correlated to orthophosphorus, ammonia, and pH especially, indicated autecological differences. For example, the more negative correlation between C.

Table 7. Partial correlation coefficients* for diatom species' biovolumes and physicochemistry of waters in regions of Lake Huron while holding the variation in biovolume with time and time2 constant. Physicochemical data from Moll et al. (in press) using 1974 Lake Huron Segmentation scheme (IJC 1976a,b).

Division	Co-Var	TP	DP	OP	N23	NH3	SiO4	O2	PH	COND	CL	SO4	ALK
Asterionella formosa	-	.28	.12	-.15	.26	.21	.30	.51	.01	-.02	-.11	.12	-.09
	t	.48	.13	-.21	.33	.15	.33	.59	.10	.08	-.06	-.09	-.03
	t2	.39	-.02	-.11	.24	.14	.25	.52	.36	.07	-.04	-.10	-.01
Cyclotella comensis & C. michiganiana	-	-.11	-.21	-.37	-.64	-.05	-.36	-.67	.41	.05	.12	.19	.13
	t	-.04	-.23	.11	-.54	.02	-.24	-.48	.41	.19	.21	.10	.24
	t2	.41	.11	-.17	-.36	.16	.03	-.08	.05	.21	.16	.08	.19
Cyclotella comensis	-	.26	.15	.02	-.56	-.52	-.00	.53	-.35	-.07	-.08	-.21	.03
	t	.10	.03	.39	-.62	-.50	-.15	.35	-.06	.17	.22	.24	.28
	t2	.42	.20	.14	-.48	-.37	.06	.29	-.10	.30	.23	.26	.31
Cyclotella michiganiana	-	-.13	-.07	-.36	-.35	.12	-.29	.22	.34	.20	.19	.34	.20
	t	.04	-.14	-.02	-.38	.03	-.13	-.29	.36	.16	.10	.02	.16
	t2	.36	.12	-.23	-.20	.11	.08	.06	.11	.16	.03	-.00	.09
Cyclotella ocellata	-	.19	.10	-.05	.20	-.19	.01	.41	-.21	.25	.13	-.05	.17
	t	.36	.25	.00	.18	-.20	.04	.47	-.16	.33	.24	.34	.23
	t2	.23	.10	.15	.05	-.24	-.10	.32	.05	.36	.30	.37	.29
Cyclotella stelligera	-	-.09	.02	-.18	-.18	.15	.06	.20	-.11	-.08	-.19	-.17	-.09
	t	-.23	-.22	-.42	-.39	.30	-.12	-.36	.17	-.02	-.09	-.11	.03
	t2	-.03	-.01	-.62	-.24	.36	.01	-.14	-.18	-.05	-.15	-.14	-.03
Fragilaria capucina	-	.57	.43	.34	.13	-.03	-.11	.31	.07	.32	.36	-.04	.29
	t	.48	.47	.04	-.22	-.22	-.43	-.07	.33	.41	.39	.14	.39
	t2	.50	.47	.08	-.26	-.22	-.49	-.17	.52	.41	.40	.13	.40
Fragilaria crotonensis	-	.50	.23	.11	-.04	-.23	.04	.04	.21	.30	.16	.04	.26
	t	.60	.42	-.05	.01	-.07	.10	.39	.12	.32	.22	.17	.20
	t2	.53	.33	.07	-.12	-.11	-.02	.24	.39	.34	.26	.18	.25
Melosira islandica	-	.42	.34	.32	.33	-.03	.34	.65	-.10	.23	.07	-.12	.17
	t	.46	.21	.05	.19	.03	.37	.55	.00	.17	.09	.12	.10
	t2	.34	.04	.20	.06	.00	.28	.43	.29	.18	.13	.13	.14
Tabellaria fenestrata	-	.25	.14	.37	.62	-.04	.22	.63	-.10	.23	.07	-.12	.17
	t	.38	.03	.39	.55	-.11	.16	.32	.18	.01	.09	.06	-.13
	t2	.47	.09	.37	.62	-.11	.20	.52	.14	.02	.09	.06	-.14
Tabellaria flocculosa	-	.28	.16	.02	.03	-.21	.08	.46	.10	.28	.14	.02	.23
	t	.50	.27	.08	.07	-.29	-.03	.53	.24	.46	.36	.27	.38
	t2	.40	.12	.23	-.06	-.34	-.16	.42	.57	.49	.41	.28	.44

* The probability that the correlation coefficient was equal to 0.00 was generally less than 0.05 if the correlation coefficient was greater than 0.25 or less than -0.25, however that varied somewhat depending upon sample size.

michiganiana and orthophosphorus suggested that this species was a better competitor for phosphorus than C. comensis. Independent corroboration of this suggestion was found in the Stoermer and Kreis (1980) study of southern Lake Huron where both taxa reached very high abundances near Saginaw Bay; but, C. michiganiana was more abundant than C. comensis on the eastern shore of the southern basin of Lake Huron, where nutrient supply was probably not as great (phosphorus and nitrogen limitation more likely) as along the western shore.

--Cyclotella ocellata

This taxon has been repeatedly reported as an oligotrophic species which is common in offshore waters (Stoermer and Yang 1970, Stoermer and Kreis 1980, Kreis et al. in press). Perhaps its ability to compete well in nutrient-poor waters was the reason that few consistent patterns with season, region, or water physicochemistry were observed. Its relative abundance was more constant seasonally that most of the other common diatoms (Table 3). Its abundance was highly variable in each region of Lake Huron, but was highest most often in the offshore waters of the Georgian Bay and central basin of Lake Huron (regions 1 and 2, Fig. 59). Its abundances were poorly correlated to inorganic nutrient concentrations, but were positively correlated to conservative ion concentrations and conductivity (Table 7).

--Cyclotella stelligera

Abundance of this species was highly variable throughout the spring-fall period in different regions of Lake Huron (Fig. 60). In both the 1974 and 1980 studies of southern Lake Huron (Stoermer and Kreis 1980, Kreis et al. in press), its abundance was greatest during July.

More than any of the other common taxa, C. stelligera was negatively correlated to all nutrient concentrations (Table 7), total as well as orthophosphorus and nitrate-nitrite nitrogen; thus, it probably was a good indicator of oligotrophic conditions. This conclusion was corroborated by the fact that it was one of the few taxa to have its lowest average abundances in region 6, nearest Saginaw Bay and along the western shore of the southern basin (Fig. 60). Plus, Hohn (1969) reported that its abundance had decreased dramatically in western Lake Erie during the recent period of its eutrophication.

--Fragilaria capucina

This taxon was most abundant during the spring (Fig. 61), except in regions where nutrient loading was suspected (region 5 near Saginaw Bay and region 7 near Mackinac City). Other reports indicated its commonness in spring and fall collections in Lake Michigan (Stoermer and Yang 1970) and Green Bay (Stoermer and Stevenson 1979). However, summer blooms have been observed in nearshore regions of Lake Ontario (Stoermer et al. 1974).

Of common diatoms in the Great Lakes, F. capucina seems to be one of the best indicators of eutrophic conditions. Its abundance was highest near Saginaw Bay and lowest in the North Channel and Georgian Bay (Fig 61). Indeed, it has been cited repeatedly as an indicator of nutrient-rich conditions in the Great Lakes (Hohn, 1969, Stoermer and Yang 1970, Stoermer et al. 1974, Stoermer and Kreis 1980, Kreis et al. in press). Its abundance was highly and positively correlated to all forms of phosphorus and negatively correlated to silica, indicating its ability to compete for silica in phosphorus-rich water (Table 7).

--Fragilaria crotonensis

This species, one of the two most common in Lake Huron, had spring and late summer-fall maxima in different regions of the Lake. In the southern

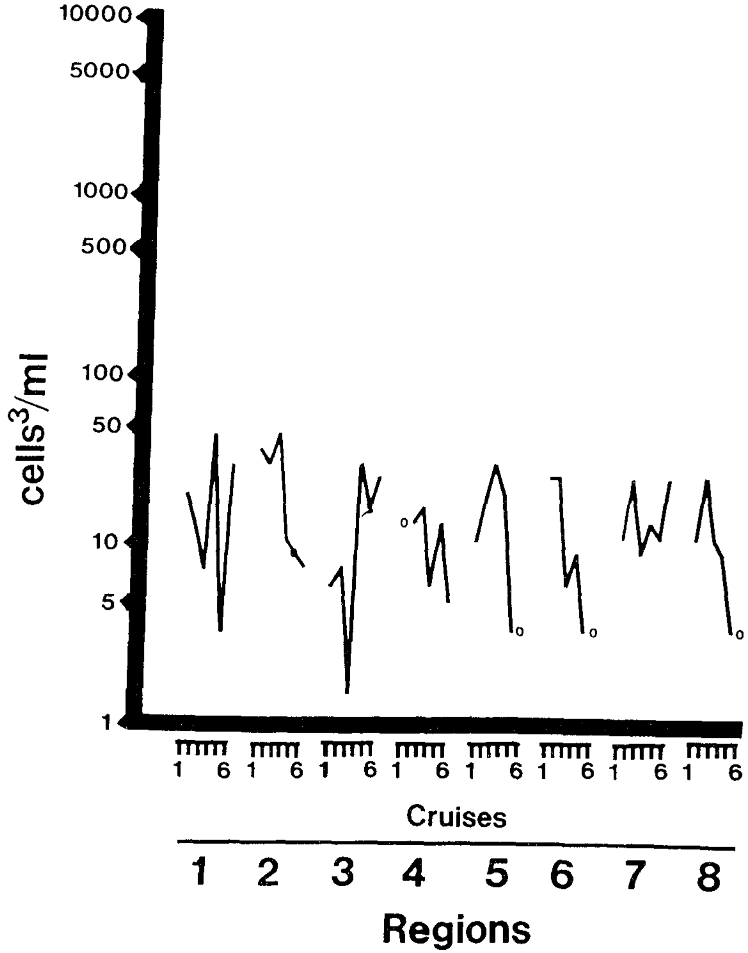

Fig. 59. Seasonal abundance patterns of Cyclotella ocellata in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

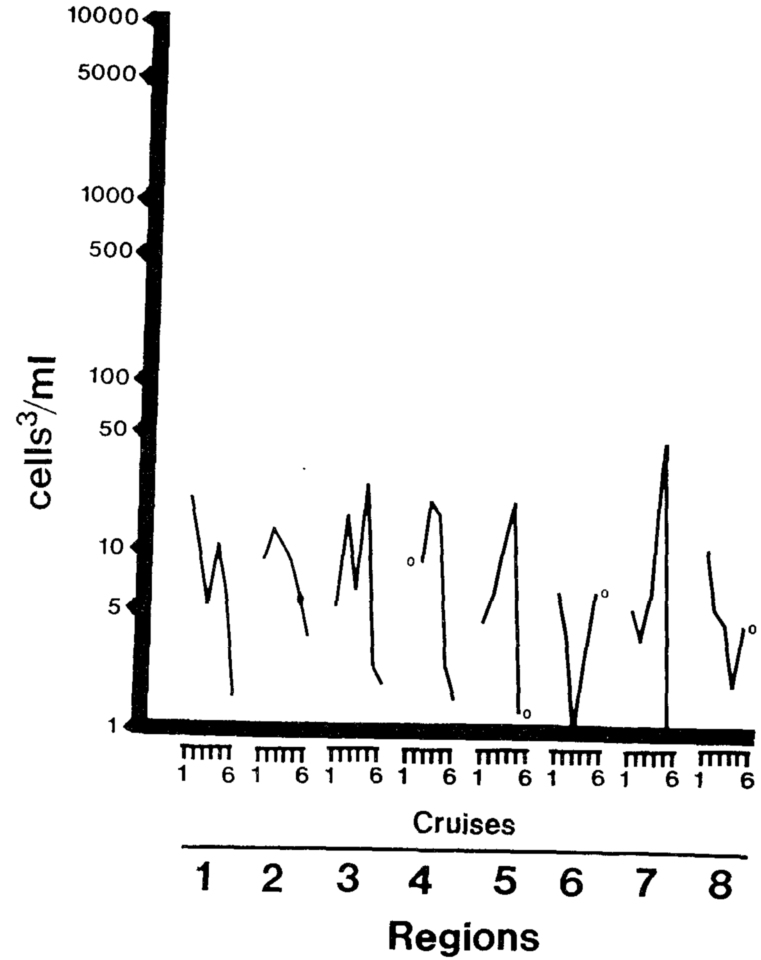

Fig. 60. Seasonal abundance patterns of Cyclotella stelligera in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

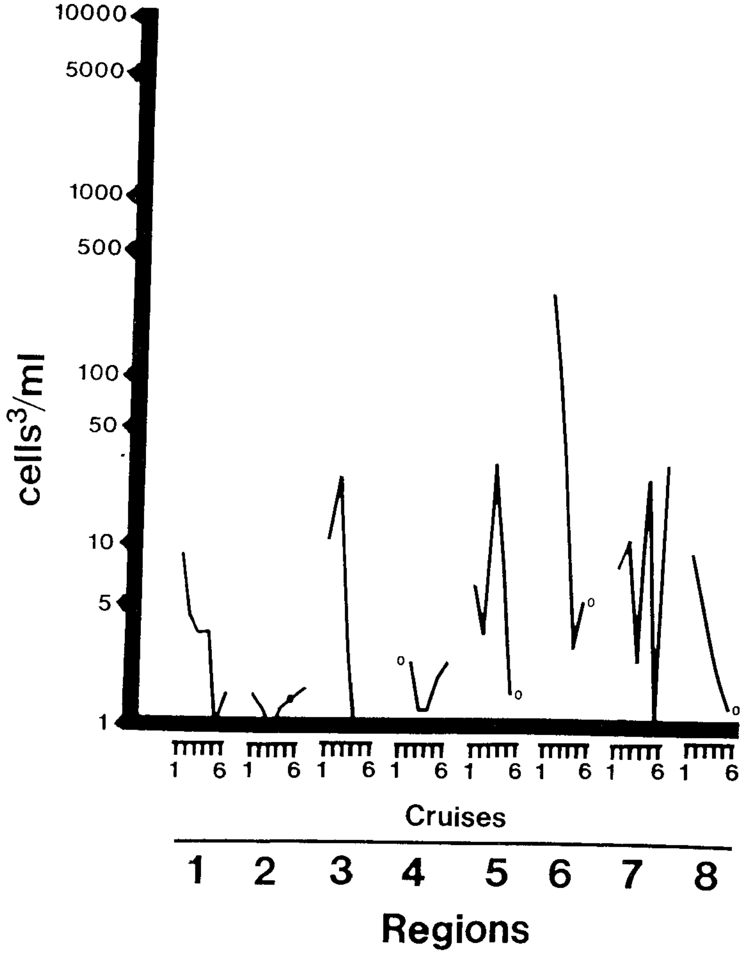

Fig. 61. Seasonal abundance patterns of Fragilaria capucina in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

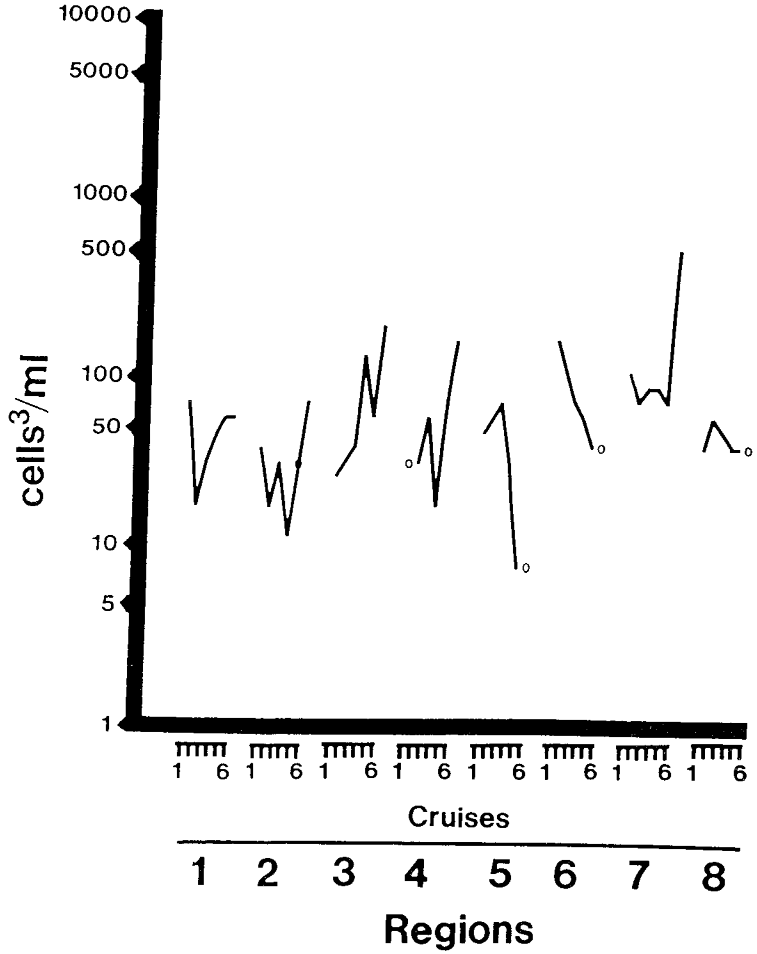

Fig. 62. Seasonal abundance patterns of Fragilaria crotonensis in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

region of the Lake, where nutrient concentrations were greater (regions 5 and 6), abundances were greatest during the spring (Fig. 62). In the northern end of the Lake (regions 3, 4, and 7), abundances peaked in the early spring and late summer to fall (regions 1 and 2). The regional variation in seasonal abundance maxima was also shown by nullification of seasonal patterns in Lake-wide relative abundances (Table 3). Relative abundances were between 10 and 20 percent until cruise 6, when it was 43 percent of the diatoms in cruise 6 samples (which were all from northern Lake Huron). Mid-summer lows were also observed in Lake Ontario (Stoermer et al. 1974) and in southern Lake Huron during 1974 (Stoermer and Kreis 1980).

Although this species was positively correlated to total and dissolved phosphorus, the lack of negative correlations with nitrogen and silica, which F. capucina had, indicated that it was not as competitive in phosphorus-rich, and nitrogen- or silica-poor waters (Table 7). This corroborated the suggestion of Stoermer and Yang (1970), that although this is a eurytopic species, it did not do well in highly polluted waters where high N:P ratios occur.

--Melosira islandica

This species was a spring bloomer in most of Lake Huron (Fig. 63, Table 3), except near the Straits of Mackinac and the St. Mary's River. It has also been observed most abundantly during the spring in southern Lake Huron (Stoermer and Kreis 1980, Kreis et al. in press), Lake Ontario (Stoermer et al. 1974), and Lake Michigan (Stoermer and Yang 1970).

Stoermer and Yang (1970) suggested that it was an offshore species that responded to nutrient enrichment, but was rapidly displaced in polluted habitats. Lake Huron data suggested a similar autecology, where its abundance was most persistent (until June) in offshore waters of the central and southern basins. It was never abundant in the nutrient-poor Georgian Bay. Although, abundant during April and May near Saginaw Bay (regions 5 and 6), its abundance decreased rapidly in June and July.

The positive correlations between this taxon and all nutrients (Table 7), more than any other common diatom, also indicated that it did well in nutrient-rich waters, but was not competitive once nutrients became somewhat limiting.

--Tabellaria fenestrata

This was the most abundant of diatoms in Lake Huron during 1980. Its large size and abundance made it the dominant component of the phytoplankton during the spring in many areas of the Lake.

This species was most abundant during the late spring (Fig. 64). Late summer and fall pulses in abundance occurred in the nutrient-rich area near Saginaw Bay (region 6) and in the northern regions of the Lake (regions 3, 4, and 7). Lake-wide, relative abundance of this species increased through June, then decreased sharply (Table 7). This species has commonly been observed as a dominant component of spring phytoplankton in the southern basin of Lake Huron (Stoermer and Kreis 1980, Kreis et al. in press); but, it was also found in abundance during other times of the year in nutrient-rich areas such as Green Bay (Stoermer and Stevenson 1979). It was widely distributed in Lake Ontario (Stoermer et al. 1974).

This species was more strongly and positively correlated to total and orthophosphorus and nitrate-nitrite nitrogen than any of the common diatoms studied in Lake Huron (Table 7). The difference between this taxon and Melosira islandica, which was also positively correlated to nutrient

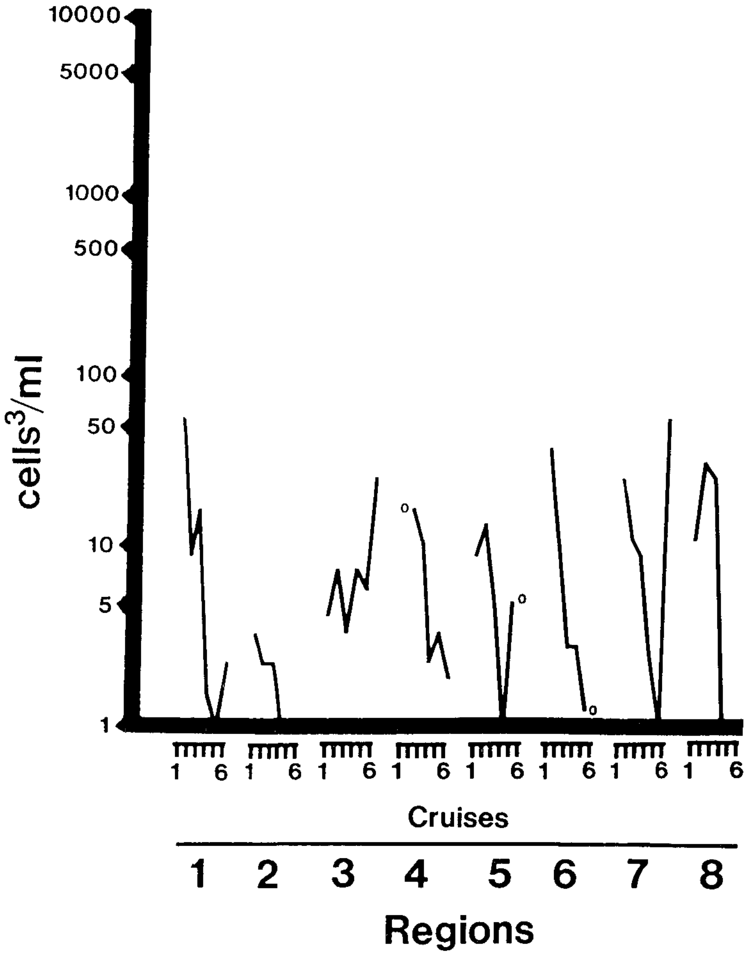

Fig. 63. Seasonal abundance patterns of <u>Melosira</u> <u>islandica</u> in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

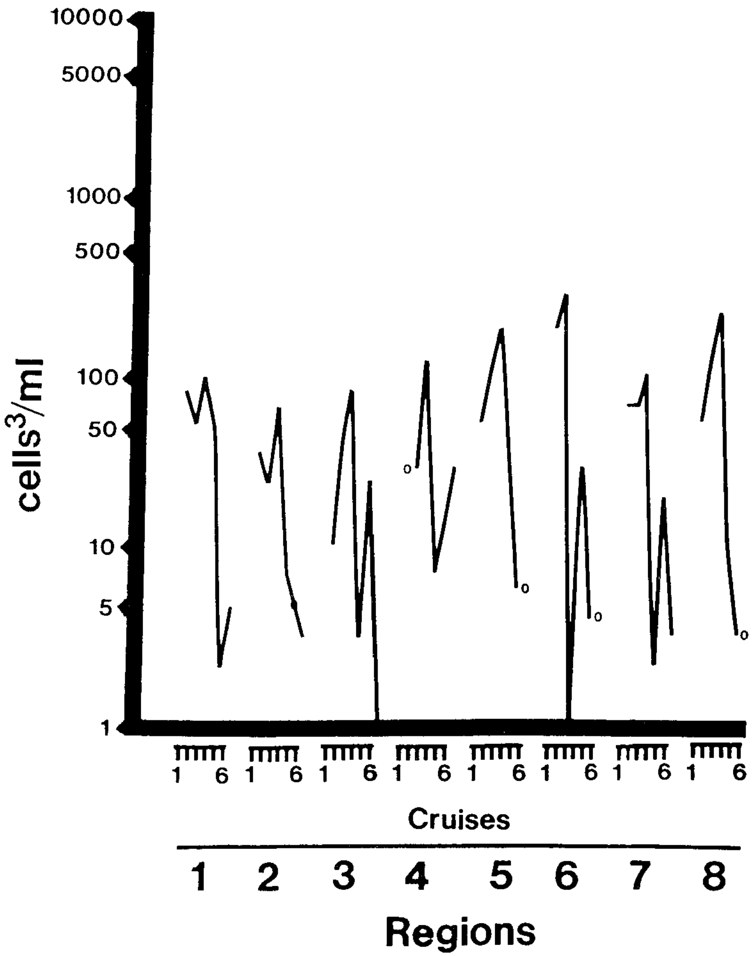

Fig. 64. Seasonal abundance patterns of <u>Tabellaria</u> <u>fenestrata</u> in different regions (Fig. 2) of Lake Huron. "0" marks missing samples.

concentrations, was a slightly weaker, but positive correlation between its abundance and silica concentrations. In Lake Huron, T. fenestrata was most abundant in the nutrient-rich areas near Saginaw Bay and along the western shore of the southern basin (Fig. 64); but here its abundance had crashed by June. Whereas, in most other areas of the Lake, the spring bloom of this species persisted until July. Thus it, like M. islandica, responded to nutrient enrichment, but would probably not have competed well in highly polluted environments where one nutrient or another rapidly becomes limiting. Stoermer and Yang (1970) also suggested that this species responded to nutrient enrichment in lower levels, in the form of upwelling. A similar conclusion could be drawn from Hohn's (1969) observation that its relative abundance remained unchanged during eutrophication of western Lake Erie.

--Tabellaria flocculosa

Although the seasonal pattern in abundance of this species was variable from region to region, in most areas of the lake it bloomed in the spring (Fig. 65). Near Saginaw Bay (region 6) and in the North Channel (regions 3 and 4) it bloomed later in the spring than elsewhere. It also bloomed again during the fall in the northern regions of the Lake. A September minimum was common. Its seasonal relative abundance pattern also showed the September minimum. Similar seasonal patterns were observed in the 1974 study of southern Lake Huron (Stoermer and Kreis 1980).

The lack of correlation of this taxon with any nutrients, except total phosphorus, indicated that it did not respond strongly to nutrient enrichment in Lake Huron (Table 7). Koppen (1978) suggested that this species develops best in hard water mesotrophic and eutrophic environments. It was strongly correlated to conservative ion concentrations and conductivity in Lake Huron.

Regionally, abundances of this taxon were greatest near the Straits of Mackinac and the St. Mary's River. Secondarily, it was abundant in the southern basin regions (5, 6, and 8). It seemed probable that the alkalinity of Lake Huron waters was generally not great enough to support large populations of T. flocculosa.

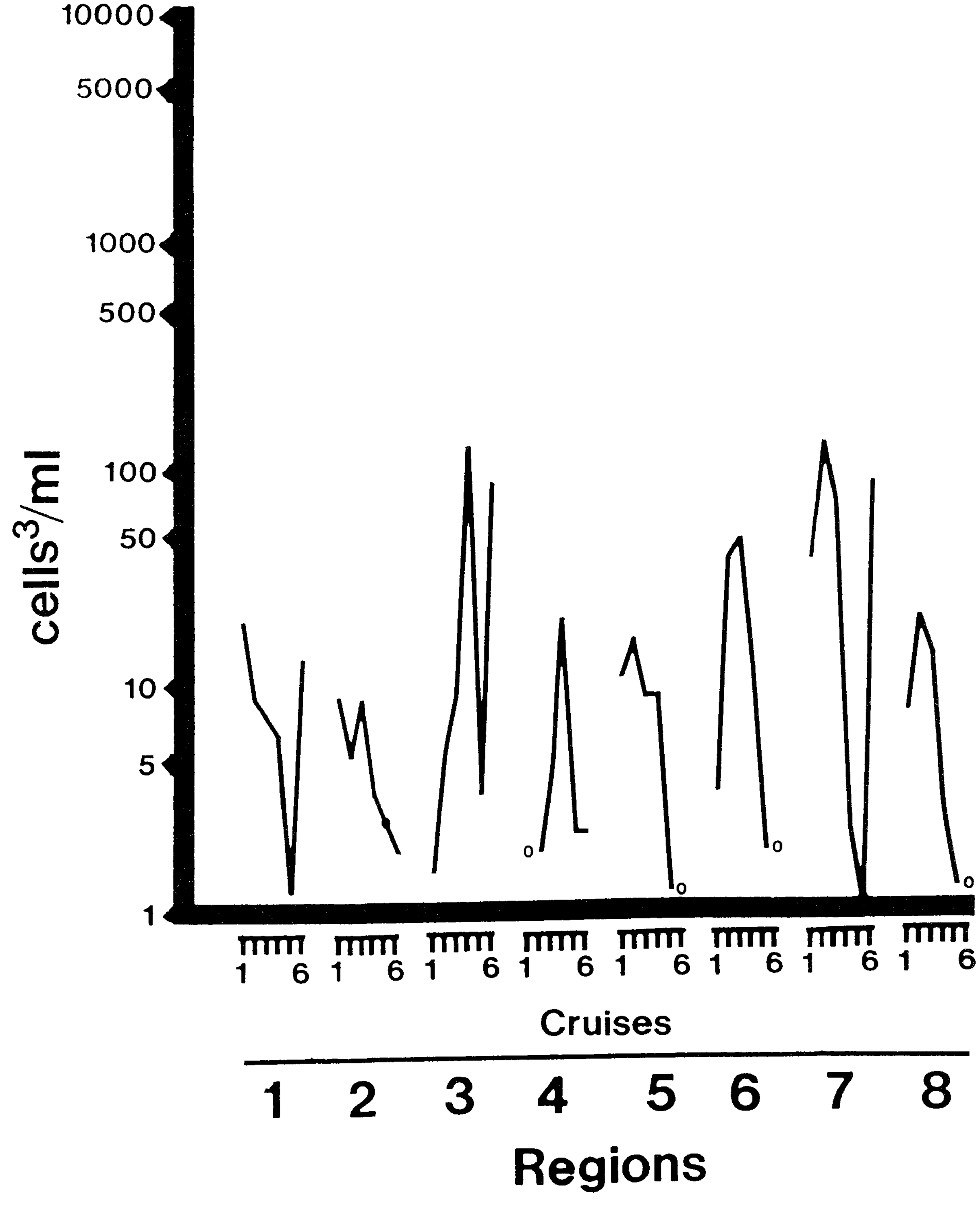

Fig. 65. Seasonal abundance patterns of *Tabellaria flocculosa* in different regions (Fig. 2) of Lake Huron. "O" marks missing samples.

DISCUSSION

Seasonal Phytoplankton Patterns in Lake Huron

Algal standing crops varied both spatially and seasonally in Lake Huron. Total algal biovolumes were higher during the spring than other seasons, however total algal abundances were actually highest during the rest of the year. Although spatial patterns in algal standing crops tended to be greater during the spring than during other seasons, generalities in the spatial patterns persisted. Algal standing crops were generally higher in nearshore waters than offshore waters and were generally higher in the nearshore waters of the southern basin than other areas of the lake.

Phytoplankton biovolume generally decreased from April, May, and June maxima to summer, fall, and winter minima. Diatom and unidentified phytoflagellate abundances, as well as abundances of most other divisions of algae, were greater during the spring than other seasons. Alternatively, phytoplankton abundances were highest during the summer, fall, and winter because of large abundances of a small colonial blue-green alga, Anacystis marina.

No change in overall phytoplankton seasonal standing crop patterns and species composition was observed during the last decade in Lake Huron. As in 1974, standing crops of algae were greatest in the spring, lowest in the summer, a weak increase in abundance of eurytopic diatoms was observed in the fall, and intermediate standing crops during the winter were observed in the 1974 study (IJC 1976b). Diatoms still comprised the major portion of biovolume throughout the year. Tabellaria fenestrata and Fragilaria crotonensis were still the dominant diatoms. Small Cyclotella spp. continued to be abundant during the summer. No significant shifts in common species of blue-green and green algae, cryptomonads, and chrysophytes were apparent during the last decade. Thus, Lake Huron generally continued to have the characteristics that are commonly associated with large oligotrophic lakes.

Georgian Bay

Several characteristics of phytoplankton assemblages in the Georgian Bay showed evidence that waters there were of the highest quality. Biovolumes of phytoplankton were lower in the offshore waters of the Georgian Bay than any other regions of Lake Huron. The spring peak in algal biovolume was lowest and of the shortest duration in the Georgian Bay, which indicated that nutrient levels after spring turnover were low and were rapidly exhausted.

The spring composition of diatom assemblages in the Georgian Bay indicated that water quality of this region was different than the rest of the lake, apparently because of low nutrient concentrations. More commonly than assemblages in other regions of the lake, Georgian Bay diatom assemblages were different than those in the rest of the lake. Higher proportions of small Cyclotella spp. comprised the spring bloom in Georgian Bay waters. The same Cyclotella spp. were also the most common taxa in the Bay during the summer and were commonly associated with low nutrient conditions in other regions of the Lake.

There were indications of minor nearshore disturbances in the Georgian Bay. Standing crops were often higher at S 125, near the mouths of the Wanapitei and French Rivers, and at the southern end of the Bay. Indications of water quality degradation in nearshore waters of the Georgian Bay have been observed by other investigators (Nichols et al. 1977). Whether the enhanced standing crops during 1980 were the result of anthropogenic disturbances, upwelling, thermal bar, or river discharge could not be determined.

There was a slight indication that the offshore waters of the Georgian Bay had become more enriched in the last decade. A spring pulse in phytoplankton was observed in 1980, whereas that pulse was not evident in 1974 (IJC 1976b). Alternatively, other factors indicated that no change occurred. First, no April sample was collected in the 1974 study, when highest biovolumes were observed in 1980. Second, the 1980 spring pulse was observed in the average standing crops for the region, but was not observed in the season pattern at S 130, one of the offshore stations studied. Third, average biovolumes (biomass) for the year were the same during 1974 and 1980, varying about 0.5 X 10^6 um^3/ml (or 0.5 g/m^3).

North Channel

Phytoplankton assemblages in the North Channel were greater than in the Georgian Bay, but generally less than in the rest of Lake Huron. Low biovolumes occurred during the spring peak and the peak was of shorter duration than in the rest of the Lake, as was the case in the Georgian Bay. However, small peaks in chrysophytes and blue-greens occurred during the summer. Perhaps nearshore hydrological influences in this narrow channel contributed to the slight indications of enrichment. High seasonal variation in algal division abundance also suggested that the signs of enrichment were artifacts of local hydrological variations. Nevertheless, the low standing crops of phytoplankton indicated high quality and low enrichment of waters in the North Channel.

The great seasonal variation in algal standing crops and unusual, often unique, species composition of phytoplankton in waters at the western end of the North Channel indicated that discharge of waters from the St. Mary's River affected the waters of the North Channel. Kreis et al. (1983) have reported and quantified this phenomenon.

Comparison of 1974 (IJC 1976b) and 1980 phytoplankton patterns indicated no change in water quality. Again, the lack of a spring peak in 1974 data may have been an artifact of no April or early May samples in this region where the spring bloom was so low in abundance and short in duration.

Offshore Regions in North and Central Basin

Low nutrient concentrations were indicated by low phytoplankton standing crops in these offshore waters. However, lower nutrient levels were indicated in some parts of the Lake by higher biovolumes and a longer duration of the spring bloom in the northern and central basins of the Lake than in the North Channel and Georgian Bay. Alternatively, higher nutrient levels were indicated in other parts of the Lake by lower biovolumes and shorter durations of spring blooms in the northern and central basins than in nearshore zones and southern basin. Spring diatom assemblages in northern and central offshore waters also indicated lower levels of nutrient replenishment after turnover than in nearshore waters. Asterionella formosa and Melosira islandica were most abundant and Tabellaria fenestrata responded more rapidly to moderate levels of seasonal enrichment than the other two species. High peaks of chrysophytes during July also indicated some enrichment. Thus the offshore waters of the northern and central basin were classified as oligotrophic, but with minor, inconclusive indications of enrichment.

Phytoplankton biovolumes were generally greater in the central basin than in the northern basin.

Comparison of 1971 (Munawar and Munawar 1975, 1982), 1974 (IJC 1976b), and 1980 phytoplankton standing crop indicated that little change had occurred in the quality of waters in the offshore regions of the northern and central basins. The same species of diatoms continued to dominate the phytoplankton, plus biovolumes (biomass) of phytoplankton remained about 1.0 x 106 um3/ml (1.0 g/m3).

Offshore Region in Southern Basin

Poorer water quality in the offshore region of the southern basin than central and northern basin was interpreted from phytoplankton standing crops in this region. Phytoplankton biovolume and the spring pulse in blue-green algae was slightly greater in the southern than central and northern basins. The frequency and intensity of deep-water peaks in algal biovolume were also greater and somewhat deeper in the southern than central basin. Deep-water algal maxima could have indicated that algal growth was great enough in the surface waters to deplete nutrients, and that those abundant nutrient resources were being recycled deeper in the water column as the particles settled (Moll and Stoermer 1982). Thus, the offshore waters of the southern basin were concluded to be oligotrophic with signs of some enrichment.

Comparison of 1971 (Munawar and Munawar 1975, 1982), 1974 (Stoermer and Kreis 1980), and 1980 phytoplankton patterns indicated slight degradation in water quality during the last decade. The seasonal patterns in algal biovolumes were slightly lower in 1971 when compared to 1980. Blue-green algal and microflagellate abundance also seemed to be higher in 1980 than 1974. However, the seasonal patterns in diatom abundance were slightly lower during 1980 than 1974. Kreis et al. (in press) observed similar patterns in phytoplankton changes during the past decade. Because of the greater number of sampling locations in their study of Saginaw Bay regions and the southern basin than this study of the whole lake, Kreis et al. (in press) made the observation that the offshore region in the southern basin was less affected by nearshore regions in 1980 than in 1974. Thus, the data suggested that transport of large amounts of nutrients from Saginaw Bay had subsided, but that "resident" nutrient levels in the southern basin had been increased, probably from past loading from Saginaw Bay.

Nearshore Regions of Lake Huron

Local disturbances in nearshore regions of Lake Huron were common. It was impractical to determine whether these signs of enrichment were due to anthropogenic impacts or upwelling events, but it did not seem reasonable to attribute them completely to nutrient transport from Saginaw Bay.

A variable seasonal pattern in chrysophytes and a significant fall pulse in diatoms indicated enrichment at S 63, near Chegoygan and the Straits of Mackinac. Whether this was due to hydrological variations in the channel, transport from Lake Michigan, or local anthropogenic disturbance could not be determined. Comparison between 1971 (Munawar and Munawar 1982) and 1980 standing crops indicated no change in the last decade.

The nearshore region east of Saginaw Bay continued to show signs of significant nutrient loading, but less than before. High spring abundances of chroococcalean blue-greens, plus high abundances of the pollution indicator *Fragilaria capucina* during June and pollution-tolerant *Fragilaria crotonensis* during September indicated significant enrichment. However, comparison of biovolumes from 1971 (Munawar and Munawar 1982) and cell numbers from 1974 (Stoermer and Kreis 1980) with 1980 data indicated a reduction in nutrient levels.

Phytoplankton assemblages in the nearshore region along the eastern shore of the southern basin showed significant signs of enrichment, second only to those along the western shore. Algal biovolumes were greater than 3 x 106 um3/ml during May and June on both shores, as well as during April on the western shore. Algal biovolume was generally lower on the eastern shore, but blue-green algal, chrysophycean, and flagellate abundances were commonly greater on the eastern than western shore. This seemed to indicate that enrichment was more continuous along the western shore than eastern shore because diatoms were constantly more dominant along the western shore. The occurrence of a spring bloom of *Fragilaria capucina* and greatest annual diatom and green algal biovolumes also indicated enrichment was greater along the western than eastern shore. The consistency in the seasonal pattern along the western shore indicated that the signs of enrichment were probably not the result of intermittent upwelling events.

Repeated observation of Lake-wide standing crop maxima and unique species compositions of phytoplankton assemblages and persistence of spring blooms at S 7, south of Sanilac, indicated that local sources of enrichment were probable. The fact that signs of enrichment were usually greater at S 7 than north at S 13 indicated that all enrichment along the western shore of the southern basin was probably not from Saginaw Bay. Although the watershed in this region supported substantial agricultural activity, the watershed was so small that it seems more probable that local point sources of pollution were responsible for some enrichment.

Comparison of 1971 (Munawar and Munawar 1982), 1974 (Stoermer and Kreis 1980), and 1980 phytoplankton patterns indicated little change along the eastern shore of the southern basin, but increased degradation along the western shore because of higher algal biovolumes in 1980 than 1971.

SUMMARY

The waters of Lake Huron were generally oligotrophic. This conclusion was based upon the following observations: first, the phytoplankton of Lake Huron was dominated by eurytopic diatoms year-round; second, abundance and biovolume was not great during the spring bloom; third, algal biovolumes were low during the summer; fourth, nitrogen-fixing blue-green algae were never abundant, only small chroococcalean forms such as Anacystis marina bloomed; and fifth, only a slight increase in phytoplankton abundance occurred during the fall. Moll et al. (in press) came to the same conclusion, which was based on a survey of nutrients, chlorophyll, and particulate materials in Lake Huron during 1980. Evans (1983) also concluded that zooplankton composition and abundance during 1980 indicated that the waters of Lake Huron were in the oligotrophic range.

Regional variation in water quality was indicated. The most enriched waters occurred in the nearshore regions of the southern basin, both on the Michigan and Ontario side of the Lake. Higher and more persistent spring blooms of phytoplankton along the western shore of Lake Huron and near Cheboygan than in many regions indicated that these waters continued to be enriched. Similar conclusions were made by Evans (1983), Kreis et al. (in press), and Moll et al. (in press).

Measures employed to decrease nutrient loading to Lake Huron through Saginaw Bay have apparently reduced eutrophication of nearshore and offshore areas near the mouth of the Bay. However, there were some indications that the offshore waters of southern Lake Huron had become more enriched, on a long-term basis, than in the past. Kreis et al. (in press) came to similar conclusions.

Long-term trends in water quality of Lake Huron were difficult to interpret because of the limited number of phytoplankton studies conducted in Lake Huron. Agreement with Moll et al. (in press), that there was little indication of a change in the water quality and level of enrichment of Lake Huron, corroborated and supported this assessment of trends. There were, however, some signs that nutrient loading to the southern basin seemed to be causing slight degradation of these waters.

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APPENDIX I

Stations used to calculate average phytoplankton and average water chemistry for regions in correlation and regional biovolume and abundance studies. These regions corresponded to stations used by Moll et al. (in press) to calculate average water chemistry, and closely corresponded to regions delineated in the 1974 segmentation scheme used by the IJC (1976a, 1976b).

Region	Station Numbers
1	27, 29, 31-33, 37-38, 43-45, 48, 51-54, 57, 61
2	111, 113-114, 117-118, 121-122, 124, 128-130, 137
3	68, 70-72, 75-76
4	73-74, 77-86
5	16, 18-21, 24, 26
6	7, 13-14, 17, 23, 25, 94
7	56, 62, 63, 64
8	6, 9, 12, 15, 90-93

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16. ABSTRACT

The phytoplankton of Lake Huron were studied to assess the water quality of this Great Lake. The phytoplankton species were counted in integrated and discretely collected water samples from all of Lake Huron except Saginaw Bay. Cell abundances and biovolumes of the algae were studied seasonally and spatially in the Lake.

Patterns of phytoplankton indicated that Lake Huron waters were generally oligotrophic. Diatoms with broad ecological ranges, Tabellaria flocculosa and Fragilaria crotonensis, dominated the phytoplankton year-round. Abundance and biovolume were not great during the spring bloom. Algal biovolumes were low during the summer. Small, coccoid blue-green algae were common, but heterocystis, nitrogen-fixing blue-greens were never abundant. Only a slight increase in phytoplankton abundance occurred during the fall.

Little evidence was observed that the water quality of Lake Huron had changed during the last decade. there were sone signs that continued loading of nutrients to the southern basin was causing some degradation of those waters. But, low standing crops of algae near Saginaw Bay indicated that nutrient loading through Saginaw Bay had been reduced.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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