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# NUTRIENT ENRICHMENT AND EUTROPHICATION OF LAKE MICHIGAN

Progress Report

MASTER

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## PROGRESS REPORT

This progress report is concerned mainly with work currently being prepared for publication. We have neither attempted to summarize past research accomplishments nor to discuss research projects for which data are still being collected or analyzed.

The research discussed below is concerned mainly with relationships between phytoplankton and major nutrients (phosphorus, silica and nitrogen). Data for all of the studies reported below are available in final form and are being utilized in reports which are presently being completed. For the most part, these reports contain data on species composition and abundance of phytoplankton and on chlorophyll *a*, primary productivity, phosphorus, silica, nitrate, ammonia, pH, chloride, specific conductance, water temperature and transparency. In general the reports are concerned with conditions in the open lake and with conditions in tributaries and the influences of tributary inputs on conditions in the lake.

### *Open Lake Studies*

Our open lake studies, conducted nearly every spring and fall since 1972, comprise a significant and unique data set on nutrient and phytoplankton conditions in Lake Michigan. The studies document changes in the phytoplankton species composition and nutrients in the lake.

General nutrient phytoplankton relationships in Lake Michigan can now be described fairly well, due in large part to previous work on this ERDA contract. There is a spring bloom of phytoplankton, the size of which is apparently controlled by supplies of phosphorus followed by the summer minimum in phytoplankton standing crops that undoubtedly results from nutrient depletion in the epilimnetic waters. Of the major plant nutrients, both phosphorus and silica, play a role in controlling production and species composition of phytoplankton in the summer. It has been shown that supplies of nitrogen have little if any effect on chlorophyll standing crops, presumably due to the fact that nitrate is never depleted in the open waters of the lake and that nitrate is one source of nitrogen for phytoplankton growth in these lakes (Schelske et al. 1974).

During the spring and summer, silica becomes limiting in the epilimnion, changing the phytoplankton composition from an assemblage dominated by diatoms to one dominated by greens and blue greens. This shift in species composition is apparently a relatively recent phenomenon (Schelske and Stoermer 1971) and its relationship to phosphorus loading has been reviewed recently by Schelske (In press).

Studies conducted on the ERDA contract in the fall of 1973 and 1975 confirmed that silica depletion and an epilimnetic phytoplankton population dominated by forms other than diatoms is a lake-wide phenomenon. In September 1973, diatoms comprised about 25% of the assemblage while blue-greens comprised about 35% (Table 1). The principal populations of blue-greens were *Anacystis thermalis* and *Anacystis incerta*. Both species were widely distributed over the northern part of the lake (Fig. 1) and were being transported, probably as senescent cells, into northern Lake Huron (Schelske et al., In press).

Although the species composition changes during the summer in the epilimnion, a phytoplankton assemblage dominated by diatoms persists in the subsurface waters where adequate supplies of silica are present

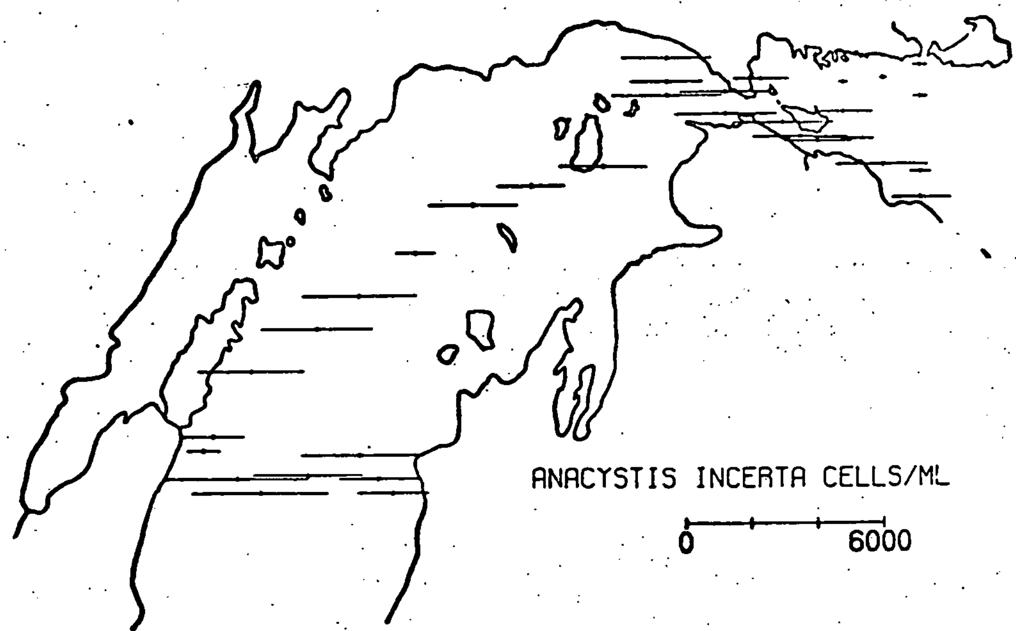
TABLE 1. Per cent composition of blue-greens and diatoms in phytoplankton assemblages in northern Lake Michigan, September 1973. Data are ranges and averages in parenthesis of data obtained from Stations 11, 20, 21, 23, 24, 25, 28, 45, 46 and 47. See Fig. 1 for location of stations and Fig. 2 for vertical distribution of temperature and nutrients.

| Depth | Blue-greens | Diatoms |
|---|---|---|
| 0 | 21-45 (30.1) | 13-36 (24.8) |
| 5 | 21-47 (36.3) | 9-39 (23.7) |
| 10 | 23-59 (36.4) | 9-50 (21.5) |
| 20 | 26-54 (38.2) | 9-49 (24.3) |
| 30 | 10-44 (23.4) | 27-67 (34.7) |
| 50-60 | 0-6 ( 4.0) | 66-94 (72.1) |
| 70-90 | 0-9 ( 2.4) | 74-98 (90.8) |

(Fig. 2). This relationship has been documented from a study of 10 stations in northern Lake Michigan during September 1973 and from a smaller number of stations in September 1975.

It is apparent that the shift in the epilimnetic species composition from diatoms to blue greens in the summer is related to silica limitation. In the Straits of Mackinac where silica is supplied by subsurface flow of water from Lake Huron, certain populations of diatoms are found that are not present in Lake Michigan outside the area influenced by silica enrichment from Lake Huron (Schelske et al., In press). The distribution of populations of *Cyclotella ocellata* and *Cyclotella stelligera* (Fig. 3) show the influence of silica supplied from Lake Huron as these populations were restricted to the Straits of Mackinac.

These studies are very important in that they confirm the predicted shift in species composition from diatoms to blue-green algae in the



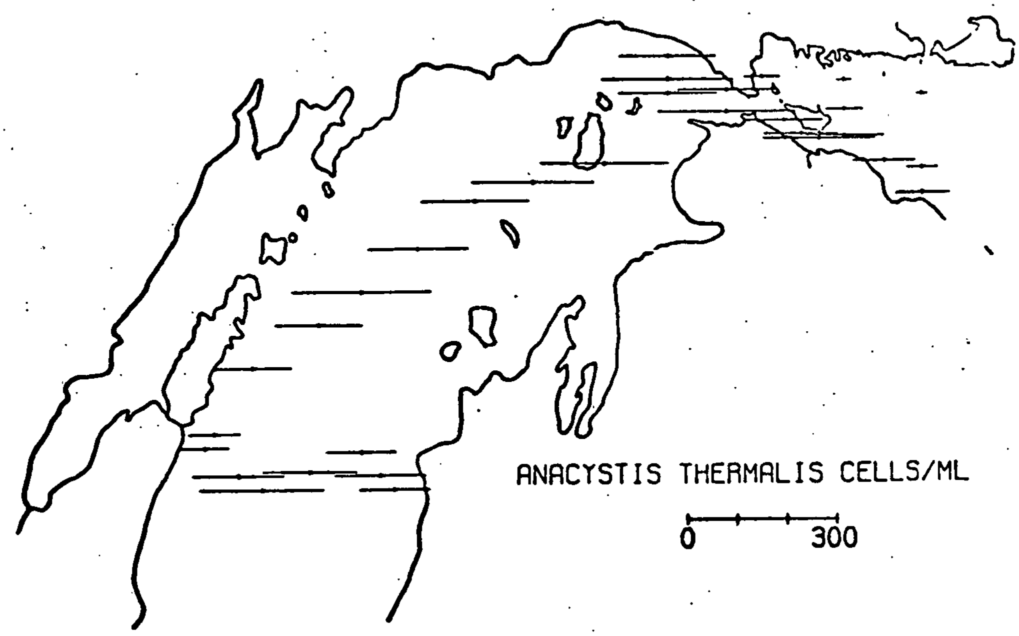




FIGURE 1. Distribution of *Anacystis incerta* and *Anacystis thermalis* in northern Lake Michigan, September 1973.

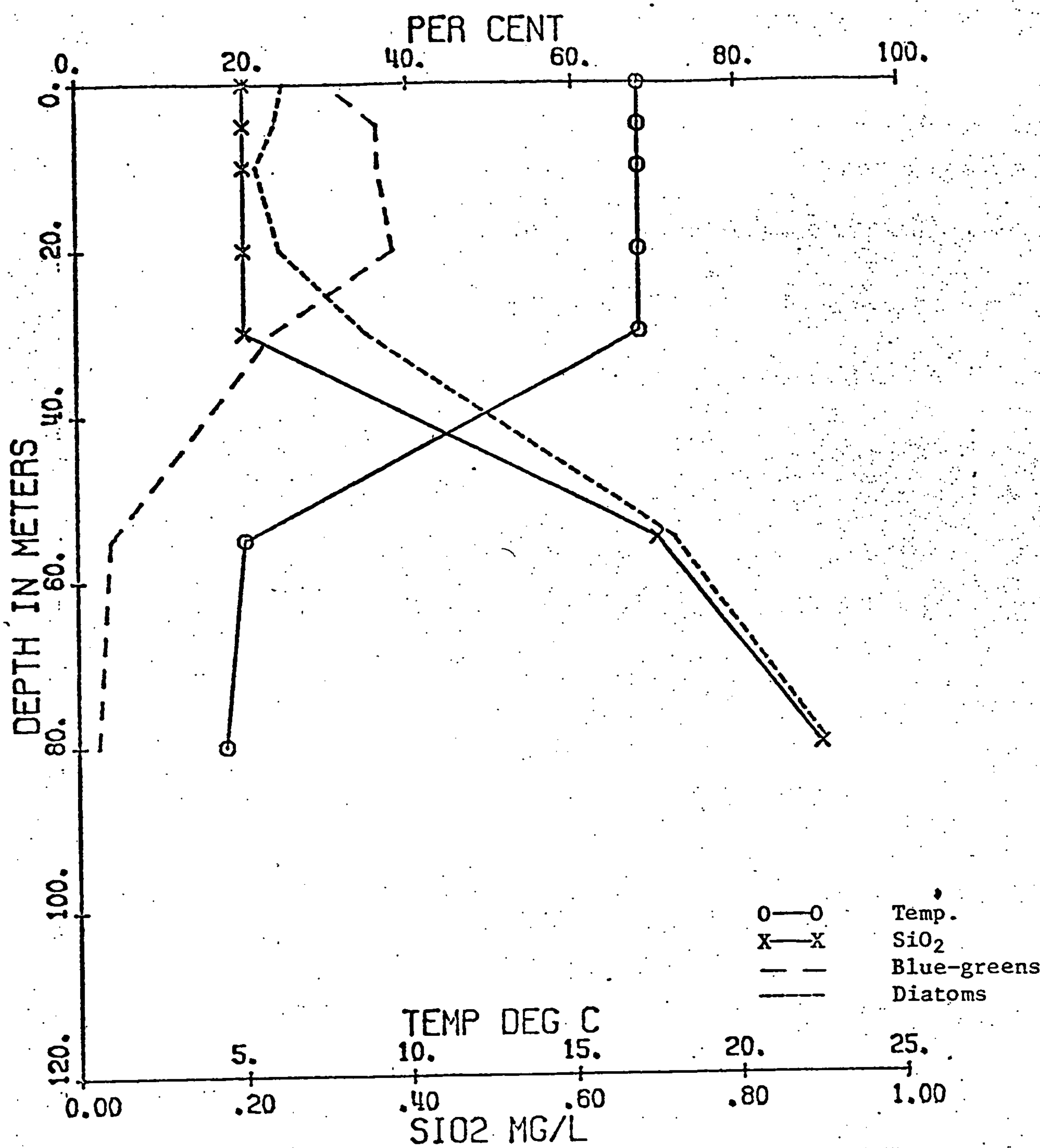



FIGURE 2. Vertical distribution of temperature, silica, blue-greens and diatoms in September 1973. Data for percent composition are averages of 10 stations in northern Lake Michigan.

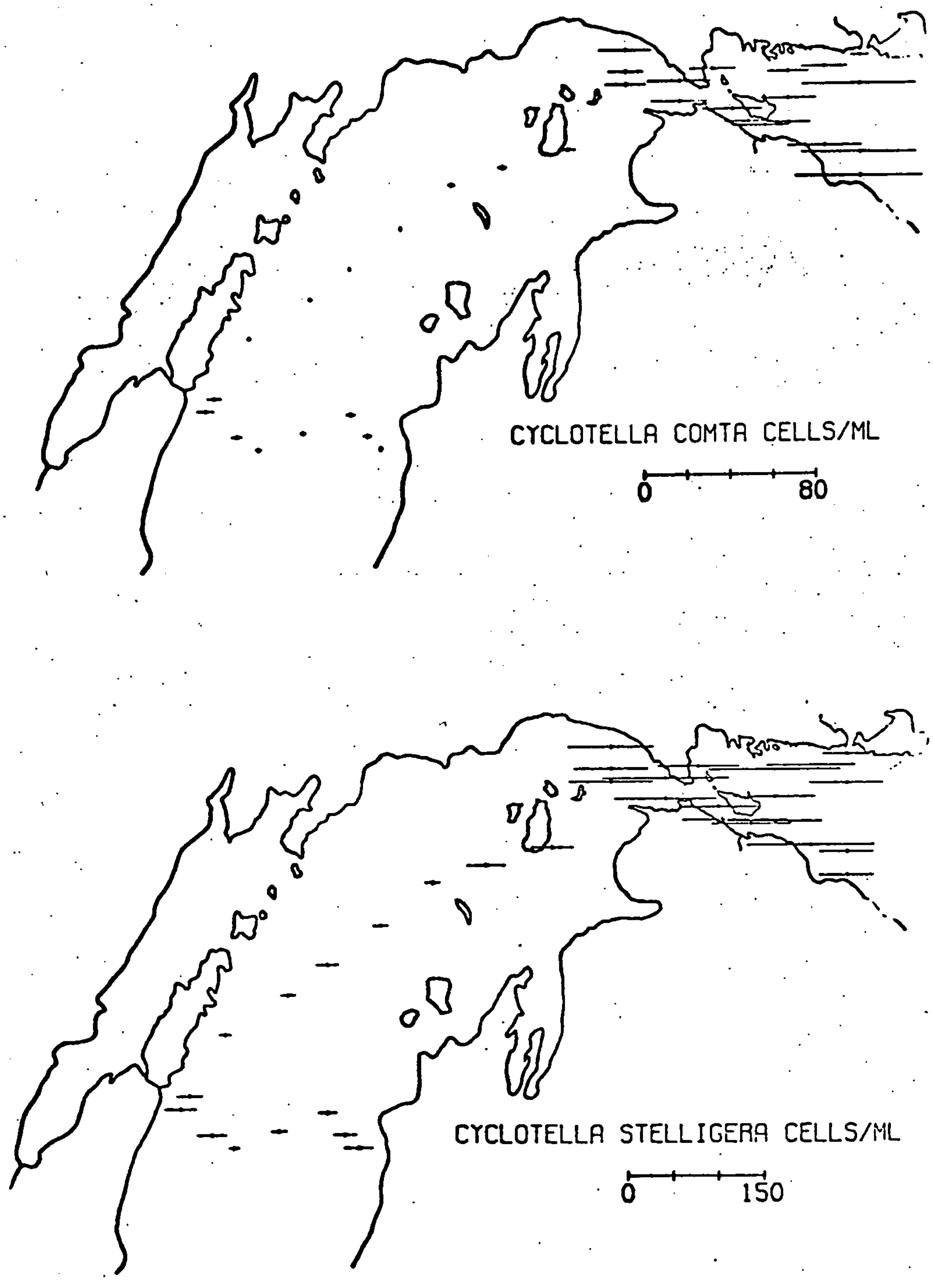



FIGURE 3. Distribution of *Cyclotella comta* and *Cyclotella stelligera* in northern Lake Michigan, September 1973.

epilimnetic waters (Schelske and Stoermer 1971) and offer additional evidence that silica limitation is the major factor restricting diatom abundance because diatoms are found in subsurface layers where adequate supplies of silica are present (Fig. 2) and in the epilimnetic waters of the Straits of Mackinac where Lake Michigan water is enriched with silica from Lake Huron.

*Tributary Studies*

Two series of tributary studies were conducted in 1972. Eleven tributaries were sampled in April 1972 as part of a general survey of open lake conditions. These data which have been reported previously showed that not only were chemical conditions different for the tributaries (Table 2), but that the phytoplankton were also different.

In another series of experiments, three tributaries were sampled several times over a ten-day period during July 1972 in conjunction with experiments on nutrient limitation in phytoplankton (Schelske, Simmons and Feldt 1975). Chemical conditions in the three rivers, Grand, Kalamazoo and St. Joseph, differed greatly for some chemical parameters, particularly silica and nitrate. The Grand River had the lowest silica concentration, 0.06 mg/liter, and the St. Joseph the highest nitrate nitrogen concentration, 0.88 mg/liter. As might be expected the phytoplankton in the rivers were also different during the experiments; however, the phytoplankton in the open lake off the rivers also varied among the sampling locations.

These tributaries are separated by only 110 km of coastline--within this area phytoplankton in the open lake initially varied from assemblages

TABLE 2. Comparison of Lake Michigan rivers Apr 1972. Average values for the top 5 meters at the river mouth. Four offshore stations have been included for comparison.

| River | T°C | pH | $SiO_2$ $mgSiO_2/l$ | $NO_3$ μgN/l | TP μgP/l | Cl mgCl/l | $^{14}C$ μgC/l/hr | Chl a μg/l |
|---|---|---|---|---|---|---|---|---|
| Grand | 8.0 | 8.11 | 2.35 | 1505 | 136.9 | 21.86 | - | 18.09 |
| Muskegon | 6.2 | 8.49 | 4.80 | 427 | 51.9 | - | - | 14.25 |
| Kalamazoo | 3.5 | 8.67 | .89 | 358 | 22.0 | 9.64 | 19.7 | 5.55 |
| St. Joseph | 15.9 | 8.32 | 2.95 | 1684 | 127.2 | 15.99 | - | 24.45 |
| Pere Marquette | 5.8 | 8.26 | 3.66 | 177 | 32.9 | 14.45 | - | 2.23 |
| Manistee | 5.4 | 8.19 | 4.58 | 266 | 21.6 | 28.01 | - | .96 |
| Manistique | 1.8 | 7.42 | 3.28 | 197 | 18.9 | 2.14 | - | .42 |
| Milwaukee transect | 3.0 | 8.38 | 1.12 | 356 | 30.7 | 11.88 | 8.95 | 6.76 |
| Manitowac transect | 2.3 | 8.56 | .84 | 272 | 7.2 | 7.47 | - | 8.34 |
| Frankfort transect | 4.3 | 8.27 | 3.50 | 208 | 17.8 | 4.58 | 2.5 | 1.56 |
| Sturgeon Bay transect | 1.9 | 8.53 | 1.00 | 222 | 3.9 | 6.74 | - | 2.73 |
| GRAN 10 | 1.0 | 8.45 | 1.36 | 244 | 6.1 | 6.64 | - | 2.34 |
| MUSK 11 | 1.9 | 8.45 | 1.30 | 280 | 7.6 | 7.64 | 3.6 | 1.90 |
| STJO 8 | 2.0 | 8.57 | 1.21 | 211 | 5.9 | 6.76 | 4.2 | 2.11 |
| SBTR 10 | 0.9 | 8.43 | 1.11 | 279 | 4.3 | 7.77 | 2.4 | 1.11 |

dominated by diatoms off the Grand River to assemblages which contained 25% flagellates and different dominant diatoms off the St. Joseph River. During the experiment, the numbers of phytoplankton in the outflow from the river increased and the numbers and composition of phytoplankton in the waters off the river mouths were highly variable on a day-to-day basis. These data illustrate the transient conditions in the lake within four miles of the shoreline.

*Grand River Studies*

Two cruises were conducted in June and September 1975 to study the Grand River and the Grand River plume in Lake Michigan. A one-day survey of water quality in the Grand River during spring flood was conducted 12 March 1976. These studies and the September 1974 cruise comprise a set of data covering a wide range of conditions in the Grand River (Table 3). Nutrient levels were high during high flow conditions regardless of the time of year. Only in September 1974 during a long dry spell were nutrients reduced to low levels by a large actively growing phytoplankton population. Phytoplankton cell counts for 24 September 1974 at three stations in the last three miles of the river (Table 4) showed that 98% of the population was diatoms. Of the most common species *Stephanodiscus tenuis* and *Melosira granulata* var. *angustissima* increased in numbers in the last 2.5 miles of river, while the other dominant species decreased. Silicate and nitrate decreased markedly over this stretch of river (Fig. 4a, b), and that change can be directly attributed to the growth of these two species.

TABLE 3. Water quality parameters at a station near the mouth of the Grand River for the four sampling periods from September 1974 to March 1976.

| Date | Flow | T°C | pH | Cl (mg/l) | $NH_3$-N (μg/l) | $NO_3$-N (μg/l) | $PO_4$-P (μg/l) | $SiO_2$ (μg/l) |
|---|---|---|---|---|---|---|---|---|
| 24 Sept 74 | Low | 16.5 | 8.79 | 33 | 23.3 | 20 | ortho 16.5 | .28 |
| 12 June 75 | High | 19.0 | 8.35 | 33 | 110 | 937 | total 200 | 3.98 |
| 3 Sept 75 | High | 20.1 | 7.74 | 20 | 112 | 890 | total 73 | 10.2 |
| 12 Mar 76 | High | 3.0 | 7.69 | 14.2 | 202 | 1312 | ortho 71.6 | 4.86 |

TABLE 4. Phytoplankton species abundance (cells/ml) at three stations near the mouth of the Grand River 24 September 1974. Approximately 40 species were identified at each station, but only the 12 most abundant species are listed. All samples were taken at 1 m. Distance is in miles from the Grand Haven breakwall.

| Species | Sta 18<br>0.3 mi upstream<br>98.4% diatoms | Sta 21<br>1.3 mi upstream<br>98% diatoms | Sta 19<br>2.5 mi upstream<br>98.5% diatoms |
|---|---|---|---|
| *Cyclotella cryptica* | 31562 | 28881 | 34348 |
| *Cyclotella atomus* | 7309 | 10681 | 11749 |
| *Stephanodiscus subtilis* | 1487 | 3372 | 3246 |
| *Stephanodiscus tenuis* | 5110 | 4021 | 2848 |
| *Melosira granulata* | 1256 | 2115 | 2220 |
| *Cylotella meneghiniana* var. *plana* | 1549 | 921 | 1592 |
| *Melosira distans* var. *alpigena* | 900 | 1193 | 1089 |
| *Synedra ulna* | -- | 230 | 356 |
| *Fragilaria pinnata* | 209 | -- | 251 |
| *Gloeocystis* sp. #1 | 104 | 481 | 251 |
| *Fragilaris crotonensis* | 230 | 230 | 230 |
| *Melosira granulata* var. *angustissima* | 1612 | 1172 | 230 |

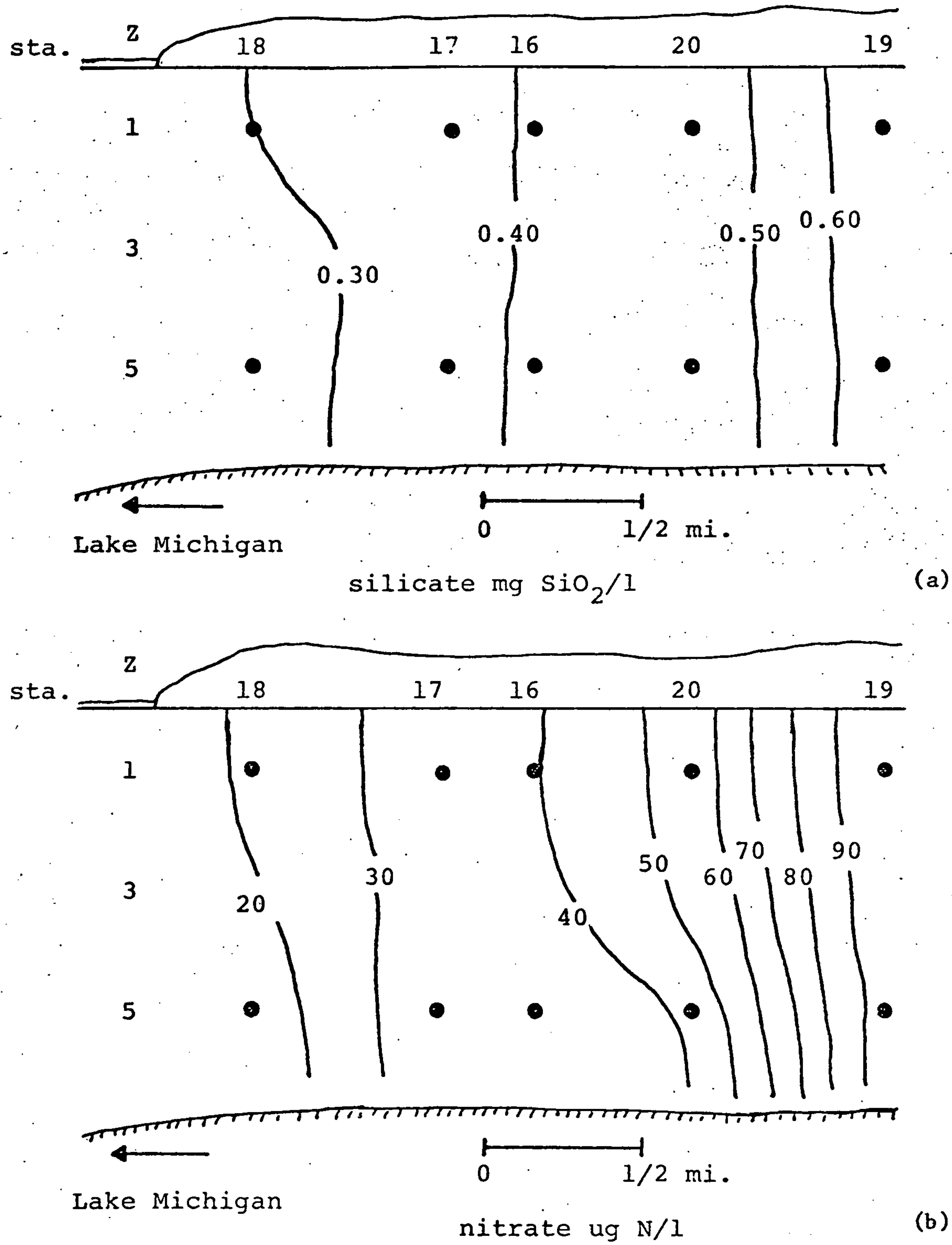



FIGURE 4. Nutrient concentrations in the last 2.5 miles of the Grand River before it enters Lake Michigan, 24 September 1974; (a) silicate, (b) nitrate.

The underway mapping technique initiated in 1974 has now been fully developed and the first computer plotted maps are available for the 1975 cruises (Fig. 5). These maps, which required approximately 3 hrs each, were made in rapid succession on 17 June 1975 during a heavy rain storm with light SW winds. The sequence shows the rapid increase in surface extent of the plume within a 6-hr period. This sequence points up the value of underway mapping for documenting frequent temporal changes occurring in the Great Lakes and for determining spatial variability in relatively small areas.

Data obtained on 3 September 1975 from a transect of stations extending 4 m into Lake Michigan from the mouth of the Grand River suggest an interesting mechanism for transporting materials from the nearshore into the open lake (Fig. 6). At this time water was upwelling at ~ 1 m offshore (Sta. 4, 5) under the influence of light east winds. Ammonia, chloride, total phosphate and river-born phytoplankton distributions all indicate that upwelled and river water were mixing in the vicinity of Sta. 4, 5 forming a water mass of intermediate temperature and density which subsequently sank along isotherms in the thermocline region of the open lake. This may be a heretofore unconsidered major source of nutrients to the thermocline, a region now recognized as a zone of high phytoplankton growth in the open lake particularly in late summer and fall.

*Chemostat Studies with Diatoms*

Construction of the chemostat system began in late October 1975 following the end of the cruise season. Progress was severely delayed

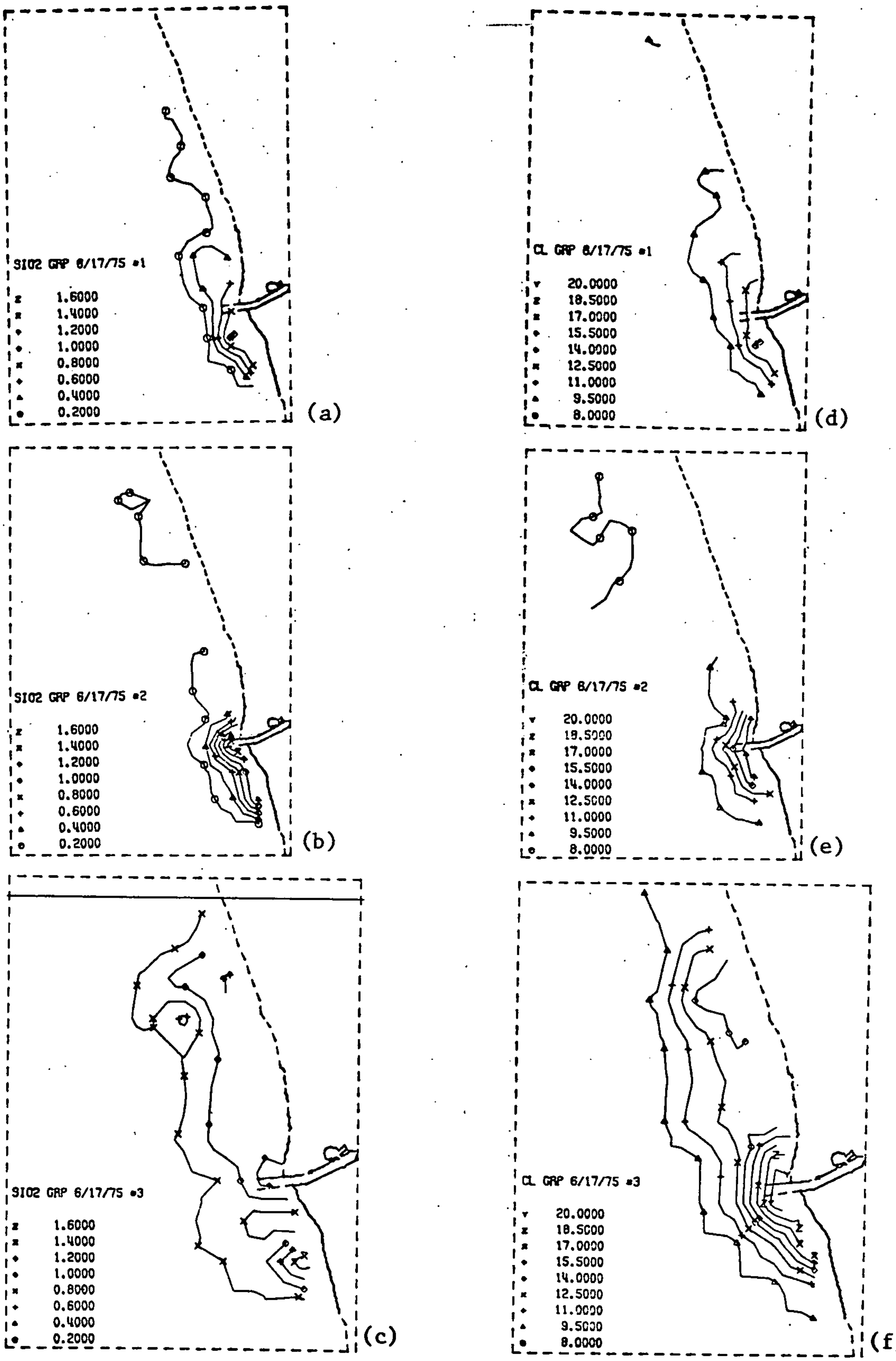



FIGURE 5. Triplicate underway maps of surface nutrients near the mouth of the Grand River, Lake Michigan, 17 June 1975. Maps were made at 3 hrs intervals: a,b,c--silicate; d,e,f--chloride.

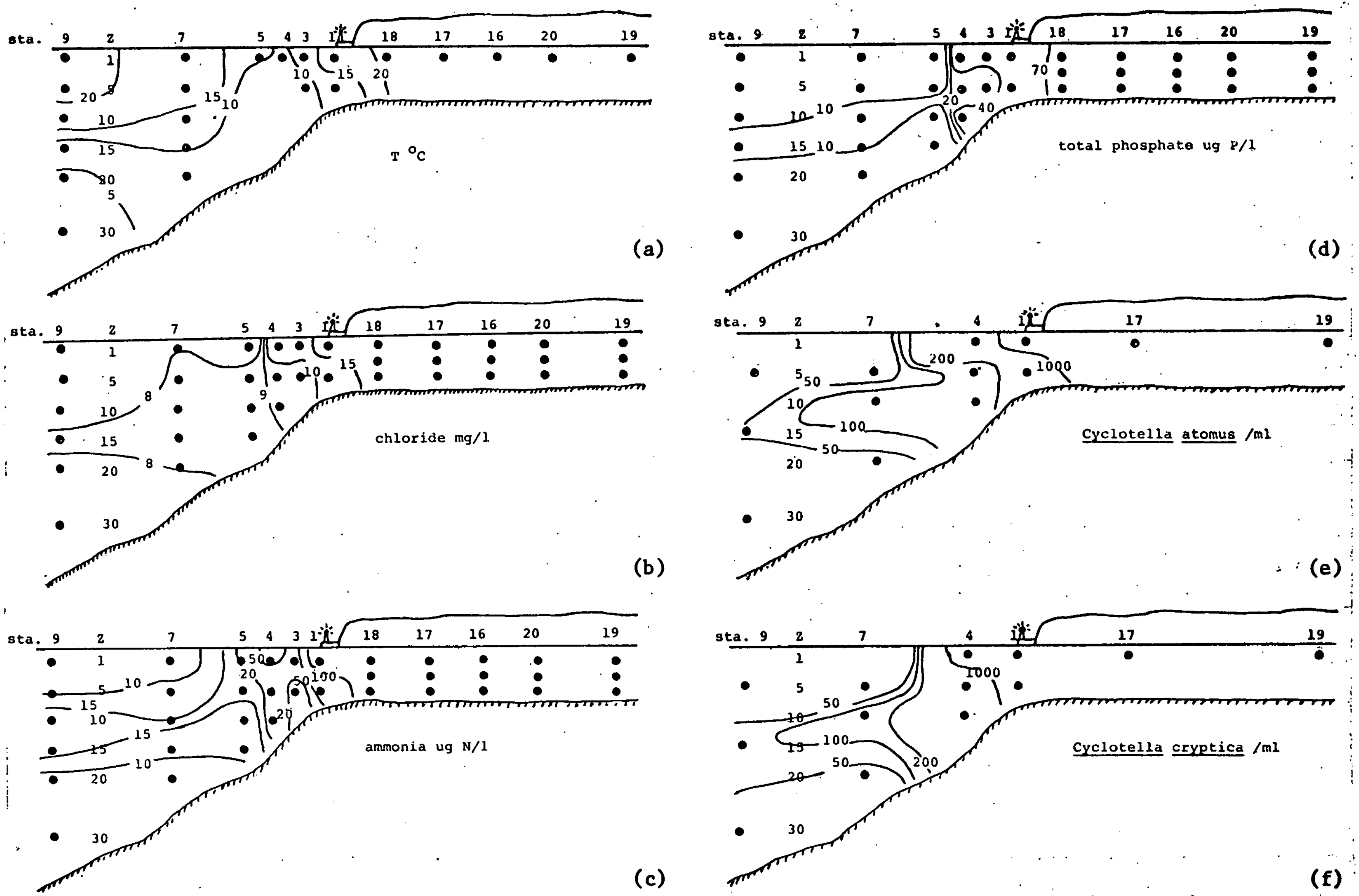



FIGURE 6. Temperature, nutrient and phytoplankton distributions in the Grand River and adjacent waters of Lake Michigan, 3 September 1975. (a) Temperature; (b) chloride mg/l; (c) ammonia µg N/l; (d) total phosphate µg P/l; (e) *Cyclotella atomus*/ml; (f) *Cyclotella cryptica*/ml.

by the slow delivery of essential parts. In particular components of the lighting and stirring systems which are normally "shelf" items required 8-10 weeks for delivery. Consequently the chemostat system was not functional until mid January 1976. Initial experiments with *Cyclotella stelligera* and *C. meneghiniana* have been unsuccessful, as the maximal growth rates obtained have been less than half those reported in the literature. It is possible that the stirring system was damaging cells; the system has been modified to avoid this problem. Experiments are currently underway with *C. meneghiniana* to determine whether slow growth rates are due to the media, high light intensity, stirring, or contamination of the culture. Experiments will be continued until 15 April, the start of the cruise season, when much of the equipment used in the chemostat studies is needed for shipboard use on other research projects.

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