GREAT LAKES RESEARCH DIVISION / Publication 19

PHYTOPLANKTON AND PHYSICAL-CHEMICAL CONDITIONS IN SELECTED RIVERS AND THE COASTAL ZONE OF LAKE MICHIGAN, 1972

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Ann Arbor, Michigan
1980

DISCLAIMER

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ACKNOWLEDGMENTS

This study was supported through a contract with the Atomic Energy Commission (C00–2003–36), now the Department of Energy (EY–76–S–02–2003), and ship support was provided through National Science Foundation grant GA–4507 to the Great Lakes Research Divison.

We are indebted to a number of colleagues who contributed to various phases of the study. Capt. Richard Thibault and the crew of R/V INLAND SEAS provided excellent logistical support and were very helpful in all phases of sample collection. J. Roth, K. White, S. Fielek, D. Willis, J. Kubus, S. Hudak, A. Schaedel, and T. Ladewski ably and conscientiously assisted with sample collection and analyses. Figures were drafted by V. Smith, R. Engel, and J. Davids. We are particularly indebted to N. Daugherty for her dedicated assistance with the preparation of the manuscript and to S. Schneider for editorial assistance. J. C. Ayers, A. M. Beeton, and E. F. Stoermer read the manuscript and provided helpful suggestions. C. H. Mortimer contributed valuable comments on minimum water temperatures in Lake Michigan.

INTRODUCTION

In 1972 as part of our efforts to obtain lake-wide data on phytoplankton and nutrients, particularly on relationships between the seasonal cycle of silica and succession in the phytoplankton assemblage, we designed a study to obtain data on coastal zone environments in Lake Michigan. Our original intent was to sample eleven selected coastal areas in the spring and fall. All these areas selected for study were sampled in April, but due to severe fall storms only three areas were sampled in September. In conjunction with another study, we also sampled three of these coastal areas in southeastern Lake Michigan several times during July.

Seven of the eleven areas selected were located at tributaries on the eastern side of the lake along the Michigan shoreline, one area was at a tributary at the northern end of the lake along the Michigan shoreline, and three areas were on the western side of the lake along the Wisconsin shoreline (Fig. 1). Although this sampling plan would at first appear to be biased for rivers along the eastern shore, it should be recognized that the drainage basin of Lake Michigan is very small in Illinois and Indiana with few tributaries and small flows. A large part of the drainage basin lies in Wisconsin but rivers in Wisconsin with large flows are tributaries to Green Bay and not the main lake.

Historical data on the phytoplankton and chemistry of Lake Michigan have been compiled and summarized recently (Tarapchak and Stoermer 1976, Torrey 1976). Three recent studies documented and discussed phytoplankton changes which have occurred in Lake Michigan since 1890 (Stoermer 1967, Stoermer and Yang 1969, Stoermer and Yang 1970). Phytoplankton assemblages originally dominated by diatoms have been altered dramatically, first from oligotrophic diatoms to more eutrophic diatoms and more recently the predicted change (Schelske and Stoermer 1971) from diatom dominated assemblages to phytoplankton assemblages with increasing proportions of blue-green and green algae has occurred (Conway *et al.* 1977, Schelske *et al.* 1976, Stoermer 1974). Phosphorus has been identified as the major nutrient limiting phytoplankton growth (Schelske 1979, Schelske *et al.* 1974). Increased inputs of this nutrient have stimulated the growth of diatoms to the extent that silica now becomes limiting in the summer, causing the phytoplankton assemblage to shift from diatoms to physiological forms of phytoplankton which do not require silica (Schelske and Stoermer 1972).

Beeton's classic studies have documented the changes in conservative ion chemistry in Lake Michigan (Beeton 1965, 1969), but these studies also pointed to the lack of suitable data to determine changes in nutrient concentrations. Torrey (1976) has listed the sources of chemistry data for Lake Michigan, and in this study we have included a section on representative values for some nutrients and other physical-chemical factors.

Little published work is available on the chemistry of tributaries to Lake Michigan. Ayers (1970), using the data collected by the U.S. Public Health Service in 1962–63, has calculated annual tributary chemical loadings. Trace metal loadings have been studied by Robbins *et al.* (1972) for a number of tributaries. Recently Sonzogni *et al.* (1978) have calculated tributary loadings of nutrients for Lake Michigan. In addition

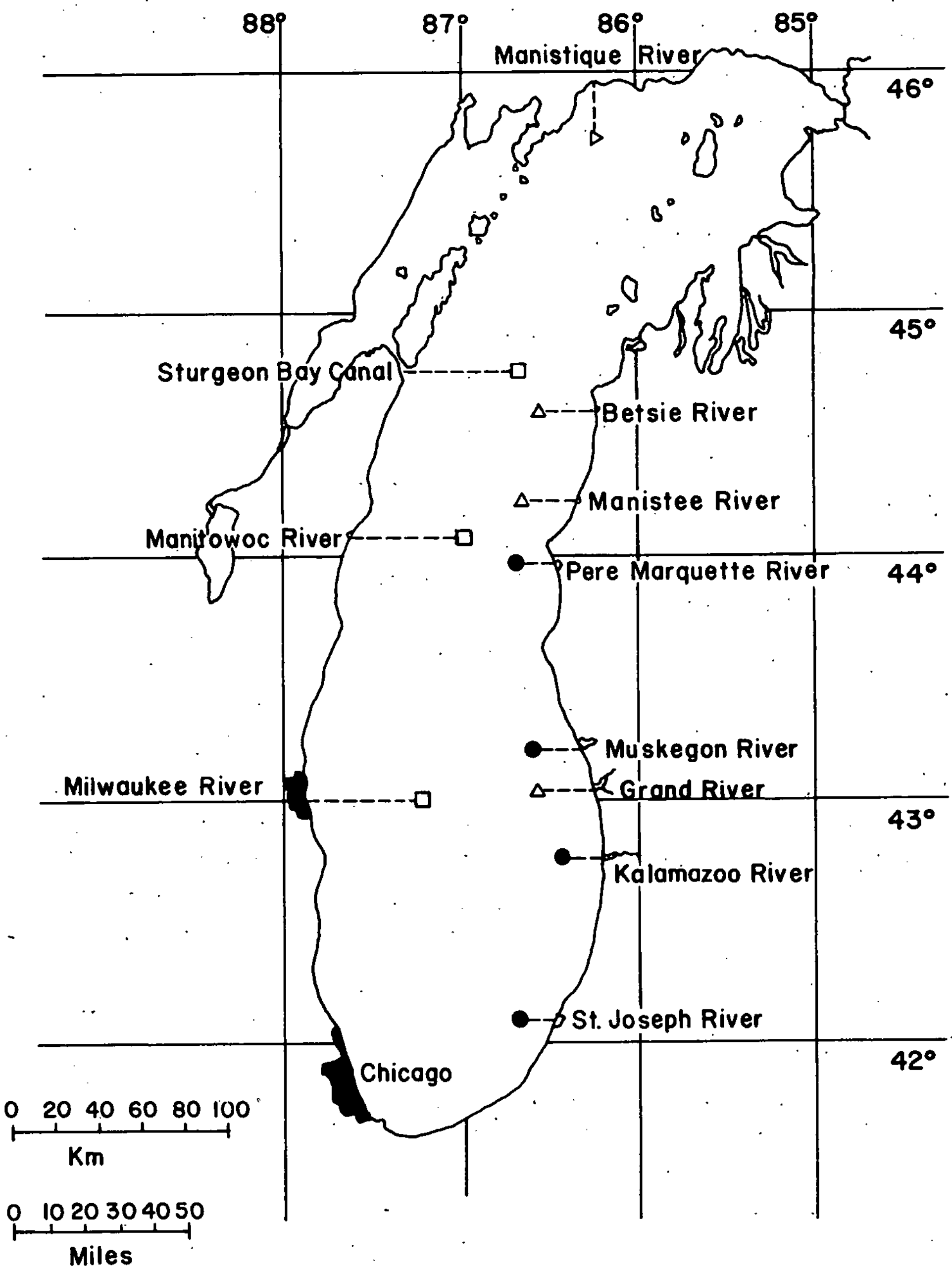

FIG. 1. Map of Lake Michigan showing transects sampled in 1972. Symbols denote the length of transects drawn to scale for each river sampled: solid circles for 13 km, open triangles for 26 km, and open squares for 52 km.

to these studies, most of the published work deals either with the Fox River, a tributary to Green Bay not included in our study, or the Grand River. The St. Joseph River has been studied by Van Landingham (1976).

The Grand River has undoubtedly been studied more than any other tributary to the main part of the lake. Recent studies of physical-chemical conditions include those by Davis *et al.* (1978) and Eadie *et al.* (in press). Phytoplankton have been considered by Stoermer (1968) and Kopczynska (1973). One of the important physical conditions in the lake that affects water quality and the distribution of phytoplankton is the thermal bar. This phenomenon, which occurs during spring warming, and to a lesser extent during autumnal cooling, was recognized first in the Great Lakes by Rodgers (1965) and studied in Lake Michigan by Huang (1972). It has been considered in studies by other workers (Stoermer 1968, Noble and Anderson 1968). Other studies dealing with the Grand River and its effect on Lake Michigan are those by Ayers and Rossmann (1967) and Stephenson and Waybrant (1971).

Tributary inputs contribute to inshore-offshore differences in water quality and biological conditions in the Great Lakes (Beeton and Edmondson 1972). These differences in inshore-offshore structure have been shown for water quality parameters by Ladewski and Stoermer (1973) and Rousar (1973). The distribution of *Melosira* species has been related to trophic conditions, partly due to inshore-offshore differences, by Holland (1968).

Rivers provide significant sources of inputs of various materials to Lake Michigan including trace metals, nutrients, and, as will be shown in this report, varied inputs of biological materials in the form of phytoplankton. To understand the dynamics of environmental processes in the lake, and in particular in the coastal zone, there is a need to obtain data on what is transported to the lake via tributary inputs and eventually to understand how these inputs affect processes within the lake. As part of the general problem it is necessary to know how one river differs from another in its input load and how these inputs have been altered due to anthropogenic factors in the drainage basin.

Generally we know that anthropogenic effects are much greater in the southern than in the northern part of the drainage basin. The major reason is that the drainage basin is more heavily populated in the southern part than in the northern part; and in addition atmospheric inputs, some of which probably originate outside the drainage basin, are much greater in the southern basin than in the northern basin.

Available data show considerable variability in the loads of trace metals and nutrients carried by different tributaries to Lake Michigan. For example, Robbins *et al.* (1972) have shown that the chromium load carried by the Grand River is ten times greater than that of any other tributary, and that it is roughly 75% of the tributary chromium load of rivers on the Michigan shoreline (Table 1). The Grand River also carries 25% of the total phosphorus tributary load (Sonzogni *et al.* in press) which for comparative purposes is equal to half the atmospheric loading of phosphorus to the entire lake surface (Eisenreich *et al.* 1977). A single tributary therefore can provide a relatively large proportion of the total input to the lake.

Tributary inputs may be more important than atmospheric inputs because tributary effects are manifested in a relatively small portion of the lake, considered either areally or volumetrically. The simple model for the area influenced by a tributary in Lake Michigan proposed by Schelske (1978a) delineates the area as 1000 to 2000 km^2 or from 2 to 4% of the lake's surface area and 15 to 30 km^3, or about .3 to .6 per cent, of the lake's volume. This model assumes that the major process associated with nutrient dispersion is advective transport and that turbulent diffusion and mixing are relatively unimportant on time scales of 4 or 5 days. Because coastal currents are generally

TABLE 1. Trace metal loadings for selected tributaries to Lake Michigan (from Robbins, Landstrom, and Wahlgren 1972). Data are mean daily loads in kg/day for trace metals. Flow is given in ft^3/sec.

	Flow	Cu	Ni	Zn	Fe	Mn	Cr	Mo
Boardman	186	.9	1.3	1.0	9	3.9	.4	.8
St. Joseph	3398	35	144	57	201	42	17	79
Kalamazoo	1296	9	53	15	146	96	7	26
Grand	3362	85	334	88	275	145	182	73
Muskegon	1889	14	37	21	170	33	21	32
Pere Marquette	608	3	11	6	45	13	2	6
Manistee	1933	11	39	10	181	35	10	28
Betsie	175	.7	1.9	.7	16	2	.3	1

parallel to shore (Mortimer 1975) and undergo reversals in direction (Csanady 1975), dispersion to offshore waters during much of the year would tend to be minimized compared to dispersal in the nearshore zone. Strong shore parallelling coastal currents when present therefore would tend to minimize dispersal to the offshore waters. Obviously mixing both with the nearshore and offshore water occurs, functioning to lessen the effect on phytoplankton by decreasing the concentrations of nutrients. The effect of nutrients would, however, still be manifested mainly in the nearshore area when advective processes predominate. The localized effect of a single tributary will be a function of the nutrient load which varies greatly from river to river (Table 2).

TABLE 2. Contributions of total soluble PO_4[a] and silica to Lake Michigan by 19 tributaries (1963-1964).[b]

River	Mean Flow (m^3/sec)	Mean Concentrations (mg/liter): Total Soluble PO_4	Mean Concentrations (mg/liter): SiO_2	Ratios: SiO_2/P	Loading (metric tons/day): Total Soluble PO_4	Loading (metric tons/day): SiO_2
Boardman	5.26	0.20	7.5	114:1	0.125	4.69
Manistique	23.9	0.04	5.8	574:1	0.082	12.0
Manitowoc	2.35	0.62	5.7	28:1	0.125	1.16
Sheboygan	3.73	0.40	3.9	30:1	0.129	1.26
Milwaukee	5.41	0.61	2.8	14:1	0.285	1.31
Burns Ditch	4.24	1.8	10	17:1	0.661	3.68
St. Joseph	58.4	0.24	6.4	82:1	1.21	32.3
Kalamazoo	32.3	0.21	5.9	86:1	0.586	16.5
Grand	53.8	0.52	5.3	31:1	2.42	24.7
Muskegon	49.0	0.06	5.6	285:1	0.254	23.8
Pere Marquette	16.1	0.03	7.8	796:1	0.041	10.9
Fox	125.0	0.28	9.4	103:1	3.03	101.8
Oconto	22.4	0.17	9.2	166:1	0.329	17.8
Peshtigo	25.2	0.08	9.8	375:1	0.174	21.4
Menominee	92.1	0.11	4.4	122:1	0.877	35.0
Ford	9.54	0.04	7.0	536:1	0.033	5.77
Escanaba	28.8	0.06	7.0	357:1	0.149	17.5
Rapid	2.27	1.59	3.1	5.8:1	0.311	0.61
Whitefish	6.43	0.18	5.7	97:1	0.100	3.17
					10.9	335

[a]PO_4 values were divided by 3.06 to convert concentrations to phosphate as phosphorus for SiO_2/P mass ratios.
[b]From Schelske 1975.

Our study was designed to sample single transects perpendicular to shore in each area of study. Such a sampling plan is not ideal because the axis of tributary plumes frequently will be parallel to shore and because the plume ordinarily flows in the same direction as the coastal currents. On the other hand, it is not possible to make a broad generalization about plume behavior which is a function of several interacting factors. Included in these factors are flow rate, nearshore current patterns that are largely wind driven, temperature difference between lake and river waters (a factor which varies seasonally), and Coriolis force. Mortimer (1975) has indicated that nearshore physical processes will usually be confined to distances <10 km from shore. At distances >10 km from shore, greater water depths provide larger volumes for mixing and dilution.

We sampled perpendicular to the shore and not along the plume axis for several reasons. First, it is time consuming and often virtually impossible to determine the axis of the plume because the pattern can be confused by shifting wind directions and nearshore current reversals (Csanady 1975). Second, in the spring and fall when rivers are at their maximum density (4° C), the plume, being colder and denser than the lake waters, may sink when it enters the lake. Third, by utilizing stations perpendicular to shore we could select them prior to the cruise and then sample the same stations more than once. It is obvious that on many occasions we missed the broadest part of the plume with this station configuration because the plume would broaden due to diffusion as it flows from the river mouth. Finally, we wanted to compare data from nearshore and offshore stations for each area and among areas, an objective best realized by locating stations perpendicular to shore.

The major purposes of this study are to provide comparative data on the biological, chemical, and physical variability of different rivers around Lake Michigan, to provide data on regional variations in nearshore and offshore conditions, and to provide a report which we hope will be useful to future investigators interested in the ecology of Lake Michigan and the Great Lakes. Data presented in this report include the abundance and species composition of phytoplankton, chlorophyll *a* and carbon-14 uptake for phytoplankton, major nutrients, and selected physical and chemical variables.

METHODS

Sampling was undertaken in April, July, and September, 1972, from The University of Michigan's R/V INLAND SEAS. Eleven transects were sampled in April. These transects originated at the St. Joseph River, Kalamazoo River, Grand River, Muskegon River, Pere Marquette River, Manistee River, Betsie River, and Manistique River in Michigan and near the entrances to the Sturgeon Bay Ship Canal, the Manitowoc River, and the Milwaukee River in Wisconsin (Fig. 1). In September only transects at the St. Joseph River, Grand River, and Betsie River were sampled. During July, transects at the St. Joseph River, Kalamazoo River, and Grand River were occupied four or five times in a 14-day period.

Stations along each transect were arranged in a geometric progression of distance from shore. The first station, with the exceptions noted below, was located at the river mouth and the remaining stations were located at .2, .4, .8, 1.6, 3.2, 6.4, and out to 52 km from the first station. It was not possible to sample all stations, but at least seven stations or the stations at least 6.4 km offshore were sampled on each transect.

The station at 0 km was a rivermouth station for all transects except the Kalamazoo River, Muskegon River, Sturgeon Bay, Manitowoc River, and Milwaukee River (Fig. 1). At the Kalamazoo River, the first five stations on the transect were located approximately .3 km farther offshore than originally planned. The exact locations of these stations west of the river piers were: .3, .5, .7, 1.3, and 2.1 km, not 0, .2, .4, .8, and 1.6 km as shown on the figures for this transect. At the Muskegon transect, the first station was located at the entrance piers for the navigation channel to Muskegon Lake. On the Sturgeon Bay transect, the first station (0 km) was located 2.0 km south of the entrance to the Sturgeon Bay and Lake Michigan Ship Canal at a distance of 1.0 km offshore. The location of this "0 km station" was 44°46.5′N and 87°18.35′W. On the Manitowoc transect there was no 0 km station and the transect was located approximately 10 km south of the Manitowoc piers to avoid possible influences of Rawley Point on nearshore characteristics. On this transect the ".2 km station" was located about 2 km from shore at 44°00.0′N and 87°40.0′W. The first station on the Milwaukee transect was located near the breakwall for the Milwaukee Harbor at 43°00.0′N and 87°52.8′W.

All water samples were taken with clean 5-liter Niskin bottles, except surface samples which were taken with a clean plastic bucket. Samples were taken at 2 and 5 m and at 5-m intervals to the bottom. At stations deeper than 50 or 55 m, the sampling interval below 10 m was increased to 10 m so no more than ten depths were measured at the deepest stations. Only data from depths $<$40 m are included in this report. Water transparency was measured at each station with a white Secchi disc. Temperature profiles were measured with a bathythermograph, and surface temperatures with a mercury thermometer on shipboard.

All methods were those used previously by Schelske *et al.* (1972, 1976). With some modifications, these are the methods given by Davis and Simmons (1979). Water samples were processed as illustrated in the flow chart (Fig. 2). Samples for chemical analyses were filtered through 47-mm HA Millipore filter papers which were pre-

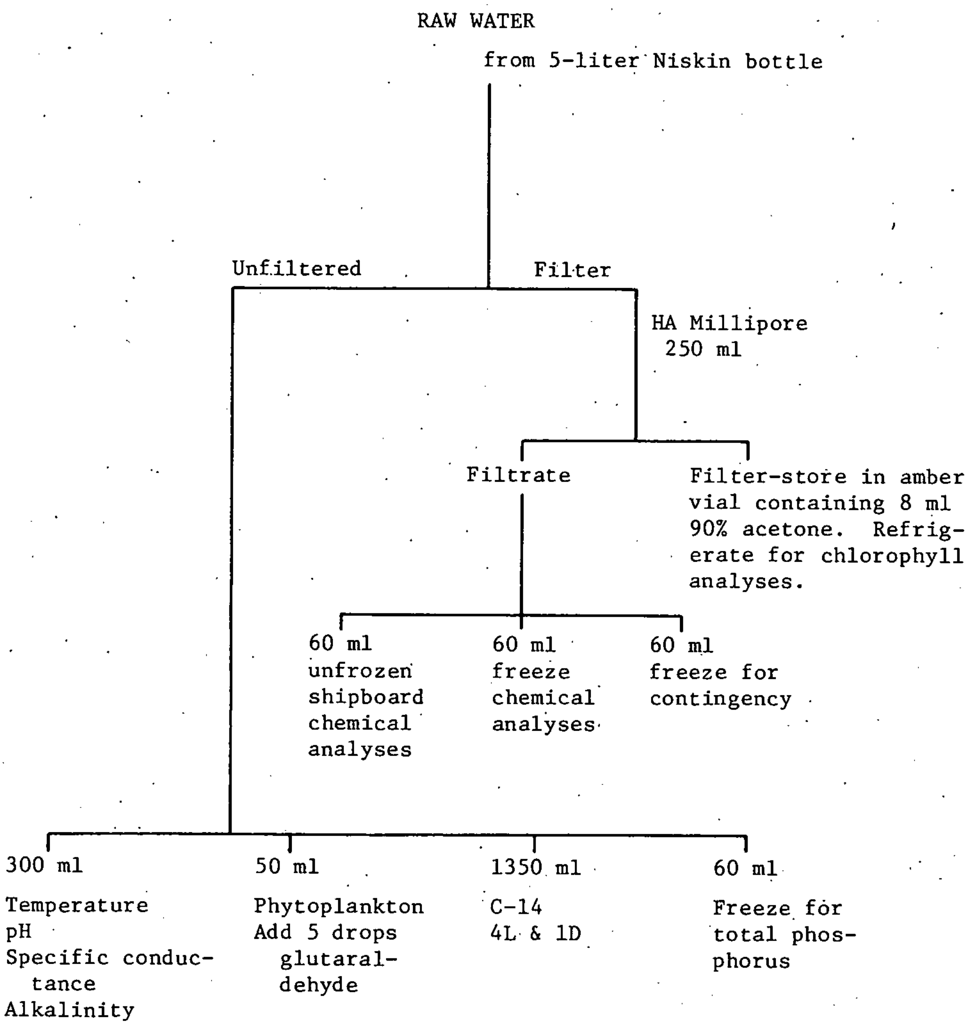

FIG. 2. Flow chart for preliminary sample processing on shipboard.

viously soaked and rinsed several times with distilled-deionized water. The Nalge conventional polyethylene bottles for chemical analyses were rinsed at least once with excess sample before filling.

A Beckman digital pH meter was used to measure pH on shipboard immediately after the samples were taken. Specific conductance corrected to 25° C was measured with a Leeds and Northrup Model 4866–60 conductivity bridge.

Samples for measurements of carbon fixation by phytoplankton were obtained at the surface and 2 m, incubated with two or three layers of window screen to reduce light intensity to 47 and 32% of the incident value, and maintained at surface-water temperatures in a daylight shipboard water bath (Schelske and Roth 1973). Results were corrected for dark bottle uptake and averaged for the two screens at each depth because differences between depths were much greater than between screens. Water samples (265 ml) were collected in glass-stoppered Pyrex bottles, injected with 2.0 μCi C-14, incubated for 3–4 hr, and filtered through 47-mm HA Millipore filters. The filters were mounted with rubber cement on 52-mm diameter aluminum planchets and stored for counting. A Low Beta Beckman Planchet Counter was used for counting. Efficiency of this counter and the absolute activity of the C-14 were determined with a Nuclear Chicago Liquid Scintillation Counter (Wolfe and Schelske 1967).

Alkalinity was determined from pH measurements on 20-ml samples to which 5 ml of 0.01N HCl were added. Alkalinity measurements were performed only on samples from 0 and 2 m where C-14 productivity was measured.

In April 1972 we first used the Technicon AutoAnalyzer II on shipboard in an effort to reduce the number of analyses which would otherwise need to be run in the laboratory, and to obtain data within a few hours of collection. Soluble reactive silica and nitrate nitrogen were successfully measured on board ship during this study. However, nitrate nitrogen data were somewhat more variable than data we have since collected on shipboard.

Dissolved reactive silica or silica was determined by the heteropoly blue method. In the method, silica is complexed with acidified molybdate to form a silicomolybdate complex which is reduced to an intense heteropoly blue. Oxalic acid was added prior to the reduction with ascorbic acid to destroy any phosphomolybdate. The color produced was measured at 630 mμ. Data are reported as mg SiO_2/liter.

Nitrate was reduced with a copper-hydrazine solution to nitrite at 54° C. The nitrite produced and the nitrite initially present in the sample were then determined by a diazotization-coupling reaction using sulfanilamide and N-1-naphthyl-ethylene diamine. The resulting red-violet colored complex was measured at 520 mμ (Kamphake *et al.* 1967). Nitrite was not analyzed separately, because quantitatively insignificant values would be expected in non-polluted oxygenated waters. Data are reported as mg NO_3–N/liter.

Samples for chlorophyll *a* (250 ml) were filtered on 47-mm HA Millipore filters and then extracted overnight at 4° C with 90% acetone buffered with magnesium carbonate. The samples were then centrifuged, and 5 ml were transferred to sample cuvettes and read in a modified Turner Model 111 Fluorometer. Samples were subsequently acidified and read in the fluorometer for phaeopigment determinations (Strickland and Parsons 1968). Readings of extracted chlorophyll *a* with the fluorometer were taken both on board ship and in our laboratories in Ann Arbor. Samples were maintained in the cold and dark until readings were taken. Results reported were corrected for phaeophytin.

Frozen samples for chemical analyses were transferred from the ship's freezers to large insulated coolers and brought back to the Ann Arbor laboratory. The duration of the trip was normally 3½ hr. Samples remained frozen during transit and were immediately stored in laboratory freezers. The containers used for transport were large plywood boxes insulated on all sides with 5 cm of styrofoam. Sometimes smaller picnic coolers were used for extra samples, and in this case blocks of dry ice were used to maintain freezing temperatures during transport.

Samples were brought back to the laboratory during or at the end of each cruise. Analyses in the laboratory were usually completed within a week to a month depending upon the availability of personnel to do the analyses.

Chemical analyses for ammonia, total phosphorus, and chloride were performed on thawed samples with the Technicon AutoAnalyzer in the laboratory. Most of the methods employed were Technicon AutoAnalyzer methods or modified ones. All analyses except the one for total phosphorus were performed on samples of filtered water.

Only a few data for ammonia nitrogen were obtained during the study. Values in April ranged from a high of 100 μg/liter at the 0 km station on the Milwaukee transect to 3–10 μg/liter at the offshore locations. Concentrations in the range of 10 μg N/liter or less more accurately represent conditions in offshore waters than values ranging as large as 100 μg N/liter which have been reported in the past (Torrey 1976). Unpublished data show vertical structure in ammonia concentrations during thermally stratified periods.

Samples for total phosphorus were concentrated by evaporation and digested with potassium persulfate for 1.5 hr in an oven at 110° C as modified from Menzel and Corwin (1965). Samples were then treated with an acidic solution of ammonium molybdate to give phosphomolybdate which was reduced by ascorbic acid to give a blue color and measured at 630 mμ with a Technicon AutoAnalyzer I. Data are reported as μg P/liter.

Chloride was determined from its reaction with mercuric thiocyanate which forms mercuric chloride. The released thiocyanate reacts with ferric ammonium sulfate to form a red complex, $Fe(SCN)_3$. The resulting color was measured at 480 mμ with a Technicon AutoAnalyzer II. Data are reported as mg Cl/liter.

Phytoplankton samples were taken at 2 m for all stations. Immediately after collection, 50 ml of water were fixed with 4% glutaraldehyde, stored at 4.0° C in the dark for 1–4 hr to ensure complete fixation, and then filtered onto a 25-mm AA Millipore filter. The filtered preparations were partially dehydrated in an ethanol series, cleared with beechwood creosote, and mounted on glass slides (Stoermer *et al.* 1974). All identifications were made with a Leitz Ortholux microscope fitted with an oil immersion objective which furnished approximately 1200 X magnification and 1.32 numerical aperture.

Cell count data are enumerations based on counting either two rows, each 10 mm in length, or one 2 mm row. Population estimates for all April and September samples were based on the longer rows. Due to the large number of samples taken in July, it was necessary to adopt the shorter rows; therefore, with the exception of the July 8 samples for the St. Joseph River, only one 2 mm row was counted for the July samples.

Statistical reliability of the data is a function of the total number of counts and the growth form of the species (Stoermer *et al.* 1978); many of the colonial and filamentous forms would not be randomly distributed on the slides prepared for enumeration. The amount of phytoplankton data was too great to consider statistical problems in the present study—it should be intuitively obvious, however, from examining data presented that statistics are not needed to be certain of major differences in species composition in the data set. Certain trends suggested by inspection may not in fact be supportable if the data were tested statistically, but these types of studies are beyond the scope of this initial investigation and presentation of the data.

Raw phytoplankton counts were coded and prepared so all data could be reduced by computer. The Shannon-Wiener information index was used as an estimate of diversity (Hutchinson 1967).

Due to identification and taxonomic difficulties, centric diatoms identified as *Stephanodiscus* sp. #16 could in fact be *S. subsalsus,* also known as *Skeletonema subsalsus.*

The primary data displays are depth-distance plots for the major physical-chemical variables on each transect. One such plot was adequate for each variable. Data for phytoplankton could not be plotted in the same manner because data were available only for 2 m and many species were included in each sample. Rather than plotting each species separately, we chose to plot data for the most dominant species as per cent composition at each station which is in fact a plot of relative abundance for each station along the transect. The absolute standing crop in cells/ml then can be determined at each station, either for the total assemblage or for the species plotted. Total cell counts for each station are graphed on each figure.

In interpreting the plots of phytoplankton species composition as a function of distance offshore, the reader must recognize that the per cent composition will tail off to zero abundance when a species is present in relatively high abundance at one station and not present at the adjacent station. Given this set of circumstances, one does not know at what point between the two stations the per cent composition reached zero. It is, of course, also not possible to determine average gradients for physical-chemical variables between some pairs of stations so caution and thought should be used in interpolation of values between stations.

RESULTS FOR APRIL

ST. JOSEPH RIVER TRANSECT

Physical-Chemical Conditions

On the St. Joseph transect in April, three areas with distinct characteristics were evident. These zones were: river mouth, river plume, and lake. The water in the river had relatively high temperatures, low pH, and high silica compared to the offshore zone (Fig. 3a). River water had temperatures >15° C with a low pH (<8.4), and a silica concentration >3 mg/liter. River water also had high nitrate (>1.5 mg/liter) and high total phosphorus concentration (>125 μg/liter).

The river plume zone extended to about 3.2 km offshore—in this zone pH was greater than in the river or the offshore waters, and silica concentrations were less than in the river or offshore waters. Both characteristics reflect greater phytoplankton growth in this nearshore zone than in waters farther offshore. On the other hand, total phosphorus and nitrate nitrogen decreased with distance offshore and were not affected as greatly by the increased photosynthetic activity in the nearshore zone. Chemical characteristics of offshore waters 13 km from shore had changed from those typical of mid lake earlier in the spring—pH had increased to 8.55 and silica concentrations were reduced to approximately 1.2 mg/liter.

There was a well-developed thermal bar on this transect with the 4° C isotherm being between 1.6 and 3.2 km from shore; water temperatures increased inside the thermal bar to 15° C at the river mouth and decreased to <2° C offshore (Fig. 3a).

The pH was 8.4 at the rivermouth station, the lowest observed on the transect, but it increased to >8.9 at the station 3.2 km from shore and was >8.75 inside the thermal bar 1.6 km from the shore (Fig. 3a). On the offshore side of the thermal bar pH decreased from 8.7 to 8.55 at the station 13 km from shore.

No data were available for chloride concentrations on this transect.

Silica concentrations at the rivermouth station were >3 mg/liter but decreased very rapidly to <.1 mg/liter at the station .4 km from the shore. Concentrations of silica were <.4 mg/liter generally at all stations <3.2 km from shore, and increased at the stations 6.4 and 13 km offshore where concentrations ranged from 1.0 to >1.2 mg/liter.

Nitrate concentrations at the river mouth were >1.5 mg/liter. At the remaining stations concentrations decreased with distance offshore ranging from .5 to <.3 mg/liter.

Large concentrations of total phosphorus were present at the river mouth and .2 km from the shore where concentrations ranged from 75 to 125 μg/liter. At the remaining stations phosphorus concentrations decreased from 25 μg/liter at .4 km to <10 μg/liter 13 km offshore.

Phytoplankton

One of the most pronounced features of phytoplankton distribution on this transect was the nearly constant decrease in phytoplankton standing crop with distance

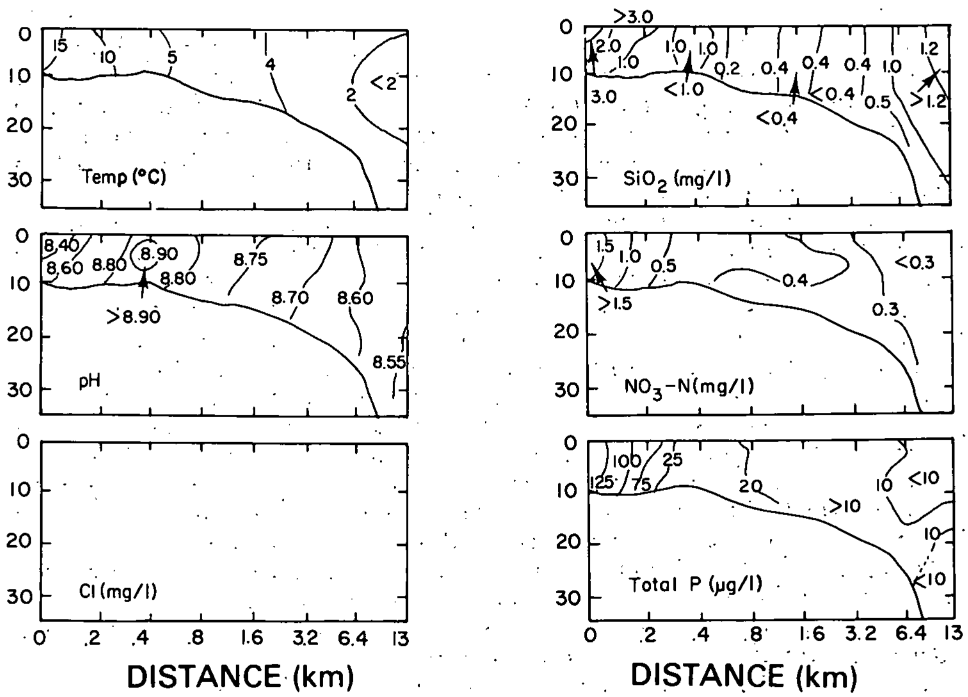

FIG. 3a. St. Joseph River transect, April 19, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

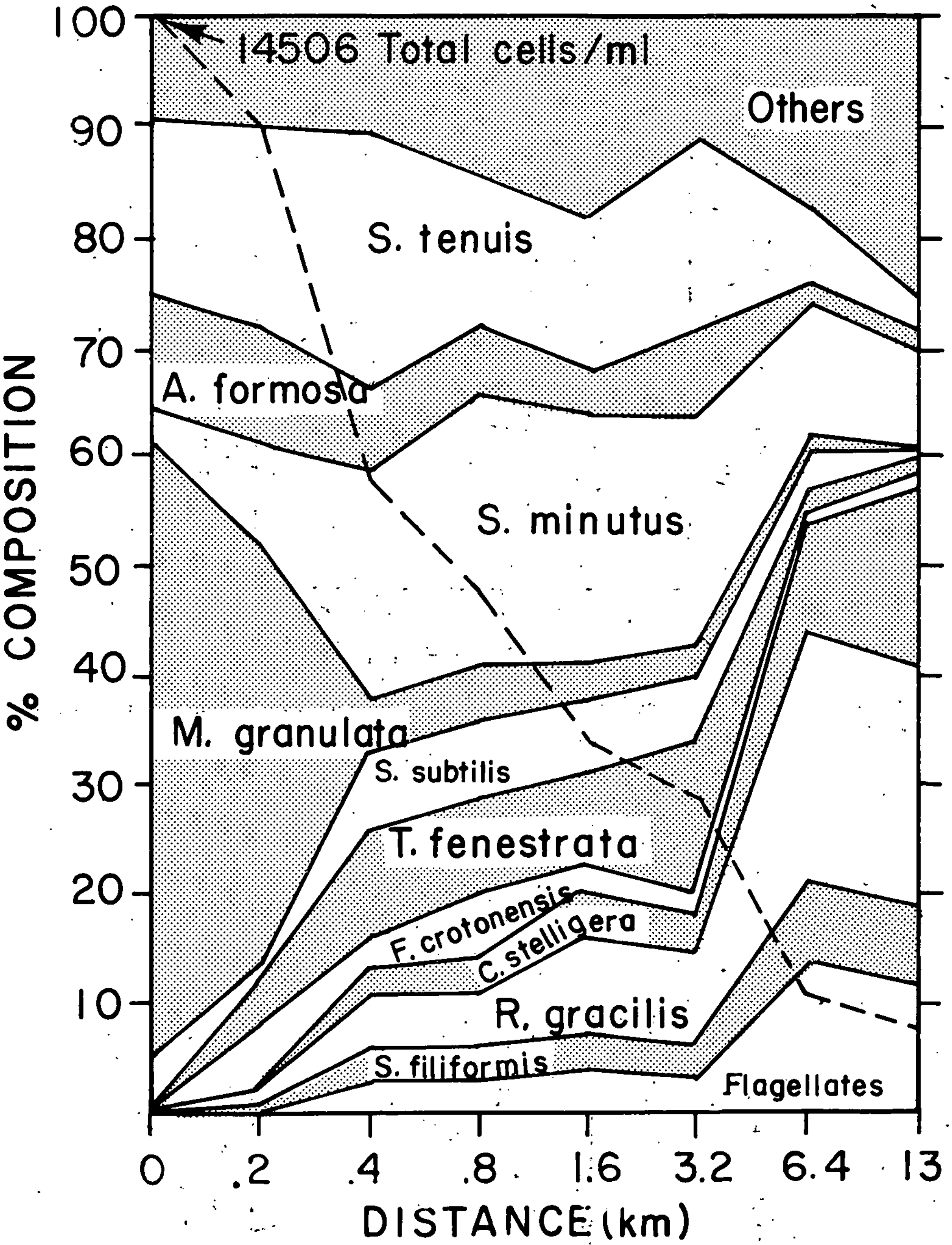

FIG. 3b. St. Joseph River transect, April 19, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

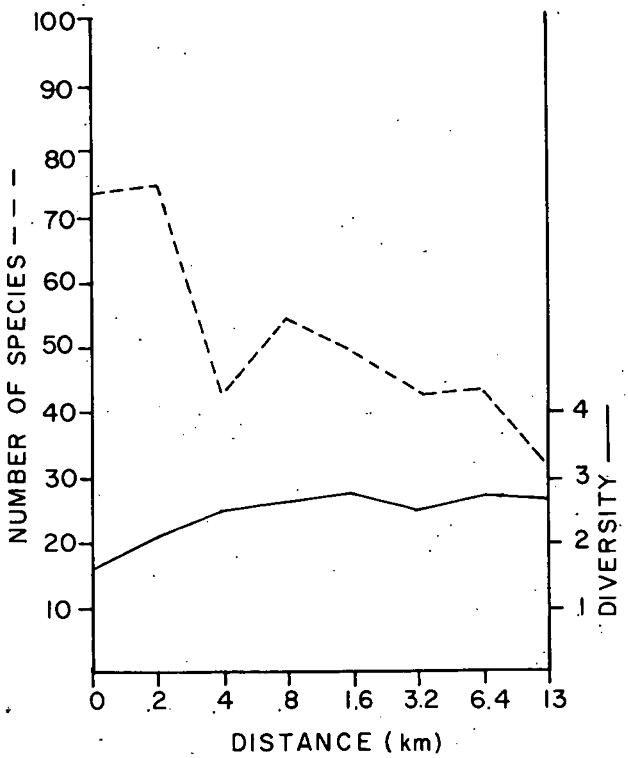

FIG. 3c. St. Joseph River transect, April 19, 1972. Number and diversity of phytoplankton species at 2 meters.

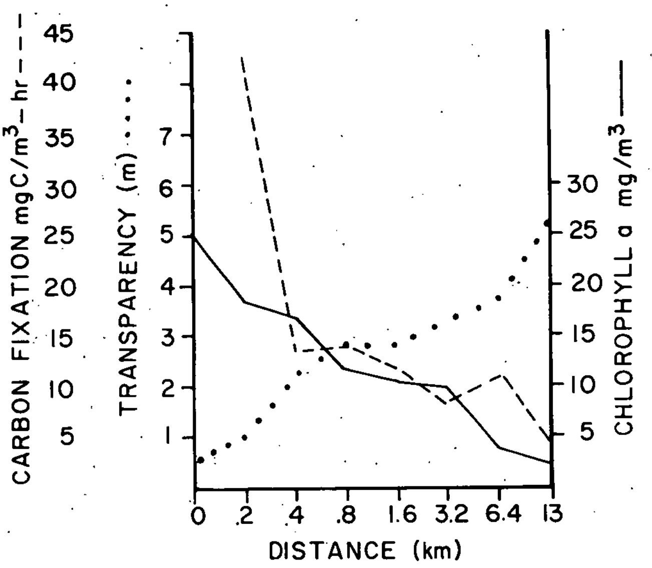

FIG. 3d. St. Joseph River transect, April 19, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

offshore (Fig. 3b). More than an order of magnitude decrease occurred from the rivermouth, where cell counts were 14500 cells/ml, to 13 km from shore where cell counts decreased to 1140 cells/ml.

The effect of the river was manifested at the two stations closest to shore or within .2 km from shore, where *Melosira granulata* comprised from 38 to 56% of the total cell counts. Relative abundance of *M. granulata* decreased drastically at stations located from .4 to 13 km offshore where relative abundances were <5% of the total cell counts. In addition to *M. granulata, Stephanodiscus tenuis* and *Asterionella formosa* were abundant species at the stations closest to shore, together comprising an additional 27 to 29% of the total cell counts.

At distances >.4 km offshore, dominant species were *Stephanodiscus minutus, Cyclotella stelligera, Rhizosolenia gracilis,* and *Synedra filiformis;* these species in general were most abundant at the stations located farthest offshore. In addition, undetermined flagellates increased with distance offshore and their relative abundance was >10% of the total cell counts at stations 6.4 and 13 km offshore.

Tabellaria fenestrata had a unique distribution in that relative abundance was greatest at four stations whose distances from shore ranged from .4 to 3.2 km.

Numbers of species were very high in the river mouth and at the station .2 km from shore, with more than 70 taxonomic entities being identified from each location (Fig. 3c). At the remaining stations, numbers of species ranged from 30 to 55 and tended to decrease with distance from shore. Diversity was lowest nearshore and tended to be uniform from .8 to 13 km from shore.

Carbon Fixation and Chlorophyll

Rates of carbon fixation and chlorophyll *a* concentrations generally decreased with distance from shore (Fig. 3d). The trend for rates of carbon fixation began at the station located .2 km from shore because no rates of carbon fixation were obtained at the river mouth. Chlorophyll *a* concentrations and rates of carbon fixation were inversely related to Secchi disc transparency which increased with distance from shore. Out to a distance 1.6 km from shore rates of carbon fixation were >10 mg C/m^3/hr and chlorophyll *a* concentrations were >10 mg/m^3, but values for both variables were <5 13 km from shore.

KALAMAZOO RIVER TRANSECT

Physical-Chemical Conditions

Little effect of inputs from the Kalamazoo River on physical-chemical characteristics was evident at the stations sampled on the April cruise (Fig. 4a). The 0 km station was not at the river mouth. Water temperatures were <4° C, so the thermal bar was not present. Close to shore the pH was 8.65, being slightly greater than offshore values which were 8.50. There was little difference in concentrations of silica and nitrate nitrogen along the transect. Total phosphorus was slightly greater at the stations <.2 km from shore where concentrations were 20 μg/liter compared to 10 μg/liter at stations farther offshore.

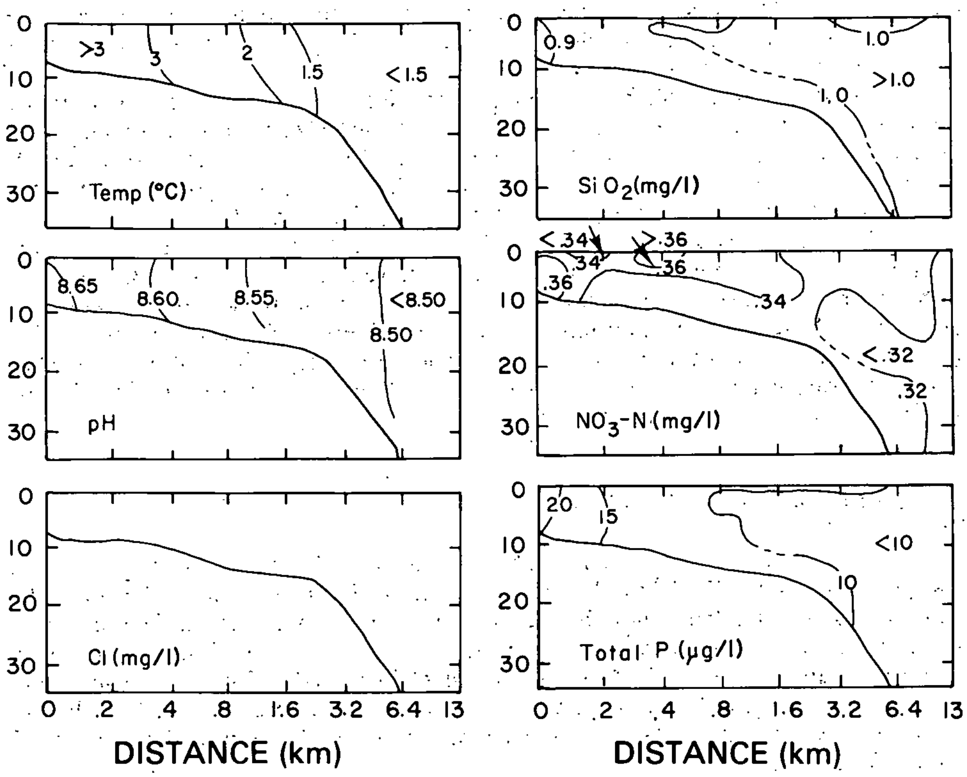

FIG. 4a. Kalamazoo River transect, April 18, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

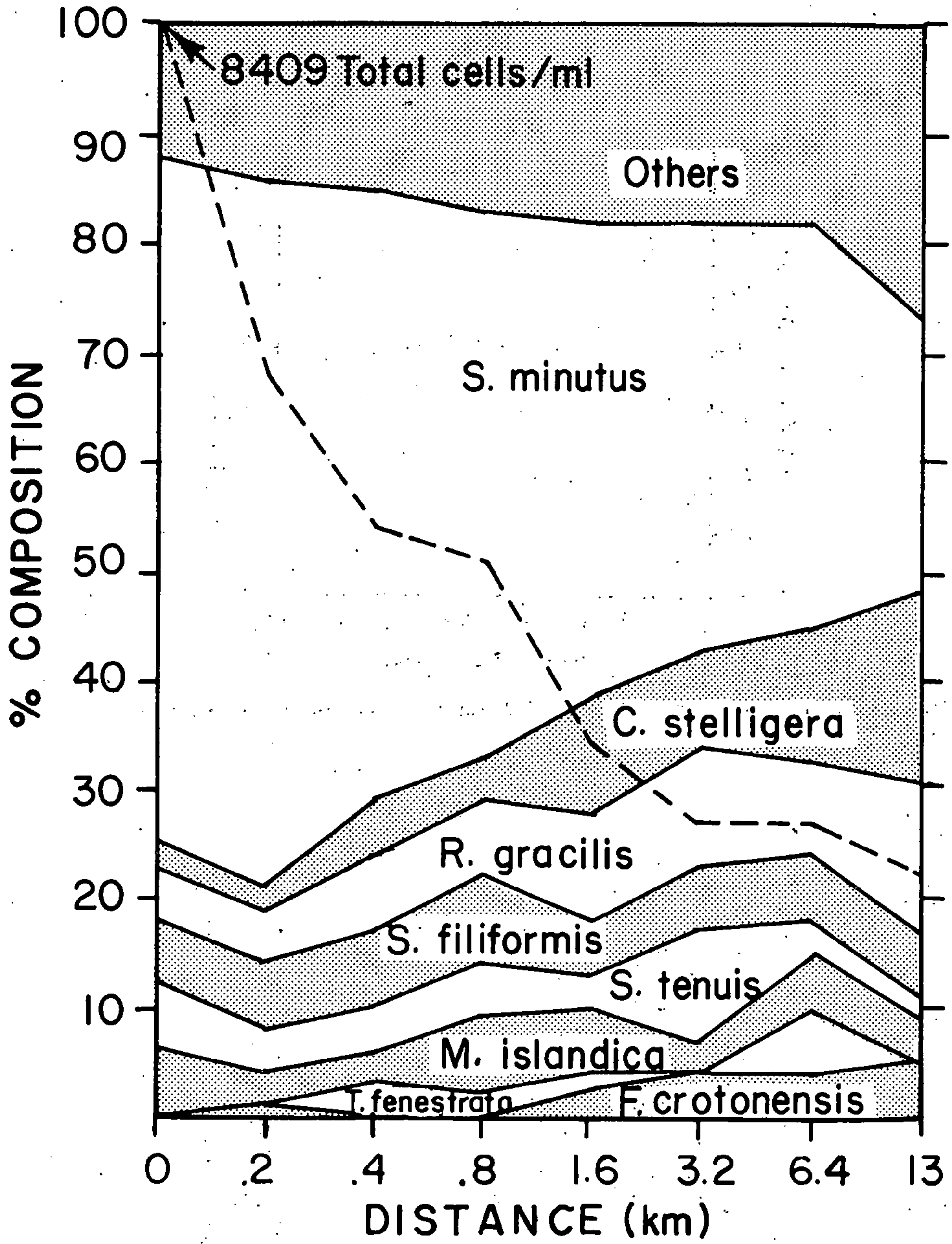

FIG. 4b. Kalamazoo River transect, April 18, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

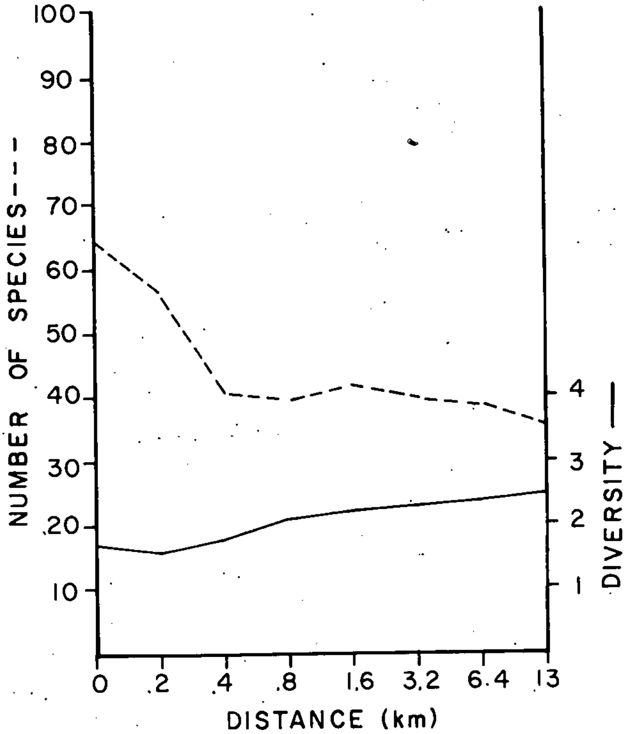

FIG. 4c. Kalamazoo River transect, April 18, 1972. Number and diversity of phytoplankton species at 2 meters.

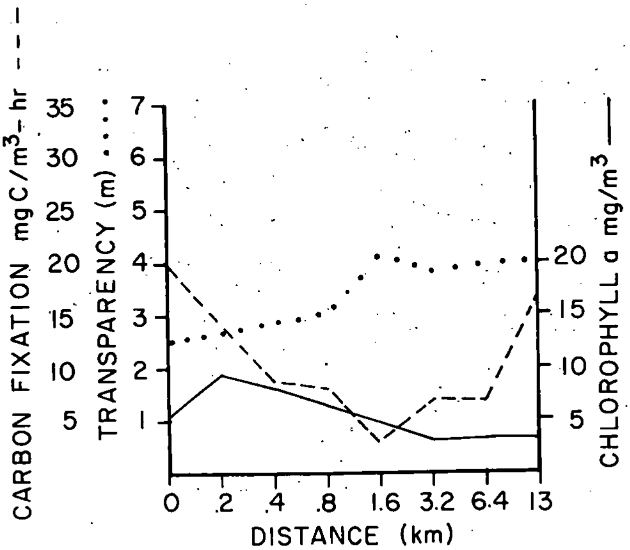

FIG. 4d. Kalamazoo River transect, April 18, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Phytoplankton

On this transect the standing crop of phytoplankton decreased at a constant rate for stations located from .2 to 3.2 km from shore (Fig. 4b). Over this distance total cell counts decreased more than 50% from 5700 at .2 km to 2250 cells/ml at 3.2 km. The rate of decrease was less at greater distances offshore so that cell densities decreased only to 1840 cells/ml at the station 13 km from shore.

Eight species comprised from 82 to 88% of the total cell counts at all stations except the station located 13 km offshore—at this station the eight species comprised 73% of the total cell counts (Fig. 4b). The most abundant species at all stations was *Stephanodiscus minutus,* comprising more than 60% of the total cell counts at the nearshore stations and decreasing to 25% of the total cell counts at the station located 13 km from shore. Other important species in terms of abundance were *Cyclotella stelligera, Rhizosolenia gracilis, Synedra filiformis, Stephanodiscus tenuis,* and *Melosira islandica.*

Largest numbers of species were 56 and 64 at the two stations nearest to shore (Fig. 4c). At the stations from .4 to 13 km offshore the number of species ranged from 36 to 42, with fewer species generally being found with distance offshore. Diversity was lowest nearshore and appeared to increase with distance offshore, although the increase was much smaller at stations located from .8 to 13 km from shore than for stations closer to shore.

Carbon Fixation and Chlorophyll

Chlorophyll *a* concentrations were only slightly greater nearshore than offshore, ranging from 3–9 mg/m^3 on the transect (Fig. 4d). Rates of carbon fixation were also low, being <10 mg C/m^3/hr except at the station located closest to shore and at the station located farthest from shore. Secchi disc transparency also varied little, ranging from 2.5 to 4 m with lower transparencies at stations <.8 km from shore than at stations farther offshore.

GRAND RIVER TRANSECT

Physical-Chemical Conditions

The thermal bar in April was located between 1.6 and 3.2 km offshore. Temperature of the water flowing out of the Grand River was >8° C (Fig. 5a). Offshore from the thermal bar at stations located from 3.2 to 26 km, temperatures ranged to 1–1.5° C.

Water on the shoreward side of the thermal bar had distinctly different physical and chemical conditions than water on the offshore side of the thermal bar. Total phosphorus was >80 μg/liter inside the thermal bar and <10 μg/liter in the offshore waters. Near the river mouth total phosphorus concentrations were as great as 160 μg/liter (Fig 5a).

On the shoreward side of the thermal bar pH was less than it was offshore from the thermal bar. Inside the thermal bar pH ranged from 8.4 to 8.1 near the river mouth and on the outside of the thermal bar pH was about 8.45. Greatest values of pH (>8.5) were found at the thermal bar.

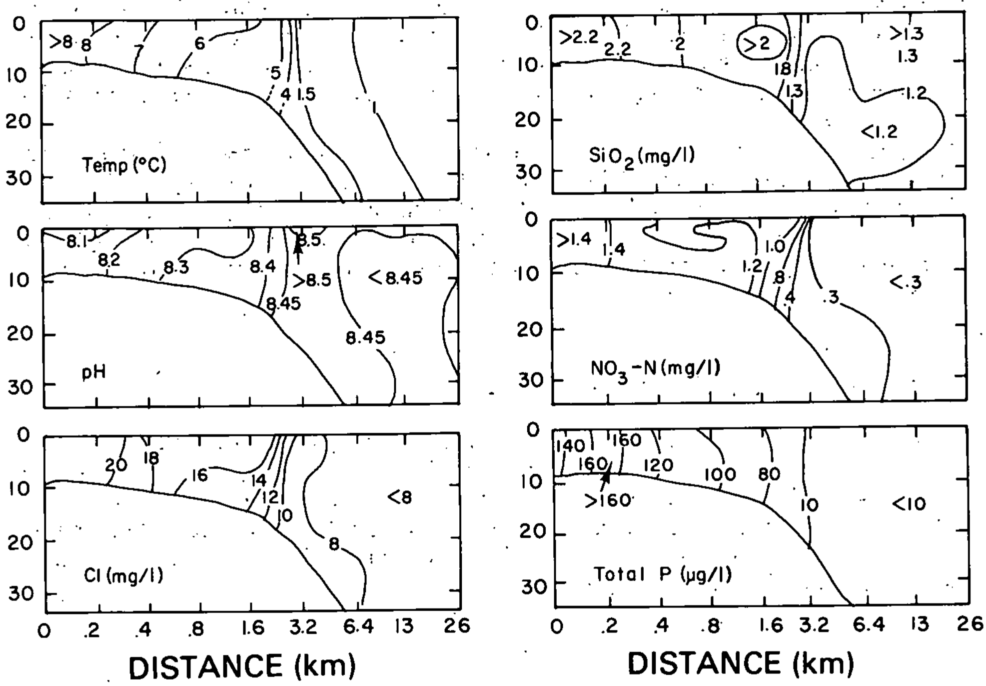

FIG. 5a. Grand River transect, April 17, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

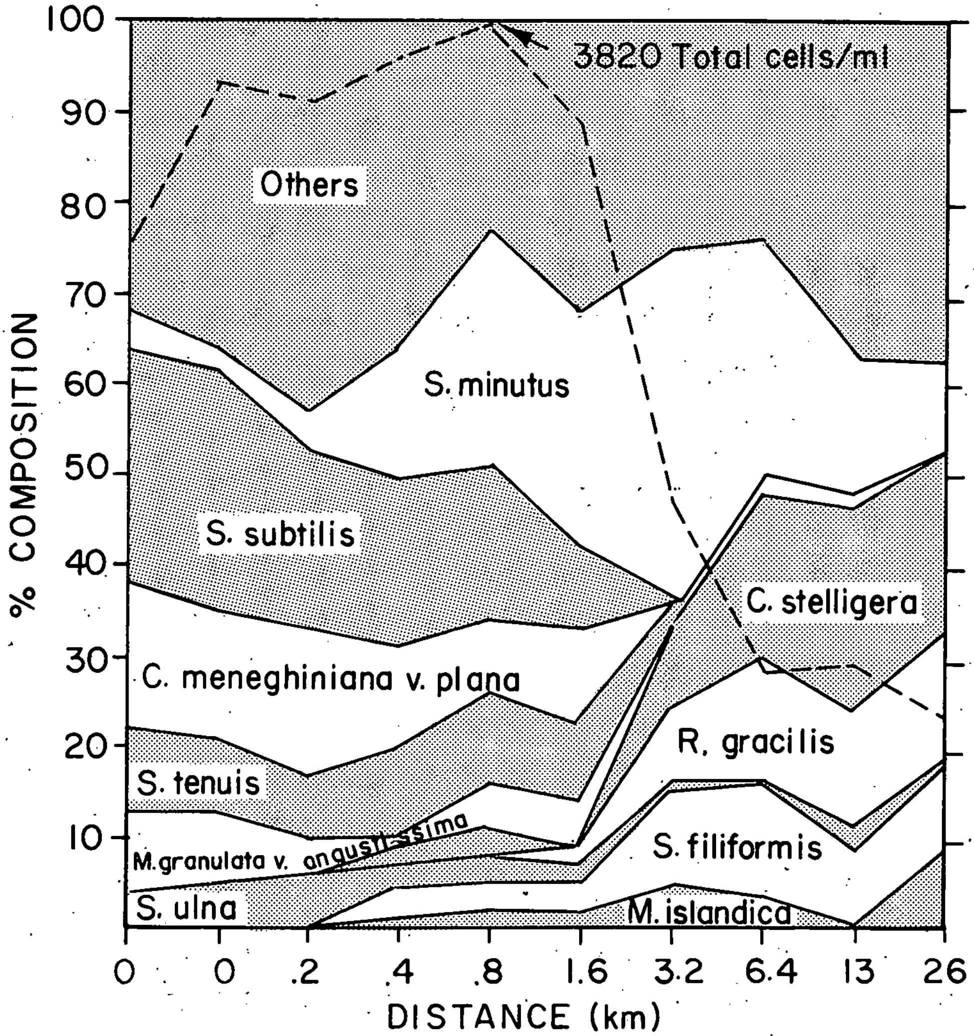

FIG. 5b. Grand River transect, April 17, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure. The 0 km station shown on the left side of the figure was taken in the river, not at the usual station at the river mouth. The other 0 km station depicted in the figure was taken at the usual rivermouth station.

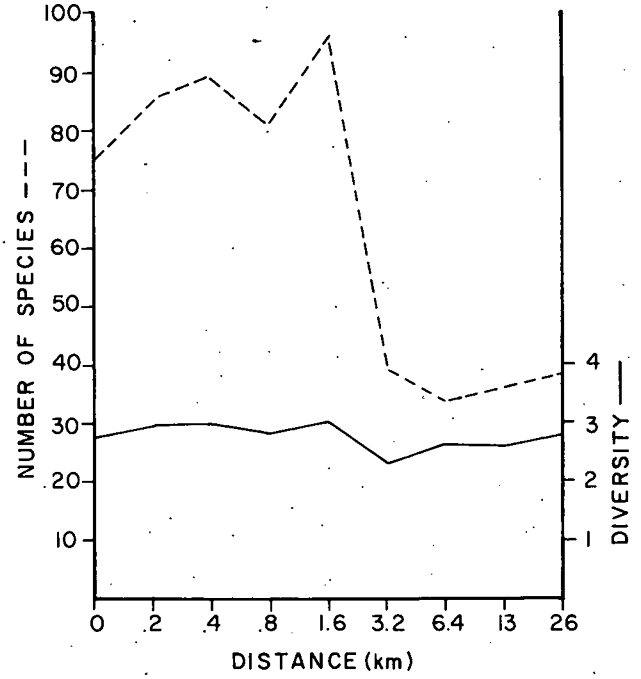

FIG. 5c. Grand River transect, April 17, 1972. Number and diversity of phytoplankton species at 2 meters.

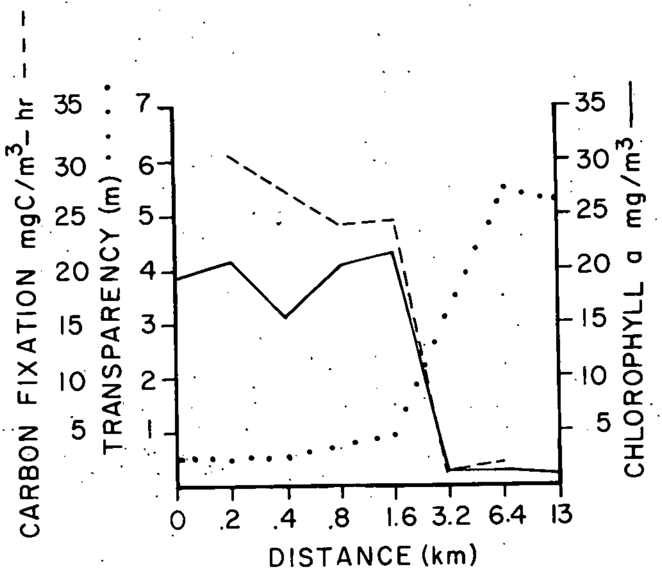

FIG. 5d. Grand River transect, April 17, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Chloride concentrations were >20 mg/liter near the river mouth and decreased to 10 mg/liter on the inside of the thermal bar. In the offshore waters chloride concentrations were <8 mg/liter.

Silica was higher in the nearshore waters with the concentrations ranging from 1.8 to >2.2 mg/liter inside the thermal bar and decreasing to <1.2 mg/liter offshore of the thermal bar. Lowest concentrations were found at depth in waters offshore of the thermal bar, indicating that silica was being utilized at the surface as water was being downwelled in the thermal bar. This explanation is supported also by the distribution of pH at the thermal bar.

Nitrate was also present in greater concentrations inshore of the thermal bar with concentrations ranging from .8 to 1.4 mg/liter, compared to concentrations outside the thermal bar which ranged from .3 to <.3 mg/liter.

Phytoplankton

In April the influence of the Grand River was apparent from the distribution of phytoplankton at all stations out to a distance of 1.6 km from the river mouth (Fig. 5b). In this zone the standing crop of phytoplankton ranged from 2850 to 3820 cells/ml with the five most abundant species being *Stephanodiscus subtilis, Cyclotella meneghiniana* v. *plana, Stephanodiscus tenuis, Synedra ulna,* and *Melosira granulata* v. *angustissima.* These five species comprised from 40–60% of the total cell counts in this zone.

Several species were relatively abundant at the rivermouth station in the category designated "others." They were *M. granulata, M. varians, Cyclotella atomus, Fragilaria pinnata,* and *Gomphonema olivaceum,* comprising 19% of the species composition.

Stephanodiscus minutus had a unique distribution in comparison to other species in that its relative abundance was greatest not only in the nearshore zone influenced by the river but also at stations extending beyond this zone of influence. The relative abundance of *S. minutus* was greatest in the zone ranging from .4 to 13 km offshore.

At the offshore stations, or at stations not directly influenced by the river, which extended from 3.2 to 26 km offshore, the standing crop of phytoplankton varied from 1780 cells/ml at 3.2 km, decreasing to 860 cells/ml at 26 km. At the three stations 6.4 to 26 km from shore cell densities were least, being <1100 cells/ml. At these three offshore stations the dominant phytoplankters were *Cyclotella stelligera, Rhizosolenia gracilis, Synedra filiformis,* and *Stephanodiscus minutus.* Also present but in much lower abundances were *Melosira islandica, Synedra ulna,* and *Melosira granulata* v. *angustissima,* generally with relative abundances of much less than five per cent. *Cyclotella stelligera,* the most abundant species, made up roughly 20% of the total cell counts at three offshore stations.

Numbers of species at stations located within 1.6 km of the shore ranged from 75 to more than 90, but at stations 3.2 km or more from shore the number of species was less than 40 (Fig. 5c). The larger number of species nearshore was undoubtedly due to many species being transported by the Grand River to the nearshore and to other factors associated with the mixing of river water and lake water. Even though there was a large variation in the number of species on the transect, the diversity was relatively constant.

Carbon Fixation and Chlorophyll

There was a distinct break in carbon fixation rates and chlorophyll *a* concentrations between the stations located 1.6 and 3.2 km from shore (Fig. 5d). At the stations located 1.6 km or less from shore, chlorophyll *a* concentrations were about 20 mg/m^3 and rates of carbon fixation ranged from 24–31 mg C/m^3/hr. At the stations farther offshore concentrations of chlorophyll *a* and rates of carbon fixation were an order of magnitude less. Likewise in the nearshore zone less than 1.6 km from shore, the Secchi disc transparency was <1 m whereas at the stations 6.4 and 13 km offshore it was >5 m.

MUSKEGON RIVER TRANSECT

Physical-Chemical Conditions

During April 1972, the thermal bar was just being established on the Muskegon River transect (Fig. 6a) because most of the water at stations .8 km or less from shore was only slightly warmer or colder than 4° C. Beyond 1.6 km offshore the temperatures were <3° C.

There appeared to be a distinct break in the chemical characteristics between stations located 3.2 and 6.4 km offshore, a boundary which was farther offshore than the thermal bar. This distinct inshore-offshore difference probably is not attributable entirely to inputs from the Muskegon River but is more likely due to longshore transport of water from the south where inputs of phosphorus and chloride are greater than to the north. Offshore values were fairly representative of those found during April at stations on other transects.

Nearshore, there were greater chloride, silica, nitrate, and total phosphorus concentrations than offshore, with the largest gradients in concentration being between the stations located at the river mouth and .2 km from shore.

Phytoplankton

The major feature related to phytoplankton distribution on this transect was the obvious break in pattern between stations located 3.2 and 6.4 km offshore (Fig. 6b), a distinction also observed for physical-chemical factors.

There was a large difference in phytoplankton standing crop at the rivermouth station, as compared to all other stations. The standing crop at the rivermouth station was 11750 cells/ml and decreased to 5170–8220 cells/ml at stations located between .2 and .8 km from shore. For stations 1.6 and 3.2 km offshore, the standing crops (ranging from 2940 to 3880 cells/ml), were only 25 to 33% of those at the rivermouth station. The phytoplankton at the rivermouth station was characterized mainly by two species of *Stephanodiscus*, *S. minutus* and *S. tenuis*, which comprised more than 90% of the total cell counts. The large relative abundance of both species was maintained out to a distance of 3.2 km offshore. At stations 6.4 and 13 km from shore both species were replaced by more typical offshore phytoplankton, particularly *Cyclotella stelligera*, *Synedra filiformis*, *Rhizosolenia gracilis*, *Melosira italica*, and undetermined flagellates. These offshore stations had relatively low phytoplankton densities ranging from 720–890 cells/ml.

Species diversity appeared to increase generally with distance offshore and was highest at the two offshore stations which had the fewest species (about 30) (Fig. 6c). At stations 3.2 km or closer to shore the number of species ranged from 42 to 61 but did not vary in relation to species diversity.

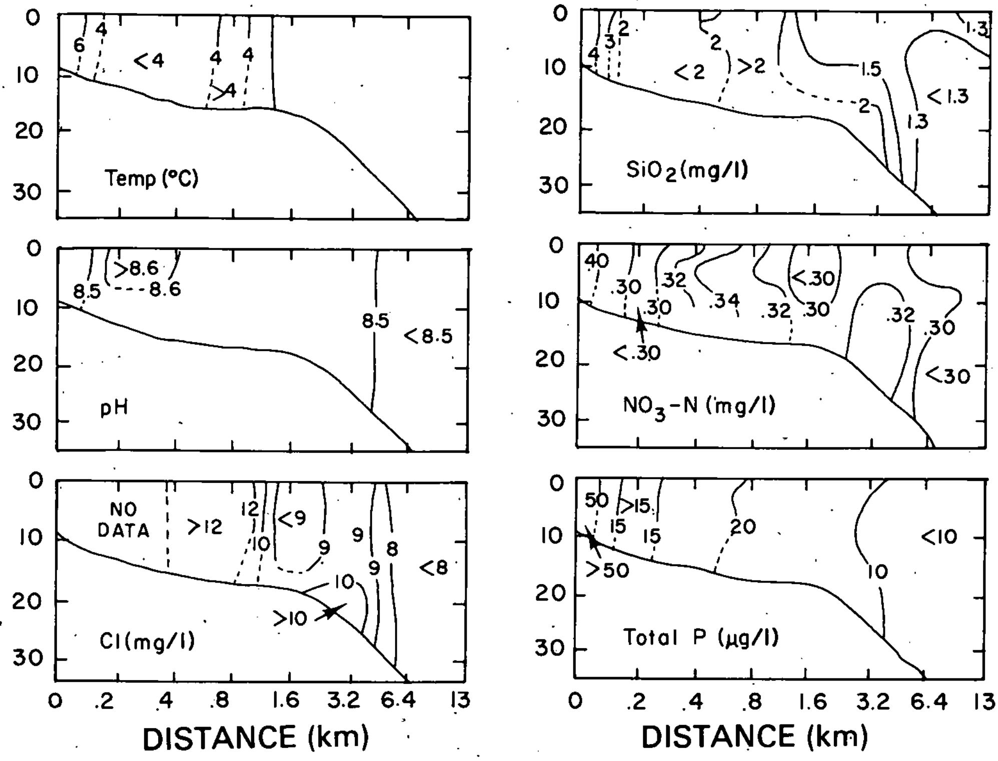

FIG. 6a. Muskegon River transect, April 17, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

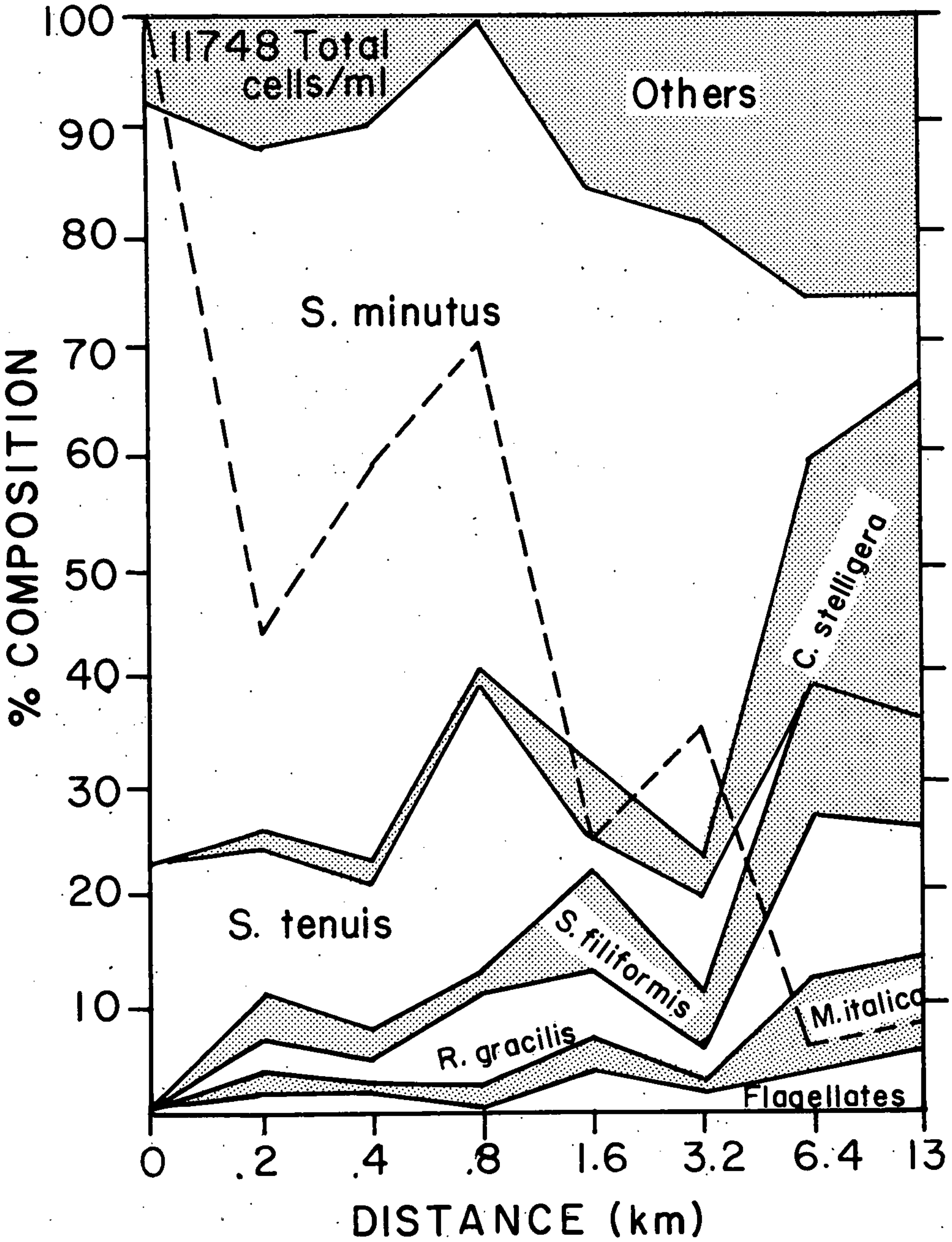

FIG. 6b. Muskegon River transect, April 17, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

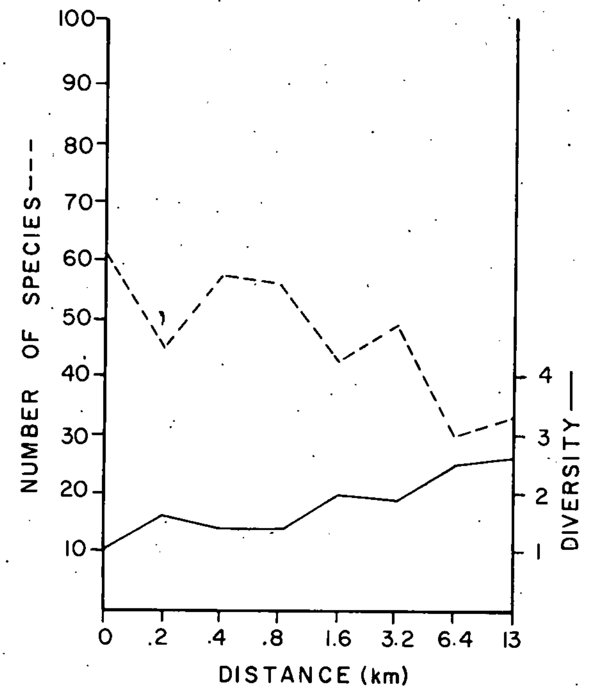

FIG. 6c. Muskegon River transect, April 17, 1972. Number and diversity of phytoplankton species at 2 meters.

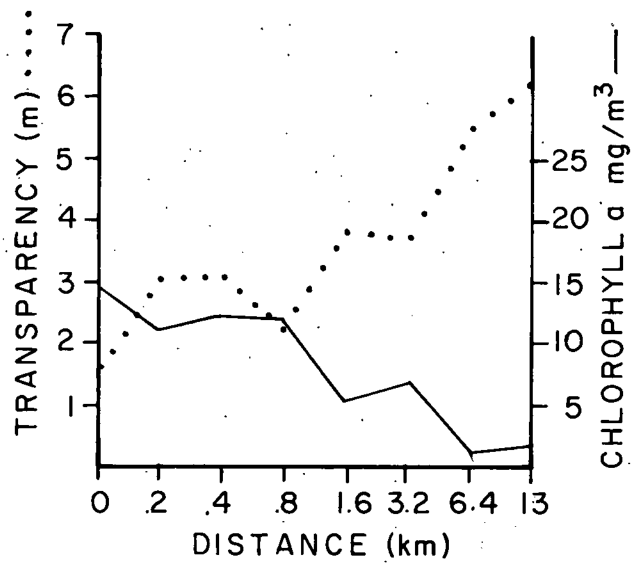

FIG. 6d. Muskegon River transect, April 17, 1972. Secchi disc transparency and chlorophyll *a* at 2 meters.

Carbon Fixation and Chlorophyll

Nearshore, out to .8 km on the Muskegon River transect, chlorophyll *a* concentrations averaged about 13 mg/m^3 and then decreased to about 2 mg/m^3 at stations located 6.4 and 13 km from shore (Fig. 6d). This break between nearshore and offshore waters was also observed from measurements of Secchi disc transparency which ranged from 4–6 m at the stations 1.6 km or more offshore, and was 3 m or less at stations .8 km or less from shore. Rates of carbon fixation were not determined on this transect.

PERE MARQUETTE RIVER TRANSECT

Physical-Chemical Conditions

Outflow from the Pere Marquette River influenced conditions in the lake to a distance <.4 km from shore on the transect sampled in April (Fig. 7a). At distances >.4 km from shore, outside the influence of the river and any effect of the thermal bar, water temperatures were <3° C.

The river obviously was warmer, and had greater chloride, silica, and total phosphorus concentrations than stations farther offshore. On the other hand, values for pH and nitrate nitrogen were less at the rivermouth station than at stations farther offshore. Gradients in most of the physical-chemical parameters with distance offshore were relatively small compared to the rivers located to the south on the eastern shore. The unique chemical feature on this transect is the relatively low concentrations for silica at the offshore stations.

Distributions of temperature, pH, chloride, and silica indicated that the station at 13 km was distinct from stations closer to shore, although other chemical parameters did not show this difference.

Phytoplankton

The influence of the Pere Marquette River on phytoplankton distribution was not readily apparent at any of the stations sampled—the river mouth was different in that the per cent species composition due to "others" represented about 55% of the total cell counts (Fig. 7b). Relative abundances of major species at the rivermouth station included in "others" were *Melosira granulata,* 4.6%; *Stephanodiscus tenuis,* 4.2%; *S. binderanus,* 4.0%; *Asterionella formosa,* 3.4%; and *Stephanodiscus subtilis,* 3.0%. At the river mouth the total standing crop was 1050 cells/ml which was lower than that observed at other stations, with the exception of the station located 13 km offshore. At stations .2 to 6.4 km offshore the standing crop ranged from 1400 to 1900 cells/ml.

In terms of per cent composition, phytoplankton varied little among the lake stations, but in terms of absolute population sizes numbers at the station 13 km offshore were much smaller due to a smaller standing crop of phytoplankton. The dominant species at the lake stations were *S. minutus, Cyclotella stelligera, Synedra filiformis, Rhizosolenia gracilis, Melosira italica,* and *Fragilaria crotonensis,* with *Stephanodiscus minutus, Cyclotella stelligera, Synedra filiformis,* and *Rhizosolenia gracilis* being most abundant. In addition, undetermined flagellates were relatively abundant at stations .8 to 13 km offshore and *Melosira islandica* was most abundant from the river mouth out to a distance 3.2 km from shore.

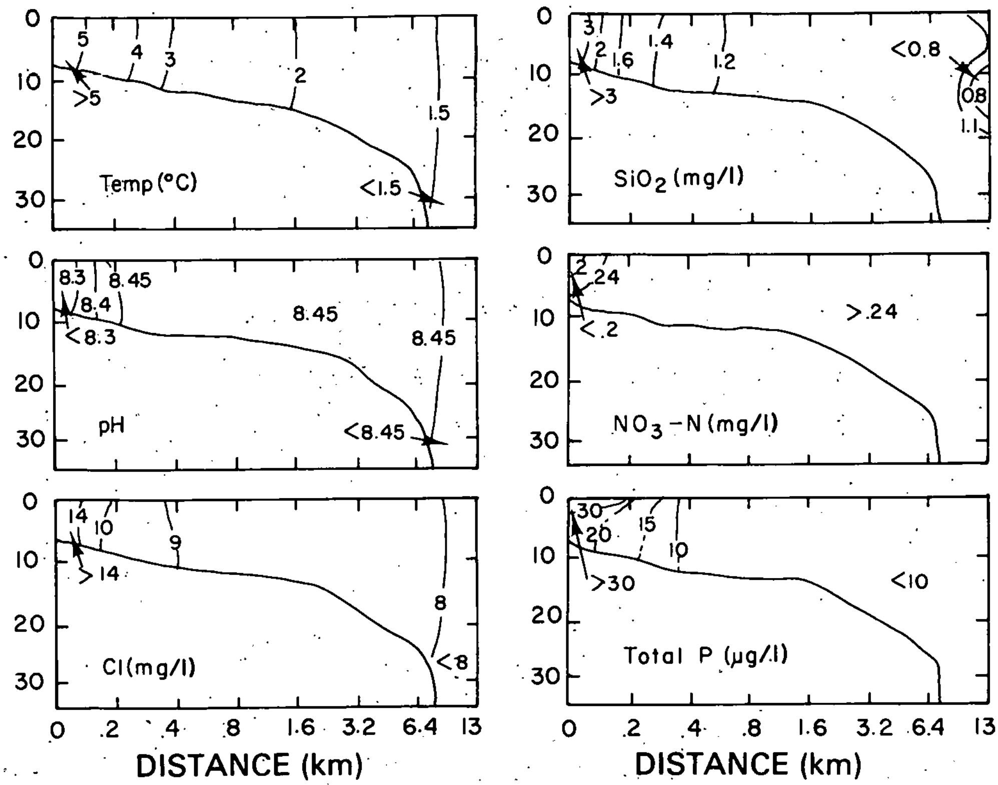

FIG. 7a. Pere Marquette River transect, April 24, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

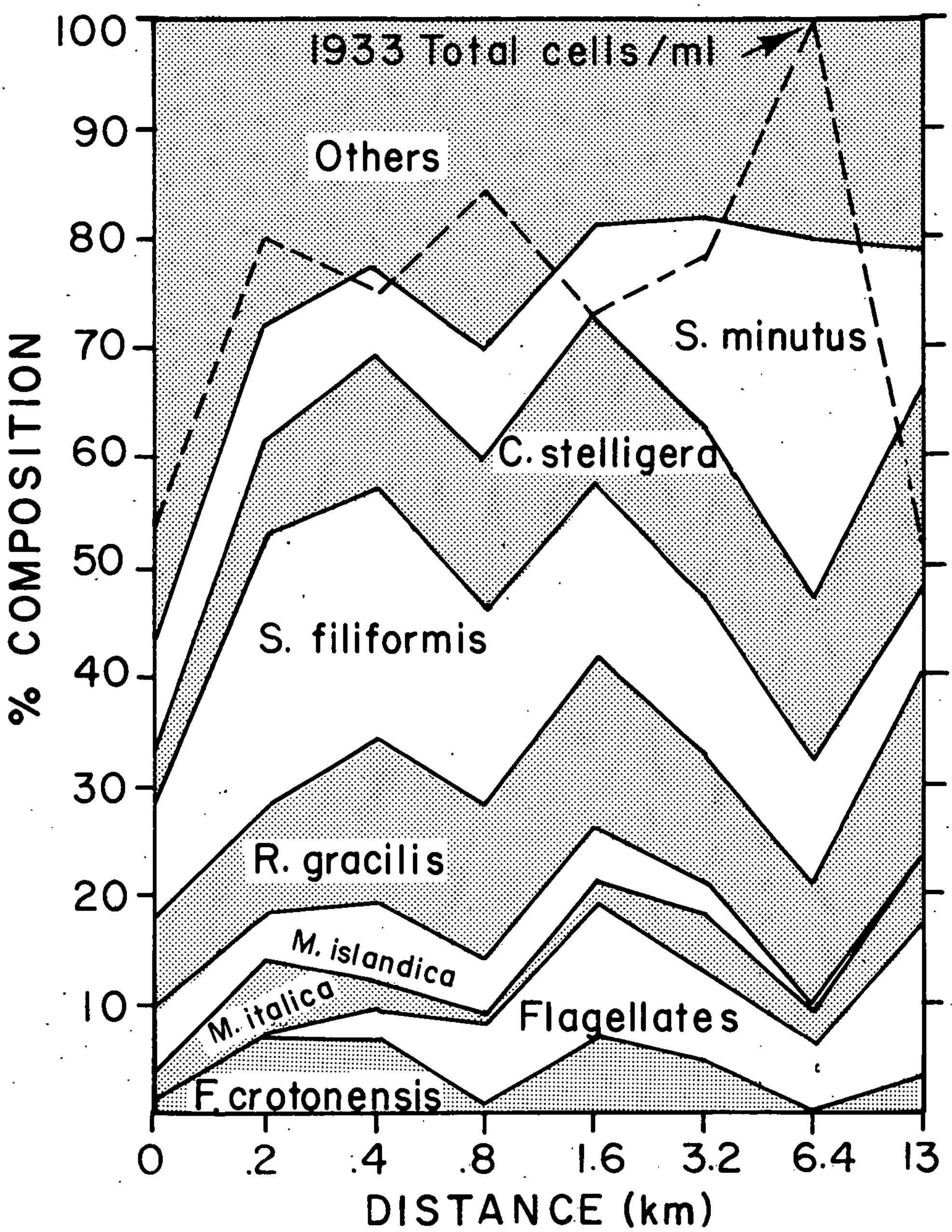

FIG. 7b. Pere Marquette River transect, April 24, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

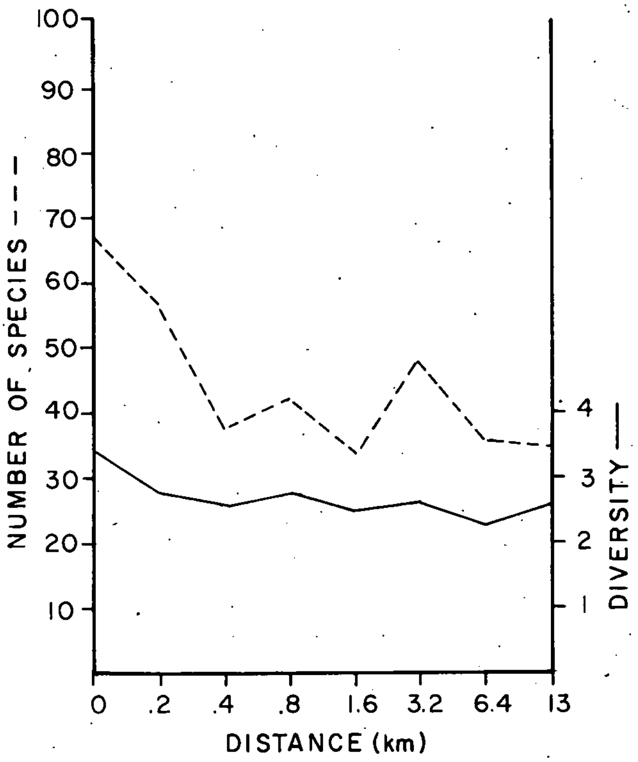

FIG. 7c. Pere Marquette River transect, April 24, 1972. Number and diversity of phytoplankton species at 2 meters.

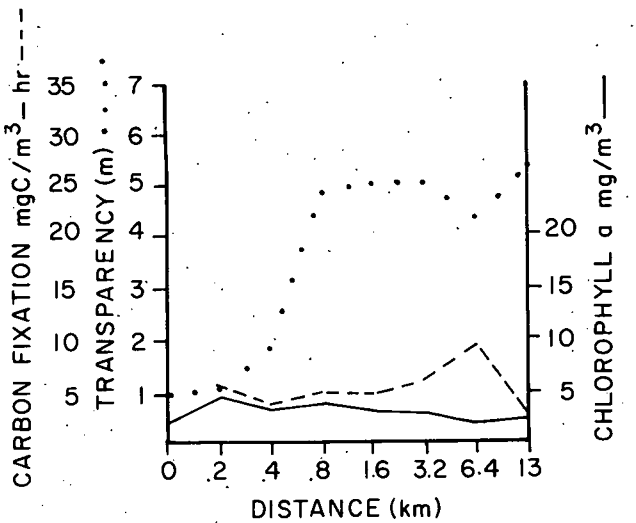

FIG. 7d. Pere Marquette River transect, April 24, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

There was no major influence of the Pere Marquette River on the phytoplankton species composition on this transect or on physical-chemical conditions. A smaller standing crop of phytoplankton was found at 13 km from shore than at stations closer to shore; whether this represents the transition from nearshore waters to offshore waters is a question which cannot be answered from only inspection of phytoplankton data. The standing crop at the 13 km station (970 cells/ml) would appear to be more characteristic of offshore assemblages on other transects than the higher standing crops closer to shore.

Numbers of species were greater at the rivermouth station and at .2 km from shore than at the other stations; species diversity also appeared to be slightly greater at these two stations than at stations farther offshore (Fig. 7c).

Carbon Fixation and Chlorophyll

There was little difference in rates of carbon fixation and in chlorophyll *a* concentrations along this transect, with values for both variables being low in nearshore waters (Fig. 7d). On this transect, however, the Secchi disc transparency was about 1 m at stations within .4 km of shore in comparison to 5 m at those located more than .8 km from shore.

This nearshore zone of decreased transparency was not related to phytoplankton standing crops, to other phytoplankton community parameters, nor to river-borne material, indicating that it was related to increased turbidity from inorganic sources along shore.

MANISTEE RIVER TRANSECT

Physical-Chemical Conditions

The thermal bar was not well developed on the Manistee River transect, with the highest water temperatures being 5° C just outside the river mouth (Fig. 8a). Other than for chloride and silica, river water apparently differed very little in chemical composition from offshore waters. Concentrations of chloride were >25 mg/liter in water near the river mouth and decreased to <8 mg/liter in the offshore waters, with concentrations >15 mg/liter being restricted to stations within .8 km from shore. Silica at the river mouth was >5 mg/liter, but concentrations decreased rapidly to 1.8 mg/liter at .2 km from the shore. At distances >1.6 km from shore concentrations ranged from 1.2 mg/liter to 1.4 mg/liter. It is possibly significant to note that concentrations of silica >1.2 mg/liter were present in the surface waters at stations 13 and 26 km offshore but concentrations in the subsurface waters at these stations were <1.2 mg/liter.

For the remainder of the variables there were only small differences in values along the transect. Total phosphorus concentrations near the river mouth appeared to be slightly elevated with surface samples having concentrations >20 μg/liter. On the remainder of the transect concentrations varied around 10 μg/liter. There were no discernible trends in nitrate concentrations over the transect with concentrations ranging from .25 to .27 mg/liter. At the river mouth, pH was <8.3 increasing to a maximum >8.45 in the surface waters .8 at 1.6 km offshore.

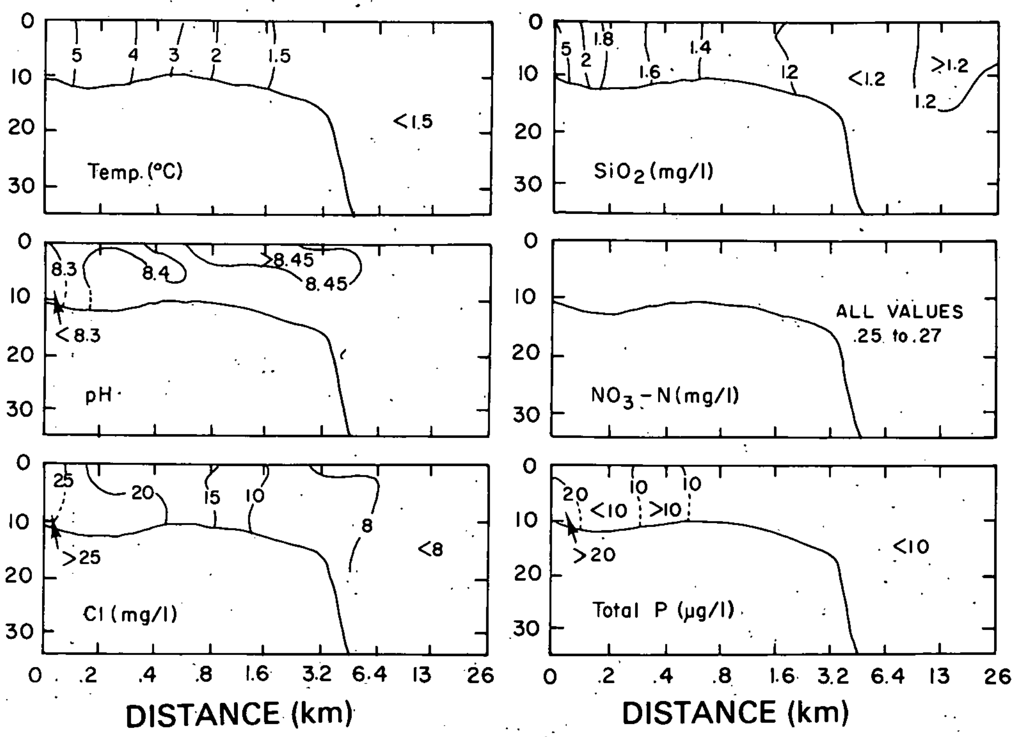

FIG. 8a. Manistee River transect, April 25, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

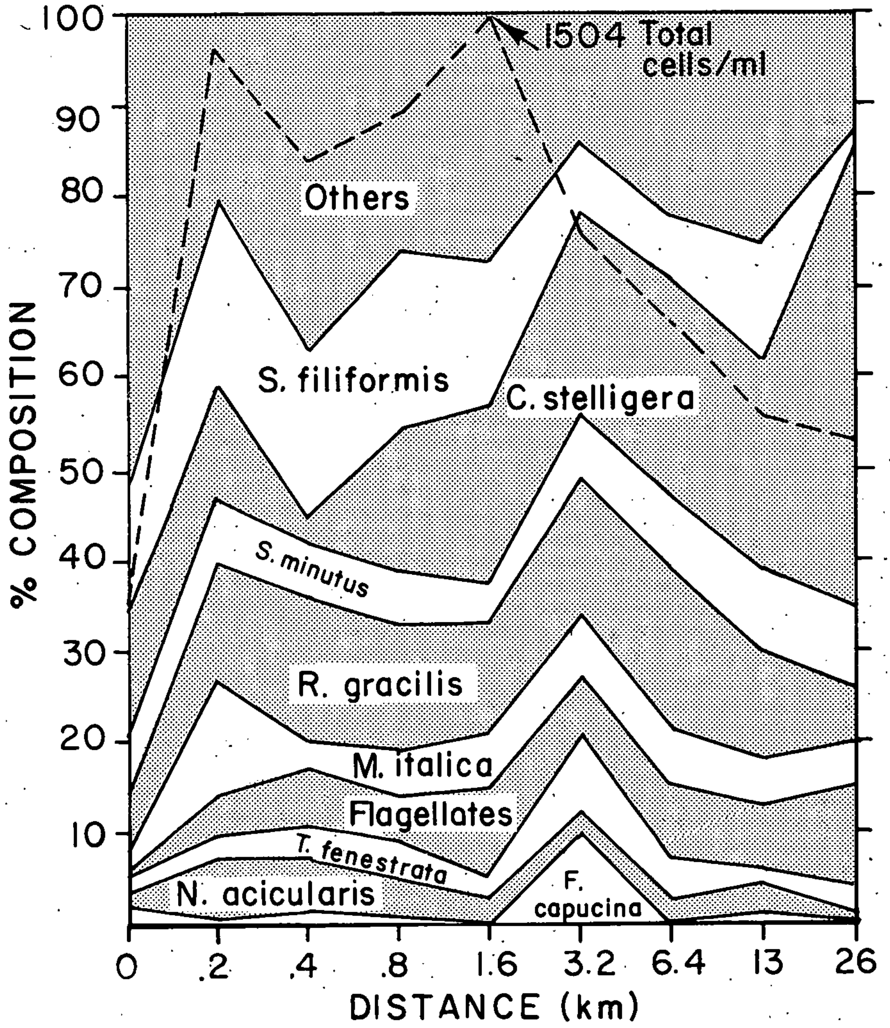

FIG. 8b. Manistee River transect, April 25, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

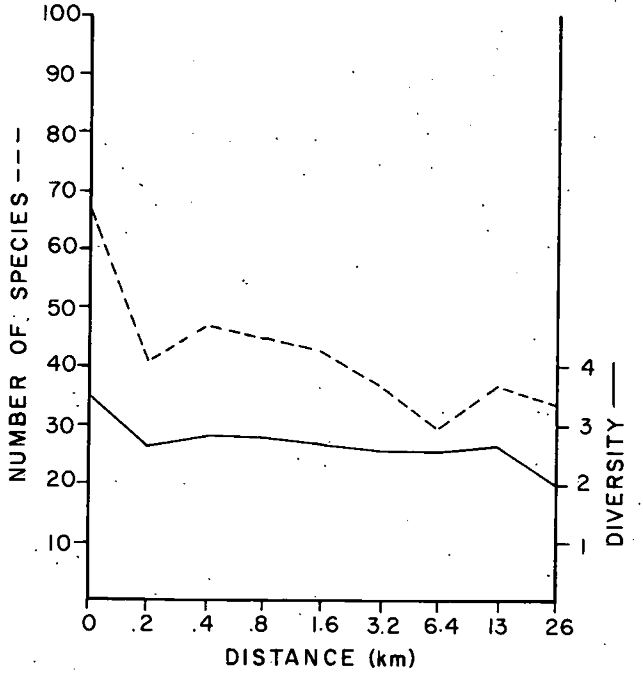

FIG. 8c. Manistee River transect, April 25, 1972. Number and diversity of phytoplankton species at 2 meters.

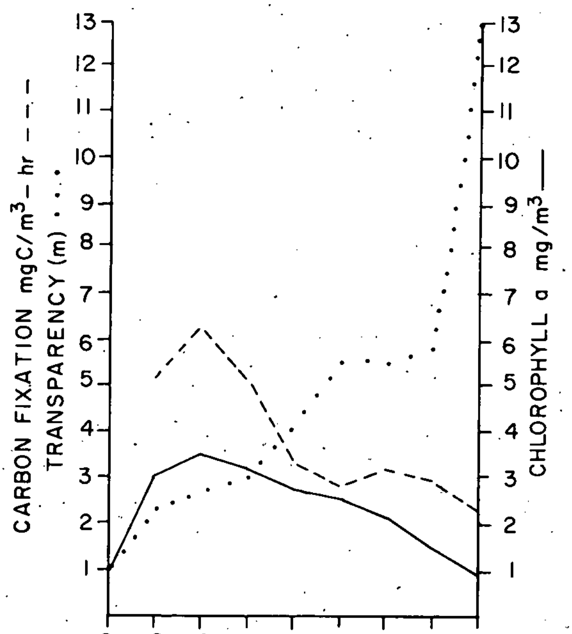

FIG. 8d. Manistee River transect, April 25, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Phytoplankton

The influence of the Manistee River on phytoplankton assemblages at the lake stations on the April transect was quite small. The rivermouth station was distinctly different in species composition from the other stations, noticeably so because of the larger proportion (50%) of the species composition attributable to "others" and a lower standing crop of phytoplankton compared to offshore stations (Fig. 8b). At the rivermouth station the standing crop of phytoplankton was only 500 cells/ml. Maximum standing crops ranging from 1200–1500 cells/ml were found at stations from .2 to 1.6 km offshore. Farther offshore standing crops decreased to the range of 800 to 1100 cells/ml.

In terms of species composition the dominant species varied little over the transect. The eight dominant entities at the rivermouth station and lake stations were *Synedra filiformis, Cyclotella stelligera, Stephanodiscus minutus, Rhizosolenia gracilis, Melosira italica,* undetermined flagellates, *Tabellaria fenestrata,* and *Nitzschia acicularis.* The only other dominant on the transect was *Fragilaria capucina* which comprised 10% of the total assemblage at the station 3.2 km from shore.

The relative abundance of most species was fairly uniform over the transect. *Nitzschia acicularis,* however, decreased in relative abundance with distance offshore and *Cyclotella stelligera* increased in relative abundance with distance from shore to 50% of the total assemblage at 26 km offshore.

The rivermouth station had the lowest standing crop, but the largest number of species, meaning that many of the 67 species were present in low relative abundance (Fig. 8c). The per cent composition of the phytoplankton grouped as "others" was 50%. Species included as "others" were: *Achnanthes affinis, Fragilaria capucina* v. *lanceolata, Nitzschia dissipata, Amphora ovalis* v. *pediculis, Cocconeis diminuta,* and *C. placentula* v. *euglypta.* Both diversity and number of species were larger at the rivermouth station than at the lake stations. At the lake stations, the number of species tended to decrease with distance offshore while diversity was relatively constant with the exception of the station 26 km offshore where diversity was lower than at any other station.

Carbon Fixation and Chlorophyll

On this transect the stations located <.8 km from shore were distinctly different from those located >1.6 km from shore. At stations close to shore, rates of carbon fixation were >5 mg $C/m^3/hr$ compared to about 3 mg $C/m^3/hr$ at the other stations, and Secchi disc transparency was <3 m compared to nearly 6 m at stations 3.2 to 13 km offshore, reaching a maximum of 13 m at 26 km offshore (Fig. 8d). Differences between nearshore and offshore stations were greater for rates of carbon fixation and for Secchi disc transparency than for chlorophyll *a* concentrations which varied only from 1–3.5 mg/m^3 along the transect.

BETSIE RIVER TRANSECT

The influence of the Betsie River did not extend beyond the station located .2 km from shore. The river water had a temperature >4° C. Its pH was smaller and its chloride and nitrate concentrations were also less than the offshore waters, whereas silica and total phosphorus concentrations were greater than those in the offshore waters.

Physical-Chemical Conditions

Water temperatures over most of the transect were very cold, being about 1° C, with the exception of the rivermouth station which was >4° C (Fig. 9a). The pH at the rivermouth station was 8.3 with values increasing to >8.4 at the remaining stations on the transect. A mass of water of pH >8.45 was located between .2 and 1.6 km from shore.

Chloride concentrations were lowest at the rivermouth station where concentrations were <5 mg/liter. At the remaining stations concentrations ranged from 7 to 8 mg/liter.

Silica concentrations at the rivermouth station were greater than at the offshore stations, with the maximum concentration being >3 mg/liter. This high concentration was restricted to the area of the river mouth, beyond which silica concentrations ranged from 1.2 to >1.4 mg/liter. Concentrations >1.4 mg/liter were generally restricted to waters more than 13 km offshore.

Concentrations of nitrate nitrogen were less at the rivermouth station than at other stations on the transect. At the river mouth the concentration was <.22 mg/liter. Over the remainder of the transect concentrations ranged from .25 to .29 mg/liter with the greatest concentrations being found at the station 3.2 km from shore.

There was very little structure in the distribution of total phosphorus. At the river mouth concentrations were >15 μg/liter but these concentrations decreased very rapidly and were <5 μg/liter on the remainder of the transect.

Phytoplankton

The phytoplankton assemblage at the rivermouth station was quite distinct from the phytoplankton assemblages at the remaining stations on the transect. There were 76 species at the river mouth with a relatively low standing crop compared to 40 or less species at the remaining stations (Fig. 9b); the per cent composition of the assemblage due to "others" was quite high at the rivermouth station and totaled 57% of the assemblage. Three species, *Achnanthes affinis, A. lanceolata* v. *dubia,* and *Amphora ovalis* v. *pediculis,* were unique dominants at the rivermouth station composing 21% of the assemblage. At the other stations there were seven dominant entities: *Synedra filiformis, Cyclotella stelligera, Stephanodiscus minutus, Rhizosolenia gracilis,* undetermined flagellates, and *Melosira italica. M. islandica* was also abundant at some of the stations on the transect but its relative abundance was less at the stations 1.6 and 3.2 km offshore than at the remaining stations on the transect.

Relative abundances of most species varied little over the transect, though *Cyclotella stelligera* and undetermined flagellates increased in relative abundance with distance offshore.

The maximum standing crop was found at .2 km offshore and was 1405 cells/ml. At the remaining offshore stations standing crops ranged from 700 to 1100 cells/ml with no consistent trend in the pattern over the transect.

At the rivermouth station diversity was greater than at any of the lake stations, which was also true for numbers of species (Fig. 9c). At the lake stations diversity appeared to decrease slightly with distance offshore.

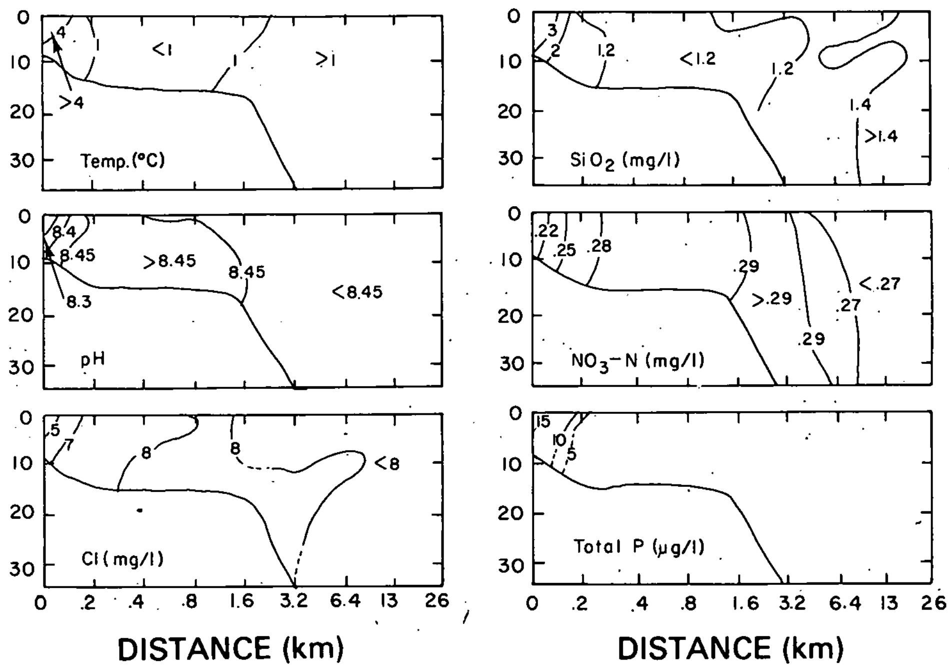

FIG. 9a. Betsie River transect, April 25–26, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

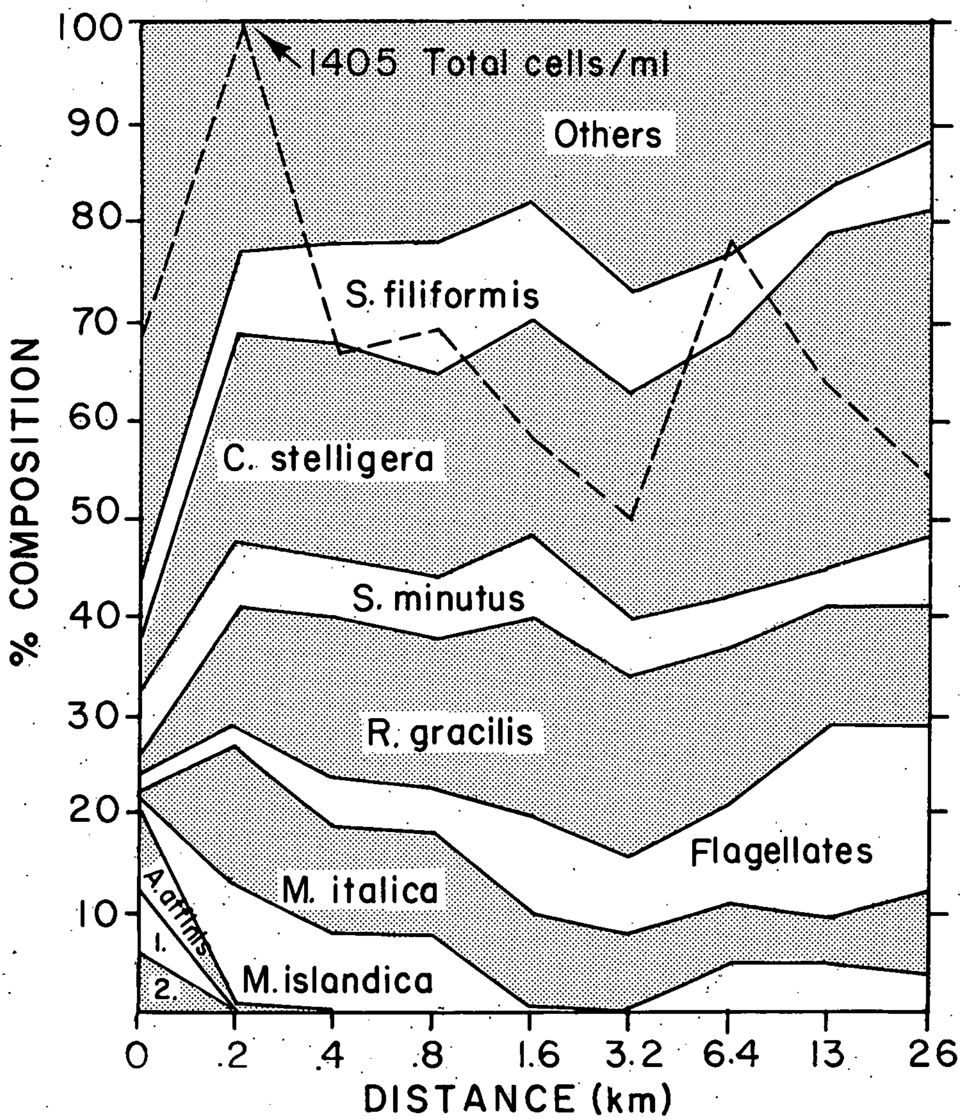

FIG. 9b. Betsie River transect, April 25–26, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure. 1. species *Achnanthes lanceolata* v. *dubia;* 2. species *Amphora ovalis* v. *pediculis.*

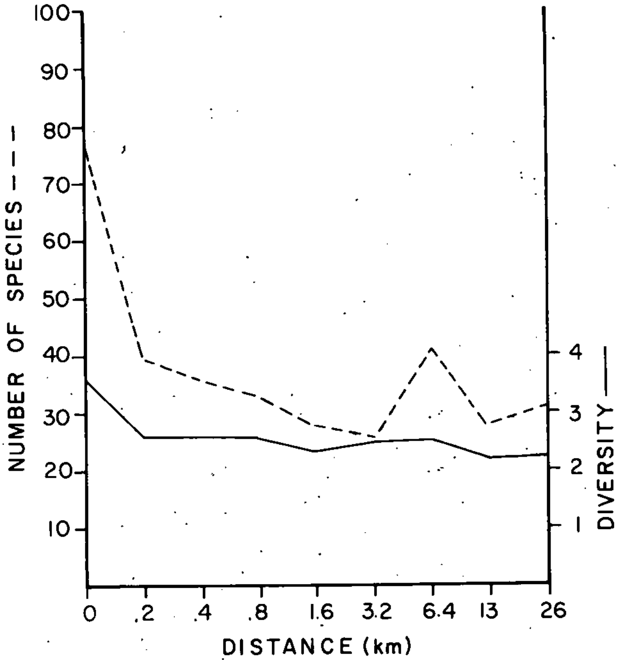

FIG. 9c. Betsie River transect, April 25–26, 1972. Number and diversity of phytoplankton species at 2 meters.

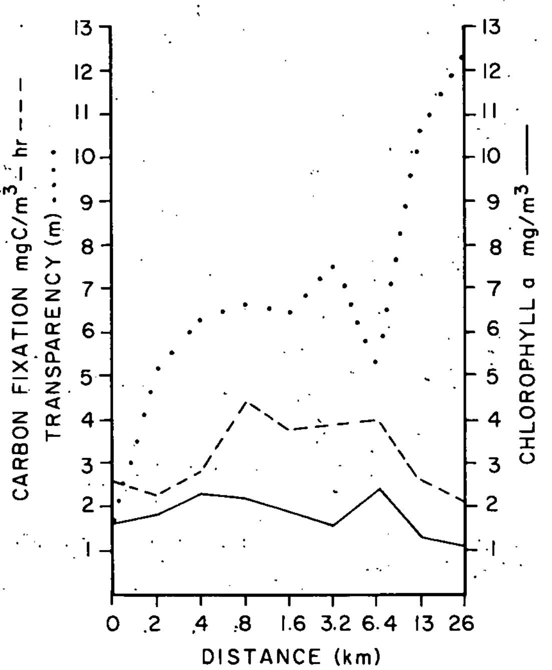

FIG. 9d. Betsie River transect, April 25–26, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Carbon Fixation and Chlorophyll

On the Betsie River transect in April chlorophyll *a* concentrations varied little, ranging from about 1–2.5 mg/m^3 along the transect (Fig. 9d). Values at 13 and 26 km were probably slightly less than values closer to shore. Rates of carbon fixation had a different pattern, with the largest values being found at stations located from .8 to 6.4 km offshore. Although larger than the values closer to shore or farther offshore, these rates were only about 4 mg C/m^3/hr or about double those at the remaining stations.

Values for Secchi disc transparency indicated that the two stations farthest offshore were markedly different because the transparency at both stations exceeded 10 m, whereas values at the remaining stations were generally 7 m or less (Fig. 9d). At the rivermouth station the transparency was $<$2 m indicating relatively high concentrations of suspended inorganic solids, staining in the water, or both, as the chlorophyll *a* concentrations indicated plankton concentrations were fairly uniform along the transect.

MANISTIQUE RIVER TRANSECT

Physical-Chemical Conditions

Water flowing out of the Manistique River, the northernmost river sampled, was 1.5° C in April, only slightly warmer than the offshore waters (Fig. 10a). Its pH was 7.5, lower than any pH observed during our study, and chloride concentrations were less than 3 mg/liter, both of which distinguished the river water from the lake. The influence of the river was not evident beyond .2 km from shore. In addition to low pH and low chloride concentration, the river water had greater silica and total phosphorus concentrations than offshore waters.

Phytoplankton

The phytoplankton assemblage at the rivermouth station differed from the assemblages at the offshore stations in that the total cell count was only 122 cells/ml for the 58 species which were identified at the rivermouth station. Three entities, *Nitzschia palea*, *Dinobryon* cysts, and *Navicula pupula*, were restricted to the rivermouth station. The greatest standing crop, 1890 cells/ml, was found at the station .2 km offshore (Fig. 10b). At the other lake stations the standing crop ranged from 1280 to 1400 cells/ml.

The eight dominant entities at the offshore stations were *Synedra filiformis*, *Cyclotella stelligera*, *Tabellaria fenestrata*, *Melosira islandica*, *Fragilaria crotonensis*, *Rhizosolenia eriensis*, undetermined flagellates, and *Dinobryon* sp. The latter species was only abundant at the three stations ranging in distance offshore from 1.6 to 6.4 km. *Fragilaria capucina* also was abundant only at two stations—at the river mouth and at .4 km from shore.

The number of species on this transect was greatest at the rivermouth station where 58 entities were identified (Fig. 10c). At the remainder of the stations the number of species ranged from 33 to 44. Diversity was also higher at the rivermouth station where 21 species were represented by only one occurrence in the cell counts, but varied little over the remainder of the transect.

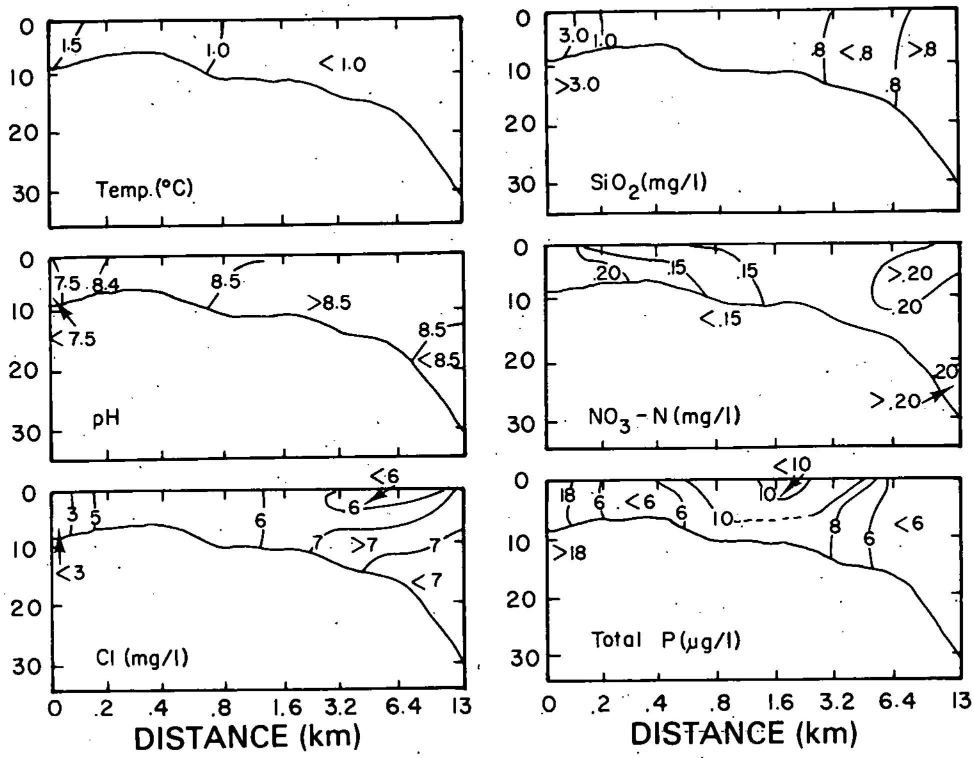

FIG. 10a. Manistique River transect, April 27, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

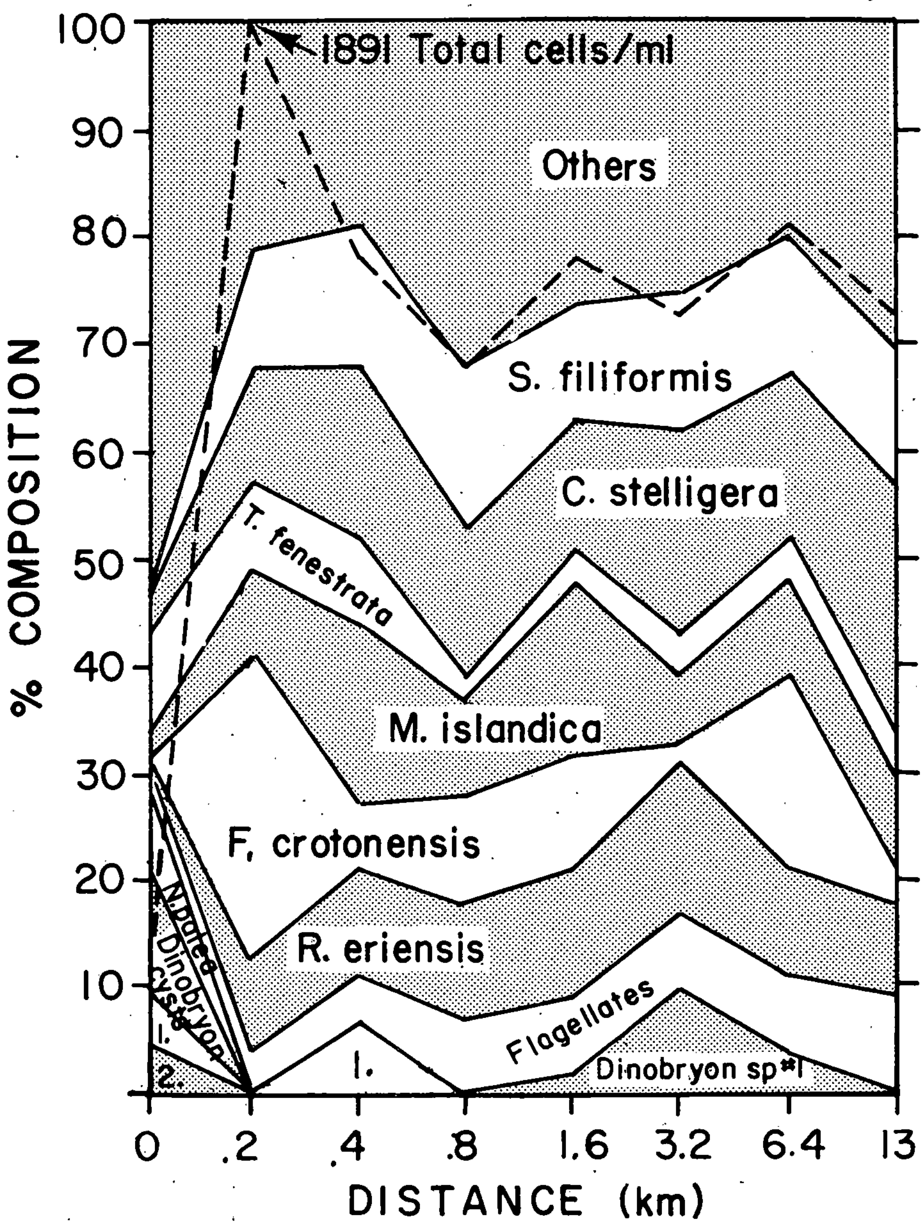

FIG. 10b. Manistique River transect, April 27, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure. 1. species *Fragilaria capucina;* 2. species *Navicula pupula.*

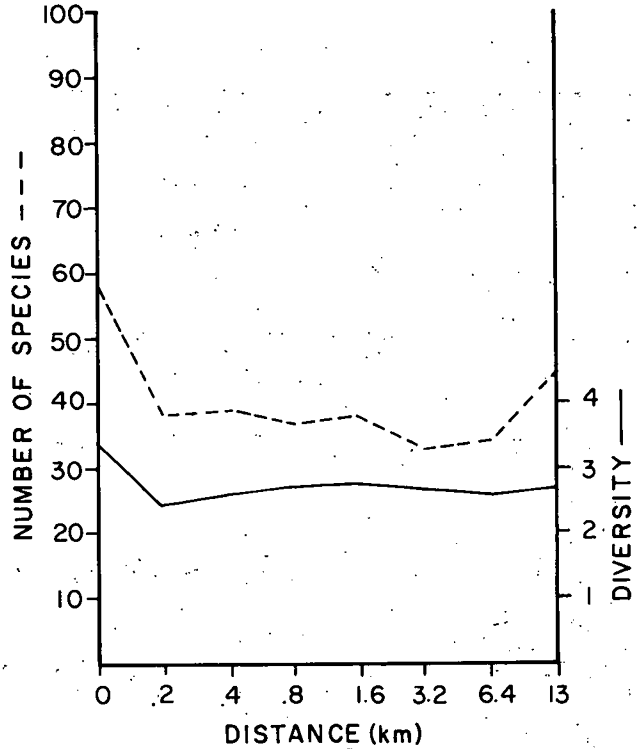

FIG. 10c. Manistique River transect, April 27, 1972. Number and diversity of phytoplankton species at 2 meters.

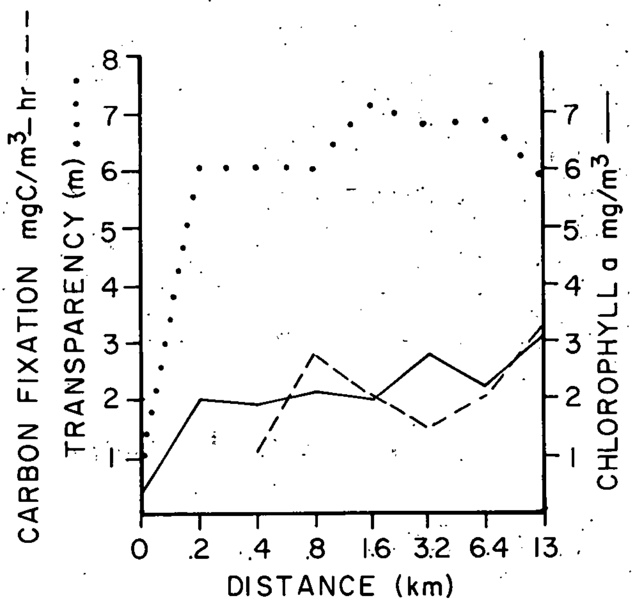

FIG. 10d. Manistique River transect, April 27, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Carbon Fixation and Chlorophyll

On the Manistique River transect the river station was distinctly different from the other stations: it had smaller chlorophyll *a* concentrations and less Secchi disc transparency than stations farther offshore (Fig. 10d). Chlorophyll *a* concentrations at the river mouth averaged only .4 mg/m^3 but ranged from 2–3 mg/m^3 at the stations located from .2 to 13 km offshore with largest values being present at the stations 3.2 and 13 km offshore. Secchi disc transparency at the river mouth was 1 m but ranged 6–7 m at the other stations. Rates of carbon fixation were not determined at the river mouth but varied little along this transect, ranging 1–3 mg C/m^3/hr.

STURGEON BAY TRANSECT

Physical-Chemical Conditions

No large rivers, only the Sturgeon Bay Ship Canal connecting Lake Michigan with Green Bay, flow into the area where this transect was located. As a consequence, there was little variation in the physical-chemical parameters studied (Fig. 11a).

Water temperatures were <2° C, being slightly warmer nearshore than offshore. Nearshore waters out to a distance 6.4 km offshore had slightly lower nitrate concentrations and higher pH values than offshore which probably reflects a greater photosynthetic activity in the nearshore zone.

Data for silica also tended to be lower nearshore, but the plot of silica concentrations showed a very complex pattern among stations <6.4 km from shore. At the offshore stations concentrations were uniform top to bottom and increased with distance offshore, being >1.1 mg/liter at 26 and 52 km offshore. Surface waters within 3.2 km from shore had pockets of water with silica concentrations <1 mg/liter. In addition, there was a pocket of subsurface water with concentrations >1.1 mg/liter between .4 and 1.6 km offshore.

Nitrate concentrations varied little, ranging from <.24 mg/liter at stations 3.2 km from shore to >.26 mg/liter at stations 13 km from shore.

The pH also varied little with most of the values being near 8.5 and with values nearshore being >8.5 and values offshore being <8.5.

Differences in total phosphorus and chloride concentrations were very small and there was essentially no variation in these parameters along the transect. Total phosphorus averaged about 6 μg/liter and chloride averaged <8 mg/liter.

Phytoplankton

On the Sturgeon Bay transect which is not influenced by river inputs, the species composition of phytoplankton was quite similar over the transect. The relative abundance of different species varied over the transect but most of the species graphed in Fig. 11b were present at every station, the major exception being that *Fragilaria intermedia* v. *fallax* was found only at the station .8 km from shore.

Six major dominants were found on this transect: *Synedra filiformis*, *Cyclotella stelligera*, *Asterionella formosa*, *Rhizosolenia eriensis*, *Fragilaria crotonensis*, and *Melosira islandica*. *Synedra filiformis* and *Fragilaria crotonensis* were more abundant nearshore whereas *Cyclotella stelligera* was the most abundant species at stations

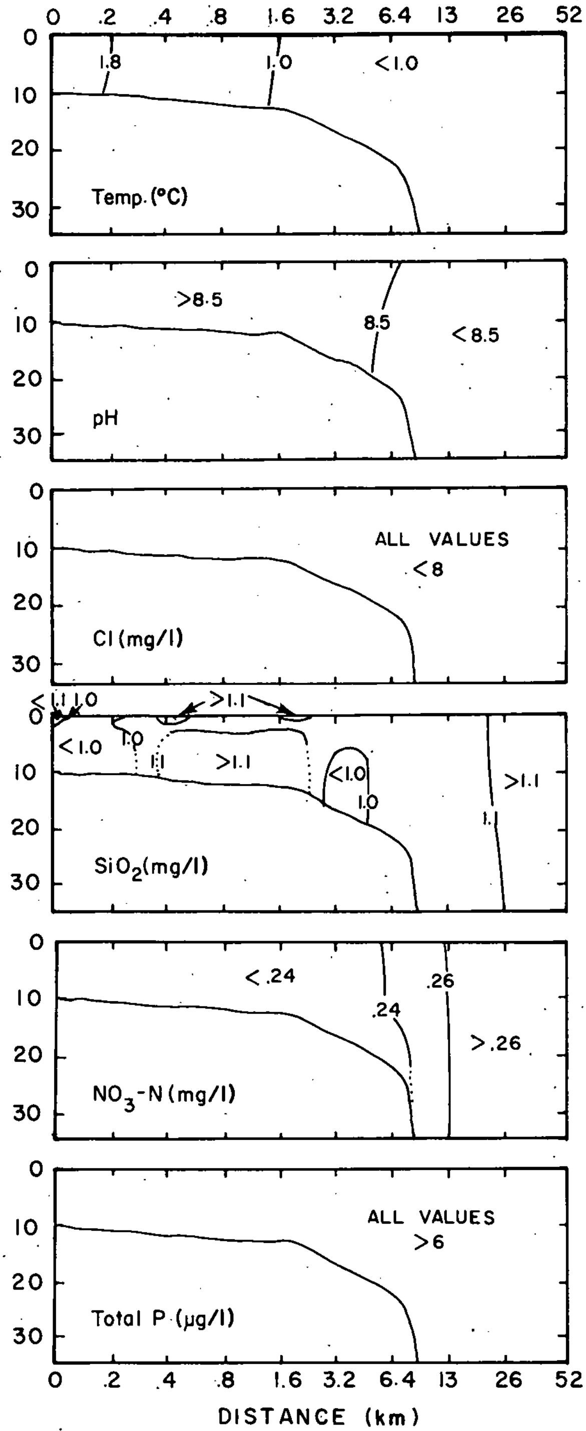

FIG. 11a. Sturgeon Bay transect, April 26, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

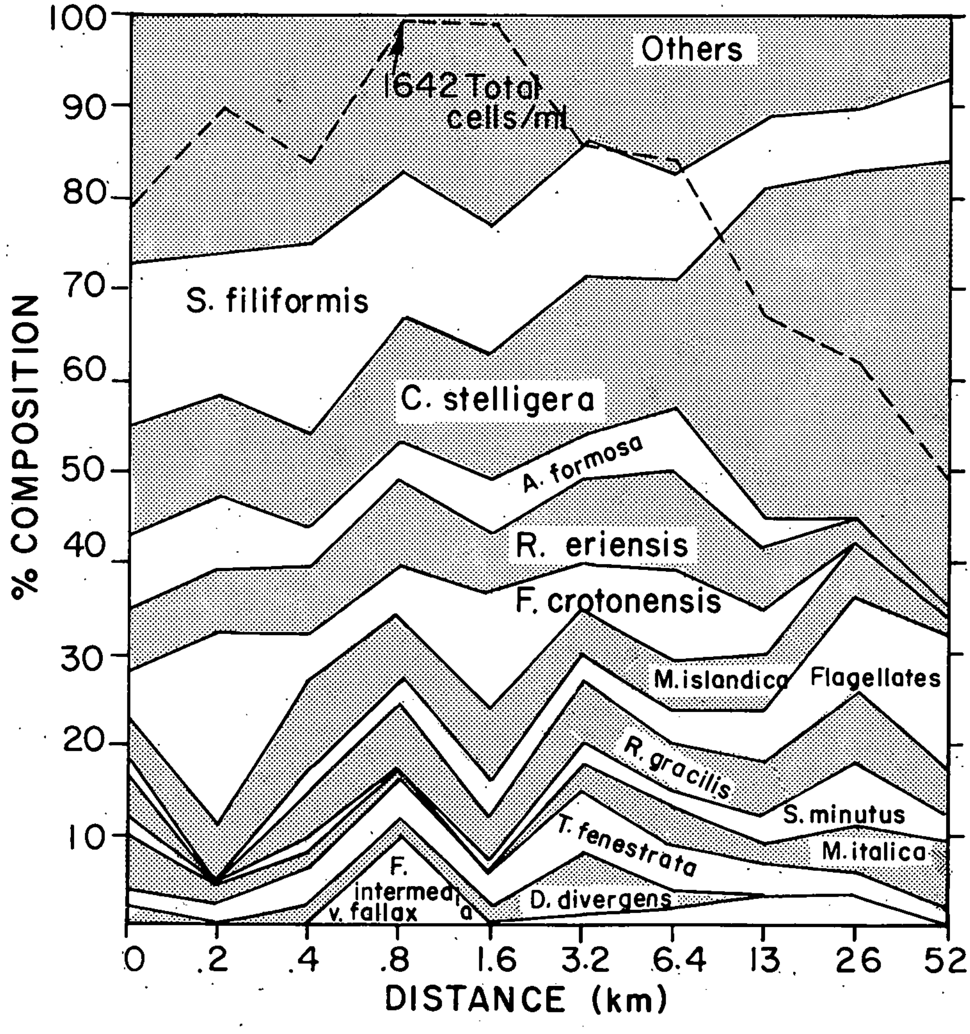

FIG. 11b. Sturgeon Bay transect, April 26, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

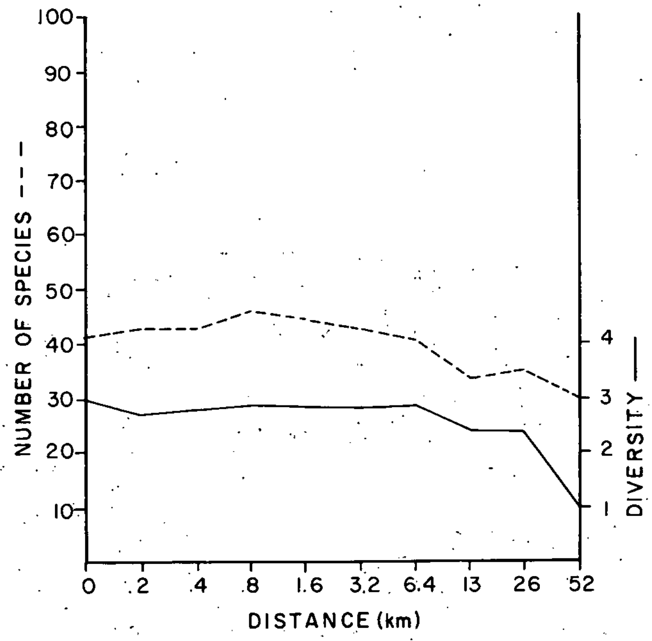

FIG. 11c. Sturgeon Bay transect, April 26, 1972. Number and diversity of phytoplankton species at 2 meters.

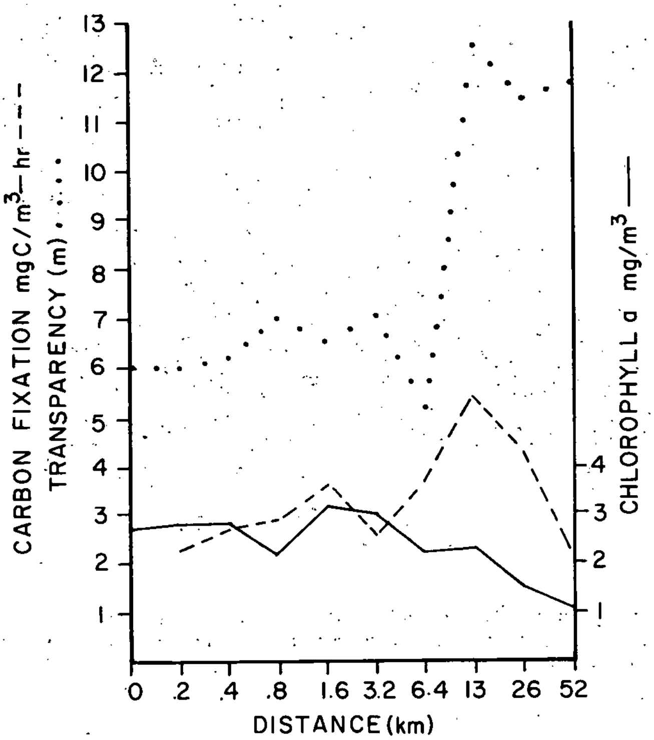

FIG. 11d. Sturgeon Bay transect, April 26, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

located from 13 to 52 km offshore where the per cent composition due to this species ranged from 36 to 49%. In addition to the six major dominants, six or seven other entities including undetermined flagellates, *Rhizosolenia gracilis, Stephanodiscus minutus, Melosira italica,* and *Tabellaria fenestrata* comprised from 24 to more than 30% of the species composition at stations on this transect.

The maximum standing crop of phytoplankton was found at stations located .8 and 1.6 km offshore where cell densities were as high as 1640 cells/ml. The standing crop of phytoplankton was obviously much less at the stations 13 or more km from shore than at the stations within 6.4 km from shore. Cell counts at the offshore stations ranged from 800–1250 cells/ml. This zone in which cell counts were lower was also the zone in which *Cyclotella stelligera* reached maximum relative abundance and the zone in which *Asterionella formosa, Fragilaria crotonensis,* and *Dinobryon divergens* disappeared from the assemblage.

The number of species on this transect was fairly constant, with the maximum numbers (45 and 46 species) being found at .8 and 1.6 km offshore, the stations which also had the largest standing crops (Fig. 11c). The number of species decreased offshore to 30 species at the station 52 km offshore. Diversity appeared to be slightly less at the stations 13 km or more offshore than at the stations closer to shore and was obviously least at 52 km offshore.

Carbon Fixation and Chlorophyll

On the Sturgeon Bay transect, water at the stations 13 km or more from shore was obviously more transparent (Secchi disc readings of about 12 m) than closer to shore (Secchi disc transparency from 5–7 m) (Fig. 11d). Chlorophyll *a* concentrations reflected this pattern to a certain extent but the differences between the nearshore and offshore values were not as great. Rates of carbon fixation, however, did not show the expected inshore-offshore pattern; in fact the greatest rates of carbon fixation were found at the station located 13 km from shore.

MANITOWOC RIVER TRANSECT

Physical-Chemical Conditions

The flow of the Manitowoc River was relatively small and entered the lake about 10 km from the transect and as a consequence its influence on the nearshore zone was quite small: the first station sampled was .2 km from shore and so there are no data on the physical-chemical characteristics of the Manitowoc River itself (Fig. 12a).

Water temperature was >2° C out to a distance .8 km from shore. If there was a break between the nearshore and offshore zones it appeared to be about 13 km from shore. Nearshore the pH was slightly elevated and the silica and nitrate nitrogen concentrations appeared to be reduced compared to those of the offshore zone, reflecting increased photosynthetic activity in these waters.

Phytoplankton

On this transect 11 species generally comprised from 80 to 90% of the phytoplankton assemblages with most species being present at all stations in relatively high abundance

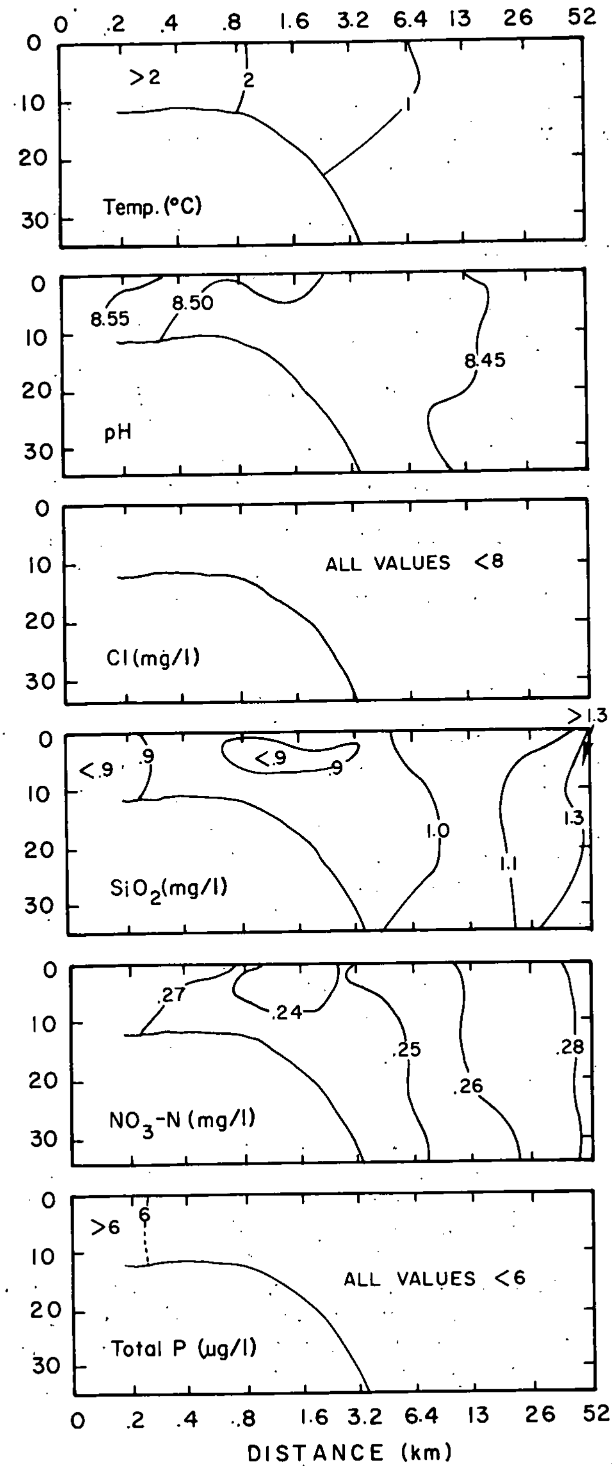

FIG. 12a. Manitowoc transect, April 22–23, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

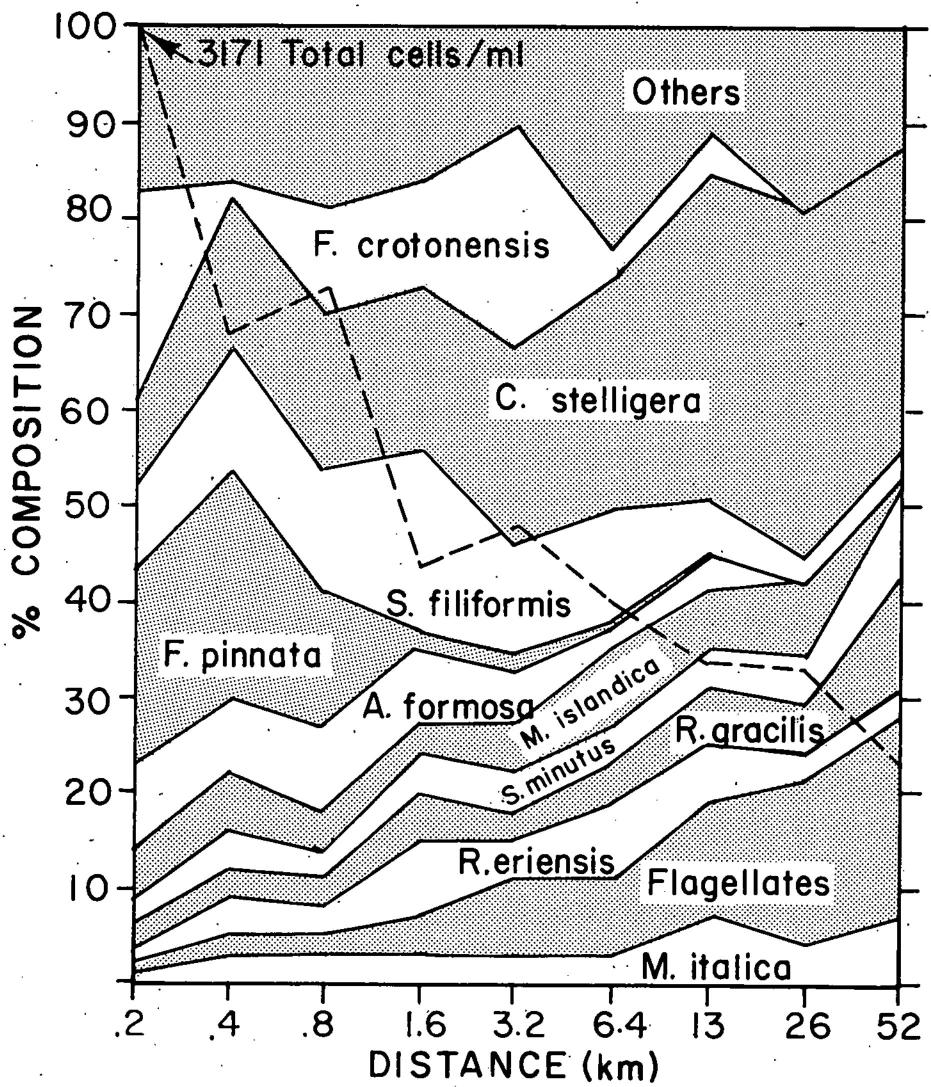

FIG. 12b. Manitowoc transect, April 22–23, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

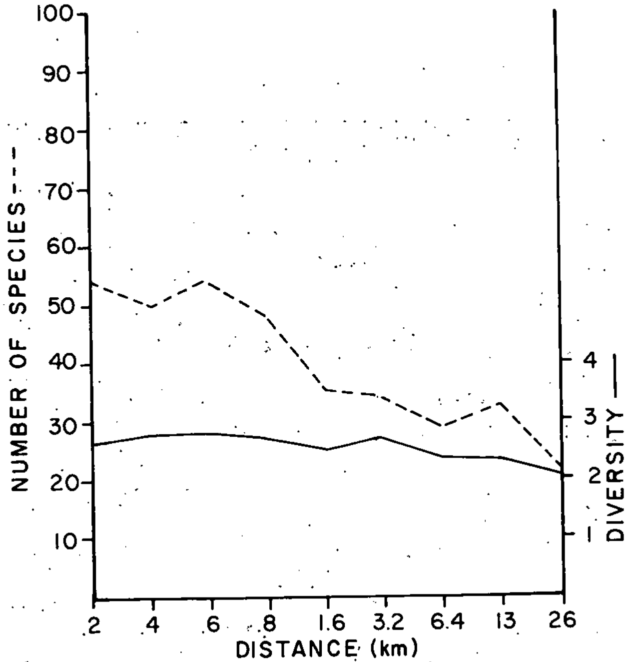

FIG. 12c. Manitowoc transect, April 22–23, 1972. Number and diversity of phytoplankton species at 2 meters.

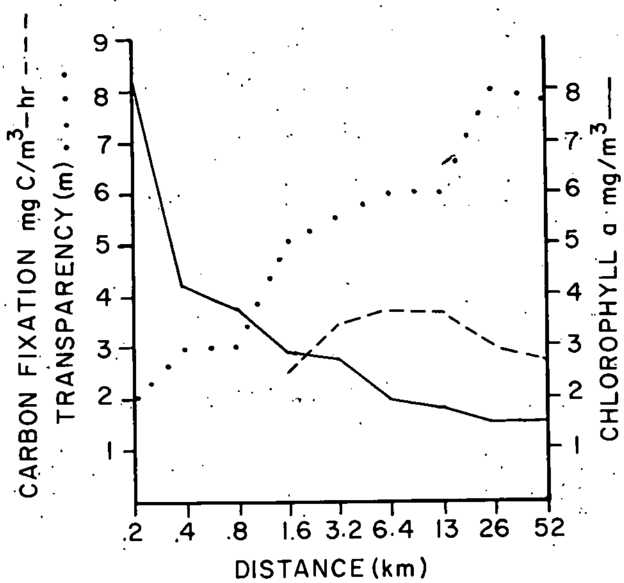

FIG. 12d. Manitowoc transect, April 22–23, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

(Fig. 12b). The eight most dominant entities were *Cyclotella stelligera, Synedra filiformis, Melosira islandica, M. italica, Stephanodiscus minutus, Rhizosolenia gracilis, R. eriensis,* and undetermined flagellates. Some species, including *Fragilaria pinnata, Asterionella formosa, F. crotonensis* and, to a lesser extent, *Synedra filiformis* decreased in relative abundance with distance offshore. The distribution of *Fragilaria pinnata* indicated that its maximum abundance was related to close proximity to the shoreline; its greatest abundance was found at stations .8 km or less from shore. *Asterionella formosa* and *Fragilaria crotonensis* were present in greatest relative abundance out to 3.2 km offshore, but were not important at the stations 26 and 52 km from shore. The opposite pattern was observed for *Cyclotella stelligera* and undetermined flagellates which increased in abundance with distance offshore. These two species comprised more than 50% of the cell counts at the stations 26 and 52 km offshore.

The standing crop of phytoplankton was greatest at the stations .8 km or less from shore with the maximum cell density of 3170 cells/ml being found at the station closest to shore. In general cell counts decreased with distance from shore but the rate of decrease was less for stations 1.6 km or more from shore than for those closer to shore. Cell counts decreased to 720 cells/ml at the station 52 km from shore.

Numbers of species were greater, being about 50 or more, at the stations .8 km or less from shore than at the stations farther offshore where numbers ranged from 21 to 36 (Fig. 12c). Diversity on this transect was not as variable as numbers of species but it appeared to be slightly less at the stations 6.4 km or more from shore than at stations closer to shore.

Carbon Fixation and Chlorophyll

On the Manitowoc River transect chlorophyll *a* concentration at the station .2 km from shore was >8 mg/m^3 but at the next station located .4 km from shore the concentration was only 4 mg/m^3 (Fig. 12d). From .8 to 13 km offshore, the chlorophyll *a* concentration appeared to decrease with distance offshore to about 1.5 mg/m^3 and then remain constant to a distance 52 km offshore. Secchi disc transparency followed the reverse pattern of chlorophyll *a* concentration with distance offshore and increased to 8 m at stations located 26 and 52 km from shore. Rates of carbon fixation from the limited data available indicated no patterns along the transect.

MILWAUKEE RIVER TRANSECT

On the Milwaukee River transect the nearshore zone extended out to a distance 6.4 km from shore and the offshore zone was obviously present at the stations 26 and 52 km from shore, but the station 13 km from shore represented a transition condition between these two zones. This pattern was typical of that found on the Manitowoc and Sturgeon Bay transects, the two other transects sampled on the western shore.

Physical-Chemical Conditions

Water temperature nearshore on the Milwaukee transect ranged from 2–3° C (Fig. 13a). Because these temperatures are <4° C there was no thermal stratification on this transect or any of the other transects sampled on the western shore in April.

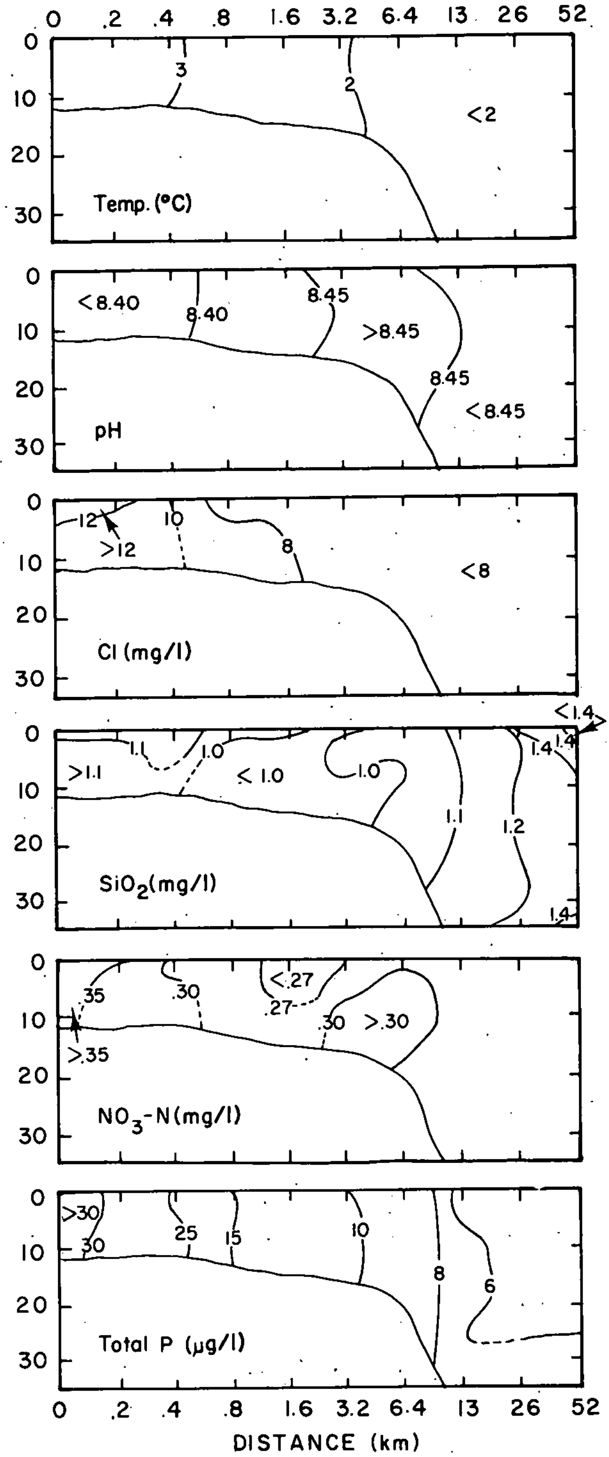

FIG. 13a. Milwaukee transect, April 19–22, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

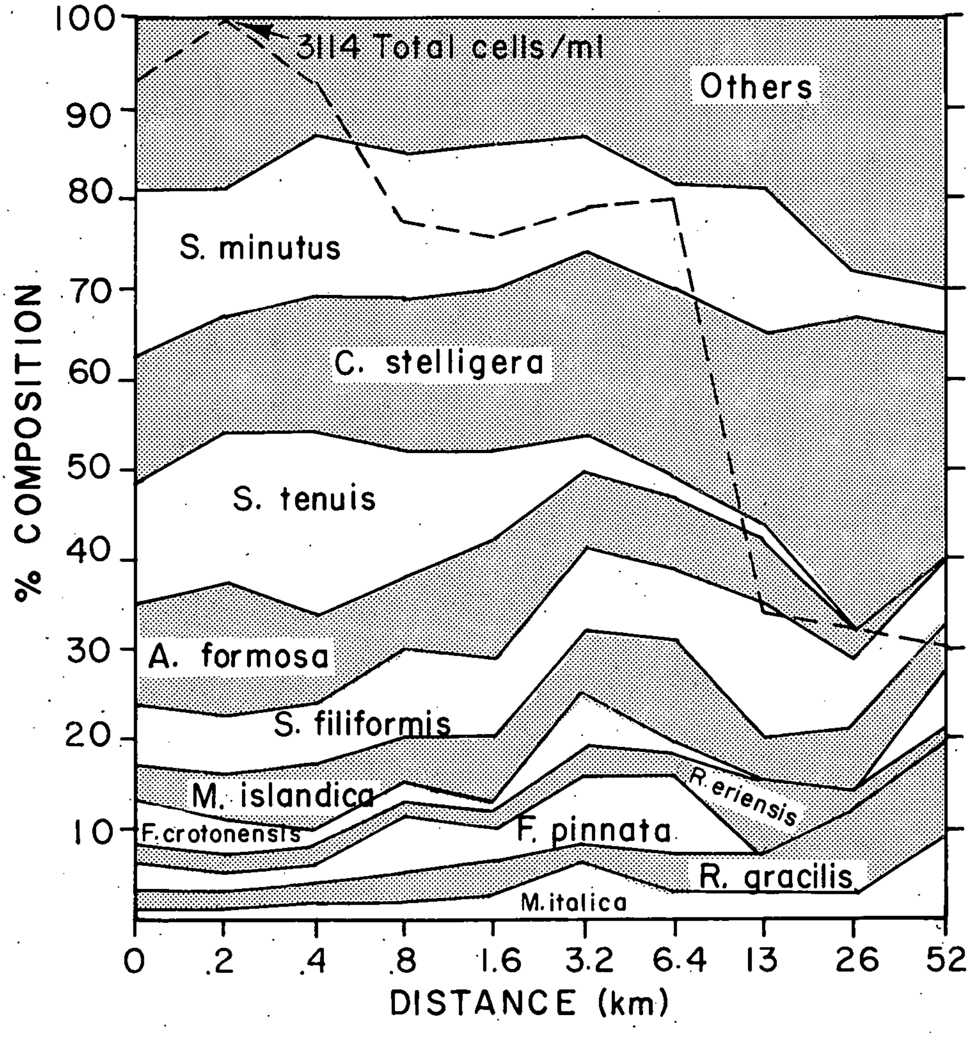

FIG. 13b. Milwaukee transect, April 19–22, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

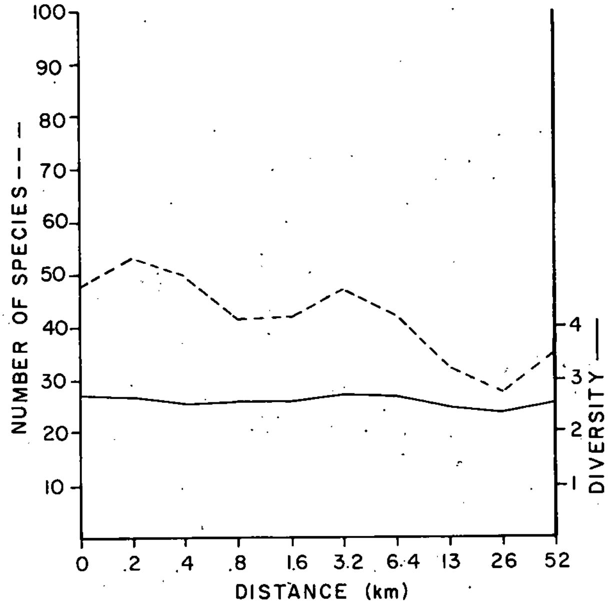

FIG. 13c. Milwaukee transect, April 19–22, 1972. Number and diversity of phytoplankton species at 2 meters.

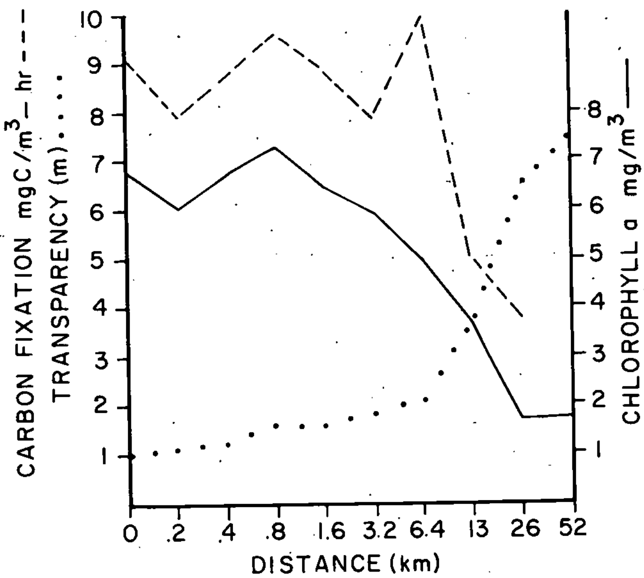

FIG. 13d. Milwaukee transect, April 19–22, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Nearshore waters, out to a distance .4 km from shore, had slightly greater chloride, nitrate nitrogen, and total phosphorus concentrations than offshore waters. The nearshore zone, where pH was greater and silica concentrations were less than the offshore waters, appeared to extend out to no more than 13 km offshore. At 6.4 km offshore pH was greater and silica was less than the offshore waters, indicating greater photosynthetic activity in this zone.

Phytoplankton

Eleven species comprised more than 80% of the phytoplankton assemblages at the stations 13 km or less offshore on the Milwaukee transect (Fig. 13b). At the stations which were 26 and 52 km from shore, nine of these 11 species comprised more than 70% of the phytoplankton assemblages; *Fragilaria pinnata* and *Stephanodiscus tenuis* were not found at these offshore stations. The relative abundances of the other species were fairly uniform over the transect. Six of the 11 species, *Stephanodiscus minutus, Cyclotella stelligera, Stephanodiscus tenuis, Asterionella formosa, Synedra filiformis,* and *Melosira islandica,* comprised from 60 to 70% of the cell counts at the stations ranging as far offshore as 13 km. Their total relative abundances ranged from 48 to slightly more than 60% at the stations 26 and 52 km offshore.

Maximum abundances of several species, *Stephanodiscus tenuis, Fragilaria crotonensis,* and *F. pinnata,* were greatest in the zone extending to 6.4 km offshore. The relative abundance of *Stephanodiscus minutus* also decreased at the stations >13 km offshore. Relative abundance of *S. tenuis* decreased most rapidly, ranging from 15 to 20% at some of the nearshore stations and decreasing to very low values at stations >13 km offshore.

Standing crops of phytoplankton were greater at stations as far offshore as 6.4 km, ranging from 2450 cells/ml to 3110 cells/ml, than at stations 13 km or more from shore where standing crops ranged from 950 to slightly more than 1000 cells/ml. Numbers of species at these offshore stations were also less, ranging from 28 to 35 species; whereas at stations closer to shore numbers of species ranged from 42 to 53 (Fig. 13c). Diversity, however, was very uniform along the transect.

Carbon Fixation and Chlorophyll

On the Milwaukee River transect there was a distinct difference in the phytoplankton community variables at the stations 6.4 km or closer to shore compared to the stations 13 km or more from shore. Rates of carbon fixation in the zone closer to shore ranged from 8–10 mg $C/m^3/hr$ and at stations farther offshore were <5 mg $C/m^3/hr$ (Fig. 13d). Chlorophyll *a* concentrations were also high in the nearshore zone, ranging from 5 to 7 mg/m^3 and Secchi disc transparencies were 2 m or less in this nearshore zone; at offshore stations, chlorophyll *a* concentrations decreased to <2 mg/m^3 and Secchi disc transparency averaged about 7 m.

RESULTS FOR JULY

Results for July represent repetitive sampling of the transects off the St. Joseph, Kalamazoo and Grand Rivers; each of these transects was sampled either four or five times in the 11-day period from July 8 to 18. In addition, stations at the mouth of the St. Joseph, Kalamazoo, and Grand Rivers were sampled more frequently, 11, 7, and 10 times respectively, so more data are available from the rivermouth stations than for the transects. The reader is reminded that the 0 km stations on the transects for the St. Joseph and Grand Rivers are rivermouth stations, but that the 0 km station on the Kalamazoo transect is not at the mouth of the river. The 0 km station and rivermouth station are therefore not the same for the Kalamazoo transect.

Because stations in July were sampled repetitively with time, it was possible to plot phytoplankton data, both as data collected on each date of sampling (the transect for each date) and as data collected at each station with time (data collected on all dates for the 1.6 km station, for example). Data have been displayed twice so the reader can determine spatial changes in phytoplankton species composition on each sampling date and can also inspect the same data plotted as temporal changes in species composition for individual stations. The large quantity of data seems to warrant this redundancy in data presentation.

ST. JOSEPH RIVER TRANSECT

In July the transect off the St. Joseph River was sampled five times: on July 8, 12, 13, 16, and 18.

Physical-Chemical Conditions

Water temperatures in the St. Joseph River were generally greater than in the offshore surface waters. On July 12, 13, and 16, temperatures in the river were approximately 24° C, 6–7° C greater than in the offshore waters (Figs. 14b–d); on July 8 and 18, differences in temperatures were less, being only about 3°C (Figs. 14a, e). Offshore temperatures ranged from a low of 15° C on July 8 to 17–19° C on the other dates.

River water had lower pH than the offshore surface waters. The difference was small, being less than .1 pH unit on July 8 when the river pH was 8.6 and ranging to a difference as great as .35 pH units on July 16 when the river pH was 8.2 (Figs. 14a, d). During July offshore values for pH generally ranged between 8.55 and 8.65.

Silica concentrations in the river water were greater than in the offshore surface waters. These differences were also small, with the greatest differences being found on July 16 and 18 when the river water had a silica concentration of .7 mg/liter and offshore concentrations were as little as .3 mg/liter (Figs. 14d, e). With the exception of July 16, offshore silica values generally ranged from .2–.3 mg/liter; on July 16 concentrations ranged between .4 and .5 mg/liter.

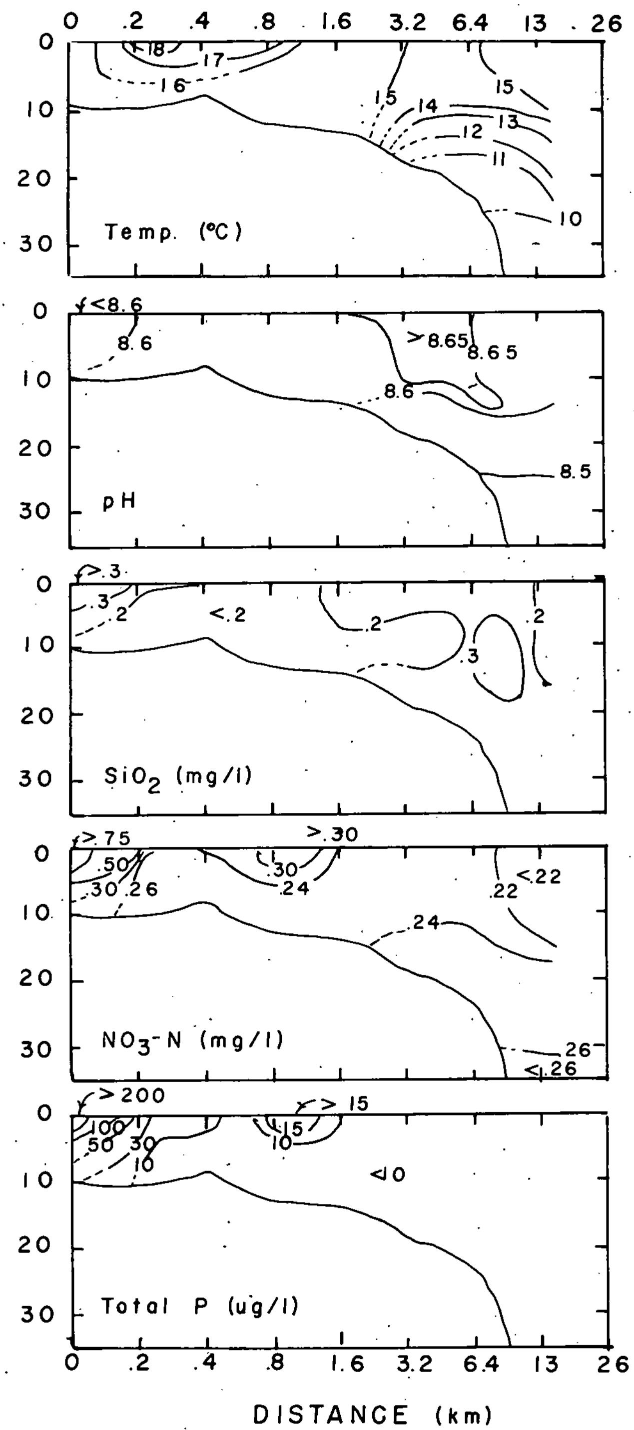

FIG. 14a. St. Joseph River transect. Physical-chemical conditions, July 8, 1972.

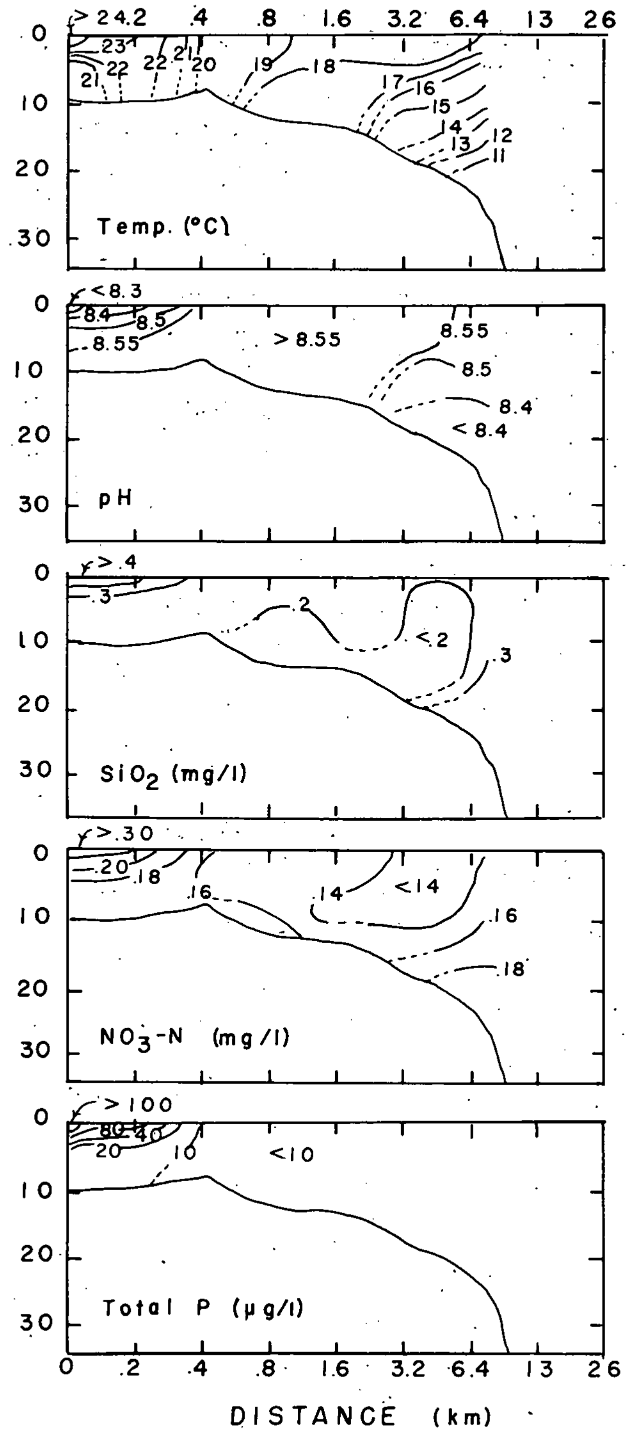

FIG. 14b. St. Joseph River transect. Physical-chemical conditions, July 12, 1972:

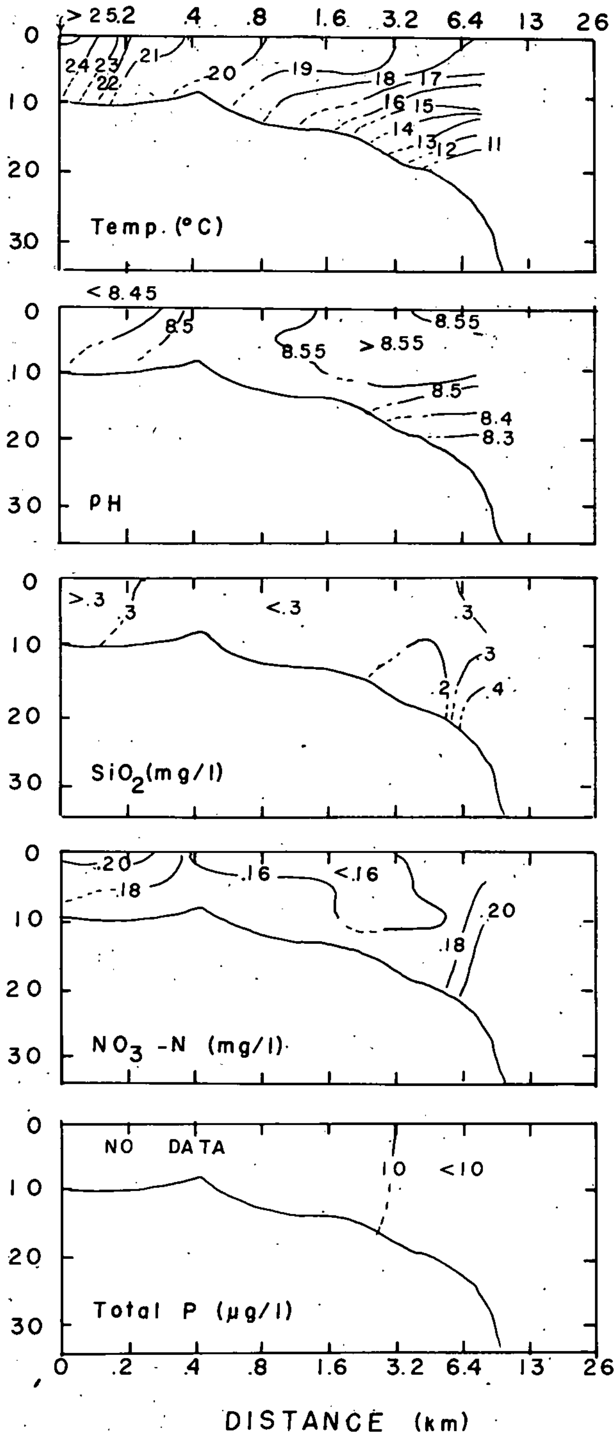

FIG. 14c. St. Joseph River transect. Physical-chemical conditions, July 13, 1972.

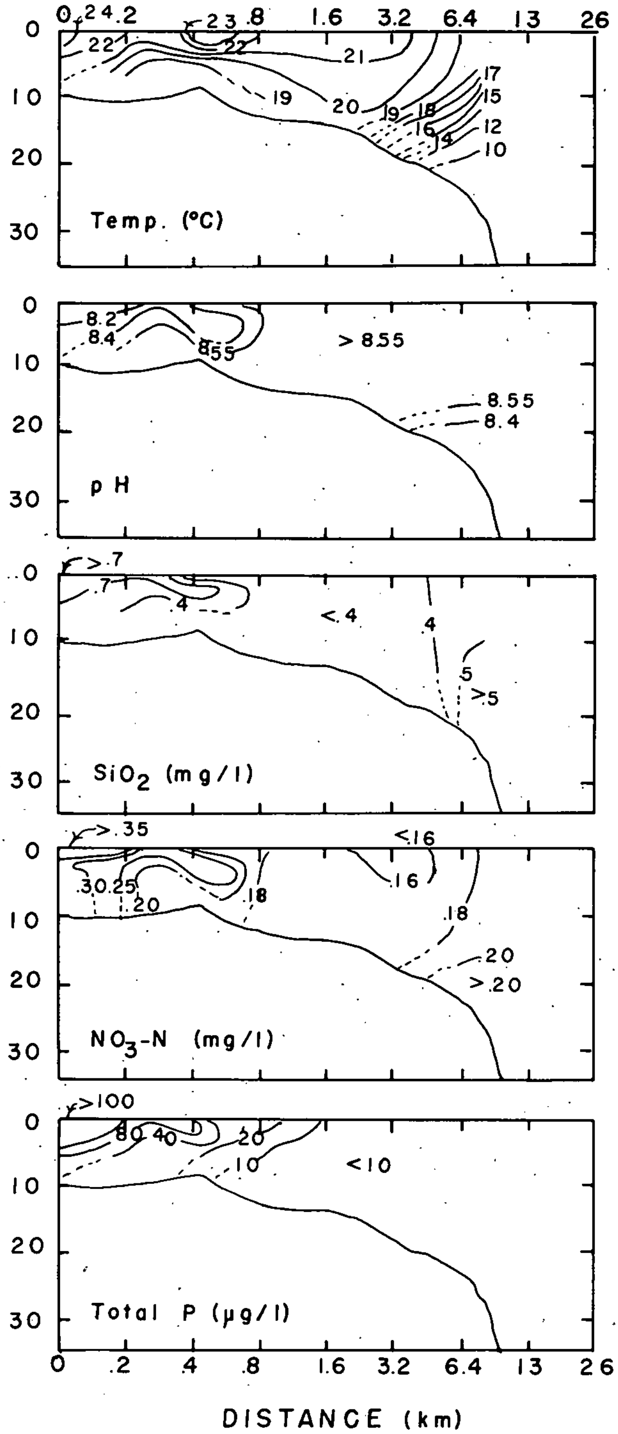

FIG. 14d. St. Joseph River transect. Physical-chemical conditions, July 16, 1972.

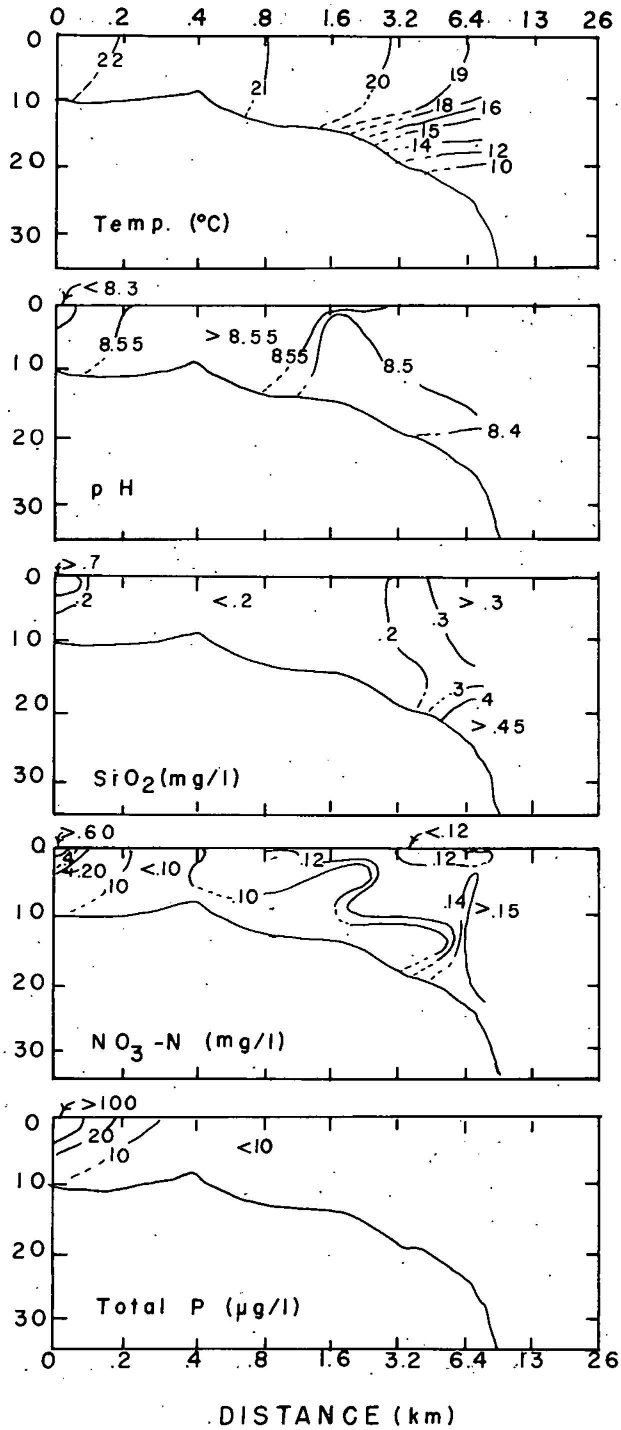

FIG. 14e. St. Joseph River transect. Physical-chemical conditions, July 18, 1972.

Nitrate concentrations in river water were generally greater than in the offshore surface waters with the largest differences being on July 8 and 18 (Figs. 14a, e) when concentrations in the river water were >.60 mg/liter. On the other dates concentrations of nitrate in river water ranged from .20 to .35 mg/liter. Nitrate concentrations in the offshore surface waters were variable ranging from .22 to .24 mg/liter on July 8 when concentrations were much greater than on any of the other dates sampled to .10 to .18 mg/liter on the remaining sampling dates. The minimum occurred on July 18 when concentrations ranged from .10 to .12 mg/liter. From July 12–18 there appeared to be a nitrate minimum in the nearshore zone at stations located between .4 and 3.2 km from shore—the higher concentrations closer to shore were due to inputs from the St. Joseph River and presumably larger concentrations farther offshore were representative of offshore waters.

Total phosphorus concentrations in the river water were >100 μg/liter on all dates in which samples were obtained ranging to >200 μg/liter on July 8 (Fig. 14). River concentrations contrasted greatly with the offshore waters where total phosphorus concentrations on all dates were <10 μg/liter.

The effect of the St. Joseph River on the chemistry of this transect was not apparent beyond stations located more than .2 km from shore, except on July 8 and July 16 (Figs. 14a, d) when there was some evidence for larger total phosphorus concentrations at the station located .4 km from shore. These data indicate either that the St. Joseph river plume did not affect a large area of the lake or that the plume was moving either north or south after it entered the lake.

Phytoplankton

In July the rivermouth station was sampled 11 times while the transect in the lake was sampled five times.

At the St. Joseph river mouth in July nine species comprised at least 91% of the total cell counts found. Standing crops ranged from 9880 cells/ml to 18800 cells/ml except on July 12 and 13 when standing crops decreased to the range of 3380 to 3750 cells/ml (Fig. 15a). Two species comprised from 73 to 90% of the total cell counts—these species were *Stephanodiscus tenuis* and *Melosira granulata*. The relative abundance of *Stephanodiscus tenuis* decreased throughout the time of collection while *Melosira granulata*, the other dominant species, increased. The combined relative abundance of the two species decreased with time as they were replaced in the phytoplankton assemblages by *Cyclotella atomus* and to a less extent by *C. cryptica*. These two species of *Cyclotella* were much more abundant on the last days of collection than on the first day. Other species present in much smaller relative abundances were *Stephanodiscus* sp. #16, *Fragilaria crotonensis, Stephanodiscus subtilis, Asterionella formosa*, and *Cyclotella meneghiniana* v. *plana*. After day 5 *Stephanodiscus* sp. #16 disappeared from the experiment. The disappearance may not be real but may be due to identification and taxonomic difficulties.

Over the course of the experiment *Stephanodiscus tenuis* and *Melosira granulata* were the dominant species at the river mouth and at .2 km offshore (Figs. 15a, b) with the exception of July 18 when *Anabaena flos-aquae* became a major component of the phytoplankton assemblage at .2 km.

At the stations .4 and .8 km from shore, the phytoplankton assemblages were variable from day to day (Figs. 15c, d), which probably reflects changing water masses at these stations. Several populations of diatoms comprised 10 or more per cent of the assemblage in different samples; species included were *Stephanodiscus tenuis, Fragilaria crotonensis, Cyclotella stelligera, Melosira granulata, Nitzschia acicularis*, and

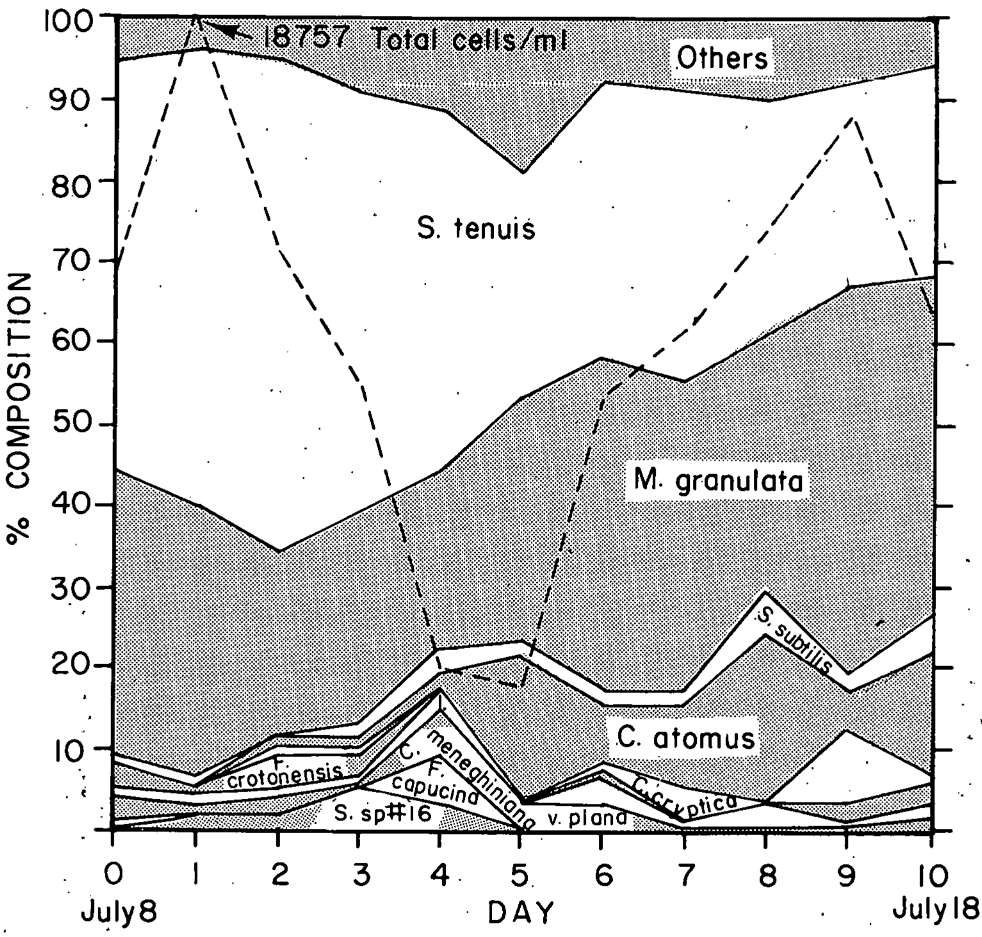

FIG. 15a. St. Joseph River transect. Phytoplankton species composition and standing crop at station 0 km offshore.

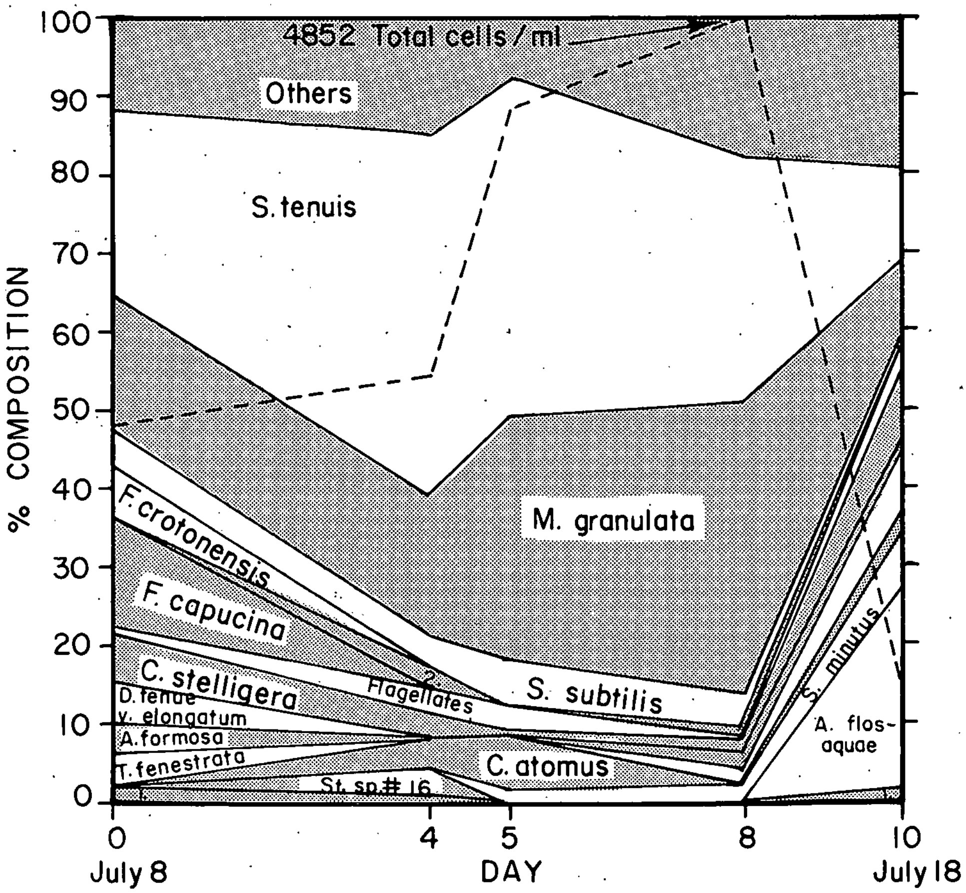

FIG. 15b. St. Joseph River transect. Phytoplankton species composition and standing crop at station .2 km offshore. 1. species *Nitzschia acicularis*, 2. species *Cyclotella meneghiniana* v. *plana*.

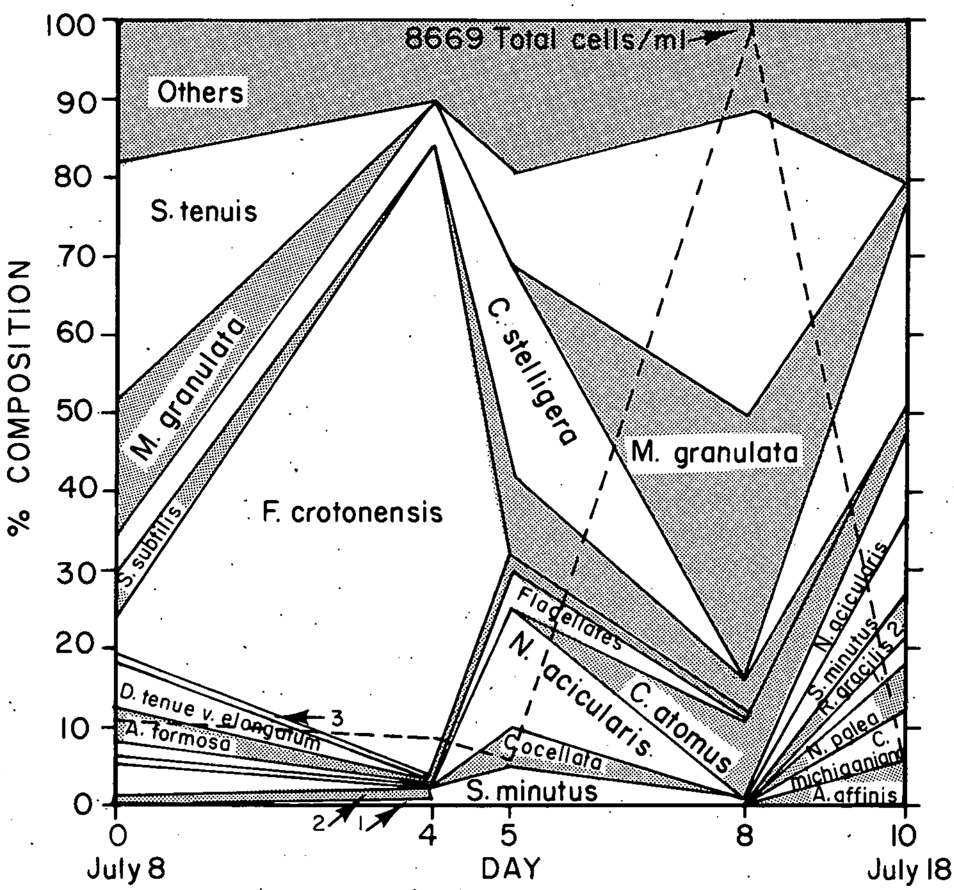

FIG. 15c. St. Joseph River transect. Phytoplankton species composition and standing crop at station .4 km offshore. 1. species *Anabaena flos-aquae*, 2. species *Rhizosolenia gracilis*, 3. flagellates.

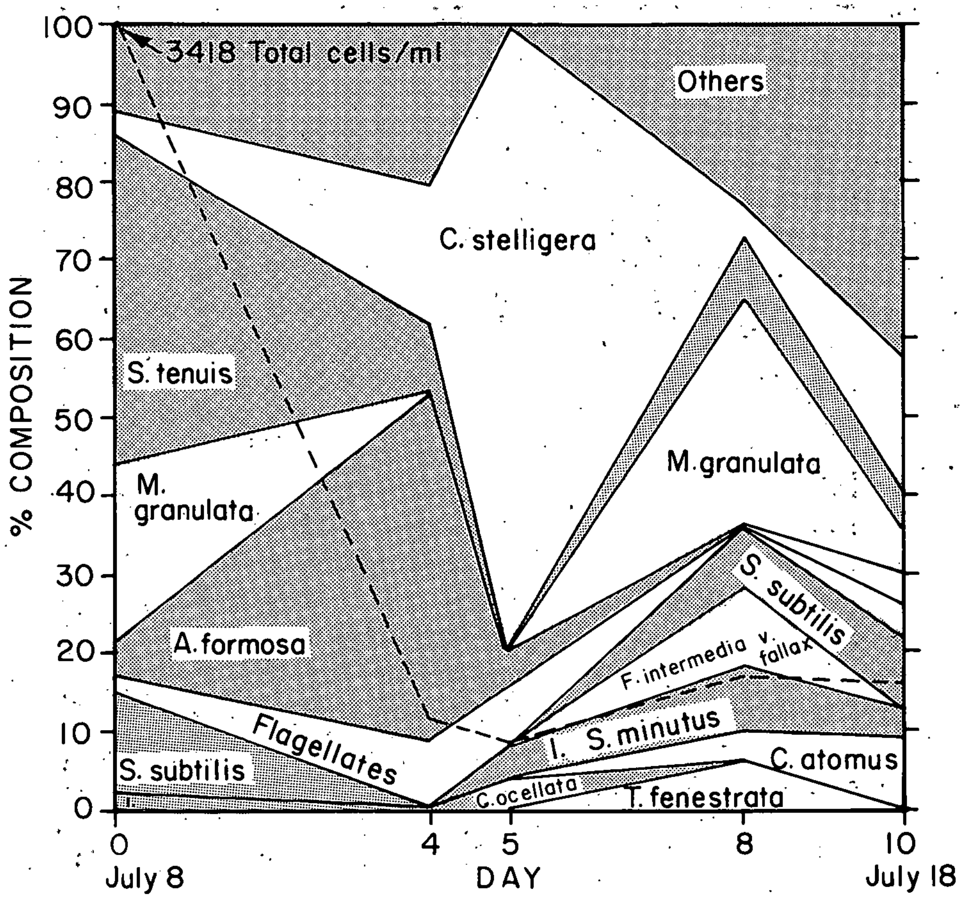

FIG. 15d. St. Joseph River transect. Phytoplankton species composition and standing crop at station .8 km offshore. 1. species *Stephanodiscus minutus.*

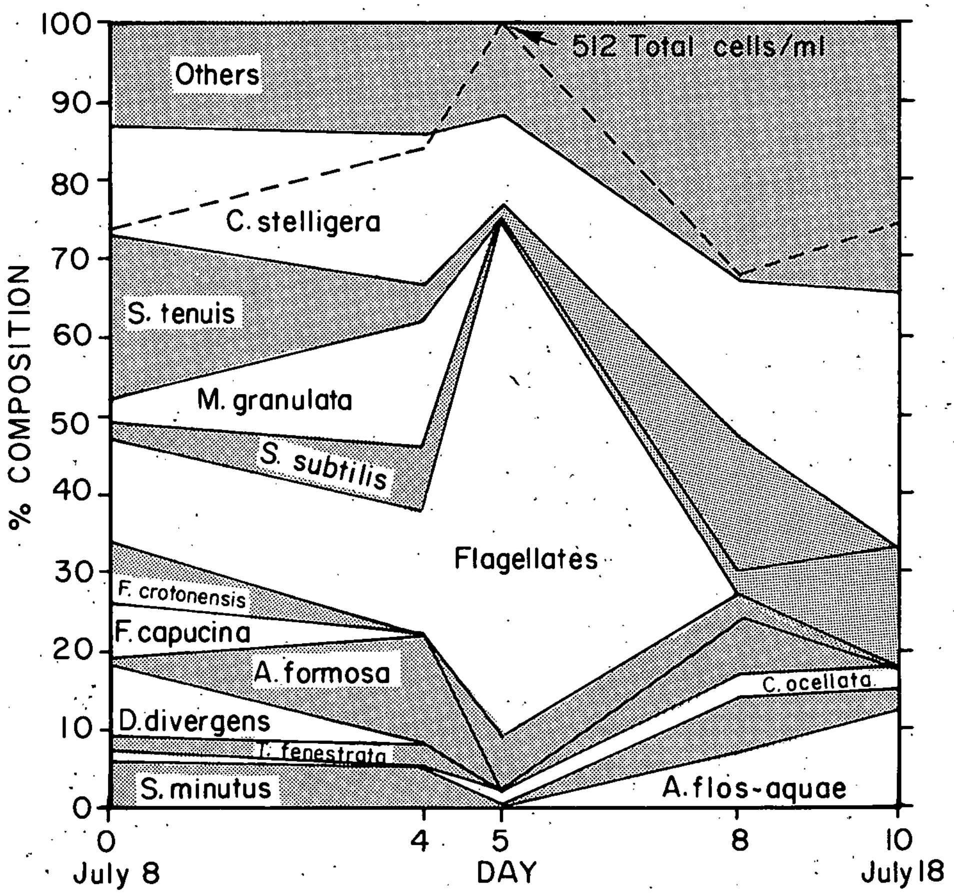

FIG. 15e. St. Joseph River transect. Phytoplankton species composition and standing crop at station 1.6 km offshore.

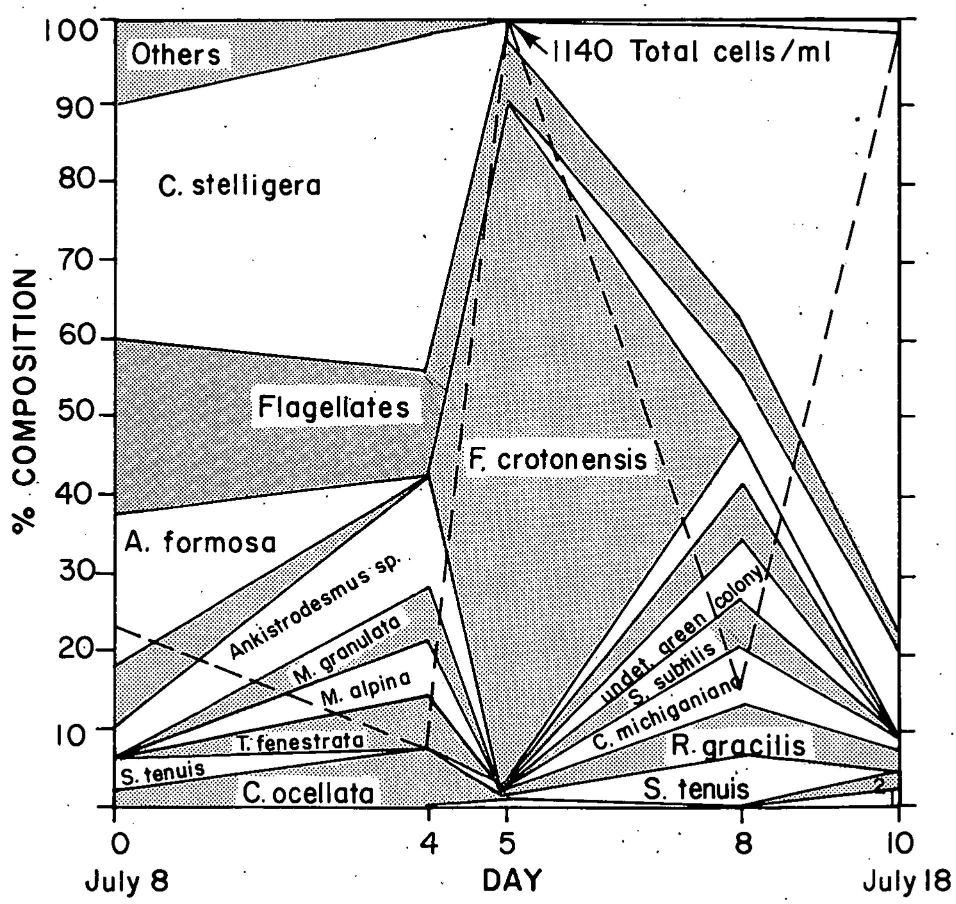

FIG. 15f. St. Joseph River transect. Phytoplankton species composition and standing crop at station 6.4 km offshore. 1. species *Mallomonas pseudocoronata*, 2. species *Cyclotella ocellata*.

Asterionella formosa. The presence of a large population of *Melosira granulata* or *Stephanodiscus tenuis* at these stations indicates plankton derived from the St. Joseph River (Fig. 15a), whereas *Cyclotella stelligera* and undetermined flagellates were the major components of the assemblage from stations ranging from 1.6 to 6.4 km offshore (Figs. 15e, f).

At the stations ranging from 1.6 to 6.4 km offshore (Figs. 15e, f) the phytoplankton assemblage over time was more uniform than at the stations located .4 and .8 km from shore (Figs. 15c, d) which were partially characterized by plankton from the river. At these offshore stations, major dominants were *Cyclotella stelligera* and undetermined flagellates. A large population of *Fragilaria crotonensis* (1000 cells/ml) on July 13 dominates the graph of relative abundance on that date (Fig. 15f); however this relationship is an artifact of the large population of *F. crotonensis* on that date and not necessarily due to a decline in abundance of the other dominant species.

On July 8 the most abundant species near the river were *Stephanodiscus tenuis* and *Melosira granulata* (Fig. 16a). Both species maintained high relative abundances out to and including the station .8 km from shore. *Stephanodiscus tenuis* was also relatively abundant at 1.6 and 3.2 km offshore. *S. subtilis* was present in small relative abundances at stations out to a distance 3.2 km from shore. *Diatoma tenue* v. *elongatum* was present in relatively high abundances at the stations .2 and .4 km from the piers. The total standing crop was 12880 cells/ml at the river mouth which declined rapidly to 2340 cells/ml at .2 km from shore (Fig. 16a). In this area influenced by the river plume the lowest standing crop was .4 km from shore, 970 cells/ml. In the offshore region, ranging from 1.6 to 13 km offshore, standing crops were much lower than near the river mouth, ranging only from 203 to 645 cells/ml. In this offshore zone, the three most abundant entities were *Cyclotella stelligera, Fragilaria crotonensis*, and undetermined flagellates. In addition, *Asterionella formosa, Dinobryon divergens*, and *Tabellaria fenestrata* were also relatively abundant at some stations.

On July 12 the major dominants at the river mouth were still *Stephanodiscus tenuis* and *Melosira granulata*. Large relative abundances of these species were maintained out to the station .2 km from shore (Fig. 16b). At .4 km from shore, *Fragilaria crotonensis* comprised 83% of the total cell counts. Its absolute abundance was relatively low because the total standing crop at the station was only 790 cells/ml. Cell densities on this sampling date were much less than those found when this transect was sampled the first time four days earlier. In this period maximum cell densities at the river mouth had decreased from 12880 to 3700 cells/ml.

Offshore phytoplankton were present at stations ranging from .8 to 6.4 km offshore. At these stations the standing crop of phytoplankton ranged from 160 to 430 cells/ml (Fig. 16b). The two most abundant species at all of these stations were *Cyclotella stelligera* and undetermined flagellates; however, at some stations *Asterionella formosa* and *Diatoma tenue* v. *elongatum* were relatively abundant.

On July 13 cell counts at the river mouth were low compared to other dates, (3420 cells/ml, Fig. 15a). A larger standing crop (4270 cells/ml, Fig. 16c) was found at the station .4 km from shore. In this region of high cell densities the major phytoplankton species continued to be *Stephanodiscus tenuis* and *Melosira granulata* but in addition a relatively large population of *Cyclotella atomus* was observed. The two major species in the zone from .4 to 3.2 km offshore were *C. stelligera* and undetermined flagellates. Relatively large populations of *C. ocellata* were found at the stations .8 to 1.6 km offshore. At the station 6.4 km offshore, *Fragilaria crotonensis* was obviously the most dominant component of the phytoplankton assemblage, comprising 88% of the total standing crop or 1000 cells/ml.

On July 16 the total standing crop of phytoplankton at the river mouth was again

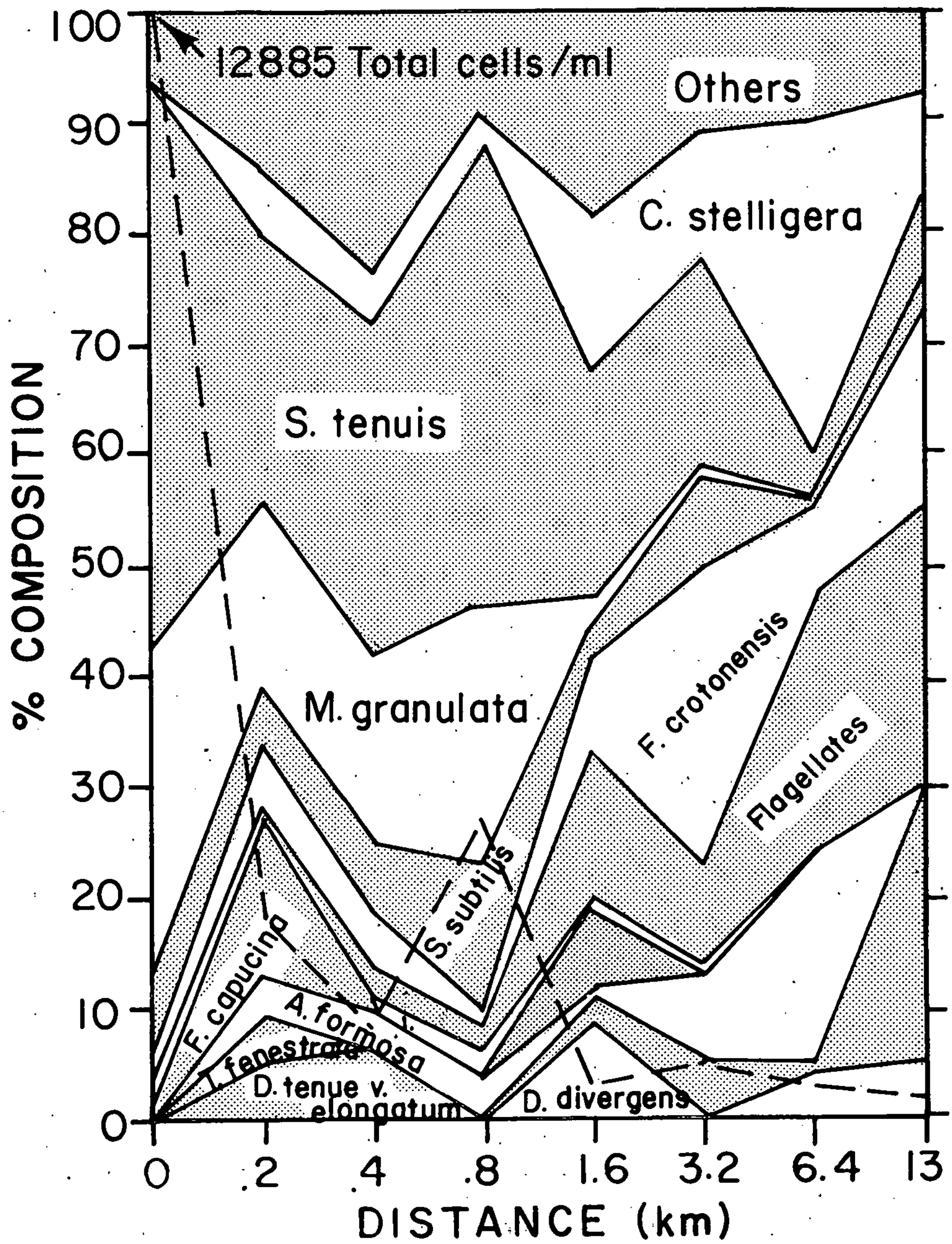

FIG. 16a. St. Joseph River transect. Phytoplankton species composition and standing crop, July 8, 1972. 1. species *Cyclotella meneghiniana* v. *plana*.

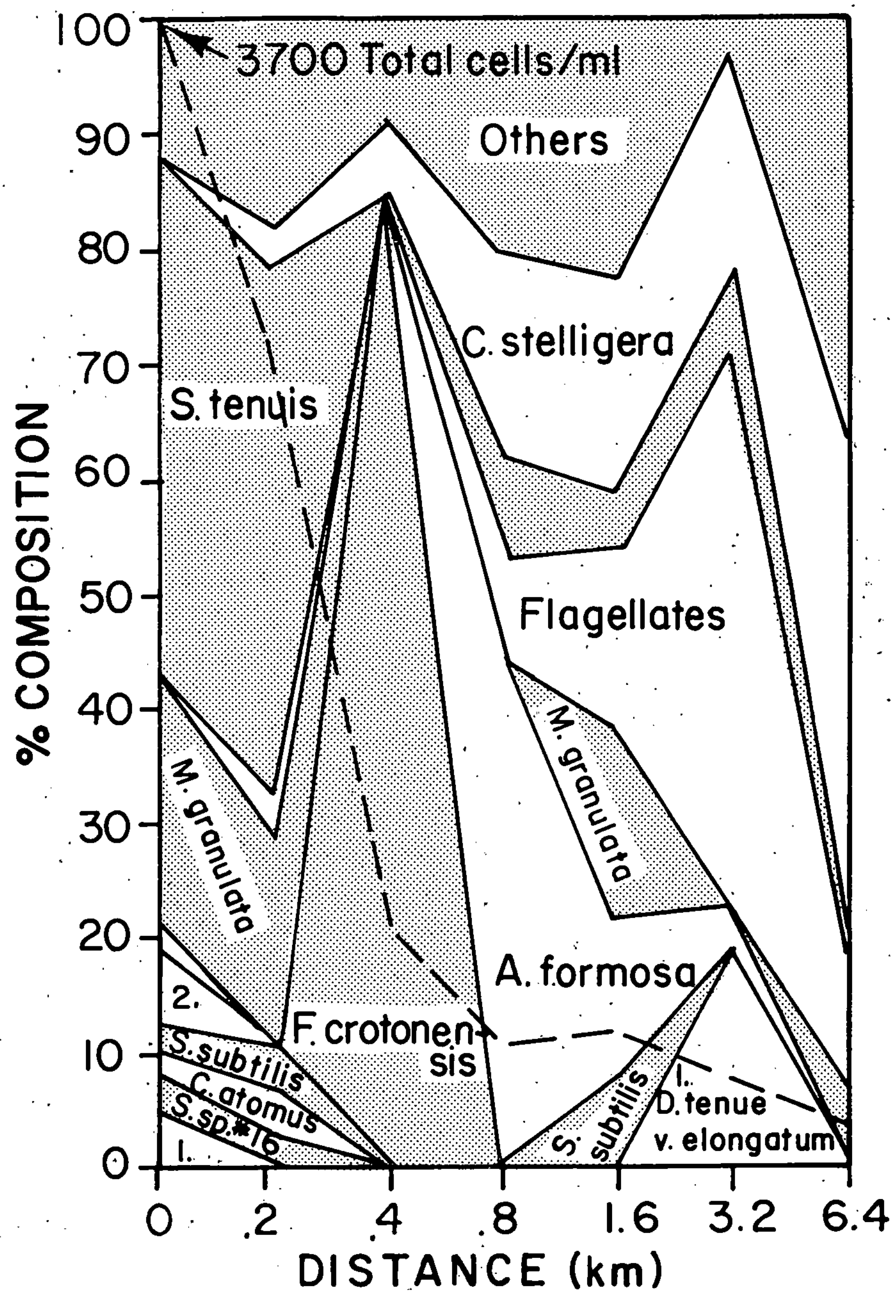

FIG. 16b. St. Joseph River transect. Phytoplankton species composition and standing crop, July 12, 1972. 1. species *Diatoma tenue* v. *elongatum*, 2. species *Fragilaria capucina*.

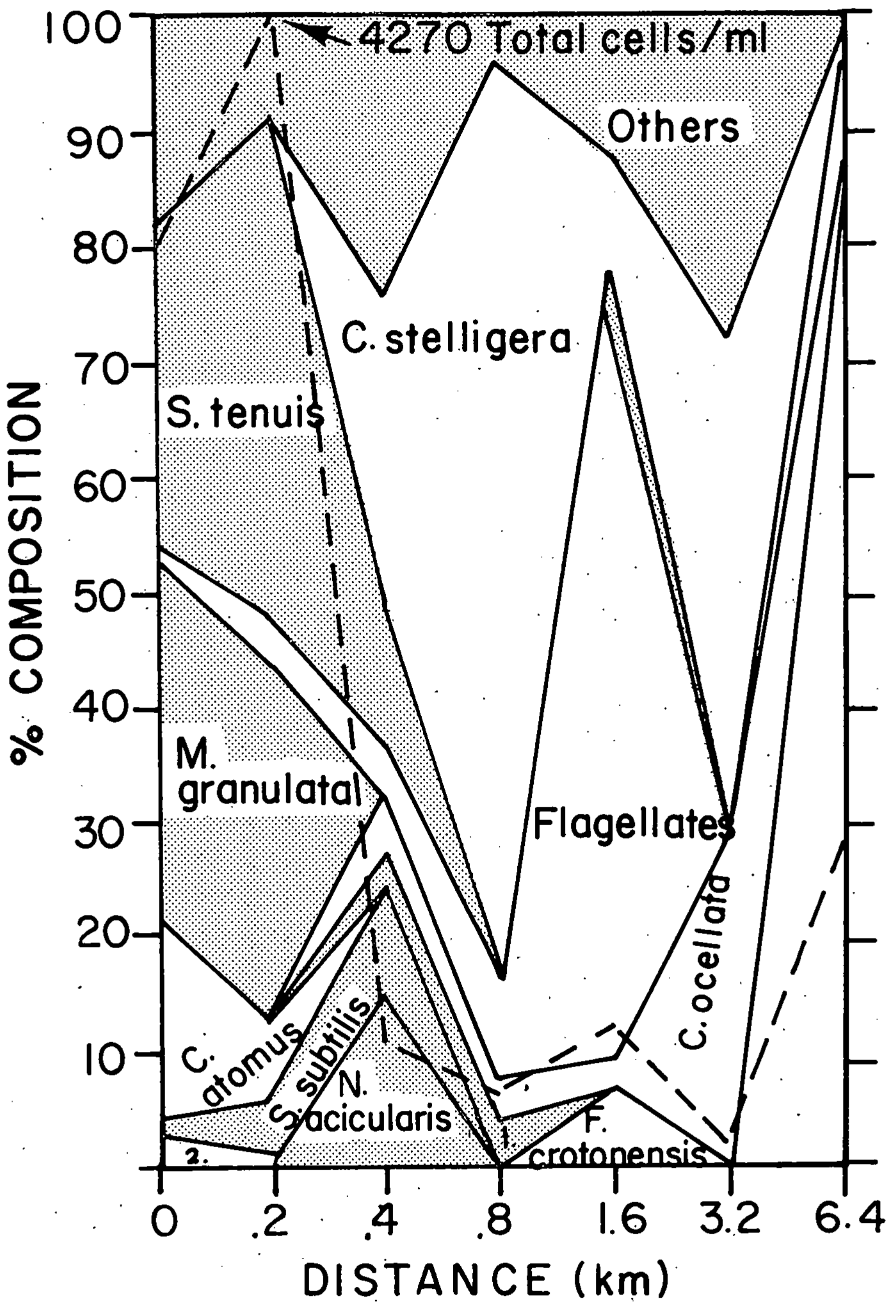

FIG. 16c. St. Joseph River transect. Phytoplankton species composition and standing crop, July 13, 1972. 1. species *Asterionella formosa*, 2. species *Cyclotella meneghiniana* v. *plana*.

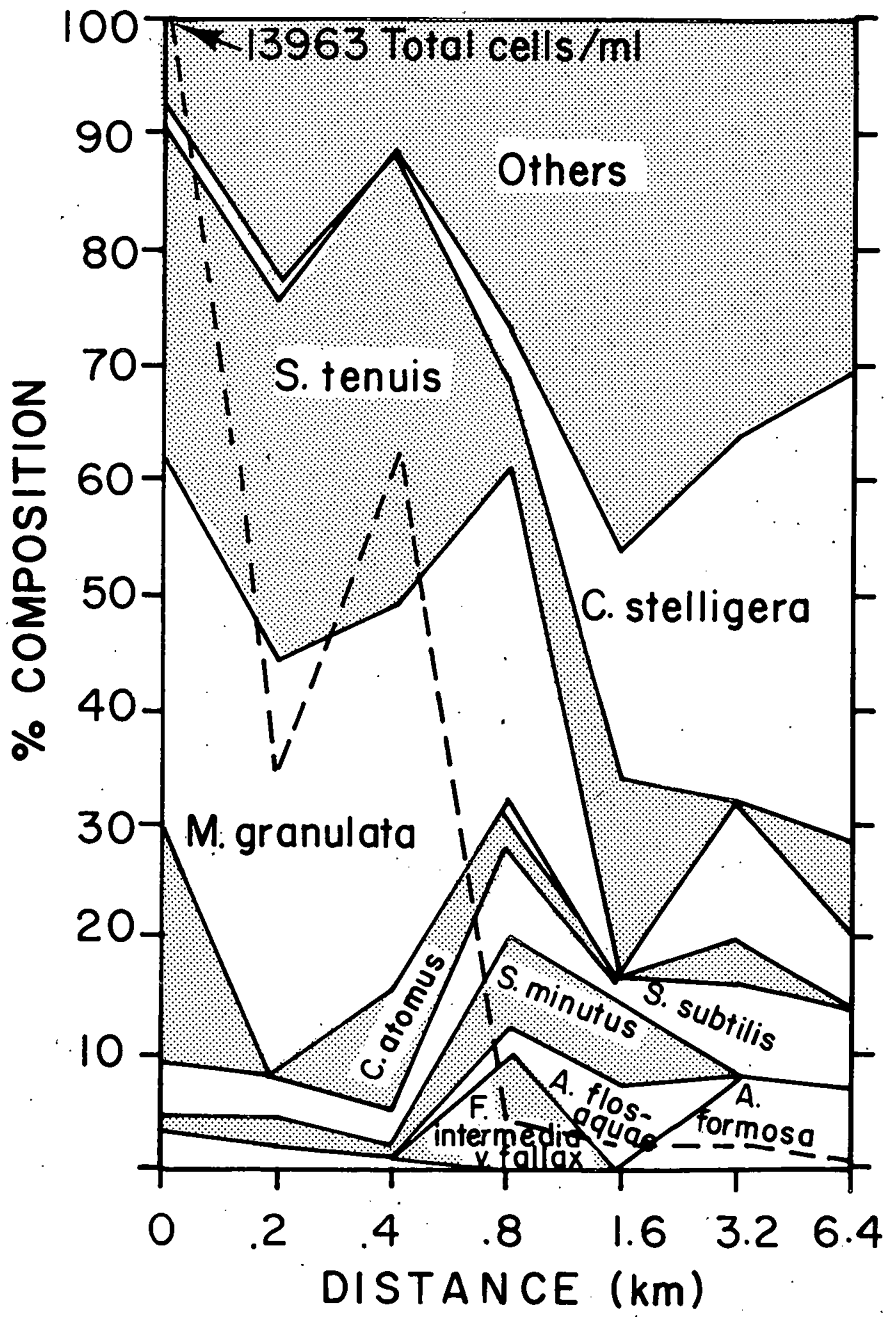

FIG. 16d. St. Joseph River transect. Phytoplankton species composition and standing crop, July 16, 1972.

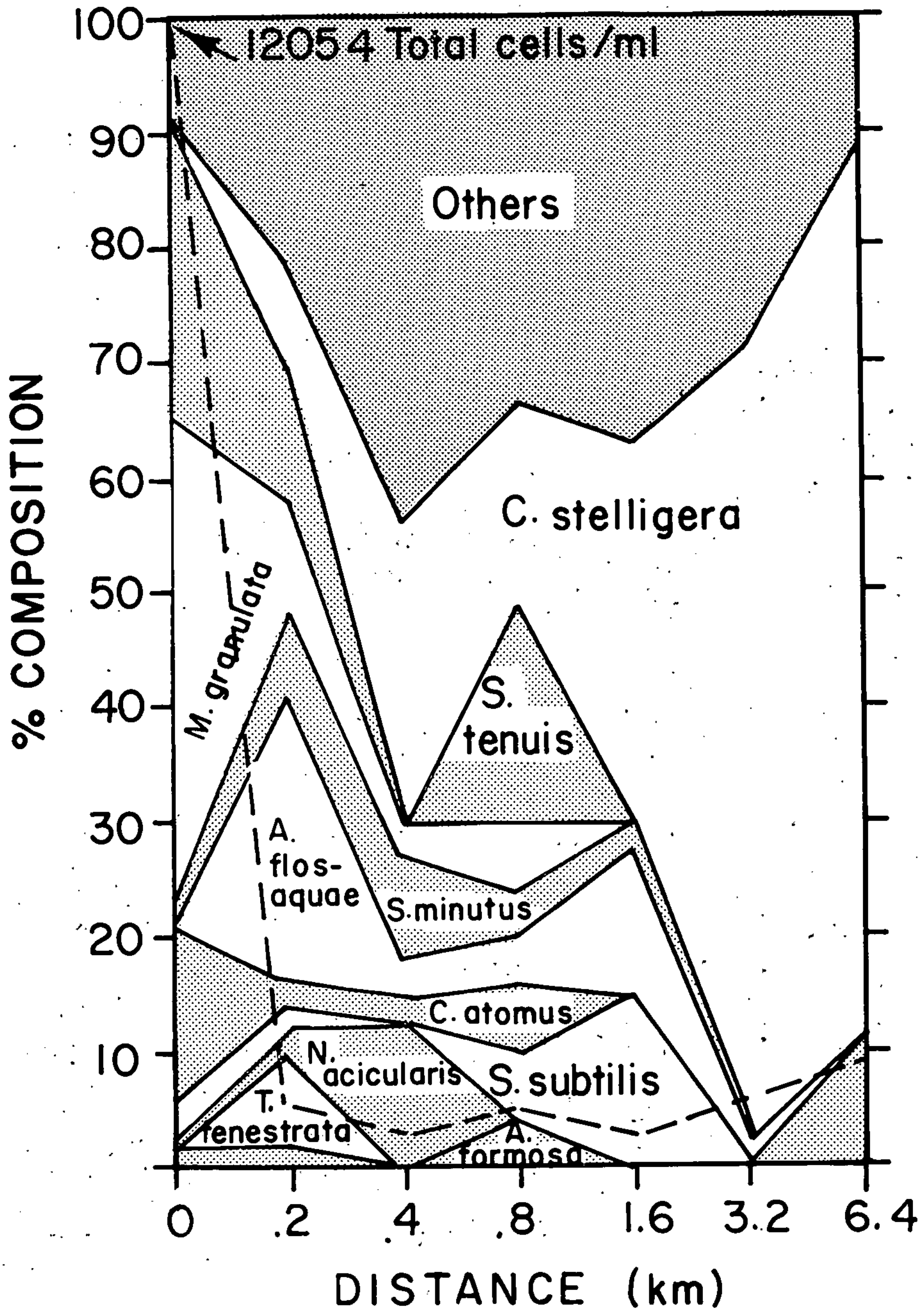

FIG. 16e. St. Joseph River transect. Phytoplankton species composition and standing crop, July 18, 1972.

high and the area influenced by the river plume extended to a distance .8 km from shore. The two most dominant species in the river plume area continued to be *Stephanodiscus tenuis* and *Melosira granulata*, with *Cyclotella atomus* being present in smaller relative abundances. In addition, *Stephanodiscus subtilis* and *S. minutus* were also present in low relative abundance, and at the station .8 km from shore *Fragilaria intermedia* v. *fallax* comprised 10% of the total standing crop.

On July 16, the total standing crop in the area influenced by the river, out to .4 km from shore, ranged from 4850 to 8670 cells/ml (Fig. 16d). At the station .8 km from shore where *Melosira granulata* was still abundant, cell counts decreased to 500 cells/ml. This decrease was apparently due to dilution with offshore water. At stations ranging from 1.6 to 6.4 km offshore cell counts were very low, ranging from 170 to 350 cells/ml. In this area the relative abundance of the dominant phytoplankter, *Cyclotella stelligera*, increased with distance offshore comprising from 20 to 40% of the total standing crop, and the portion of the assemblage designated "others" ranged from 31 to 46% indicating a variable assemblage at these stations. In addition to *C. stelligera*, *Stephanodiscus subtilis*, *S. minutus*, *Asterionella formosa*, *Anabaena flos-aquae*, and *Fragilaria intermedia* v. *fallax* were present but in much lower abundances at some stations. *Melosira granulata* and *Stephanodiscus tenuis* were also important components of the assemblages at some of these offshore stations.

On July 18 the standing crop of phytoplankton at the river mouth was 12050 cells/ml but this declined drastically to 690 cells/ml at the station located .2 km from shore (Fig. 16e). *Stephanodiscus tenuis* and *Melosira granulata* again were the two most dominant species at the rivermouth station. In addition, *Cyclotella atomus* comprised 15% of the total cell counts. In addition to these three species, *Anabaena flos-aquae* and *Tabellaria fenestrata* were found in relatively high abundances at the station .2 km from shore. The dominant species in the area from .4 to 6.4 km offshore was *Cyclotella stelligera* whose relative abundance ranged from 17 to 77% of the total standing crop (Fig. 16e). Its greatest relative and absolute abundance was found at the stations 3.2 and 6.4 km offshore where standing crops ranged from 380 to 1130 cells/ml with the larger standing crop being found at the station 6.4 km from shore.

Numbers of species in the St. Joseph River were greater than at the stations farther offshore on all dates the transect was sampled. The maximum number of species at the rivermouth station was 69 on July 8—on the other sampling dates numbers ranged from 28 to 37 species (Figs. 17a–e). With the exception of July 13, numbers of species at the nearshore stations were generally >30. At most of the offshore stations <20 species were found. On July 12, 13, and 18 <10 species were found at a number of offshore stations.

Species diversity on the St. Joseph River transect appeared to be quite variable from cruise to cruise. On July 13 and 18 the diversity appeared to decrease with distance offshore but on the other three dates of sampling there was no discernible pattern to the distribution of diversity with distance offshore (Figs. 17a–e).

KALAMAZOO RIVER TRANSECT

The transect off the Kalamazoo River was sampled only four times in July, on July 10, 13, 14 and 17.

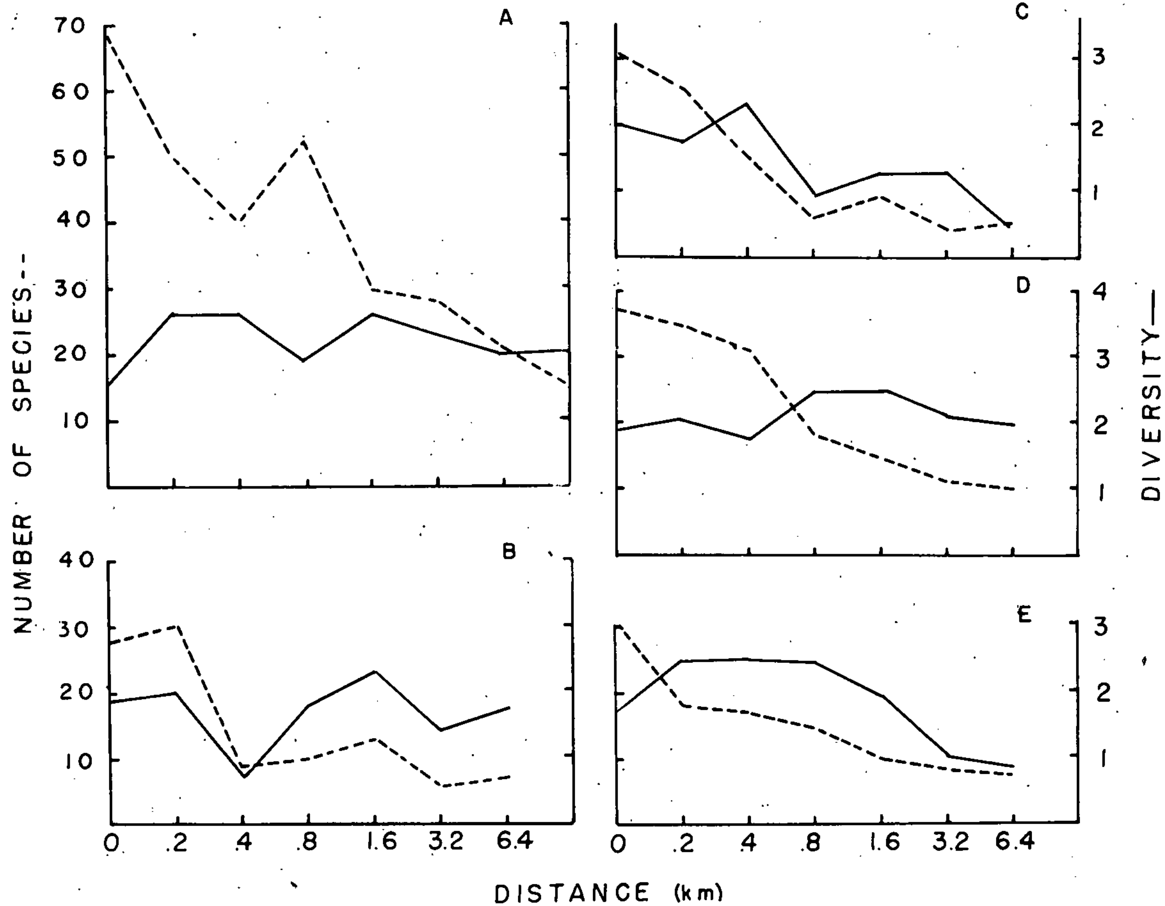

FIG. 17. St. Joseph River transect. Number and diversity of phytoplankton species. a. July 8, 1972; b. July 12, 1972; c. July 13, 1972; d. July 16, 1972; e. July 18, 1972.

Physical-Chemical Conditions

Physical-chemical characteristics of the station nearest to shore were quite different on July 10 than on the succeeding days of sampling (Fig. 18). On July 10 the 0 km station had lower temperatures, higher pH, and lower concentrations of silica, nitrate, and total phosphorus than were found during the other 3 days of sampling. The river temperature was 15° C, about 5° C lower than on the other days of sampling. The pH was >8.6, about .2–.3 pH units greater than on the other days of sampling. Silica concentrations were <.3 mg/liter, much less than the .9–1.6 mg/liter found on the other days of sampling. Nitrate nitrogen concentrations were .16 mg/liter compared to concentrations ranging from .28 to .40 mg/liter on the other days of sampling. And finally, total phosphorus concentrations were <7 μg/liter on July 10, much less than the 30–80 μg/liter found on the other days of sampling.

Offshore surface waters sampled during this period were much less variable than the nearshore waters even though the station farthest offshore was only 6.4 km from shore. (Figs. 18a–d). Water temperature ranged from 15–19° C, pH ranged between 8.55 and 8.65, silica concentrations generally ranged from .4–.5 mg/liter but at the station located 3.2 km from shore concentrations were as low as .3 mg/liter. Nitrate nitrogen concentrations ranged from .16–.18 mg/liter and total phosphorus concentrations were all <10 μg/liter.

Phytoplankton

The Kalamazoo River and the Kalamazoo River transect were sampled less frequently than the other two rivers. In July only seven samples were obtained from the rivermouth station and the lake transect was sampled four times.

During the experiment the river flow increased greatly. Associated with this was an increase in cell counts at the river station. This increase in flow apparently reduced the phytoplankton diversity. Six species of diatoms comprised more than 95% of the total cell counts on the last two days in which the river mouth was sampled (Fig. 19a) and the standing crops and relative abundances of these species changed very markedly during the course of the experiment.

The standing crop of phytoplankton in the river was slightly more than 9000 cells/ml on the first two days of sampling and then increased dramatically to 37600 cells/ml by the last day of sampling (Fig. 19a). This rapid increase in standing crop was due mainly to one species, *Cyclotella cryptica*, which comprised from 49 to 83% of the assemblages on the last five days of sampling. Two other species, *Melosira granulata* v. *angustissima* and *Stephanodiscus subtilis*, were important components of the assemblage during this time maintaining a fairly constant relative abundance as total cell counts increased.

At the beginning of the experiment, the assemblage in the river was dominated by *Cyclotella meneghiniana* v. *plana* and *Melosira granulata* which continued to have large populations until the end of the sampling period (Fig. 19a). In addition, *Tabellaria fenestrata* and *Fragilaria capucina* were present on the first day of sampling, comprising collectively 26% of the total standing crop. But these two species disappeared by July 12 when the assemblage was dominated by *Cyclotella atomus*.

On the first day of sampling the total standing crop of phytoplankton at the 0 km station was 440 cells/ml but on the other three days of sampling, after stream flow increased, the standing crop was greater than 5000 cells/ml and reached a maximum of 11460 cells/ml on the last day of sampling (Fig. 19b). The influence of increased flow

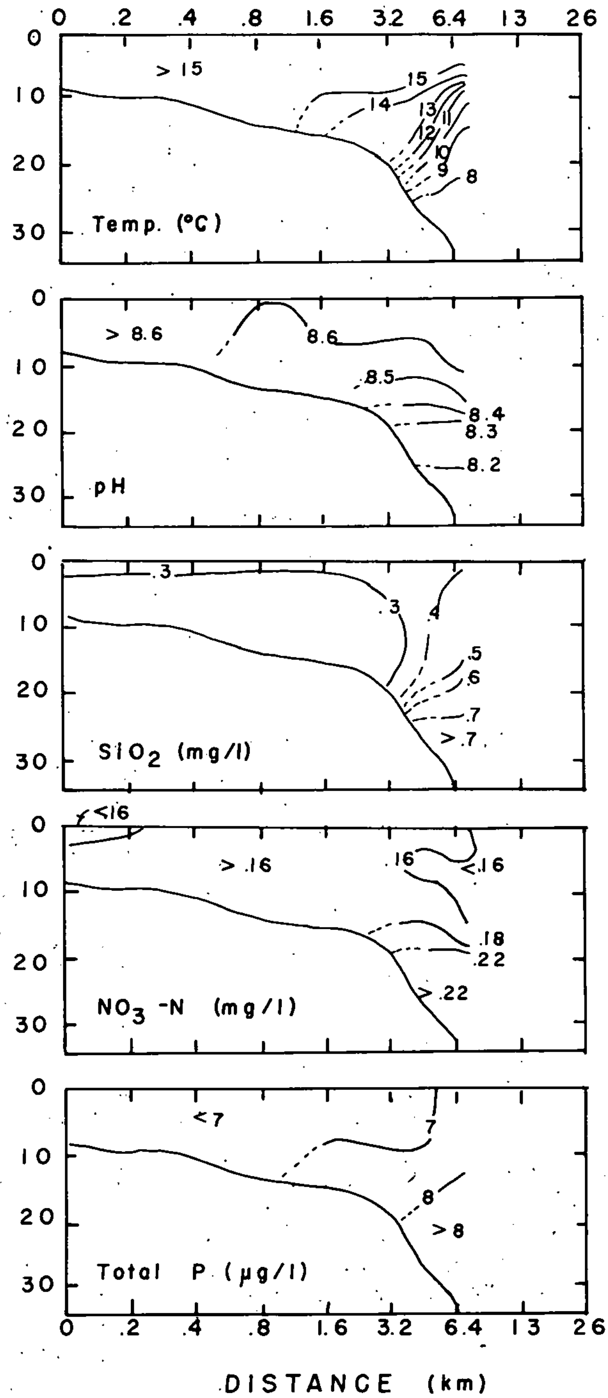

FIG. 18a. Kalamazoo River transect. Physical-chemical conditions, July 10, 1972.

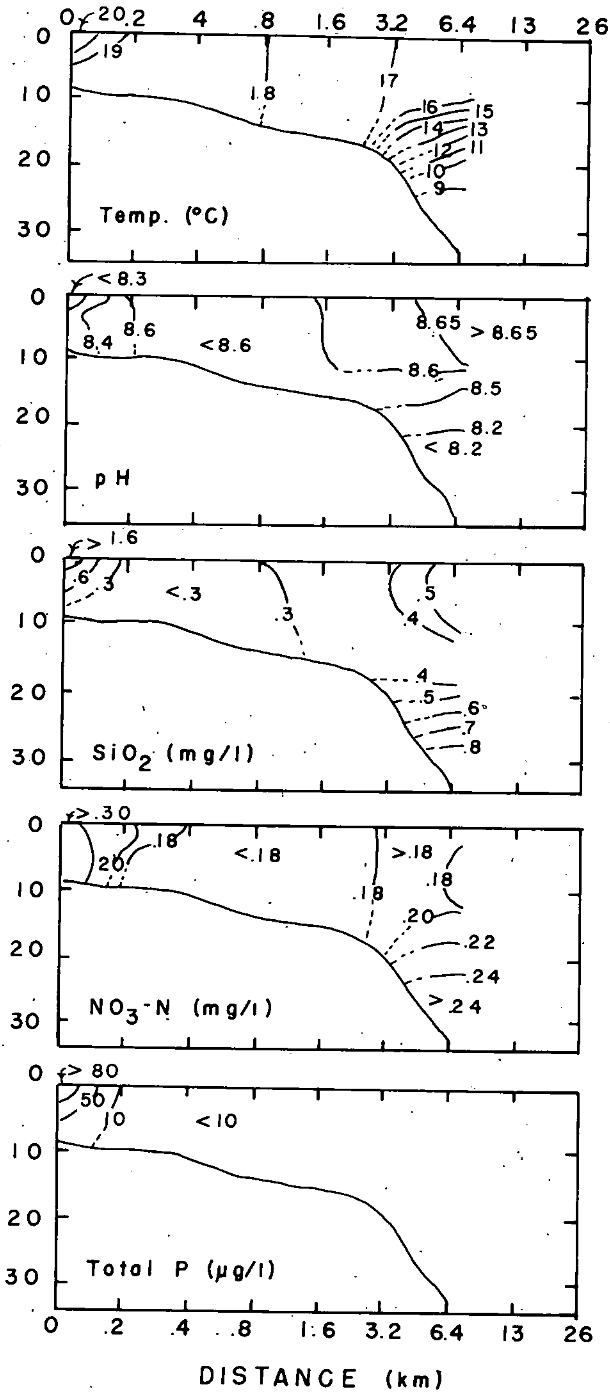

FIG. 18b. Kalamazoo River transect. Physical-chemical conditions, July 13, 1972.

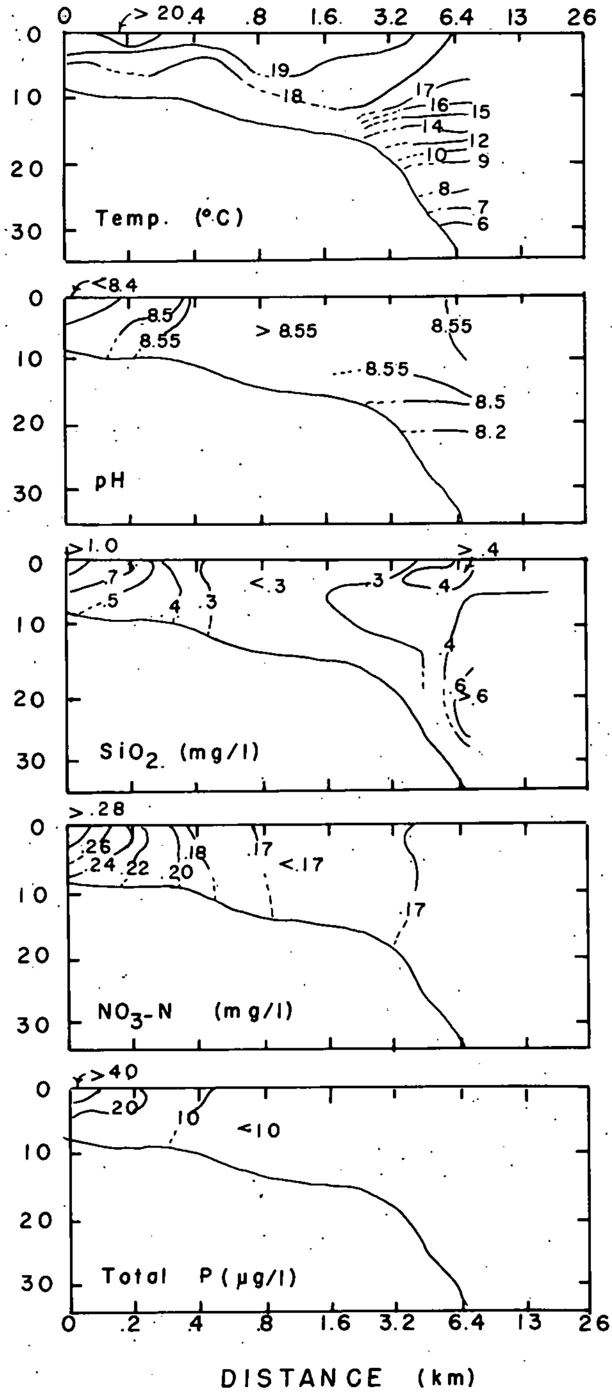

FIG. 18c. Kalamazoo River transect. Physical-chemical conditions, July 14, 1972.

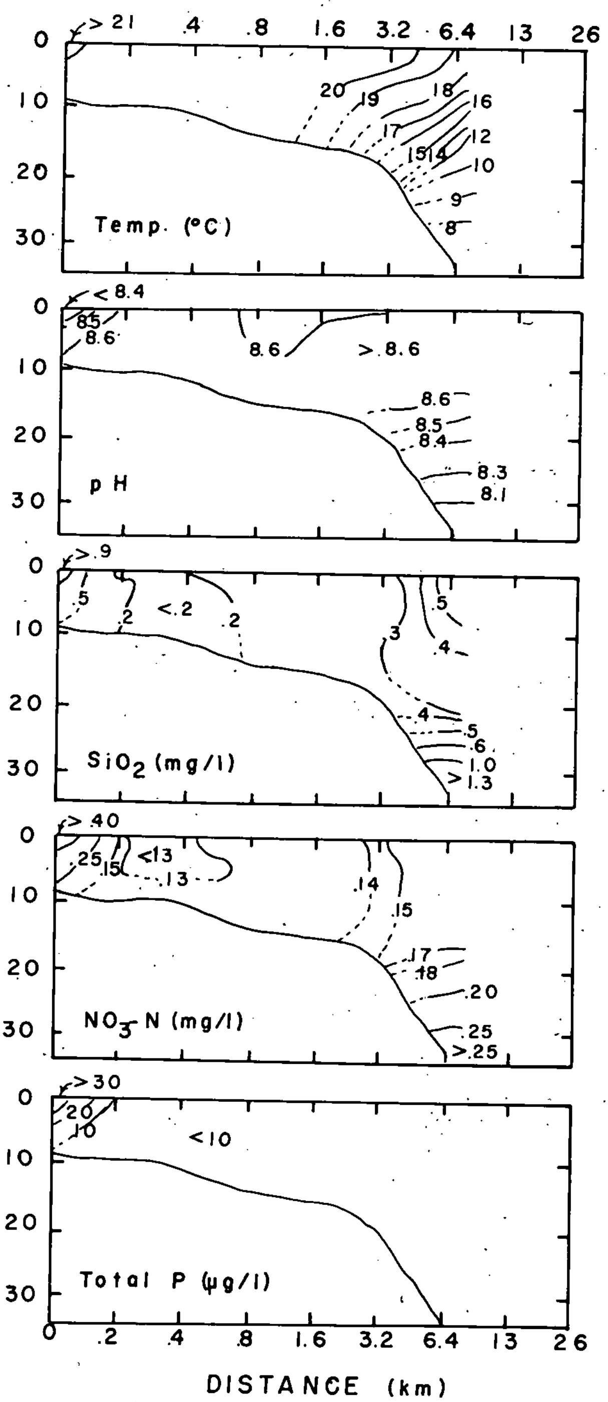

FIG. 18d. Kalamazoo River transect. Physical-chemical conditions, July 17, 1972.

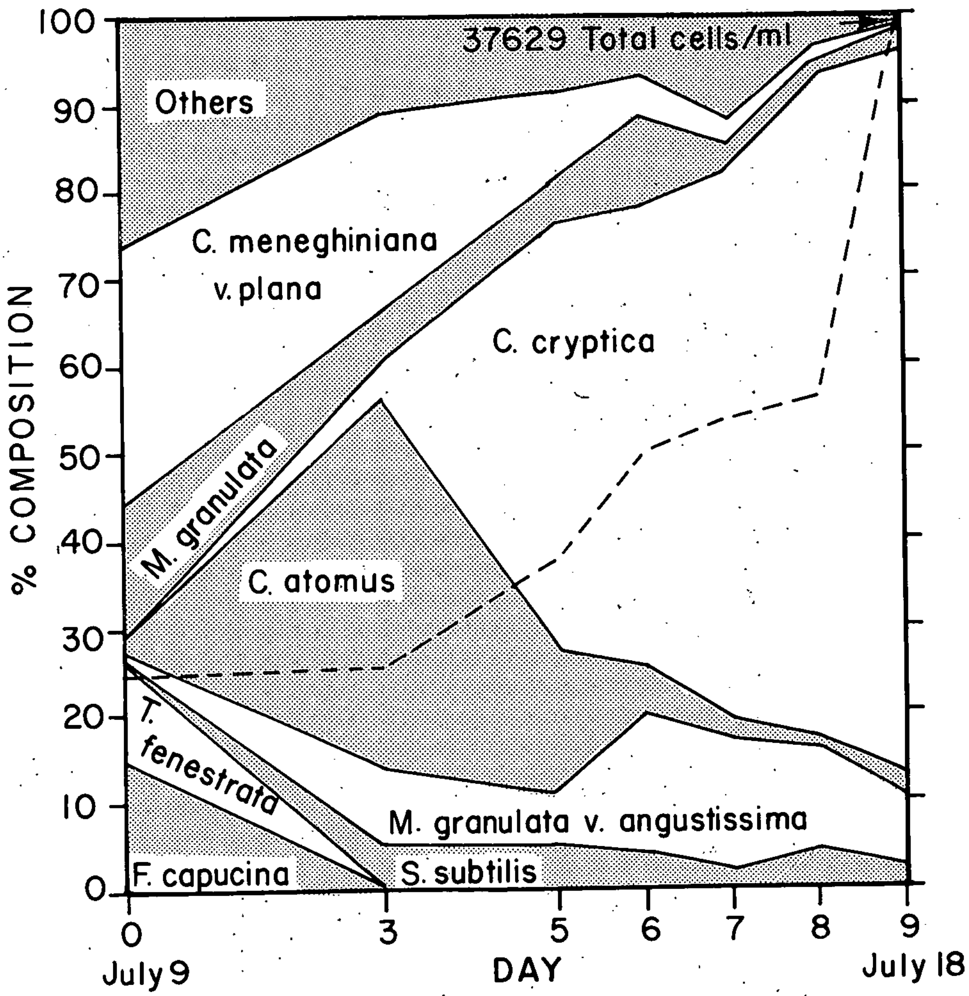

FIG. 19a. Kalamazoo River transect. Phytoplankton species composition and standing crop at rivermouth station.

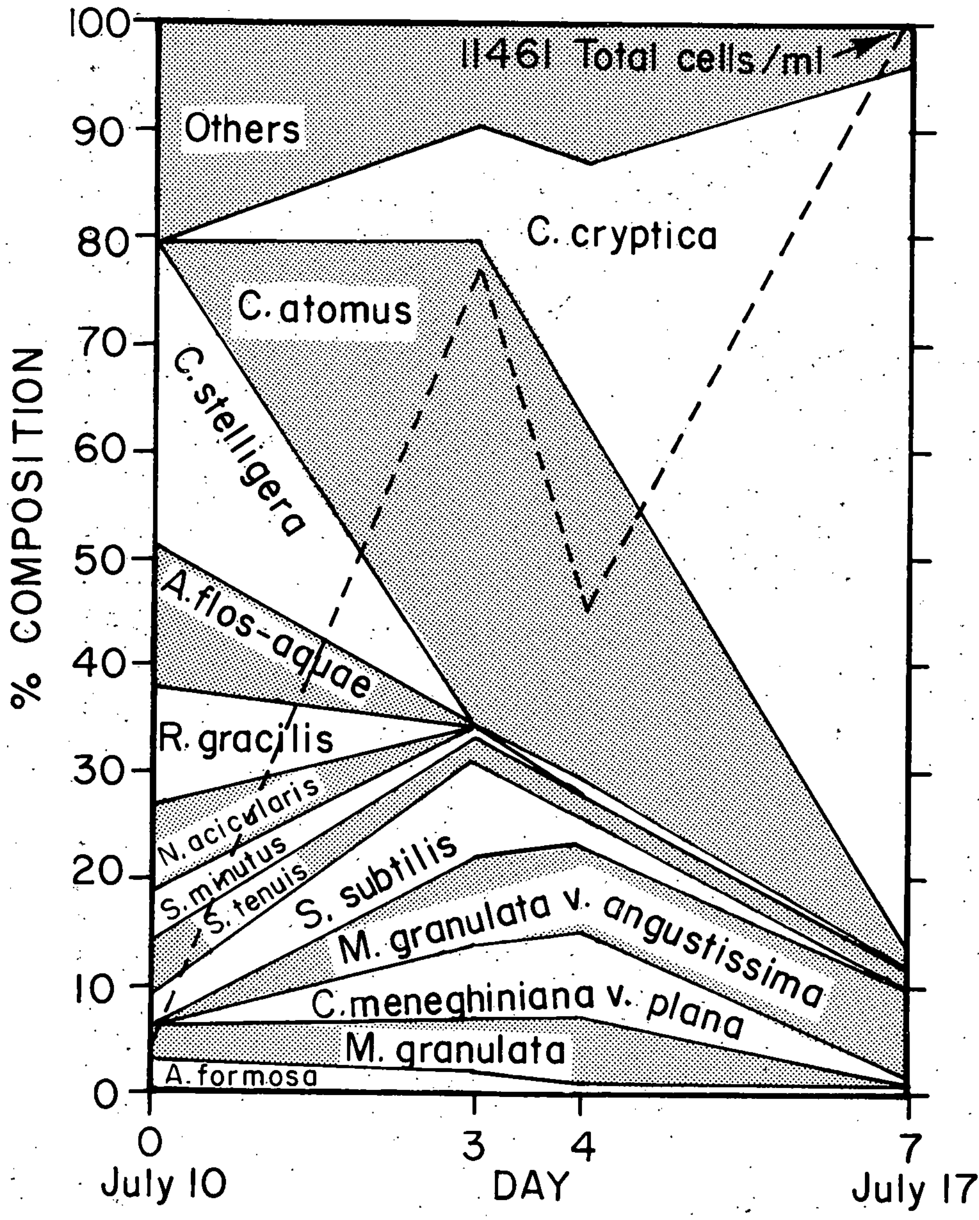

FIG. 19b. Kalamazoo River transect. Phytoplankton species composition and standing crop at station 0 km offshore.

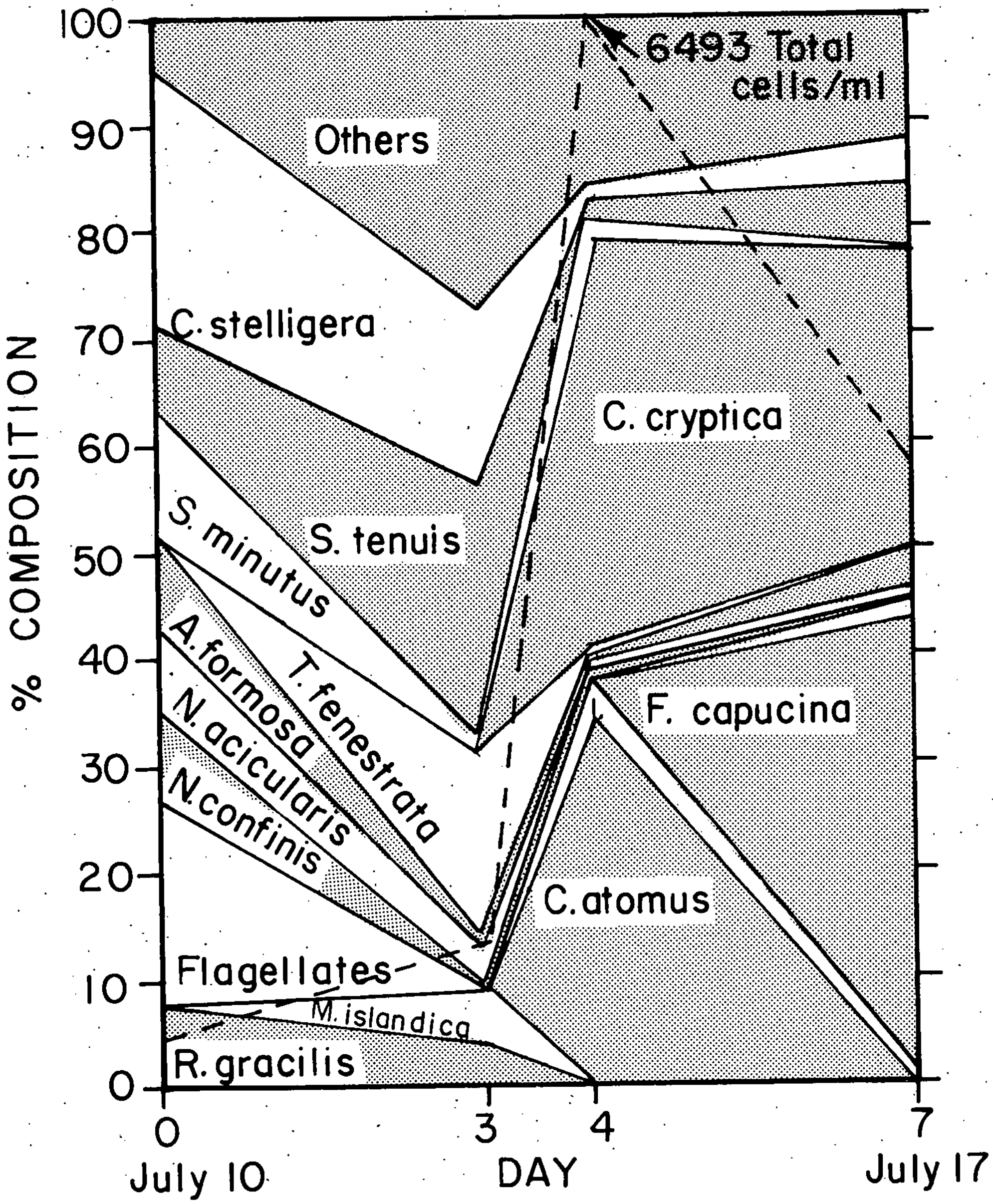

FIG. 19c. Kalamazoo River transect. Phytoplankton species composition and standing crop at station .2 km offshore.

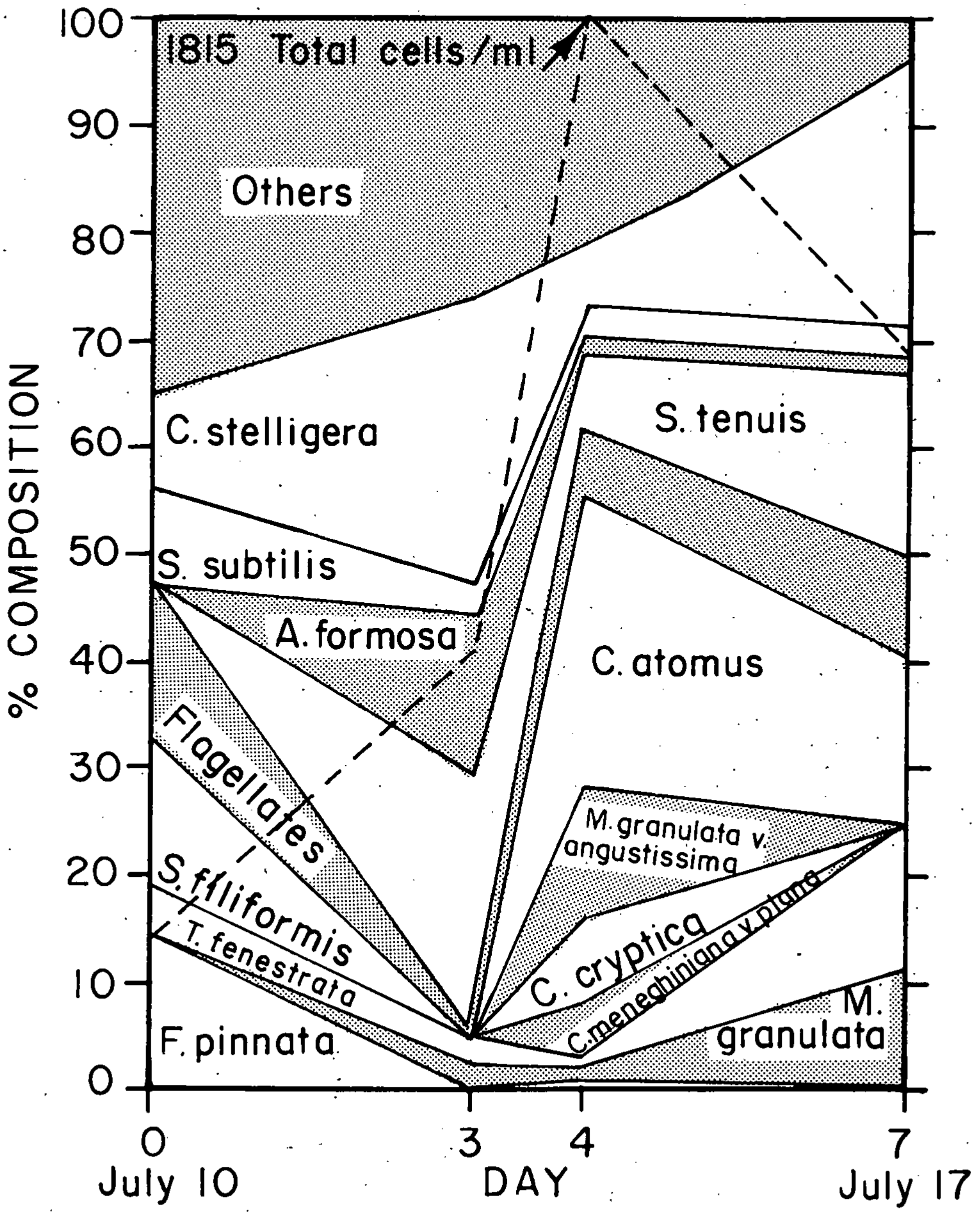

FIG. 19d. Kalamazoo River transect. Phytoplankton species composition and standing crop at station .4 km offshore.

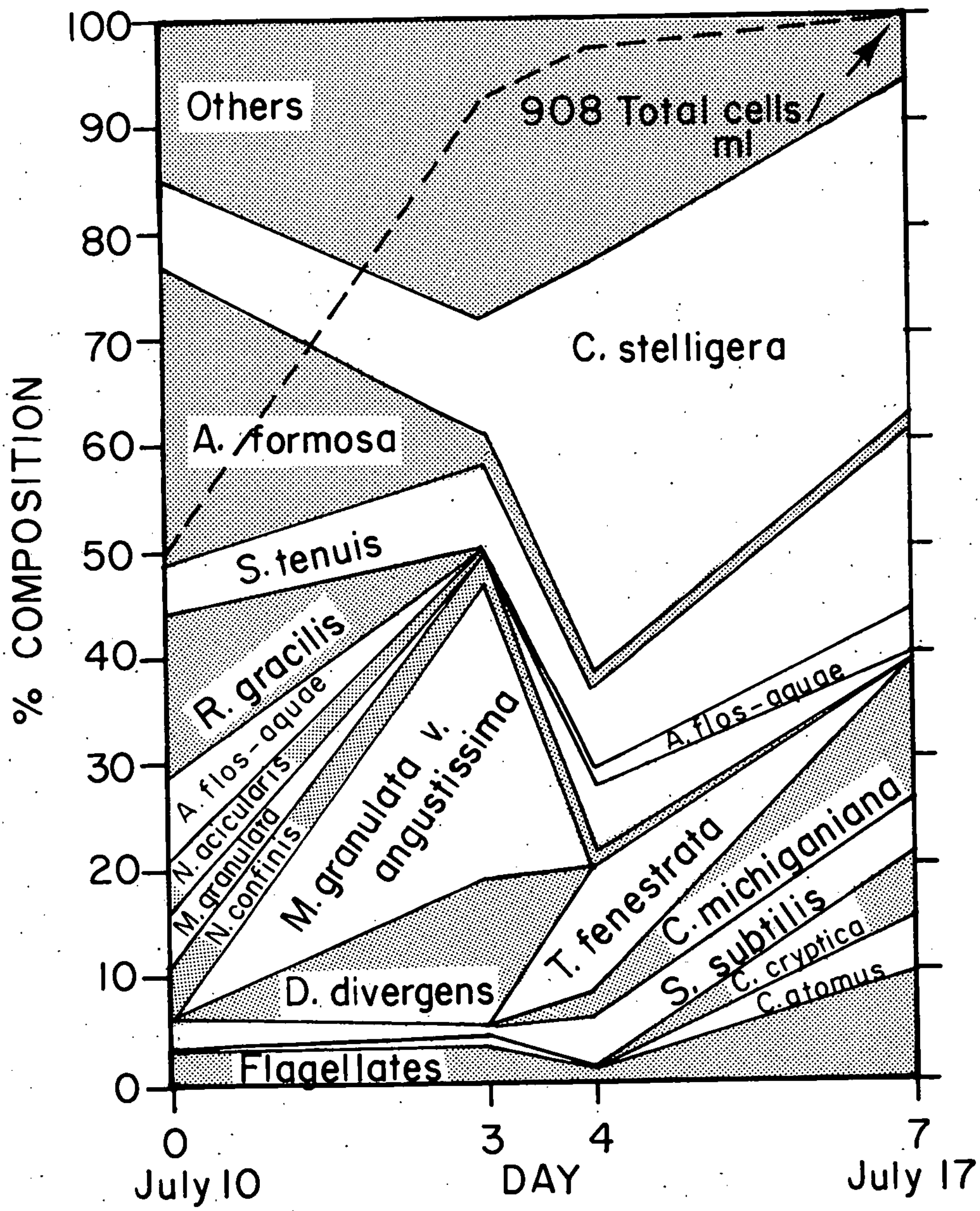

FIG. 19e. Kalamazoo River transect. Phytoplankton species composition and standing crop at station .8 km offshore.

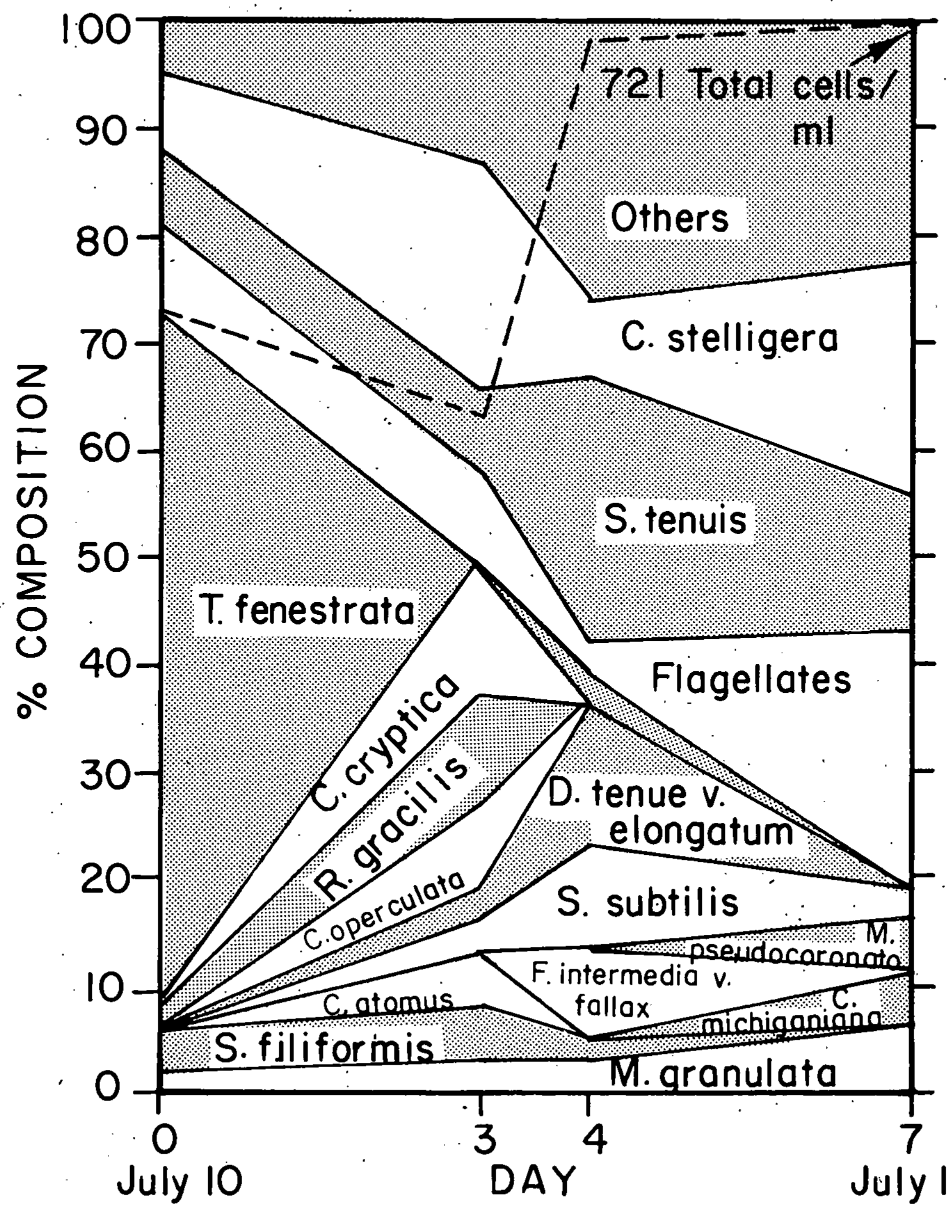

FIG. 19f. Kalamazoo River transect. Phytoplankton species composition and standing crop at station 1.6 km offshore.

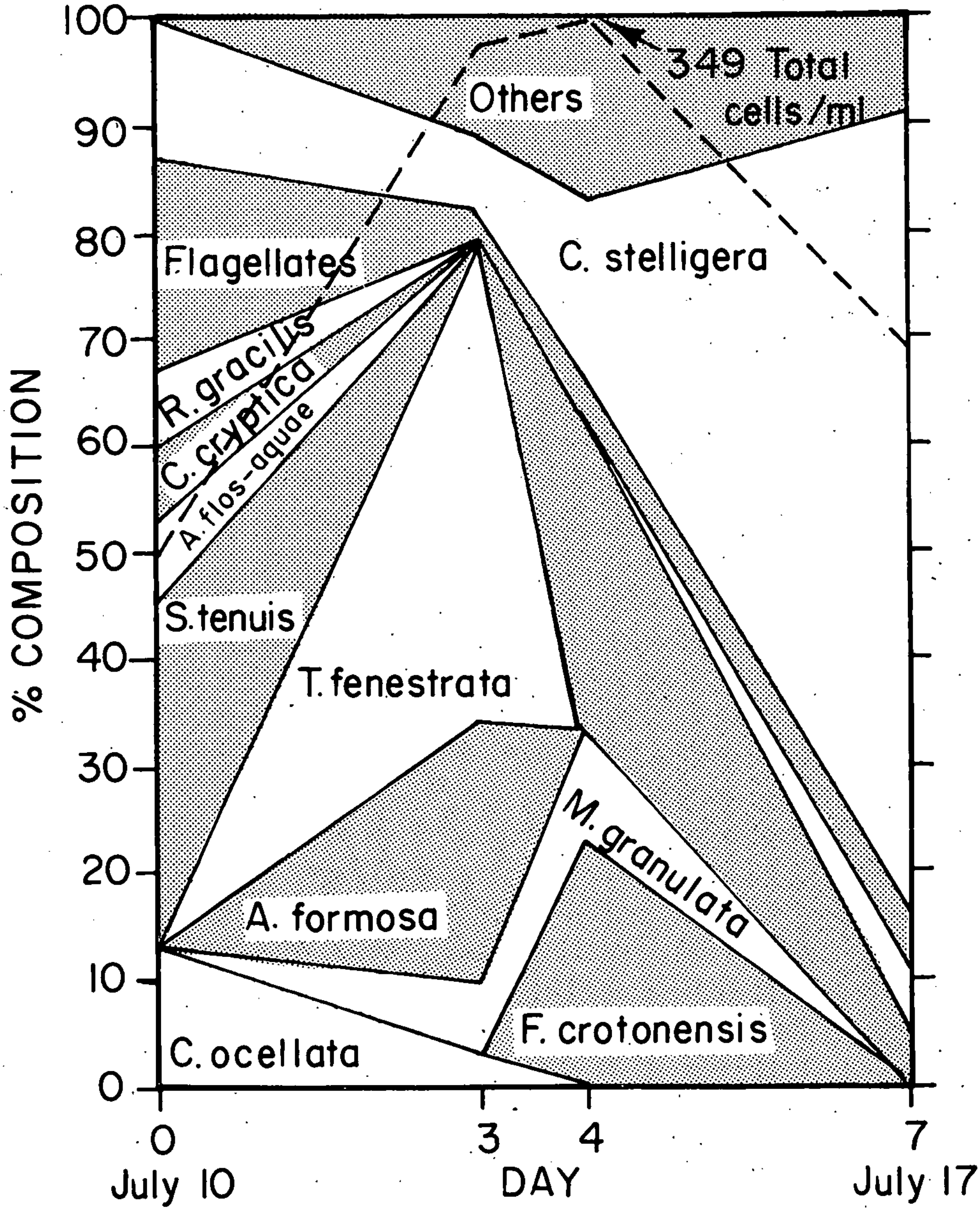

FIG. 19g. Kalamazoo River transect. Phytoplankton species composition and standing crop at station 3.2 km offshore.

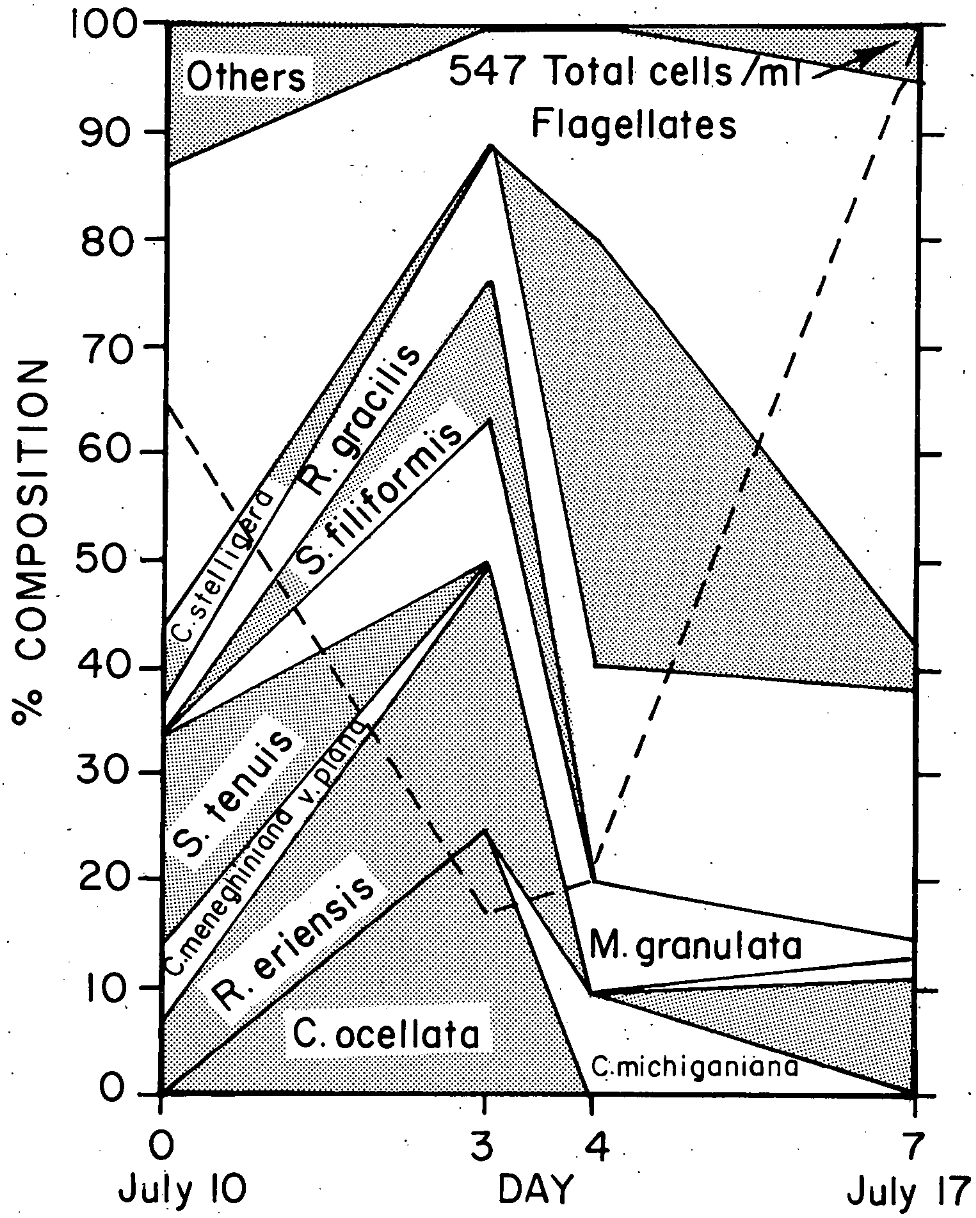

FIG. 19h. Kalamazoo River transect. Phytoplankton species composition and standing crop at station 6.4 km offshore.

on standing crop was most obvious at the station 0 and .2 km from shore, but the species present in abundance at the rivermouth station, *C. cryptica* and *C. atomus*, were also found .4 and .8 km from shore (Figs. 19c–e). On the first day of sampling, however, the phytoplankton assemblages at the station closest to shore and at the station .2 km from shore were for the most part characteristic of the assemblages found in the offshore waters. The most abundant species at each station was *Cyclotella stelligera*, with smaller populations of *Stephanodiscus tenuis, S. minutus, Asterionella formosa*, and *Nitzschia acicularis*. In addition, there was a large population of *Anabaena flos-aquae* at the station closest to shore and a large population of undetermined flagellates at the station .2 km from shore.

At the offshore stations, .8 km or more from shore, *Cyclotella stelligera* was generally the most abundant species in collections, followed by *Stephanodiscus tenuis;* however, assemblages at these stations were characterized by high variability in occurrence of different entities in large relative abundances (Figs. 19e–h). Included in this list of sporadic dominants were *Asterionella formosa, Tabellaria fenestrata, Melosira granulata* v. *angustissima, Dinobryon divergens, Fragilaria crotonensis, Rhizosolenia eriensis, Cyclotella ocellata*, and undetermined flagellates.

On July 10 the standing crop of phytoplankton on the Kalamazoo River transect was very low, with all values being in the range which would be considered typical of offshore phytoplankton standing crops. Standing crops ranged from 175 to 524 cells/ml with the maximum cell density being observed at 1.6 km from shore (Fig. 20a).

There appeared to be no consistent pattern to the distribution of dominant species on this transect. For example, *C. stelligera* was the major dominant at the two stations closest to shore and one of the dominants at the three stations the greatest distance from shore, but was relatively unimportant at the other stations (Fig. 20a). Likewise, at the station located .4 km from shore, 57% of the total standing crop was attributable to the category designated as "others." The variable nature of phytoplankton distribution on this transect is further illustrated by the relative abundance of other species on the transect: *Asterionella formosa* which comprised 28% of the total standing crop at the station .8 km from shore, *Tabellaria fenestrata* which comprised 64% of the total standing crop at the station located 1.6 km from shore, and *Stephanodiscus tenuis* which comprised more than 20% of the total standing crop at the stations located 3.2 and 6.4 km from shore. Additionally, undetermined flagellates had relatively high abundances at the stations .2 and .4 km from shore and 3.2 and 6.4 km from shore, but were found in relatively low abundances at the other stations.

On July 13, three days after the first sampling, the total standing crop of phytoplankton on the Kalamazoo River transect had increased from 440 to 8880 cells/ml at the station located closest to shore (Fig. 20b). Forty-seven per cent of the assemblage at this station was *Cyclotella atomus*, which was being supplied by the Kalamazoo River. Standing crops decreased drastically from the station .4 km from shore to the station located 6.4 km from shore with the cell densities decreasing from 740 cells/ml to only 90 cells/ml.

The pattern of phytoplankton abundance on the transect was similar to that on July 10 in that the pattern from station to station was variable. At the stations located .2 and .4 km from shore the major components of the phytoplankton assemblage were *Cyclotella stelligera, Stephanodiscus tenuis*, and *Tabellaria fenestrata* (Fig. 20b). At .8 km from shore the three major species were *Melosira granulata* v. *angustissima, Dinobryon divergens*, and *Asterionella formosa*. At the station 1.6 km from shore 45% of the total cell counts were attributed to the category designated "others": *Cyclotella stelligera, C. atomus, Rhizosolenia gracilis*, and *Synedra filiformis* were the dominant species. The three most dominant species 3.2 km from shore were *Tabellaria fenestrata*

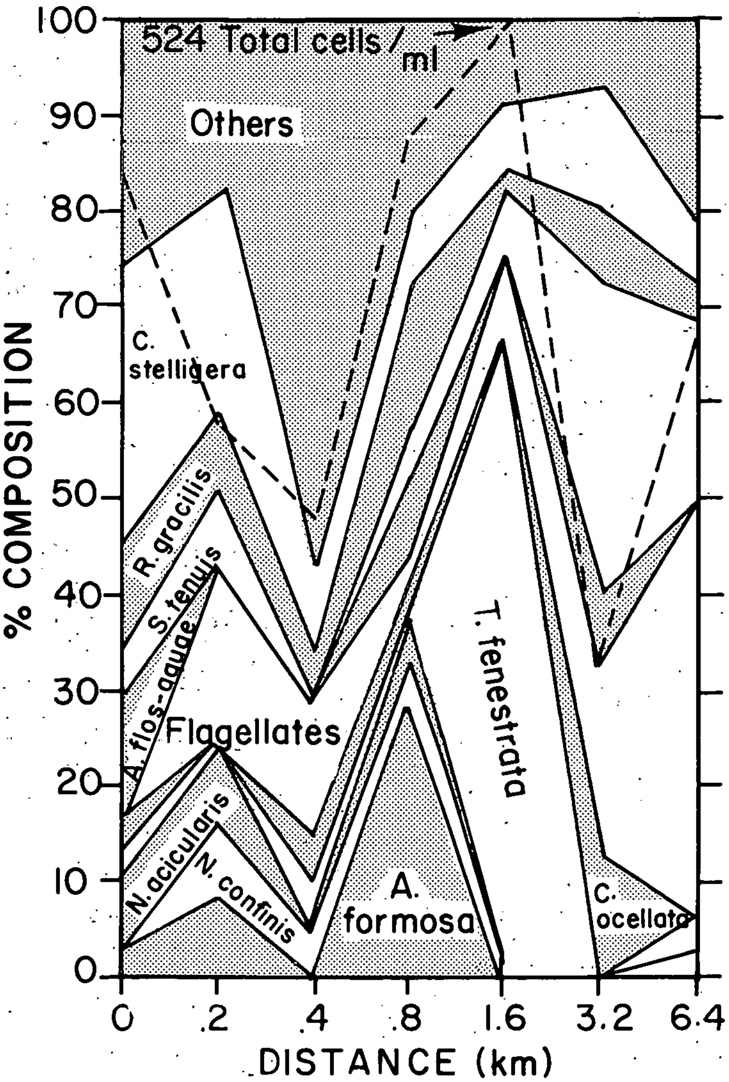

FIG. 20a. Kalamazoo River transect. Phytoplankton species composition and standing crop, July 10, 1972.

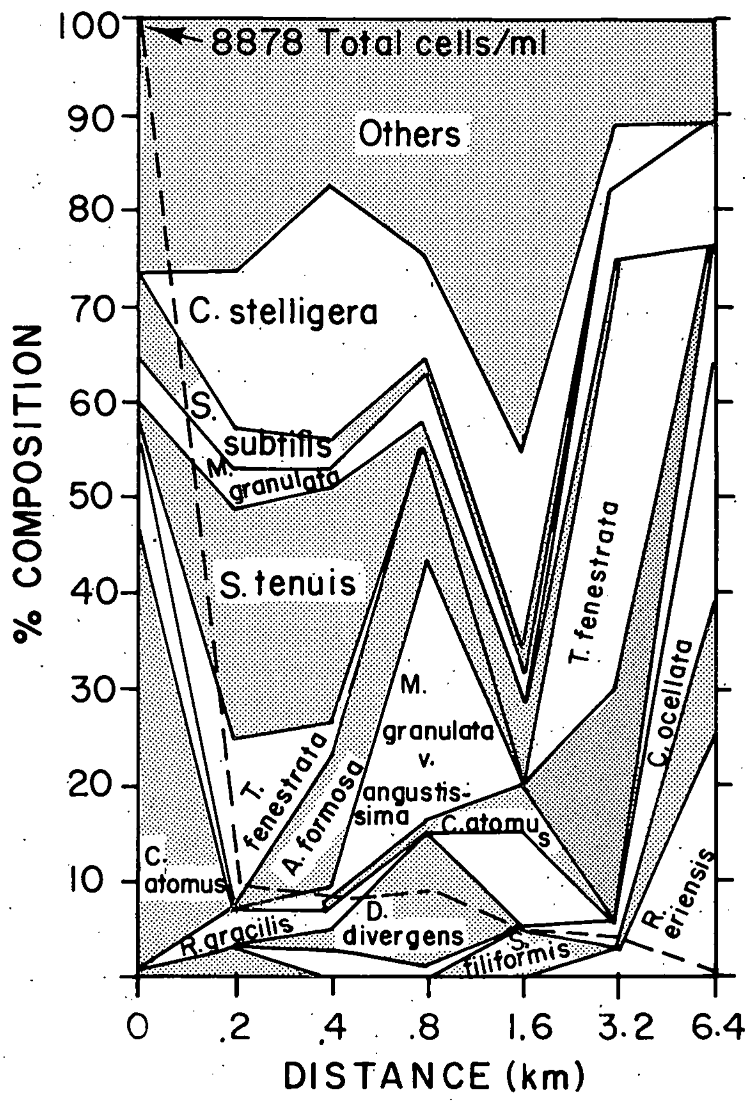

FIG. 20b. Kalamazoo River transect. Phytoplankton species composition and standing crop, July 13, 1972.

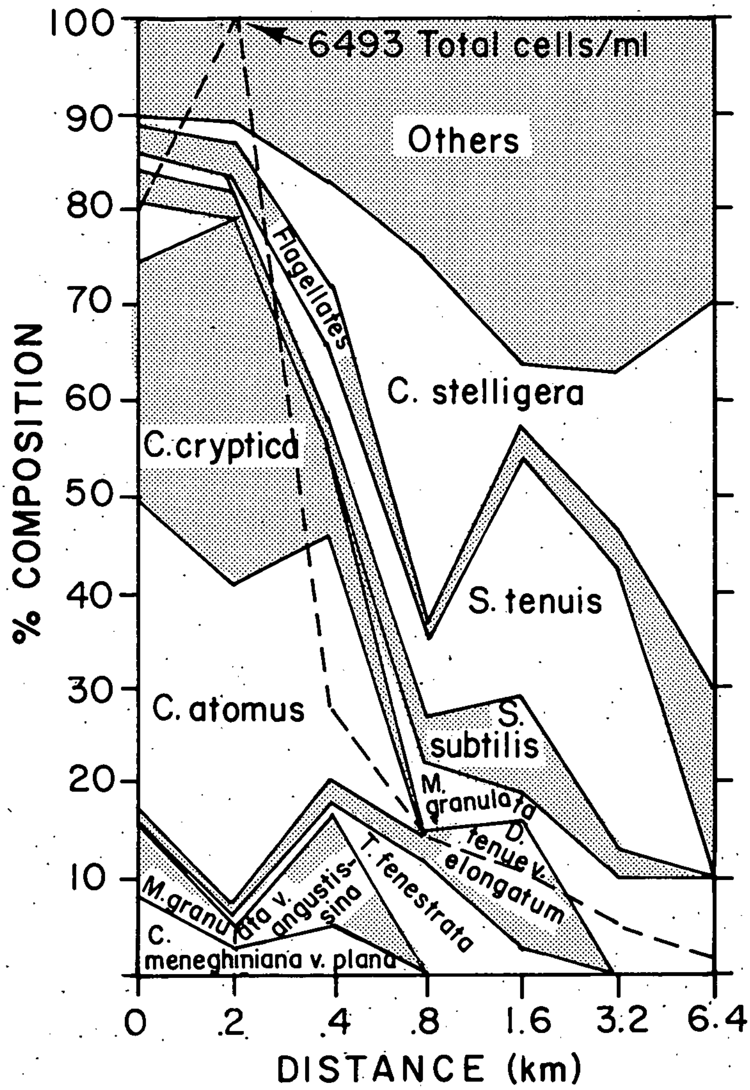

FIG. 20c. Kalamazoo River transect. Phytoplankton species composition and standing crop, July 14, 1972.

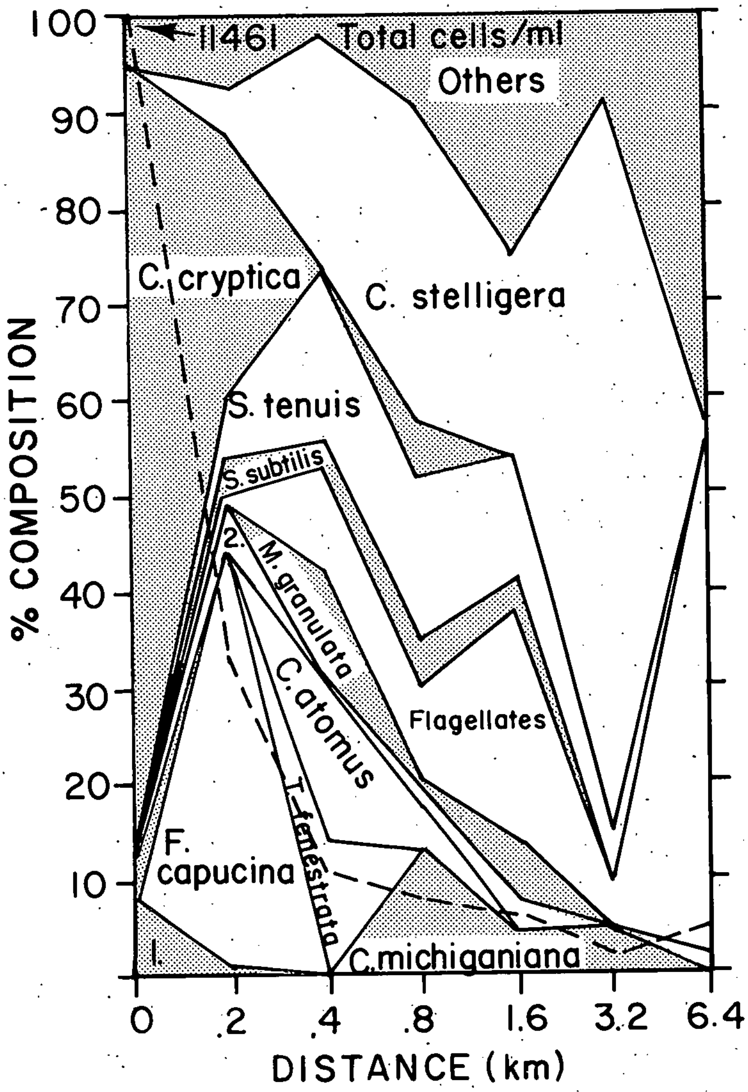

FIG. 20d. Kalamazoo River transect. Phytoplankton species composition and standing crop, July 17, 1972. 1. species *Melosira granulata* v. *angustissima*, 2. species *Asterionella formosa*.

(comprising 45% of the assemblage), *Cyclotella stelligera,* and *Asterionella formosa.* At the station 6.4 km from shore the two dominant species were *Rhizosolenia eriensis* and *Cyclotella ocellata.* In addition, *Melosira granulata, Rhizosolenia gracilis,* and *Synedra filiformis* were present in relatively large abundances. These five species comprised more than 85% of the total standing crop at this station.

The largest standing crop of phytoplankton on July 14, 6490 cells/ml, was found at the station .2 km from shore; standing crop at the station closest to shore was also high, approximately 5200 cells/ml (Fig. 20c). Standing crops were much lower at the stations offshore ranging from 1810 cells/ml at .4 km from shore to 120 cells/ml at 6.4 km from shore. The dominant species out to a distance of .4 km from shore were *Cyclotella atomus* and *C. cryptica,* species supplied by the Kalamazoo River, which comprised as much as 72% of the total cells in this area. Other species present in relatively small abundances were *C. meneghiniana* v. *plana* and *Melosira granulata* v. *angustissima.*

Phytoplankton distributions on July 14 (Fig. 20c) were much less variable than those noted for July 10 and 13 (Figs. 20a, b). The zone extending from .8 to 6.4 km offshore was characterized by standing crops of phytoplankton ranging from 120 to 880 cells/ml and by large proportions of phytoplankton in the categories designated "others" (ranging from 25 to 37% of the assemblage). In this zone the two major species were *Cyclotella stelligera* and *Stephanodiscus tenuis* and other dominant species were *S. subtilis, Melosira granulata,* and undetermined flagellates. *Diatoma tenue* v. *elongatum* and *Tabellaria fenestrata* were relatively abundant at the stations located .8 and 1.6 km from shore.

On July 17 the maximum standing crop was 11460 cells/ml and was found at the station closest to shore (Fig. 20d) which was due mainly to the input of *Cyclotella cryptica* from the river (Fig. 19a). Eighty-two per cent of the assemblage at this station was due to *C. cryptica* which with *Fragilaria capucina* were the dominant species at the station .2 km from shore. Total cell counts were 3800 cells/ml .2 km from shore and were much lower at .4 to 6.4 km offshore, decreasing from 1270 to 240 cells/ml. In this zone *Cyclotella stelligera, Stephanodiscus tenuis,* and undetermined flagellates were the most abundant species. In addition, the species attributed to the category designated "others" increased generally with distance offshore. Undetermined flagellates reached their maximum abundance at the station located 6.4 km from shore where they comprised 53% of the total cell counts.

On the Kalamazoo River transect there was no obvious break in numbers of species with distance offshore. In general numbers tended to decrease with distance from shore, ranging from as high as 35 species at the station closest to shore on July 13 to a low of five species at the station 6.4 km offshore on July 14 (Figs. 21a–d). There were also no discernible trends in species diversity with distance offshore but in general diversity appeared to decrease slightly with distance offshore, being generally lower at 3.2 and 6.4 km offshore. There was little difference in diversity with the overall range for all transects being from 1.3 to a maximum of 2.6.

GRAND RIVER TRANSECT

The Grand River transect was sampled on five days in July, on July 9, 11, 13, 15 and 16. Direct effects of river water were noticeable at the station located .4 km from shore on all dates but, based on data for total phosphorus, conditions were only slightly modified at the station located .8 km from shore.

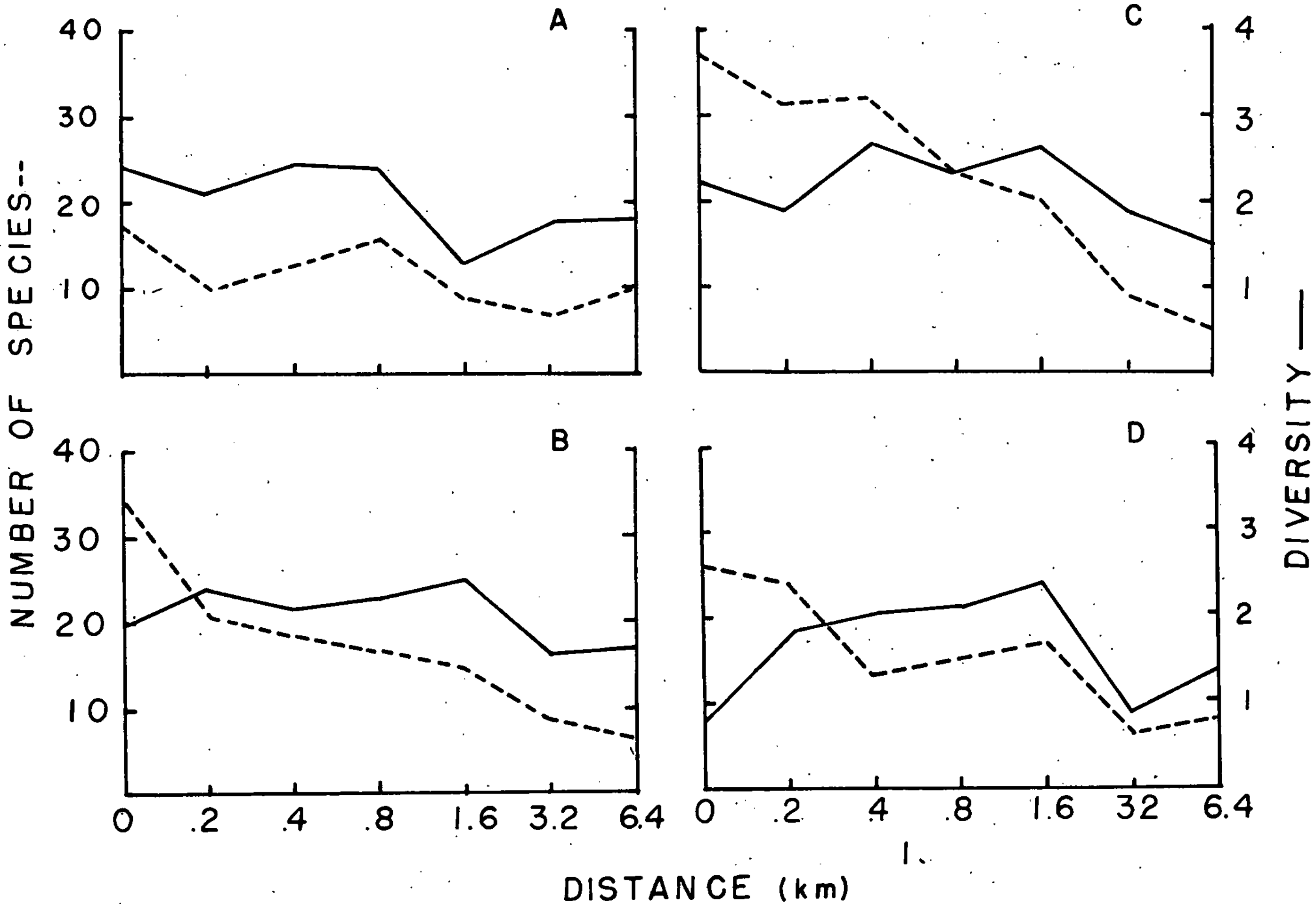

FIG. 21. Kalamazoo River transect. Number and diversity of phytoplankton species. a. July 10, 1972; b. July 13, 1972; c. July 14, 1972; d. July 17, 1972.

Physical-Chemical Conditions

On all five dates of sampling the Grand River had a greater temperature than the offshore surface waters, ranging from 19–23° C (Figs. 22a–e). Offshore surface waters were much more variable in temperature ranging from 11–20° C. This variability is probably best explained as being due to episodes of upwelling along the coast. Lowest temperatures were found on July 9 when the surface waters, more than .8 km from shore, had temperatures ranging from 11–12° C and when the 8° C isotherm was only 10 m or less from the surface. On all dates there was evidence of vertical thermal stratification at the stations located at least 6.4 km from shore. Vertical isotherms on July 11, 13, and 15 indicated well-mixed waters in the nearshore zone and also probably indicated transport longshore. On July 16 the 23° C isotherm was found 3.2 km from shore; this was the only date sampled in which temperatures out to this station exceeded 20° C at all depths.

The pH in the river water ranged from 8.1–8.4 and was lower than that found in the offshore surface waters where values ranged from 8.5–8.7 (Figs. 22a–e). These high pH values indicate high rates of photosynthetic activity by phytoplankton, particularly if one considers that upwelling would generally be expected to decrease pH values.

Silica concentrations in the surface waters were quite low and not variable, generally ranging from .2–.5 mg/liter (Figs. 22a–e). Like pH these low values in upwelled waters at the surface indicate relatively recent photosynthetic activity by phytoplankton. Largest values for silica were found on July 16 when the river water had a silica concentration >.6 mg/liter.

Nitrate nitrogen concentrations were not variable, generally ranging from .18–.20 mg/liter (Figs. 22a–e) in the surface waters. The lowest concentration for surface waters was found on July 15 when the Grand River water had <.15 mg/liter.

Total phosphorus concentrations in river water were much greater than those found in the offshore waters. Concentrations in river water ranged from approximately 30–225 μg/liter (Figs. 22a–e); greatest concentrations (150–225 μg/liter) were found on July 15 and 16. Offshore waters on all dates had concentrations of total phosphorus <10 μg/liter.

Phytoplankton

In July, the Grand River transect was sampled five times and samples were obtained at the river mouth on ten different dates between July 9 and July 18.

At the rivermouth station throughout this period seven species of diatoms comprised from 88 to 98% of the total cell counts. *Cyclotella atomus* was by far the most abundant of these species comprising from 44 to 80% of the total cell counts (Fig. 23a). The other species at this station were *C. meneghiniana* v. *plana, Stephanodiscus subtilis, Cyclotella cryptica, Melosira granulata, M. distans* v. *alpigena,* and *Stephodiscus minutus.* Two of these species, *Cyclotella meneghiniana* v. *plana* and *Stephanodiscus subtilis,* probably decreased in relative abundance during the sampling period. On the other hand, two species, *Cyclotella cryptica* and *Melosira distans* v. *alpigena,* increased in relative abundance during the experiment. Both increases occurred primarily after July 15 when total cell counts also increased so the absolute abundances of these two species increased greatly during the experiment. On July 18 *Cyclotella cryptica* comprised 29% of the total phytoplankton assemblage and its absolute abundance was 6200 cells/ml. From July 9 to 15 total cell densities generally ranged from 10000 to 17200 cells/ml. Largest total cell densities were found from July 16–18 ranging from 21000 to 31000 cells/ml (Fig. 23a).

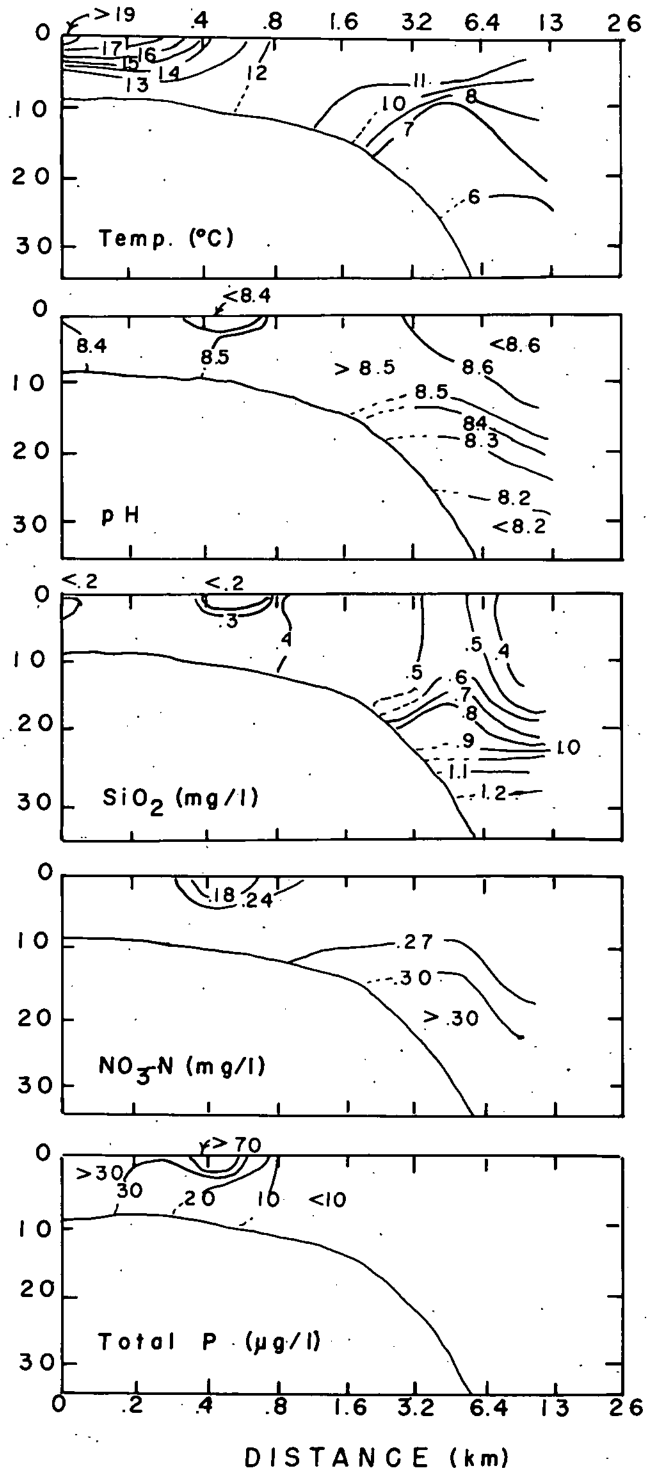

FIG. 22a. Grand River transect. Physical-chemical conditions, July 9, 1972.

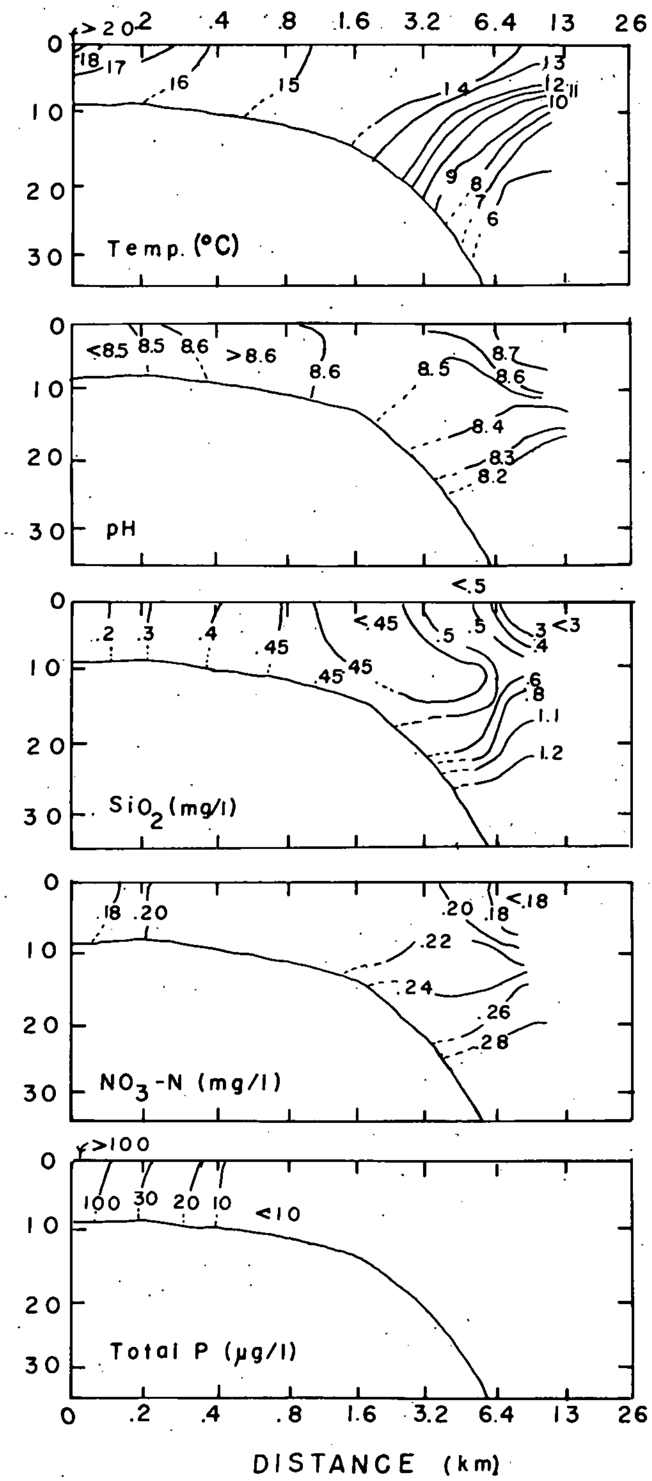

FIG. 22b. Grand River transect. Physical-chemical conditions, July 11, 1972.

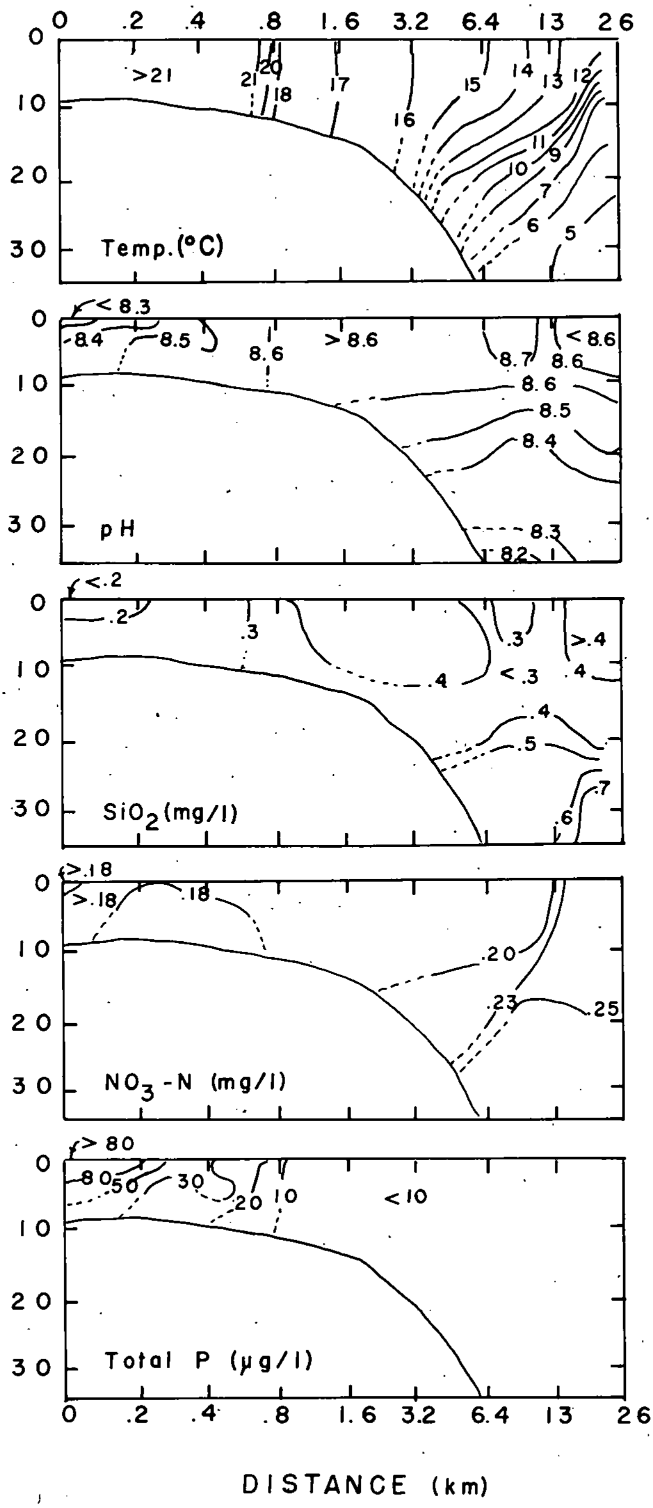

FIG. 22c. Grand River transect. Physical-chemical conditions, July 13, 1972.

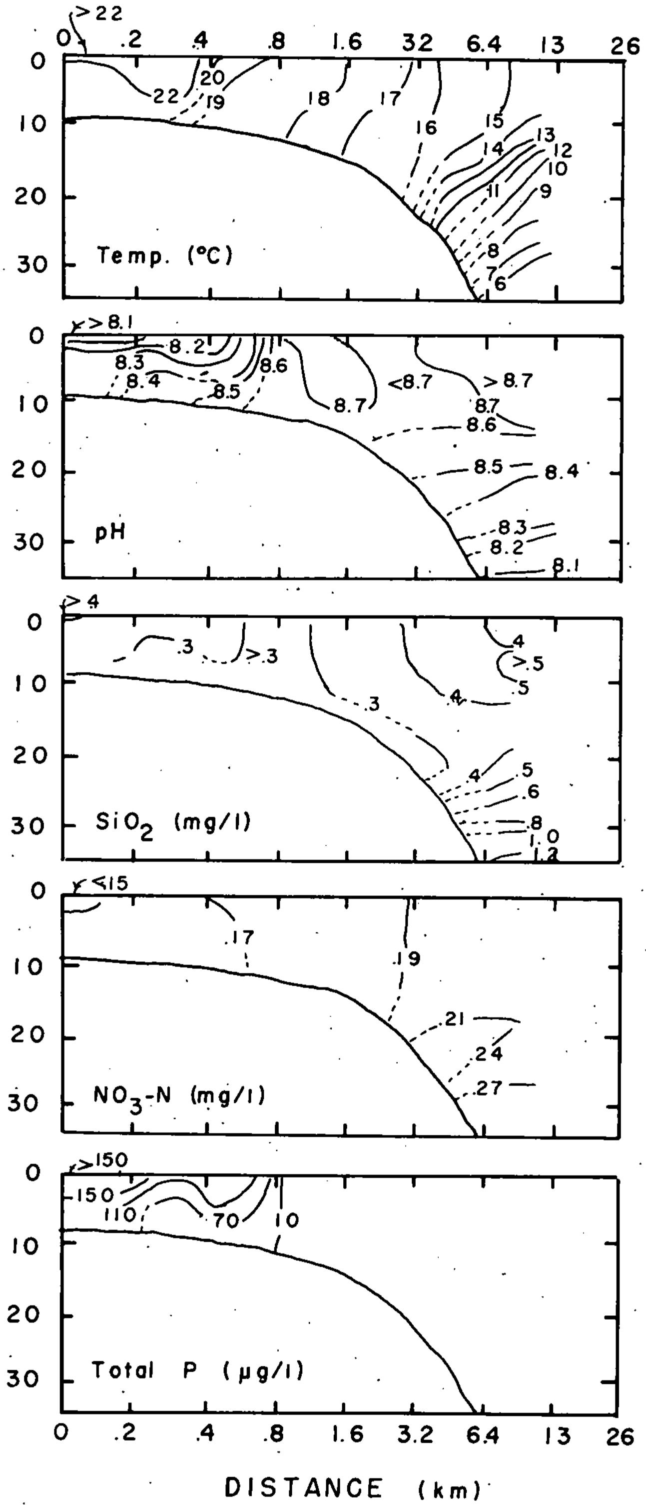

FIG. 22d. Grand River transect. Physical-chemical conditions, July 15, 1972.

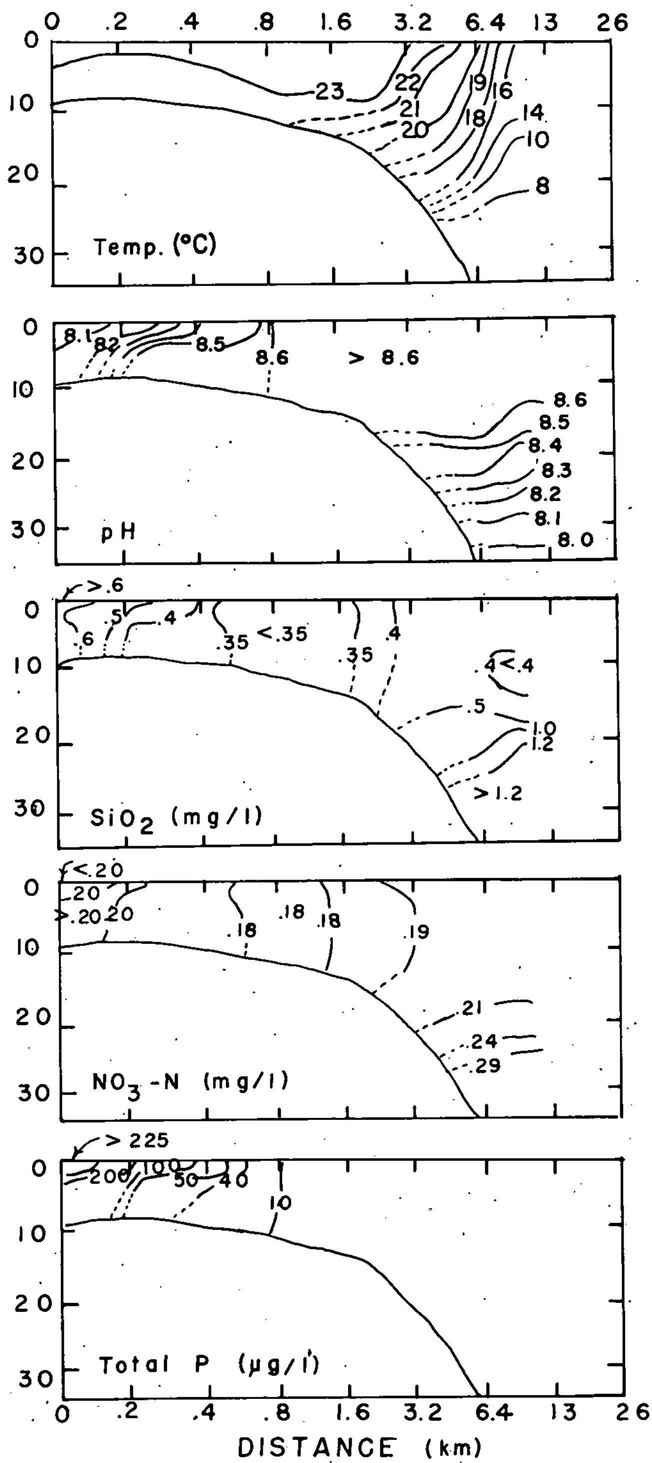

FIG. 22e. Grand River transect. Physical-chemical conditions, July 16, 1972.

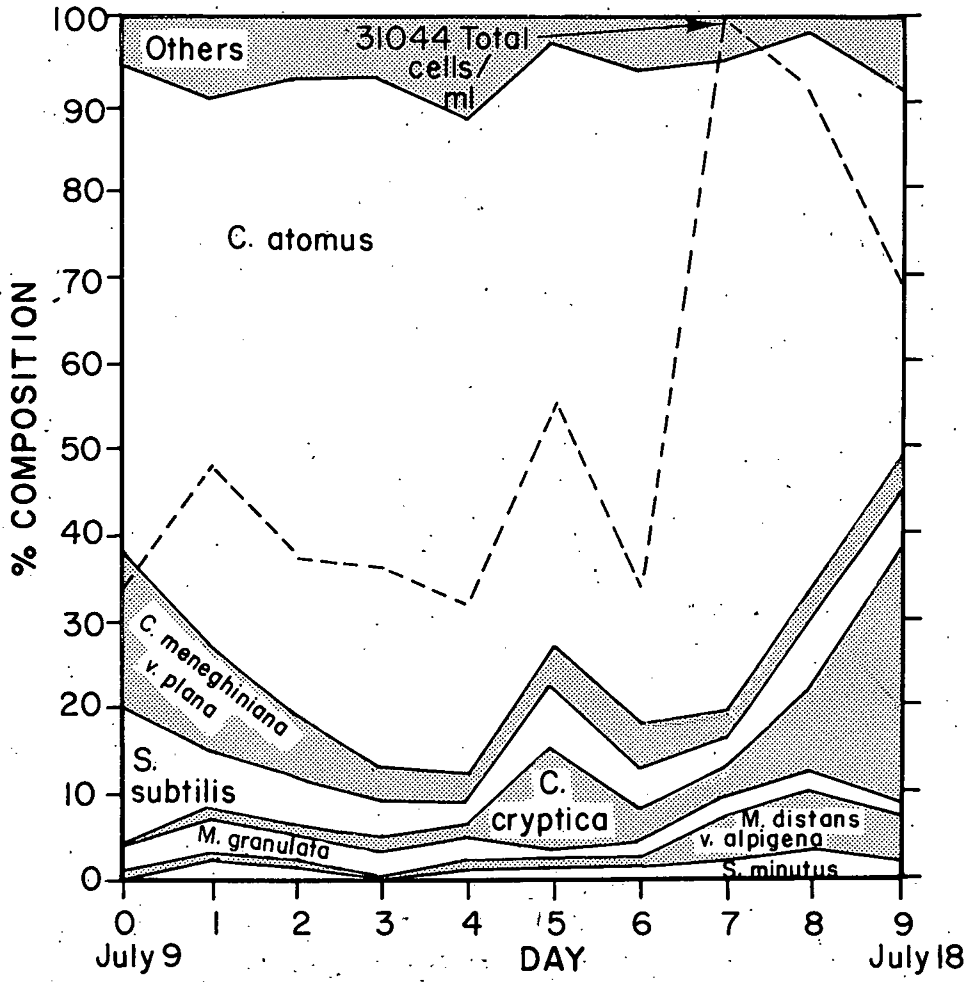

FIG. 23a. Grand River transect. Phytoplankton species composition and standing crop at station 0 km offshore.

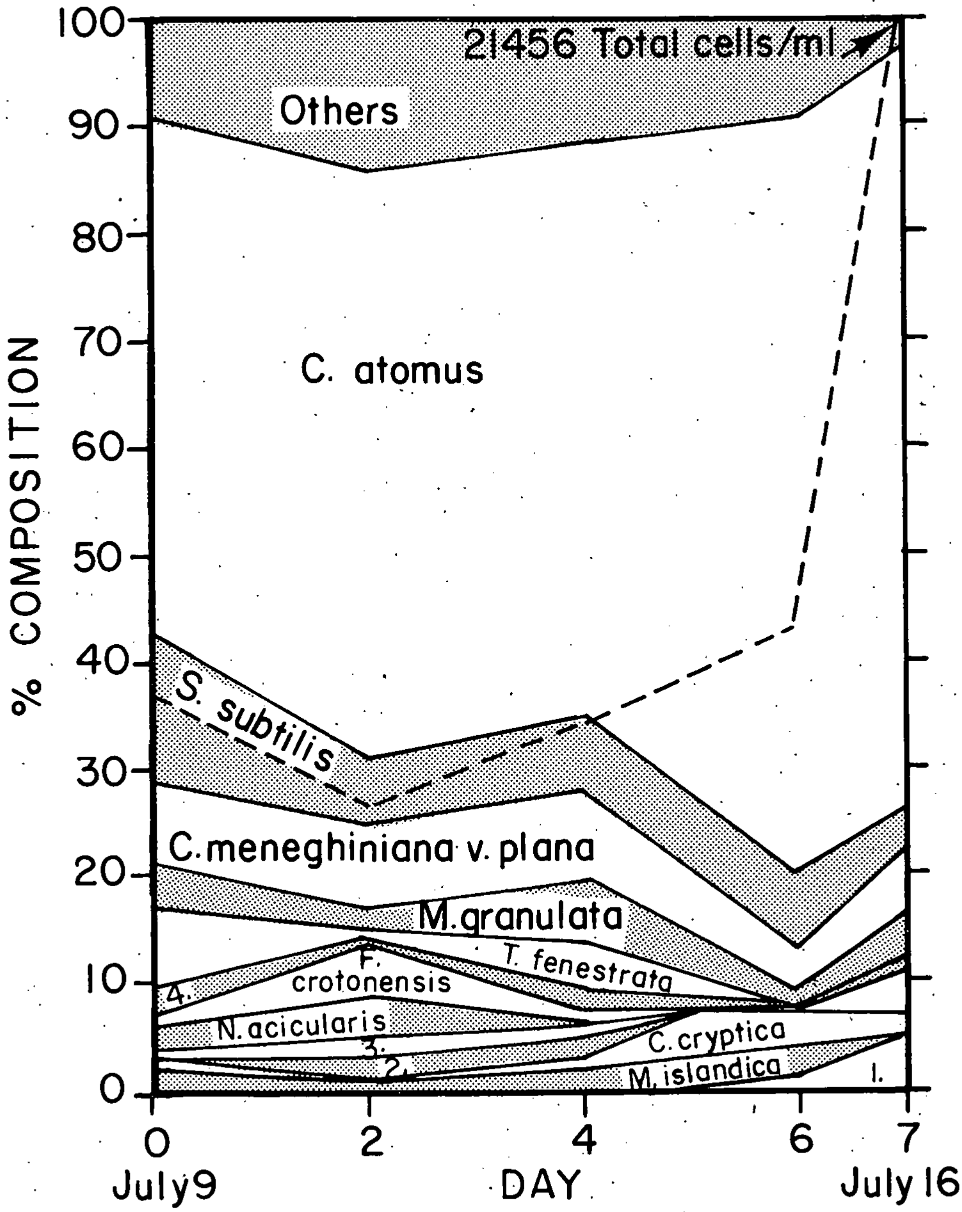

FIG. 23b. Grand River transect. Phytoplankton species composition and standing crop at station .2 km offshore. 1. species *Melosira distans* v. *alpigena*, 2. species *Diatoma tenue* v. *elongatum*, 3. species *Stephanodiscus tenuis*, 4. species *Melosira granulata* v. *angustissima*.

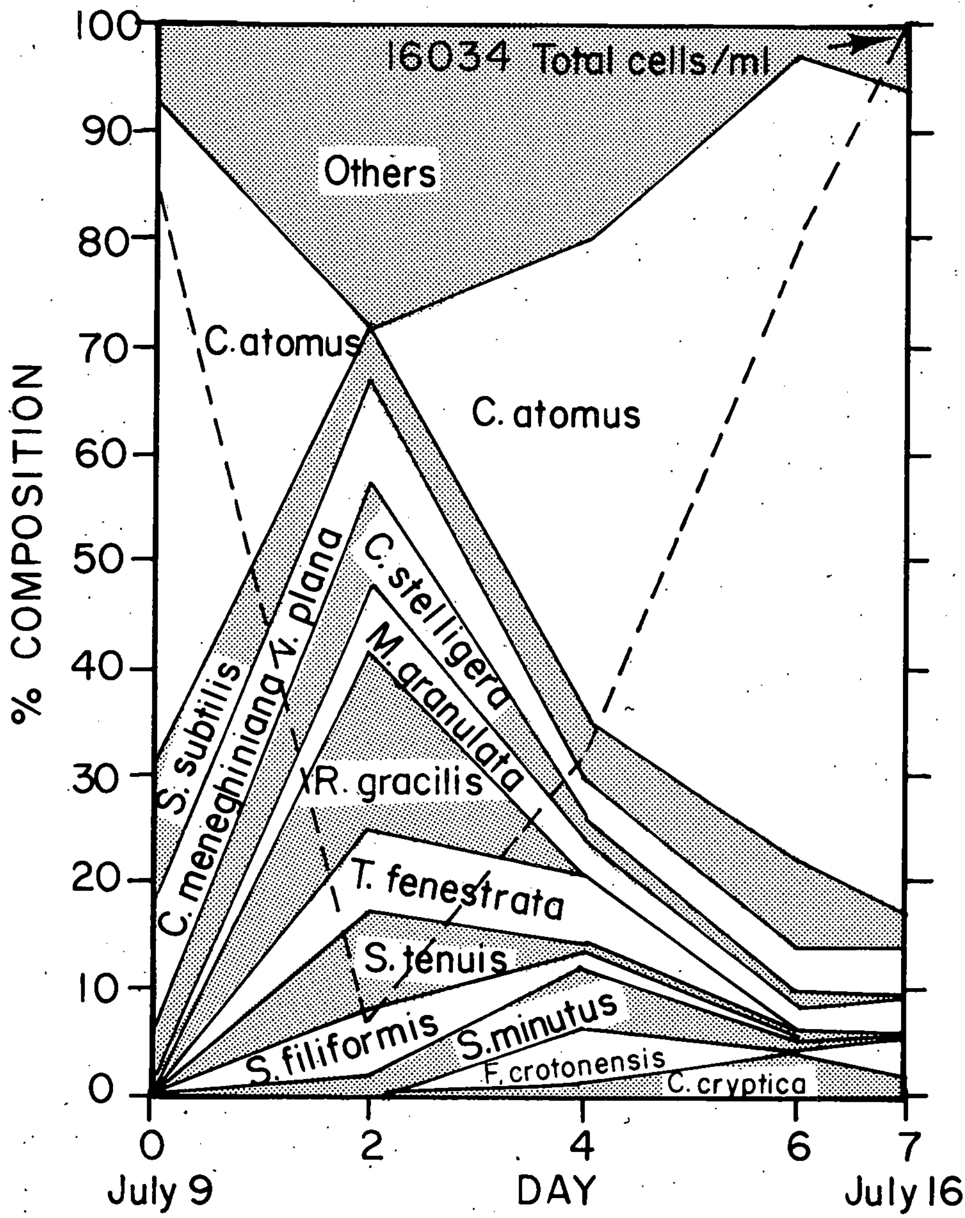

FIG. 23c. Grand River transect. Phytoplankton species composition and standing crop at station .4 km offshore.

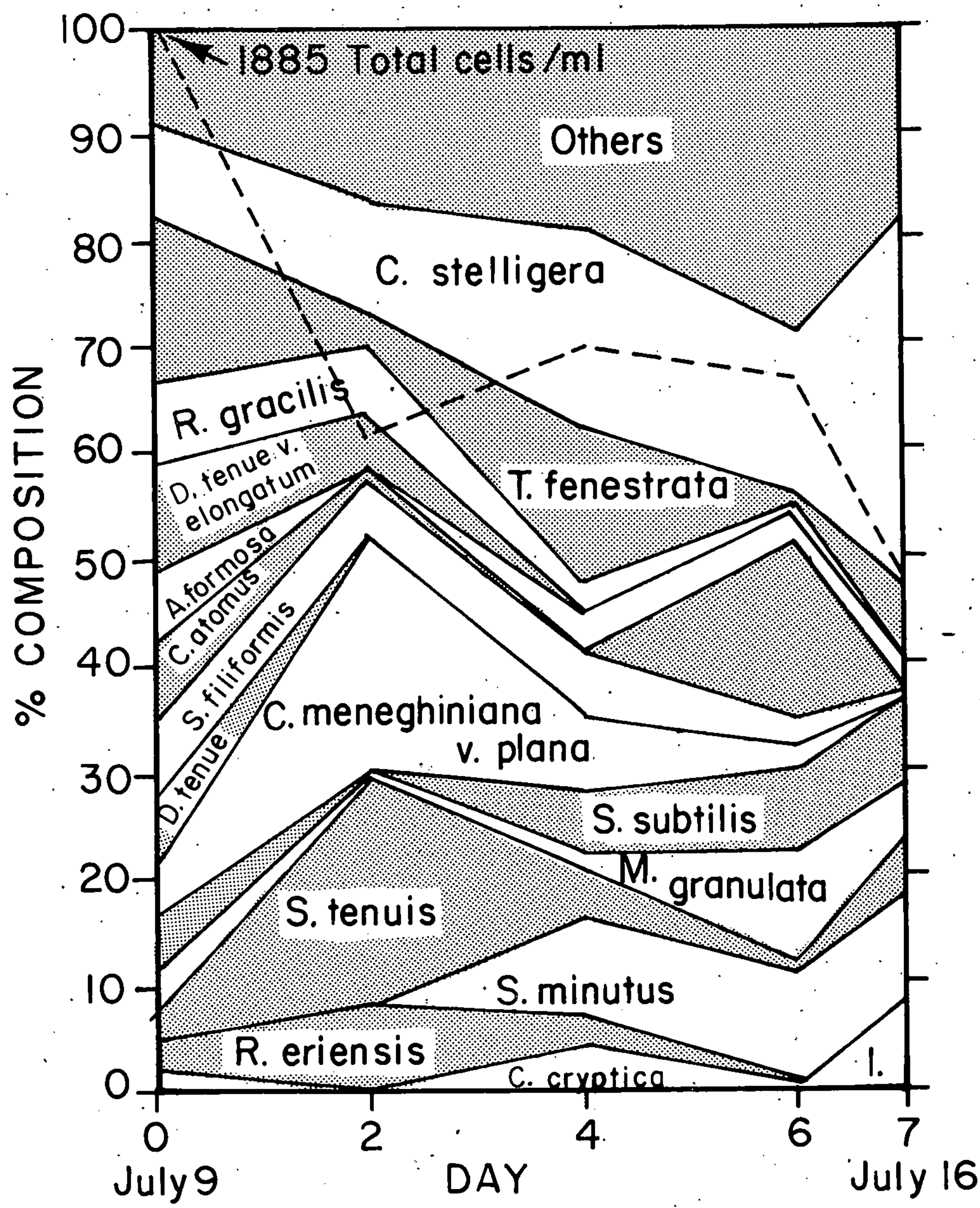

FIG. 23d. Grand River transect. Phytoplankton species composition and standing crop at station .8 km offshore. 1. species *Coelastrum microporum.*

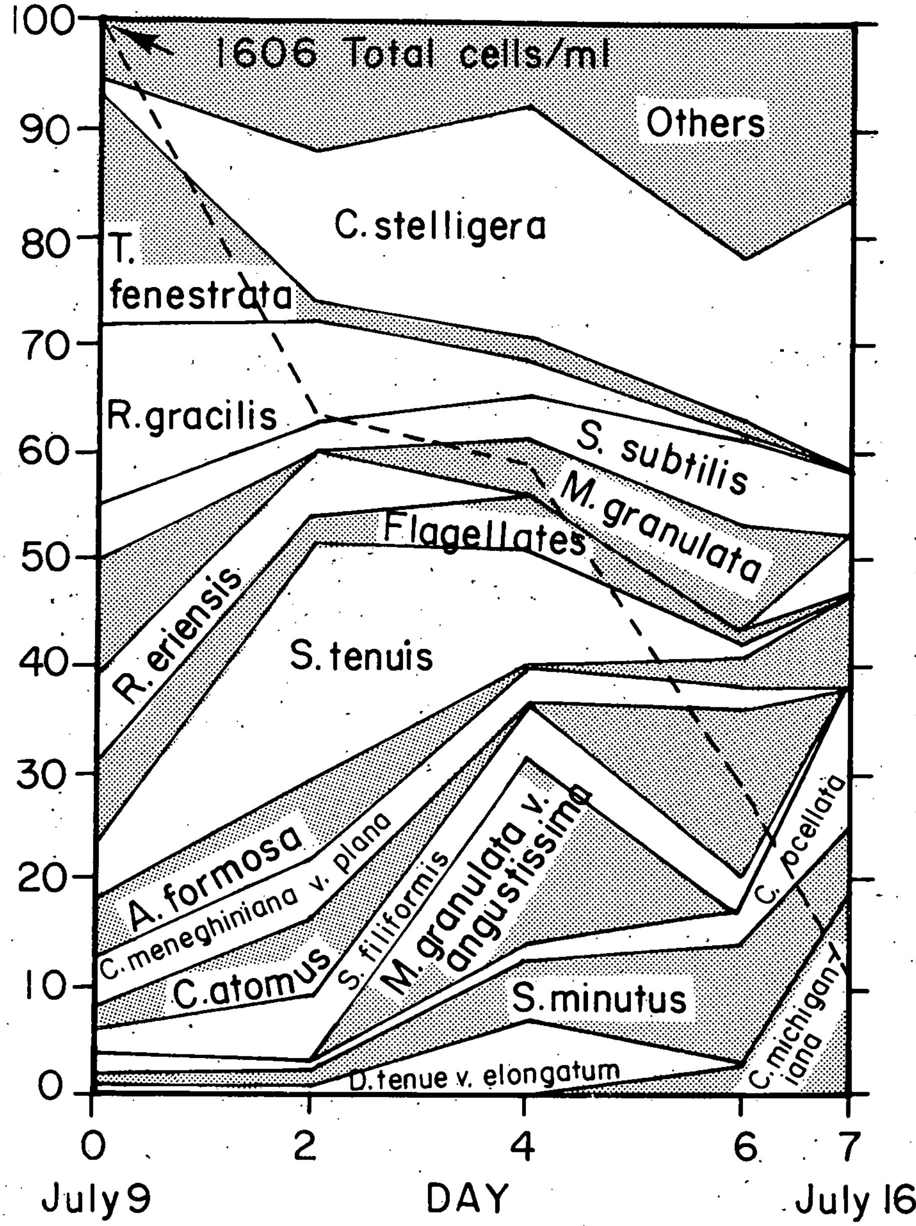

FIG. 23e. Grand River transect. Phytoplankton species composition and standing crop at station 1.6 km offshore.

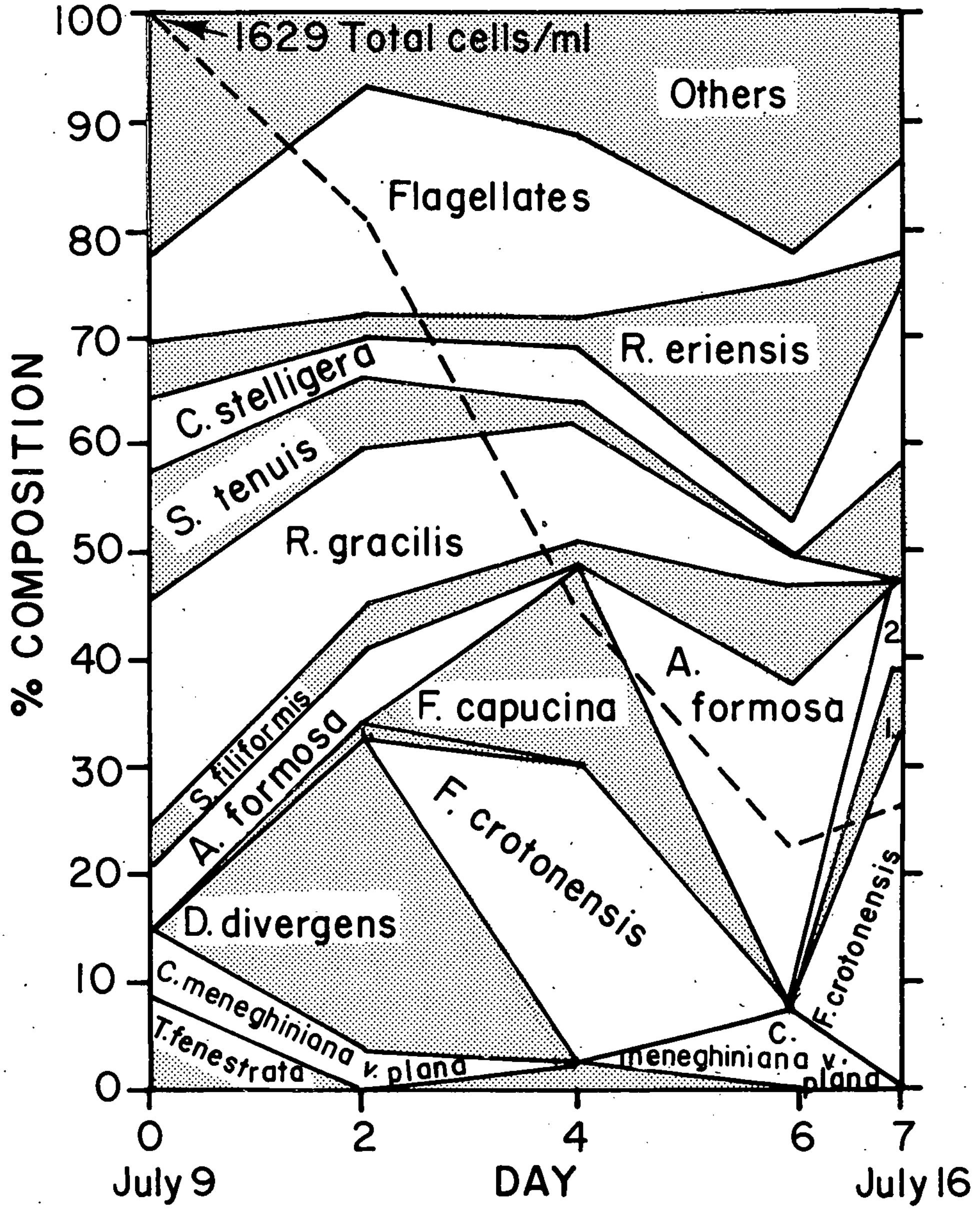

FIG. 23f. Grand River transect. Phytoplankton species composition and standing crop at station 3.2 km offshore. 1. species *Cyclotella ocellata*, 2. species *Cyclotella michiganiana*.

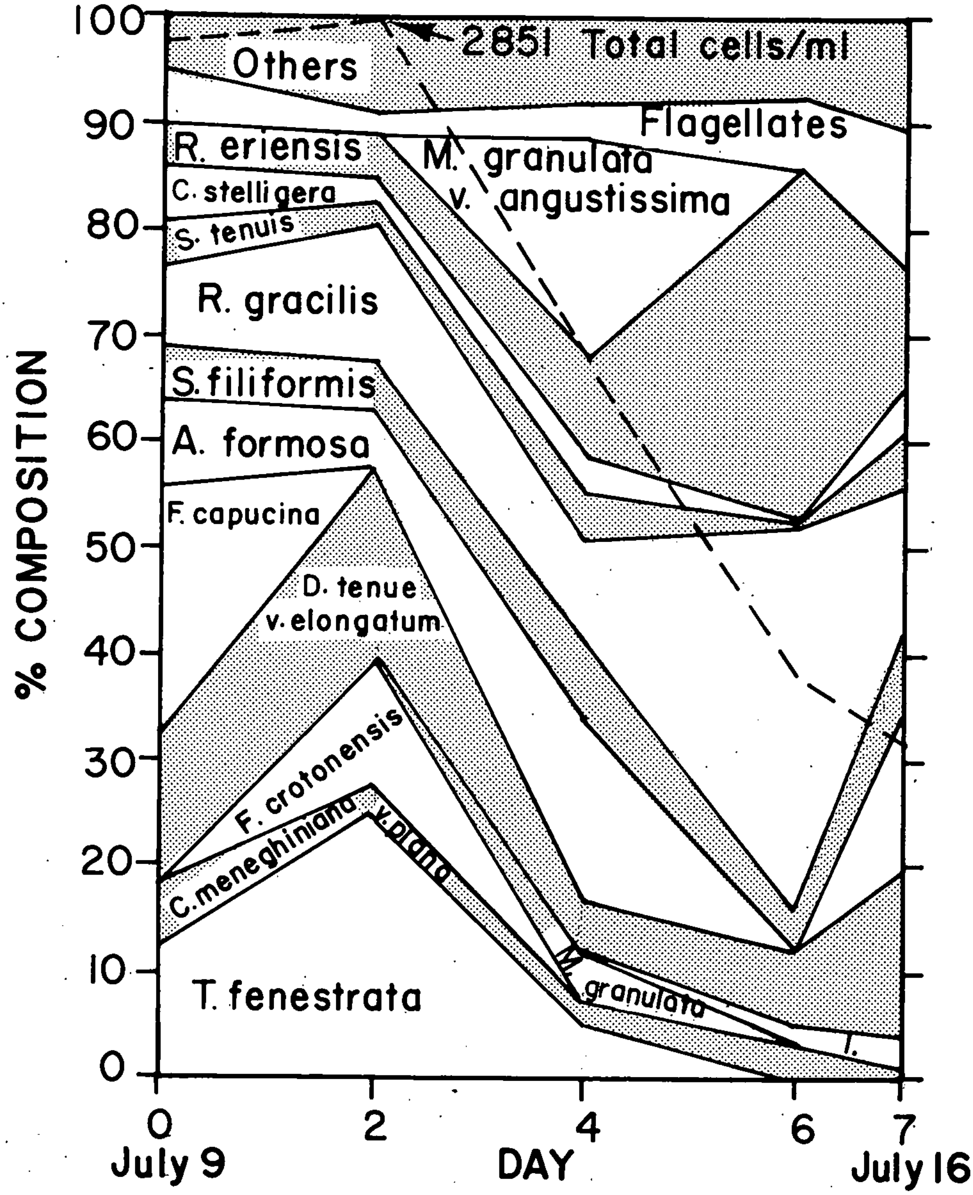

FIG. 23g. Grand River transect. Phytoplankton species composition and standing crop at station 6.4 km offshore. 1. species *Cyclotella ocellata*.

The dominant feature for this transect was the large abundance of *Cyclotella atomus* at the rivermouth station and the stations .2 and .4 km from shore (Figs. 23a–c). Except on July 11 the relative abundance of the species exceeded 45% at these stations. The other dominant feature on all five sampling days was the increasing proportion of total cell counts in the phytoplankton assemblages due to the category designated "others" at the stations .8 and 1.6 km from shore or at the stations where *C. atomus* was not a dominant part of the assemblage (Figs. 23d, e) and to a less extent at the stations 3.2 and 6.4 km from shore (Figs. 23f, g).

Dominant species and standing crop of phytoplankton found at the stations ranging from the river mouth to either .2 to .4 km offshore were fairly uniform from July 9 to July 15 (Figs. 24a–d). Total cell counts ranged from 10000 to 13500 cells/ml and, as noted previously, *Cyclotella atomus* was obviously the most dominant phytoplankter. Two other species, *Cyclotella meneghiniana* v. *plana* and *Stephanodiscus subtilis,* were also dominants at the river mouth and .2 km offshore. Conditions on July 16 (Fig. 24e) were quite different from the preceding days in that the standing crop of phytoplankton increased so that the total cell counts in the zone out to .4 km ranged from 16000 to 31000 cells/ml.

In general, maximum cell densities were found at the rivermouth station but there were two exceptions; on July 9 and July 15 the maximum cell counts were found at the station .4 km offshore (Figs. 24a–e). In general, minimum cell counts were found at the stations .8 and 3.2 km offshore with slightly higher cell counts being found at the station 6.4 km from shore. On July 13 when a station 13 km from shore was sampled cell counts were also greater at that station than at the stations .8 to 3.2 km from shore.

In July the area out of the river's influence generally began .8 km from shore (except on July 11 and possibly on July 15 when the effect of the river did not extend as far offshore); this area was marked by a sharp drop in cell counts (Fig. 24). The species composition of this offshore area was quite variable and total cell counts were greater at the beginning of the experiment and tended to decrease with time (Figs. 23d–g). Total cell counts ranged from 1000 to 2850 cells/ml on July 9 and 11 and from 730 to 1800 cells/ml on July 15. By the end of the experiment on July 16 total cell counts had decreased to a minimum of 190 cells/ml and a maximum of 920 cells/ml.

The extreme variability in the offshore areas can best be illustrated by considering the distribution of the most abundant species sampled during the experiment. *Rhizosolenia gracilis,* for example, was quite abundant in the offshore areas on July 9 and 11 (Figs. 24a–b). Its relative abundance decreased and was less pronounced on July 13 at the stations .8 and 1.6 km from shore but at the station 13 km offshore it comprised 53% of the total standing crop (Fig. 24c). The relative abundance of *Stephanodiscus tenuis* was greatest in samples collected July 11 with relative abundances being quite high at stations ranging from .4 to 3.2 km offshore (Fig. 24b) and exceeded 20% at the stations .8 and 1.6 km from shore. This entity also was quite abundant in the offshore area on July 9, 13 and 16 (Figs. 24a, c, e). *Tabellaria fenestrata* was present in relative abundances which exceeded 20% at 1.6 km on July 9 (Fig. 24a). This species was also found in relatively large abundances on July 11, particularly at the station 6.4 km offshore where the relative abundance was 25% (Fig. 24b).

Variability of distribution in space and time can also be illustrated by other species. *Cyclotella stelligera* was a dominant species on the transects on all dates sampled with the exception of July 9 (Fig. 24a), but its maximum relative abundance was found at stations .8 and 1.6 km offshore (Figs. 23d–g). Relative abundance of the species decreased markedly at distances >1.6 km offshore and on July 15 its relative abundance was nearly zero 6.4 km offshore (Fig. 24d). *Diatoma tenue* v. *elongatum* was found in relatively low abundances on the first three days of sampling and its

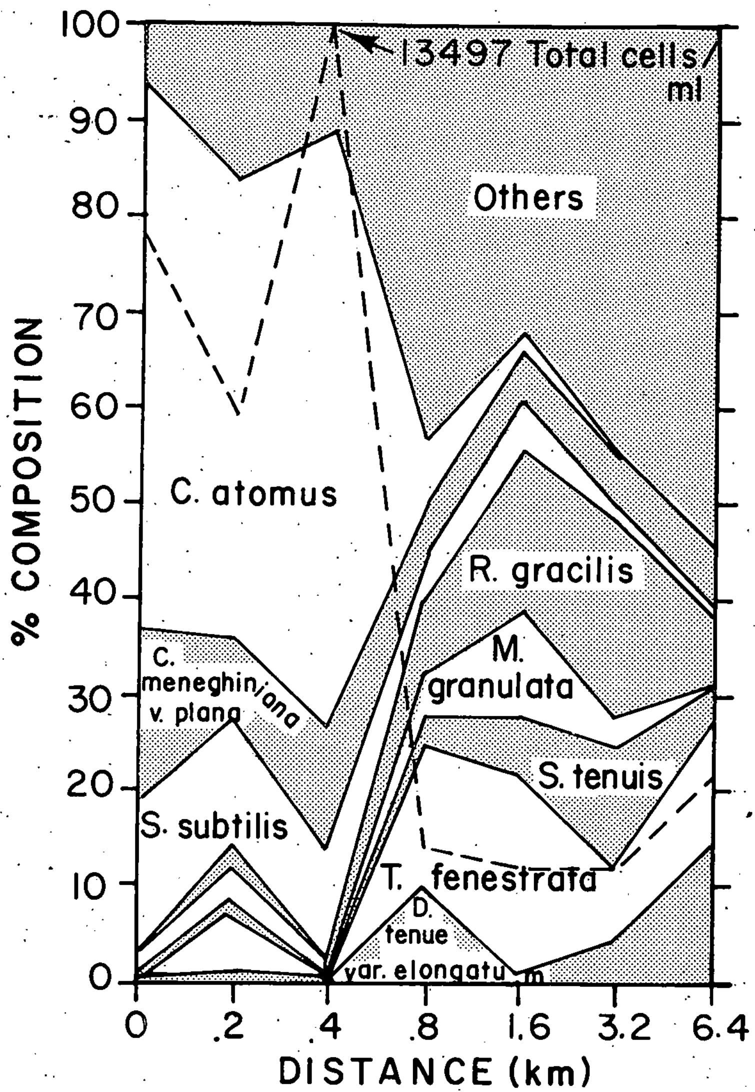

FIG. 24a. Grand River transect. Phytoplankton species composition and standing crop, July 9, 1972.

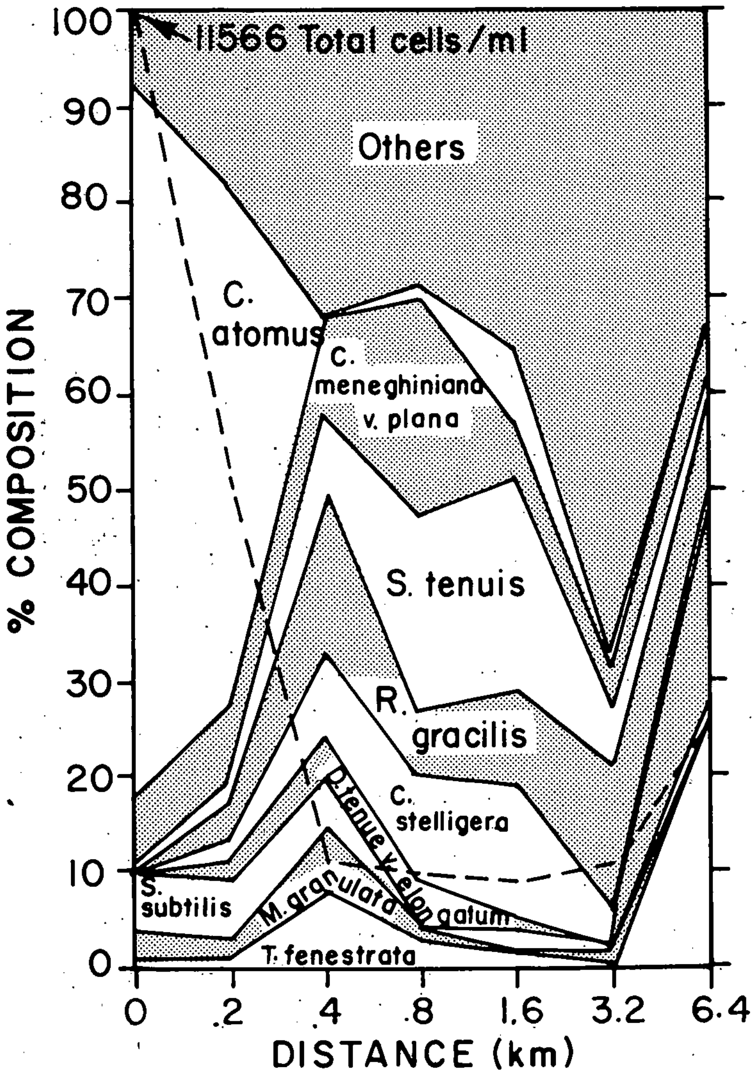

FIG. 24b. Grand River transect. Phytoplankton species composition and standing crop, July 11, 1972.

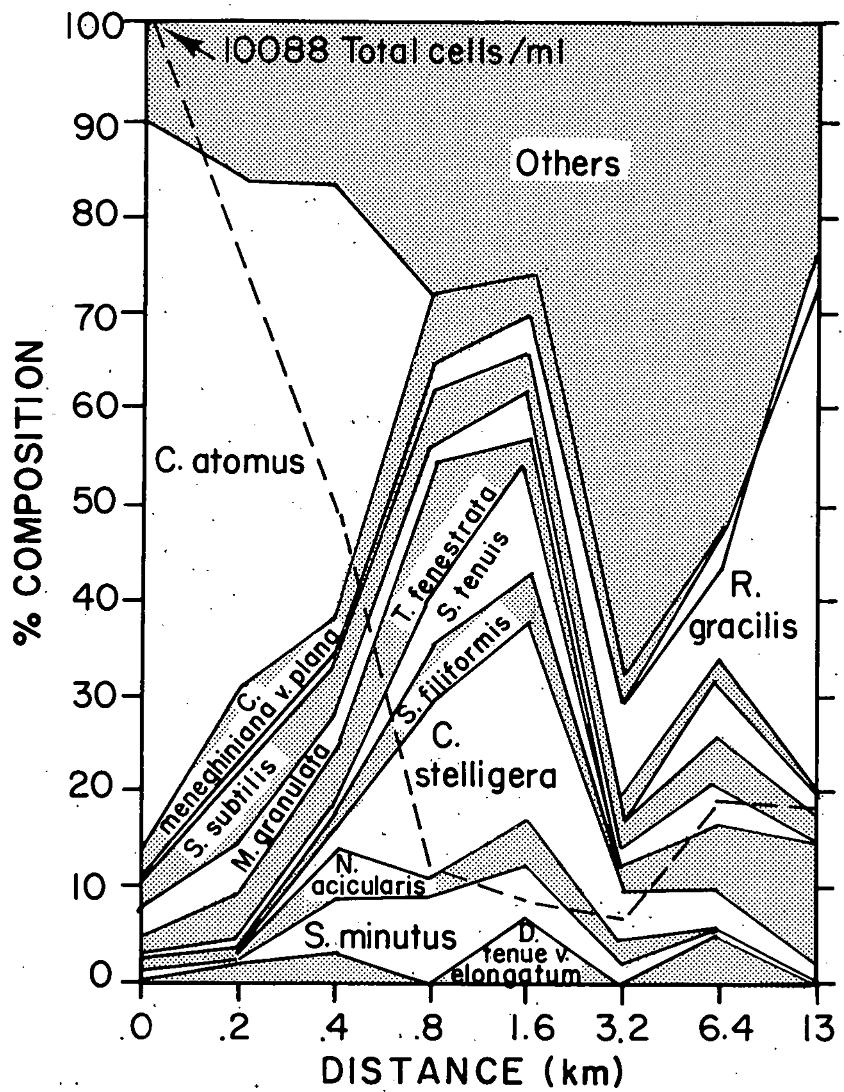

FIG. 24c. Grand River transect. Phytoplankton species composition and standing crop, July 13, 1972.

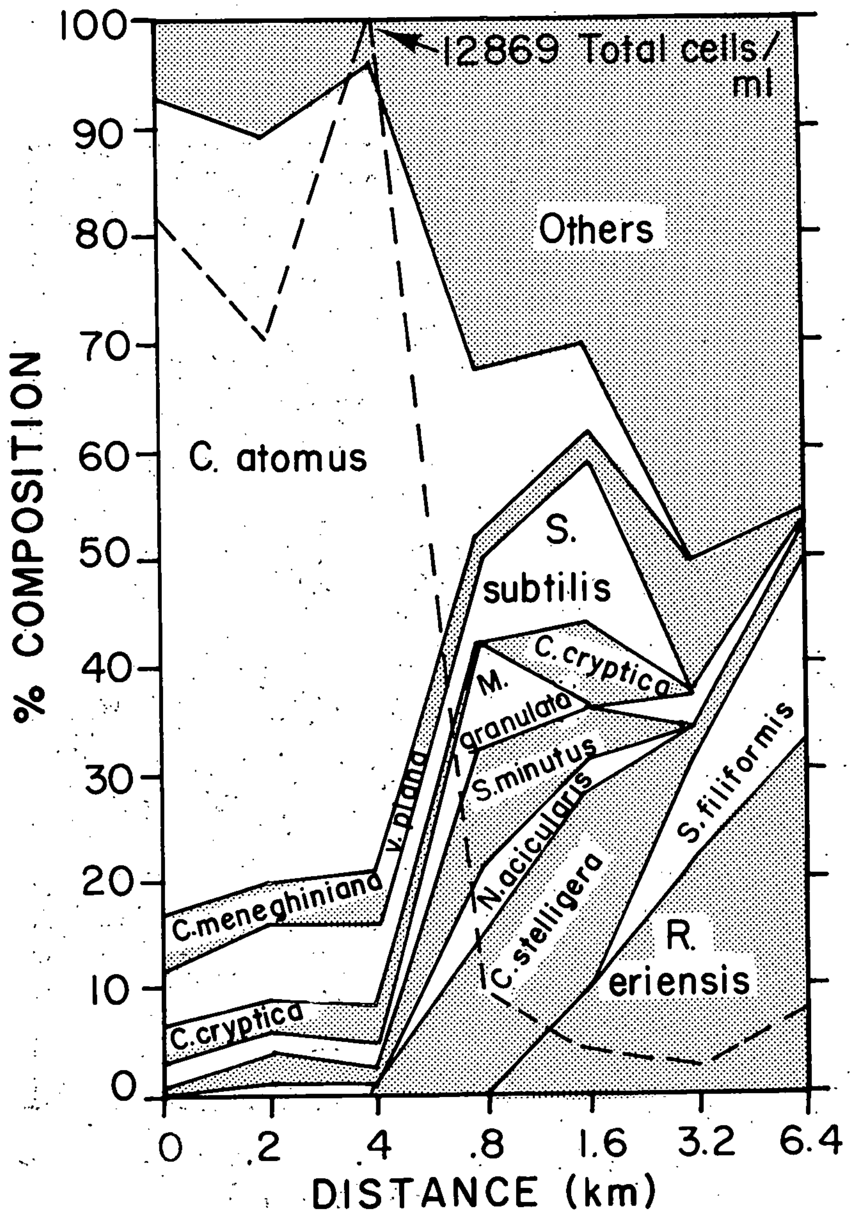

FIG. 24d. Grand River transect. Phytoplankton species composition and standing crop, July 15, 1972.

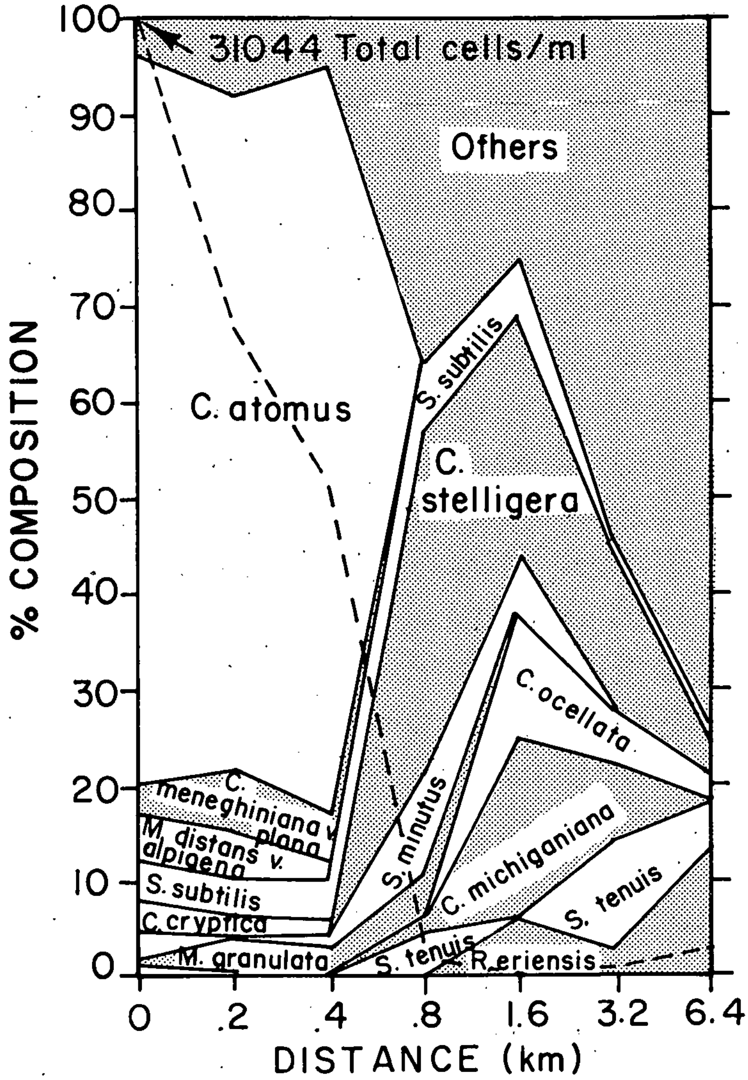

FIG. 24e. Grand River transect. Phytoplankton species composition and standing crop, July 16, 1972.

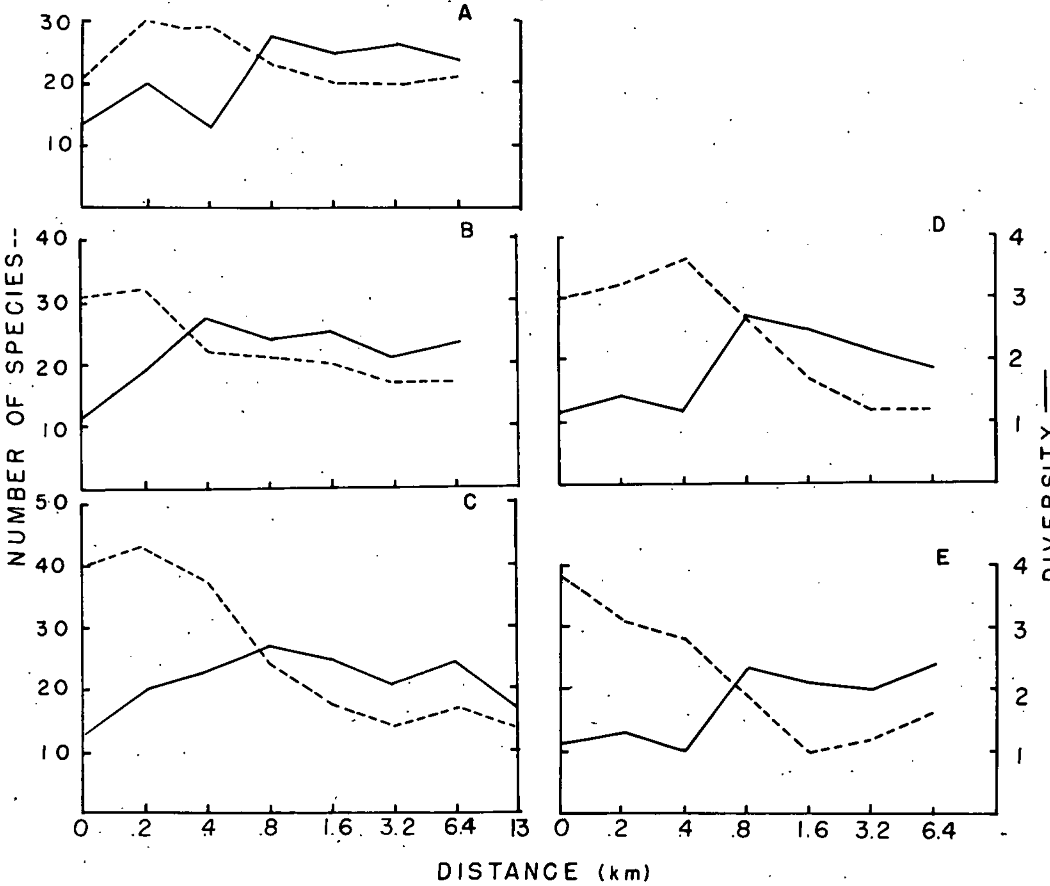

FIG. 25. Grand River transect. Number and diversity of phytoplankton species. a. July 9, 1972; b. July 11, 1972; c. July 13, 1972; d. July 15, 1972; e. July 16, 1972.

maximum relative abundance appeared to be quite variable (Figs. 24a–c). For example, on July 9, 10% of species composition at .8 km and 13% of the relative species composition at the 6.4 km station were due to this species; whereas at the intermediate station the relative abundance was <4% at both stations (Figs. 23d–g). *Rhizosolenia eriensis* was a pronounced dominant in samples collected on July 15 at 3.2 and 6.4 km from shore with a maximum relative abundance of 33% (Fig. 24d). This species was also found at these stations on July 16 but the relative abundances were much less, ranging from 3% to 13% (Fig. 24e). Two species of *Cyclotella, C. ocellata* and *C. michiganiana,* were found in relatively large abundances on July 16 at stations greater than 1.6 and 3.2 km offshore (Fig. 24e). Neither species appeared to be relatively abundant at any other sampling time.

On the Grand River transect the largest numbers of species were generally found at the nearshore stations and at the rivermouth station. At these stations numbers of species ranged from 27–43 with the exception of the rivermouth station on July 9 where only 21 species were found (Figs. 25a–e). At the offshore stations located 1.6 km or more from shore the number of species generally ranged between 10 and 20.

Diversity on the Grand River transect was lower at nearshore stations than at offshore stations. At the nearshore stations it was generally <2.0, ranging to as low as 1.0, and at the offshore stations values were generally >2.0 (Figs. 25a–e).

RESULTS FOR SEPTEMBER

GRAND RIVER TRANSECT

Physical-Chemical Conditions

The Grand River differed from the other two transects sampled in September in that the influence of the river was measurable some distance from shore and in that vertical temperature and chemical stratification was found at the stations located offshore. The influence of the river was evident out to a distance of at least .8 km from shore because concentrations of chloride, silica, nitrate nitrogen, and total phosphorus were all greater in this zone than in the offshore waters (Fig. 26a).

At the offshore stations the thermocline extended from a depth of about 15 m at the station 3.2 km offshore to slightly >30 m at the station 26 km from shore. Below the thermocline pH was less and silica and nitrate nitrogen concentrations were greater than in the epilimnion. There appeared to be no vertical differences in chloride and total phosphorus concentrations at the stations located more than 6.4 km offshore.

Phytoplankton

The standing crop of phytoplankton in the rivermouth sample was 5590 cells/ml which decreased markedly to approximately 1130 cells/ml at the station 1.6 km offshore (Fig. 26b). Farther offshore cell counts ranged from approximately 500 cells/ml at the station 3.2 km from shore to 190 cells/ml at the station 26 km from shore.

A number of species were abundant at the stations <1.6 km from shore, including *Melosira granulata* and *Cyclotella atomus* which were the most abundant. In addition, undetermined flagellates and six species of diatoms, *Melosira distans* v. *alpigena, Fragilaria crotonensis, Stephanodiscus subtilis, Cyclotella cryptica, Asterionella formosa,* and *Cyclotella stelligera,* were present in relatively large abundances.

C. stelligera, Anacystis thermalis, Oocystis spp., and *Coelosphaerium* sp. were the dominant entities which accounted for more than 70% of the total cell counts at the station 13 km from shore. The blue-greens, *Anacystis thermalis* and *Coelosphaerium* sp., and the green alga, *Oocystis* spp., were not present at the nearshore stations where silica concentrations were greater than in the offshore waters.

On this transect a large proportion of the total cell counts at all stations was due to the category designated "others." The per cent composition of "others" ranged from 25% to slightly more than 30% at all stations and was not related to the number of species recorded because more than 90 species were recorded at the river mouth and less than 20 species were found at the two offshore stations (Fig. 26c). Diversity varied little along the transect, but appeared to be less at the stations located 13 and 26 km from shore than at the stations closer to shore.

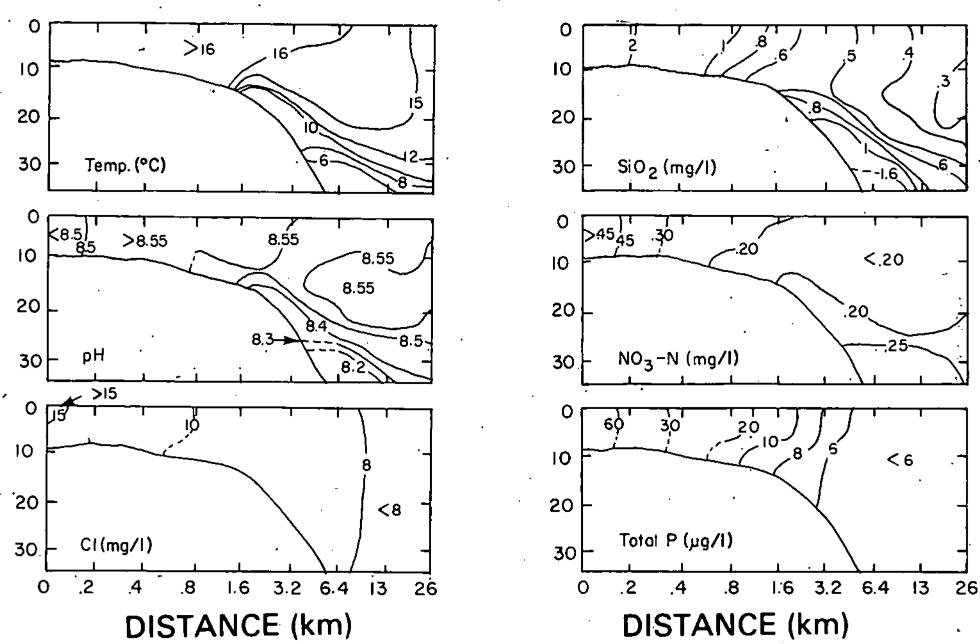

FIG. 26a. Grand River transect, September 27, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

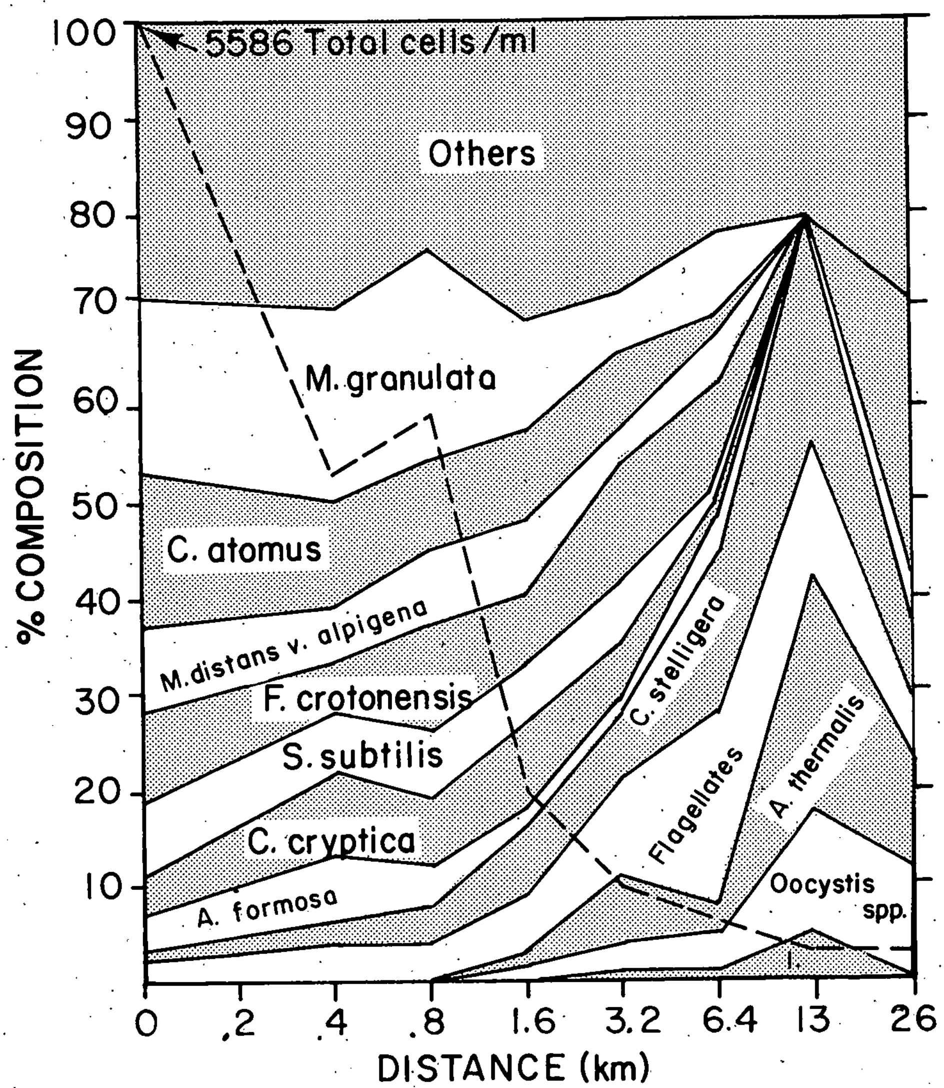

FIG. 26b. Grand River transect, September 27, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure. 1. species *Coelosphaerium* sp.

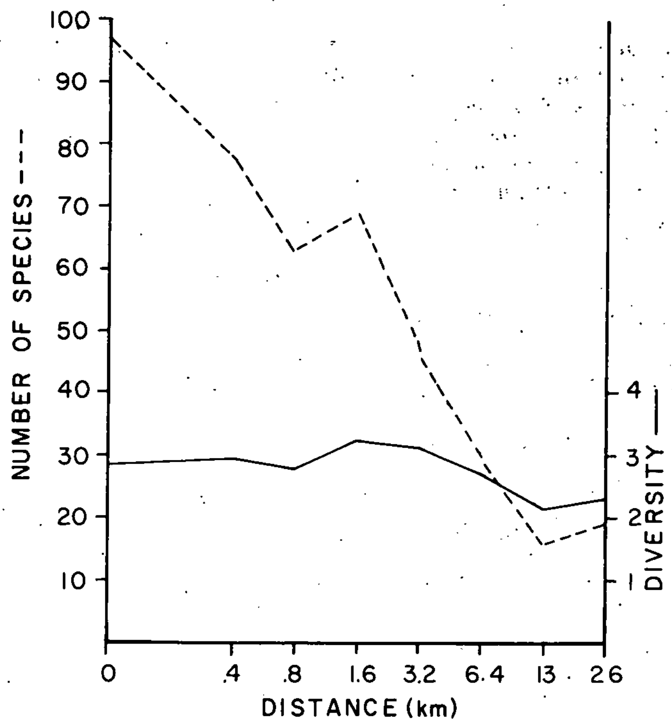

FIG. 26c. Grand River transect, September 27, 1972. Number and diversity of phytoplankton species at 2 meters.

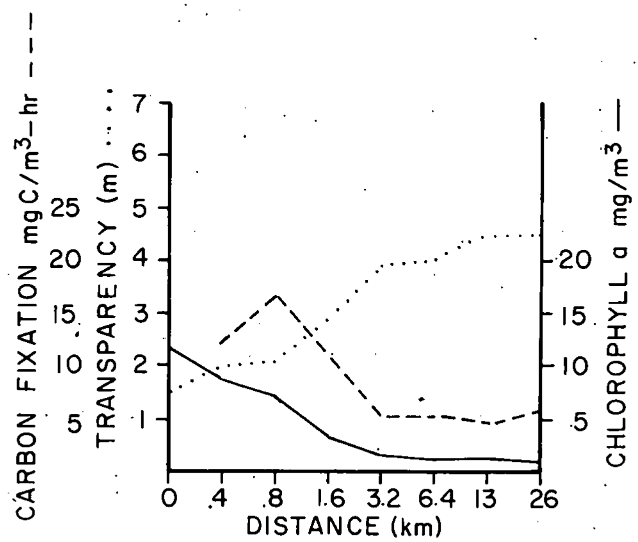

FIG. 26d. Grand River transect, September 27, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Carbon Fixation and Chlorophyll

Higher chlorophyll *a* concentrations were found in the nearshore zone out to a distance .8 km from shore than were found at the stations farther offshore (Fig. 26d). At the rivermouth station the chlorophyll *a* concentration was 12 mg/m^3 but it decreased to 1 mg/m^3 at the stations located from 6.4 to 26 km offshore. Rates of carbon fixation at the stations from .4 to 1.6 km offshore ranged from 11–17 mg C/m^3/hr as compared to an average of about 5 mg C/m^3/hr at the stations 3.2 km or more offshore.

PERE MARQUETTE RIVER TRANSECT

Physical-Chemical Conditions

On the Pere Marquette transect there was no temperature stratification out to a distance 6.4 km from shore, with temperatures varying slightly above and below 16° C (Fig. 27a). Little stratification would be expected as the water depths were <25 m. River water had slightly different physical-chemical characteristics than the offshore waters: its pH was lower and chloride, silica, and total phosphorus concentrations were greater. The influence of the river, however, was not great and was not evident at the station located .2 km from shore. Data for nitrate nitrogen were not plotted because there was no consistent variability.

Phytoplankton

On this transect the rivermouth sample in terms of standing crop was decidedly different from the other stations. The standing crop at the river mouth was 3680 cells/ml which decreased to the range of 380 to 720 cells/ml at the other stations on the transect (Fig. 27b).

The dominant species at the rivermouth station was *Melosira granulata* which comprised more than 60% of the total standing crop. At this station about 20% of the standing crop was due to the category designated "others."

At the lake stations *M. granulata* was present at all stations sampled except the station 6.4 km from shore. The dominant offshore phytoplankter was *Fragilaria crotonensis* which comprised more than 60% of the population at the station 1.6 km from shore and was present in very large relative abundances at most of the other stations. Other diatoms present in the offshore waters were *Tabellaria fenestrata, Asterionella formosa, Cyclotella stelligera, Fragilaria capucina,* and *Diatoma tenue* v. *elongatum.* The latter two species had their peak relative abundance at the station located .4 km from shore. The blue-green alga, *Anacystis thermalis,* and the green alga, *Oocystis* spp., were common at the stations ranging from .2 to 6.4 km offshore. Undetermined flagellates were also found at the offshore stations but were most abundant at the stations 3.2 and 6.4 km from shore where they comprised 13 to 17% of the assemblage.

Sixty-eight species were identified from the rivermouth sample which was a much larger number than at the other stations (Fig. 27c). About 40 species were recorded .2 and .4 km from shore, but the number of species present at the stations farther offshore was much less ranging from 22 to 27. There was no apparent pattern in species diversity.

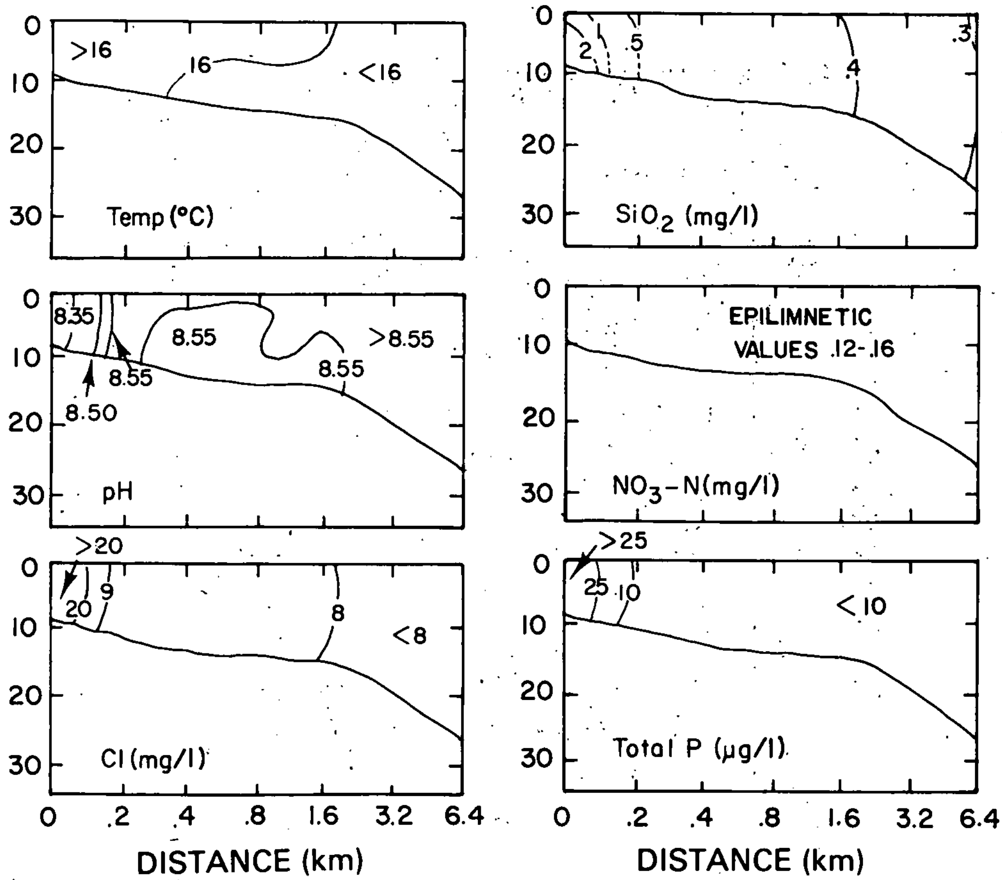

FIG. 27a. Pere Marquette River transect, September 26–27, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

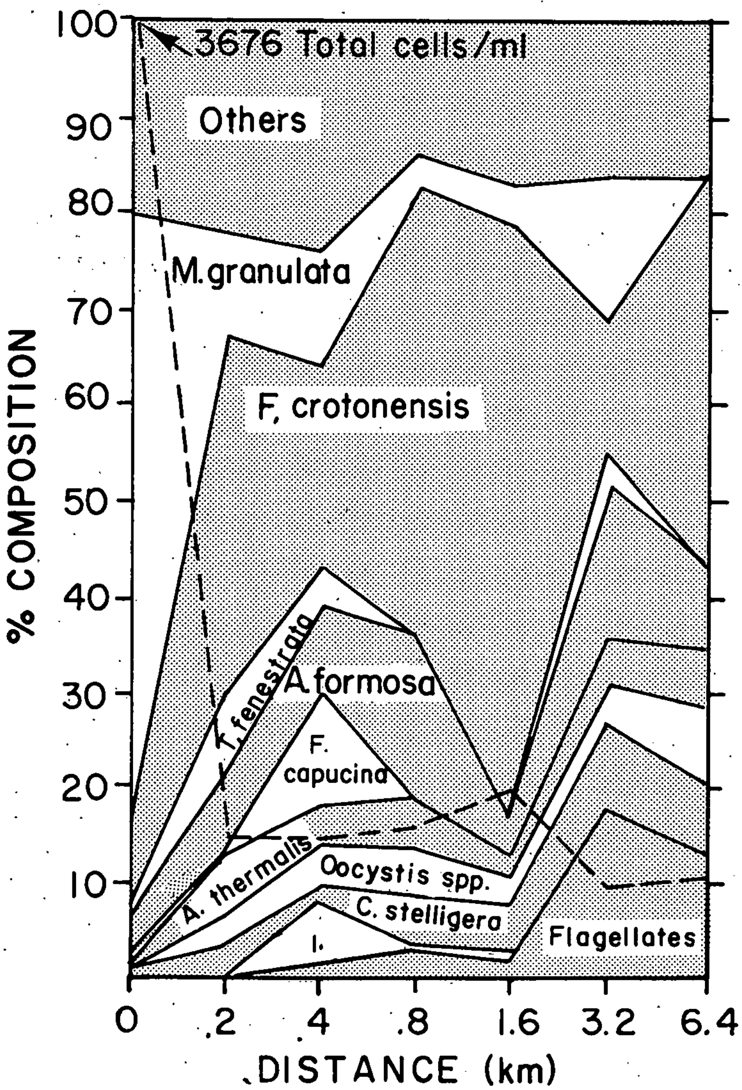

FIG. 27b. Pere Marquette River transect, September 26–27, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure. 1. species *Diatoma tenue* v. *elongatum*.

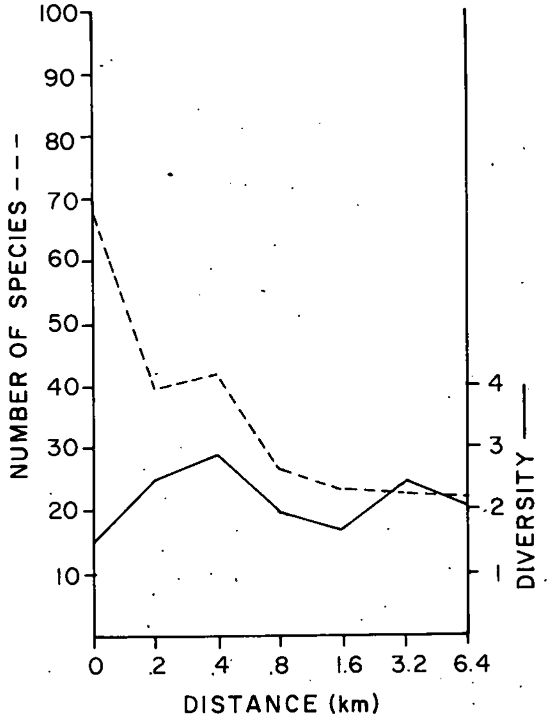

FIG. 27c. Pere Marquette River transect, September 26–27, 1972. Number and diversity of phytoplankton species at 2 meters.

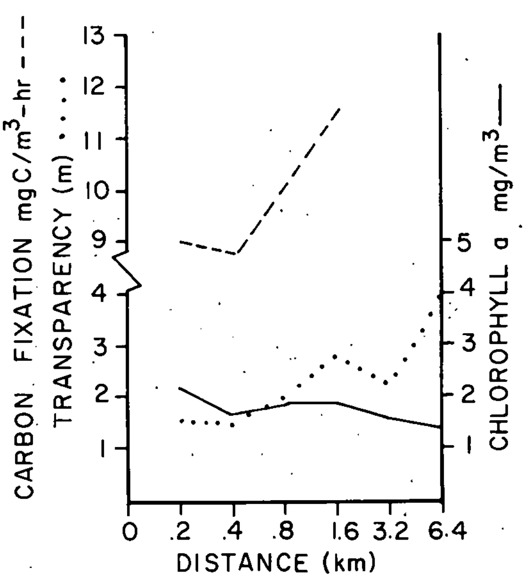

FIG. 27d. Pere Marquette River transect, September 26–27, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Carbon Fixation and Chlorophyll

There was little variation in any of the phytoplankton community parameters measured on the Pere Marquette transect. Rates of carbon fixation, however, were much greater than on the two other transects sampled in September, ranging from 9–11.5 mg C/m^3/hr (Fig. 27d). No data were obtained at the two stations farthest offshore which may have biased the results. These relatively high values for carbon fixation contrasted with relatively low chlorophyll *a* concentrations which ranged from 1.5 to 2.2 mg/m^3 along the transect.

Secchi disc transparency also was quite low on the transect with all values being less than 4 m (Fig. 27d).

This transect only extended to 6.4 km which possibly was not far enough offshore to detect inshore-offshore differences.

BETSIE RIVER TRANSECT

Physical-Chemical Conditions

Water in the nearshore zone, extending out to a distance at least 3.2 km offshore, had a temperature >15°C (Fig. 28a). Farther offshore the surface temperature decreased to <15°C and there was thermal stratification above 25 m at the station 13 km offshore. Other than the offshore thermal stratification below 25 m, there was not much variation in the other variables measured on this transect. Data for nitrate nitrogen and total phosphorus were not plotted due to lack of variability.

Phytoplankton

No sample was taken at the river mouth on the transect and only 1190 cells/ml were found in the sample taken .2 km from shore (Fig. 28b). The standing crop decreased very rapidly to the minimum of 210 cells/ml found 6.4 km offshore.

The most dominant species on this transect was *Fragilaria crotonensis,* particularly at stations .8 and 3.2 km offshore where it comprised more than 65% of the total standing crop of phytoplankton.

At the two nearshore stations, in addition to *Fragilaria crotonensis, Melosira granulata, Asterionella formosa, Tabellaria fenestrata, Stephanodiscus binderanus,* and *S. tenuis* were dominant species.

In the offshore waters the dominants, in addition to *Fragilaria crotonensis,* were *Asterionella formosa, Oocystis* spp., *Cyclotella comta, C. stelligera, Rhizosolenia gracilis,* and undetermined flagellates, the latter entity comprising more than 20% of the total standing crop 6.4 km offshore.

More species were identified from the sample taken .2 km offshore than at the other stations; fifty-five species were present at this station compared to about 20 species at the other stations (Fig. 28c). Diversity was variable, but with data for only five stations no definite pattern of variability could be ascertained.

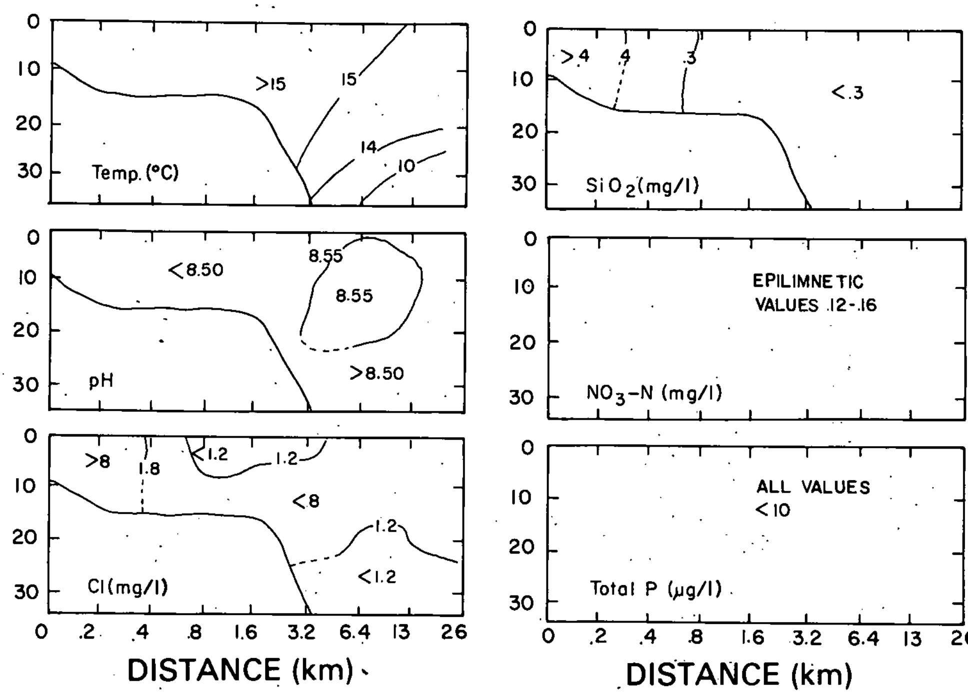

FIG. 28a. Betsie River transect, September 25–26, 1972. Depth-distance isopleths of physical-chemical conditions. Depths are in meters.

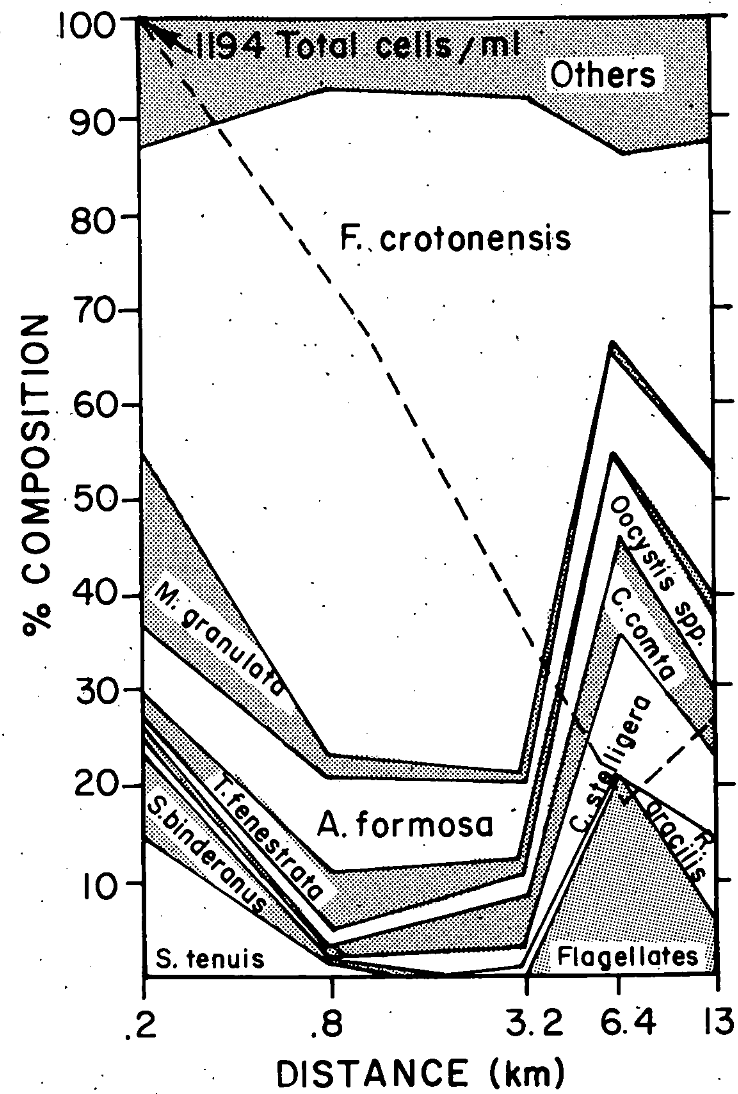

FIG. 28b. Betsie River transect, September 25-26, 1972. Phytoplankton species composition and standing crop at 2 meters. Standing crop (cells/ml) is represented by the dashed line and is expressed as per cent of the greatest cell density shown on the figure.

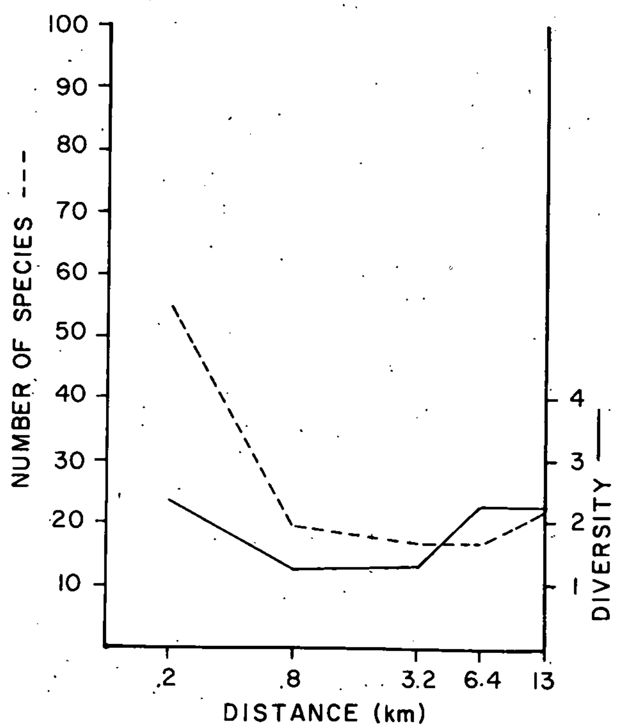

FIG. 28c. Betsie River transect, September 25–26, 1972. Number and diversity of phytoplankton species at 2 meters.

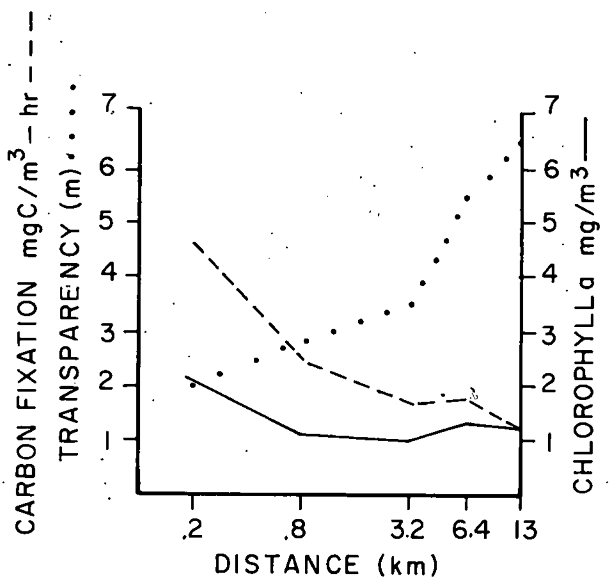

FIG. 28d. Betsie River transect, September 25–26, 1972. Secchi disc transparency and chlorophyll *a* and carbon fixation, at 2 meters.

Carbon Fixation and Chlorophyll

Rates of carbon fixation and chlorophyll *a* concentration were obviously greater at the stations located .2 km from shore than at the adjacent stations, but values for either variable were large compared to those on other transects in September (Fig. 28d). Transparency values obviously exceeding 5 m were greater at the stations 6.4 and 13 km from shore than at the station closer to shore.

DISCUSSION

CONDITIONS IN APRIL

Collections in April 1972 were made prior to the period of thermal bar formation in the lake. A thermal bar, however, was present at some of the stations but it was probably due to the outflow of warm river water rather than to the general warming of nearshore waters in the lake. Large flows from rivers contributed water warmer than 4° C to the nearshore area near the river mouth, but where there was a small, or no, river effect, nearshore waters were <4° C (Table 3). For example, at the St. Joseph River and the Grand River, the two rivers with the largest flows, water temperatures at the river mouth were >15° C and >8° C respectively. On the remainder of the transects, sampled in April, water temperatures at the nearshore station or at the river mouth were either <4° C or only slightly >4° C. On transects off the smaller rivers the 4° C isotherm was located <.4 km from shore. On the Wisconsin side of the lake, all three transects had temperatures which in general were <2° C at the nearshore stations, precluding thermal bar formation.

TABLE 3. Water temperature (°C) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

	Kilometers									
Rivers	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	1.9	1.3	1.3	1.0	0.9	0.9	0.9	0.8		
Betsie	4.5	1.0	0.8	0.8	0.9	1.2	1.2	1.5	1.7	
Manistee	5.4	4.2	3.4	2.0	1.5	1.0	1.0	1.0	1.3	
Pere Marquette	6.0	4.2	3.0	2.2	2.0	1.9	1.9	1.1		
Muskegon	6.2	3.1	3.3	4.1	2.0	2.4	1.8	1.9		
Grand	–	7.8	7.0	6.0	6.0	1.2	1.0	1.0	1.0	
Kalamazoo	3.5	3.1	2.9	2.2	1.6	1.1	1.6	1.2		
St. Joseph	16.0	10.0	6.0	4.8	4.1	3.8	2.0	2.0		
Milwaukee	3.0	3.0	3.0	2.6	2.2	2.0	1.3	1.0	1.0	1.5
Manitowoc	–	2.3	2.1	2.0	1.4	1.1	1.0	0.9	1.0	1.0
Sturgeon Bay	1.9	1.8	1.3	1.0	1.0	0.9	0.9	0.7	0.8	0.9

In addition to affecting the size of water masses with temperatures >4° C, the large rivers influenced nearshore chemical characteristics more than the smaller rivers due mainly to the fact that the larger rivers, St. Joseph and Grand as examples, carry a larger chemical load than the smaller rivers. Although the concentration of materials in the river is important, the extent of the area affected by the river input is primarily a function of the amount of flow and not the concentration. In the case of the two large rivers contributing the largest load of phosphorus to the lake, the concentration of total phosphorus in both the Grand River and the St. Joseph River was also greatest being >100 μg/liter (Figs. 5, 3), whereas of the smaller rivers only the concentration at the Kalamazoo River exceeded 50 μg/liter (Fig. 4).

Temperature

In the open waters of the lake, temperatures were cold, being <2° C at stations 6.4 km or more from shore (Table 3). As might be expected, the coldest temperatures were at the north end of the lake, being <1° C off Manistique, and the warmest offshore temperatures were 2° C at the south end of the lake on the St. Joseph transect.

Temperatures <2° C are not unusual for early spring. Minimum surface temperatures approach 0° C during winter (Rousar 1973, Mortimer 1975) so 2° C temperature for the entire offshore water mass may represent a sizable spring input of heat to the system. Samples were taken prior to the formation of the spring thermal bar—temperatures >4° C on some transects (Betsie, Manistee, Pere Marquette, Muskegon, and Grand transects) appear to be due to plumes of warm river water rather than to water warmed in the lake (Table 3). That the maximum temperature on the Kalamazoo transect was 3.5° C provides additional evidence that the thermal bar had not formed because this transect originated south of the river mouth. The Kalamazoo River is located along the eastern shore between the Grand River and the St. Joseph River, two rivers with warmer water and larger flows than the Kalamazoo River (Table 1). Water warmer than the lake probably was also flowing out of the Kalamazoo River, but the warm water plume was not intersected by our transect.

Hydrogen Ion Concentration

Measurements of pH showed distinct differences among the rivers (Table 4). The Manistique River differed from the other rivers with the lowest pH (7.0) recorded during the study. The low pH presumably resulted from large organic pollutional loads or to low pH waters from the drainage basin. Wood chips and foamy water observed during sampling were evidence of organic pollution in the river.

TABLE 4. Hydrogen ion concentration at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

	Kilometers									
Rivers	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	7.40	8.47	8.46	8.46	8.52	8.53	8.55	8.53		
Betsie	8.26	8.43	8.45	8.48	8.44	8.41	8.46	8.46	8.42	
Manistee	8.16	8.42	8.40	8.47	8.45	8.47	8.41	8.39	8.45	
Pere Marquette	8.23	8.45	8.49	8.49	8.47	8.46	8.48	8.43		
Muskegon	8.49	8.63	8.60	8.56	8.54	8.59	8.40	8.45		
Grand	8.11	8.10	8.24	8.28	8.28	8.50	8.44	8.45	8.46	
Kalamazoo	8.66	8.63	8.59	8.58	8.51	8.55	8.48	8.47		
St. Joseph	8.33	8.68	8.93	8.80	8.75	8.73	8.60	8.56		
Milwaukee	8.38	8.37	8.37	8.45	8.44	8.48	8.48	8.44	8.44	8.57
Manitowoc	–	8.56	8.51	8.50	8.53	8.46	8.48	8.45	8.40	8.43
Sturgeon Bay	8.53	8.54	8.53	8.52	8.52	8.51	8.45	8.48	8.42	8.43

Values of pH for offshore waters (stations 6.4 km or more offshore) on all transects were in the range of 8.4 to 8.5 with many of the values being between 8.40 and 8.45 at stations 13 km or more offshore. The pH in nearshore waters on the Muskegon and Kalamazoo transects ranged from 8.5–8.6 and on the St. Joseph transect was even higher, ranging from 8.7–8.9. Higher values for pH in the nearshore waters can be attributed to greater photosynthetic activity in the offshore waters—data on cell counts and chlorophyll concentrations support this conclusion.

Chloride

Data on chloride for some rivers could be used to trace river plumes, both due to relatively low and relatively high concentrations. Chloride concentrations representative of the open lake ranged generally from 7.5 to 8.4 mg/liter (Table 5), so higher or lower values nearshore indicate significant inputs of river water. Both the Manistique and Betsie Rivers had smaller chloride concentrations than the open lake. Whether the Manistique plume could be traced for several kilometers on the basis of low chloride concentrations is questionable because waters in this area of northern Lake Michigan frequently are mixed with waters from Lake Huron which also have lower chloride concentrations than Lake Michigan. Values of chloride <7 mg/liter at other offshore stations are not to be expected, probably being due to unresolved analytical problems related to analysis of frozen samples.

TABLE 5. Chloride concentration (mg/liter) at 2 meters on transects off Lake Michigan rivers, April 1972.

	Kilometers									
Rivers	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	2.3	5.3	5.5	5.3	6.7	4.7	5.6	7.4		
Betsie	4.5	7.8	7.9	7.4	8.0	8.0	5.8	7.3	7.1	
Manistee	–	18.8	19.0	14.2	10.1	8.1	8.1	7.6	7.2	
Pere Marquette	15.3	10.5	8.5	7.7	8.2	8.3	8.3	5.7		
Muskegon	–	–	–	13.9	8.9	9.7	7.1	7.6		
Grand	22.0	21.0	17.6	14.8	17.7	8.1	7.7	5.0	7.3	
Kalamazoo	10.6	9.0	9.4	9.0	6.8	8.5	8.4	7.9		
St. Joseph	16.2	12.5	9.1	8.8	9.5	6.3	7.7	–		
Milwaukee	12.0	11.0	9.9	6.1	7.4	7.8	7.7	7.1	7.0	7.5
Manitowoc	–	7.7	7.7	6.7	–	7.7	7.7	7.9	7.7	7.7
Sturgeon Bay	5.9	7.2	7.3	7.3	7.7	7.3	7.4	7.5	7.5	7.3

Water from the Grand and St. Joseph Rivers was apparently present 1.6 km offshore as chloride concentrations were obviously elevated at the 1.6 km stations and intervening stations between the shore. High chloride values out to 1.6 km offshore were also found on the Manistee transect.

The relatively large chloride concentrations on the Kalamazoo transect may not have originated in the Kalamazoo River but may have been due to inputs of chloride from other rivers, most likely the Grand or St. Joseph or to the expected larger concentration of chloride in nearshore waters. Data on water temperatures (Table 3) suggest that there was little input of water from the Kalamazoo River at the stations sampled.

Specific Conductance

Data for specific conductance show the same patterns as those for chloride, with the lowest values in the Manistique and Betsie Rivers and the highest values for the Grand, St. Joseph, and Manistee transects. It is obvious from the data in Table 6 that this parameter could also be used to trace river water.

TABLE 6. Specific conductance (μmho/cm, 25°C) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

	Kilometers									
Rivers	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	084	313	307	304	311	317	317	312		
Betsie	302	307	322	317	313	320	307	322	322	
Manistee	578	353	357	328	312	294	301	300	302	
Pere Marquette	358	336	330	333	331	330	325	322		
Muskegon	423	324	343	357	316	326	312	298		
Grand	530	523	524	481	452	284	300	307	307	
Kalamazoo	342	327	337	326	321	317	322	321		
St. Joseph	519	412	347	347	336	344	306	308		
Milwaukee	367	361	347	327	314	312	315	312	308	305
Manitowoc	–	311	310	317	314	326	314	322	323	317
Sturgeon Bay	322	323	317	322	327	324	327	312	322	318

Due to problems with temperature compensation at low temperatures on our conductivity bridge, the data can be used only for relative comparisons. Open lake specific conductance should have been in the range between 265 and 280 μmho/cm corrected to 25° C (Table 6), therefore our values are roughly 10 to 20% greater than the expected absolute values. A value of 259 μmho/cm is given by Rousar (1973) as the average offshore specific conductance; however, this average is probably low due to minimum values including some as small as 251. A slightly larger value, 265 μmho/cm, is probably more realistic; it represents the maximum found by Rousar at two of the three offshore stations and is more consistent with unpublished data.

Inputs from tributaries not only affected the distribution of conservative chemical parameters, but also the distribution of nutrients.

Total Phosphorus

Open lake values for total phosphorus appeared to be generally <7 μg/liter at stations 6.4 km or more offshore, except for the St. Joseph transect (Table 7). Largest

TABLE 7. Total phosphorus (µg/liter) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

	Kilometers									
Rivers	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	18.3	6.1	4.7	11.0	9.6	10.4	5.1	6.1		
Betsie	26.7	3.8	3.7	4.5	3.4	3.6	3.3	4.1	5.2	
Manistee	22.9	8.0	10.1	6.9	5.7	6.5	5.5	6.0	5.0	
Pere Marquette	35.6	15.9	–	6.6	6.1	7.6	6.7	5.3		
Muskegon	51.1	13.6	19.5	10.7	10.2	10.7	5.1	8.5		
Grand	141.2	176.1	111.6	–	92.5	6.8	7.9	5.8	5.1	
Kalamazoo	24.6	16.6	15.9	8.7	8.3	9.5	7.7	9.0		
St. Joseph	136.8	77.1	22.1	20.4	16.1	16.0	13.6	6.1		
Milwaukee	30.8	29.8	24.8	15.0	14.0	9.9	8.3	4.4	2.3	2.6
Manitowoc	–	8.6	5.2	4.8	2.6	4.1	2.3	3.8	2.5	4.5
Sturgeon Bay	3.6	–	3.7	4.0	4.7	3.2	3.9	5.7	4.1	3.8

concentrations of total phosphorus were in the Grand and St. Joseph Rivers: phosphorus concentrations were elevated for at least 1.6 km offshore on the Grand transect and for 6.4 km offshore on the St. Joseph transect.

Total phosphorus concentrations at the river mouth or 0 km station for all transects were greater than the open lake excepting the Sturgeon Bay transect. Because the Sturgeon Bay transect runs offshore from the ship canal between Green Bay and Lake Michigan and was not directly affected by tributaries one possibly should not expect higher concentrations.

Data in Table 7 indicate we may have underestimated total phosphorus in the open lake because concentrations probably should average about 8 µg/liter (Schelske 1977, Bartone and Schelske in prep.). We do not believe that the larger concentrations nearshore are significantly underestimated.

Chlorophyll *a*

Concentrations of chlorophyll *a* in the open lake during the April sampling appeared to range between 1 and 2 mg/m^3 (Table 8). Largest values were found off the Grand and St. Joseph Rivers where total phosphorus concentrations were also largest. Relatively large values for total phosphorus were found out to 1.6 km offshore on the Grand River transect as were large chlorophyll *a* concentrations; likewise, relatively large chlorophyll *a* and total phosphorus concentrations were found on the St. Joseph transects, but large concentrations were present out to 3.2 km offshore, a greater distance than on the Grand River transect.

In general the largest chlorophyll *a* concentrations on each transect were associated with the largest total phosphorus concentrations.

Nitrate Nitrogen

Open lake values for nitrate nitrogen generally ranged from .26 to .29 mg/liter (Table 9). The St. Joseph and Grand rivers were obviously contributing nitrate to the

TABLE 8. Chlorophyll *a* (mg/m³) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

Rivers	Kilometers									
	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	0.42	2.00	1.92	2.13	2.08	2.81	2.20	3.15		
Betsie	1.56	1.78	2.33	2.16	1.88	1.61	2.42	1.25	1.10	
Manistee	0.96	3.09	3.53	3.21	2.84	2.55	2.20	1.51	1.00	
Pere Marquette	2.23	4.13	3.21	3.69	2.92	2.64	1.72	1.99		
Muskegon	14.25	11.41	12.25	11.86	5.47	6.69	1.38	1.90		
Grand	18.09	21.45	15.80	20.13	23.46	3.26	2.26	1.96	–	
Kalamazoo	5.55	9.28	8.06	6.59	4.70	3.12	3.41	3.06		
St. Joseph	24.45	18.55	16.83	11.90	10.16	9.80	3.65	2.11		
Milwaukee	6.76	5.96	6.83	7.26	6.39	5.96	4.96	3.72	1.66	1.76
Manitowoc	–	8.34	4.17	3.80	2.87	2.79	1.99	1.81	1.56	1.53
Sturgeon Bay	2.73	2.78	2.75	2.27	3.15	3.00	2.16	2.31	1.54	1.11

TABLE 9. Nitrate nitrogen (mg/liter) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

Rivers	Kilometers									
	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	.201	.135	.141	.143	.161	.110	.201	.216		
Betsie	.217	.279	.285	.272	.289	.292	.236	.259	.268	
Manistee	.258	.246	.262	.236	.258	.262	.262	.252	.244	
Pere Marquette	.171	.266	.232	.222	.242	.262	.272	.203		
Muskegon	.436	.308	.302	.344	.281	.304	.247	.276		
Grand	1.50	1.50	1.15	1.92	1.20	.298	.302	.175	.273	
Kalamazoo	.379	.342	.377	.344	.293	.330	.330	.309		
St. Joseph	1.71	.951	.404	.403	.420	.311	.293	.126		
Milwaukee	.360	.344	.286	.205	.270	.291	.297	.294	.299	.268
Manitowoc	–	.271	.271	.211	.234	.251	.256	.263	.270	.287
Sturgeon Bay	.200	.231	.224	.227	.222	.226	.237	.263	.252	.270

lake with concentrations being about six times greater than those in the open lake. Nitrate nitrogen loads contributed by these two rivers would be relatively large compared to other tributaries because the Grand and St. Joseph are two of the rivers with the greatest flows (Table 2). The remaining tributaries represent relatively smaller sources of nitrate and some like the Pere Marquette and Betsie actually diluted the open lake waters with smaller concentrations than those in the open lake.

Silica

The open lake values for silica were mainly in the range of 1.2 to 1.4 mg/liter with all values except those on the Manistique transect being >1.0 mg/liter (Table 10). Most of the tributaries had silica concentrations two- to three-fold greater than the open lake;

TABLE 10. Dissolved reactive silica (mg/liter) at 2 meters at stations on transects off Lake Michigan rivers, April 1972.

Rivers	Kilometers									
	0	.2	.4	.8	1.6	3.2	6.4	13	26	52
Manistique	2.92	0.86	0.89	0.90	0.81	0.77	0.80	0.89		
Betsie	3.69	1.18	1.11	1.11	1.33	1.20	1.28	1.39	1.42	
Manistee	5.23	1.73	1.16	1.37	1.19	1.12	1.14	1.25	1.21	
Pere Marquette	3.87	1.61	1.26	1.15	1.17	1.19	1.15	1.10		
Muskegon	4.84	1.23	2.00	2.65	1.22	1.41	1.35	1.26		
Grand	2.34	2.20	2.06	1.85	1.94	1.23	1.22	1.35	1.24	
Kalamazoo	0.85	0.93	1.01	0.98	1.05	1.00	0.99	1.08		
St. Joseph	3.11	1.14	0.07	0.22	0.44	0.36	1.00	1.19		
Milwaukee	1.04	0.97	1.12	0.96	0.86	0.97	1.02	1.16	1.48	1.38
Manitowoc	–	0.89	1.01	0.89	0.90	0.88	1.01	1.02	1.04	1.32
Sturgeon Bay	0.96	1.00	1.06	1.03	1.07	1.06	1.07	1.03	1.17	1.02

however, off the Kalamazoo, Milwaukee, Manitowoc, and Sturgeon Bay transects, where there were no significant tributary inputs, silica concentrations were less than or equal to open lake values. These low silica values therefore appeared to be related more to nearshore biological processes than to direct influence by the tributaries.

The effect of nearshore processes on utilization of silica by diatoms is particularly obvious off the St. Joseph transect where silica concentrations in the river were >3.0 mg/liter but offshore decreased to 0.1 to 0.4 mg/liter at the stations from .4 to 3.2 km from shore (Table 10). These low silica values undoubtedly reflect large amounts of silica utilized in diatom growth because chlorophyll *a* standing crops in this nearshore zone with the lowest silica concentrations exceeded 10 mg/m^3 (Table 8).

Phytoplankton Standing Crop and Species Composition

In the April collections a total of 282 taxa was identified, 238 of which were diatoms. The assemblages at stations were dominated by diatoms with most of the samples containing 90% or more diatoms. The number of species at the open lake stations ranged from 28 to 37, excepting off the Manistique which had 44 species (Table 11). Many more species were found at the 0 km stations than in the offshore stations with numbers ranging from 48 to 76, excepting the Sturgeon Bay station, which has no river flow and the atypical Manistique station which had only 34 species.

The structure of phytoplankton assemblages in April can be related to several spatial factors including river inputs, nearshore zones, and offshore zones for the four different areas of the lake which were sampled. The four areas were along the southeastern, northeastern, and western shorelines and the transect off the Manistique River at the north end of the lake. Large effects due to river inputs were only observed for the transects off the Grand and St. Joseph rivers in the southeastern area.

In addition to having the two rivers which influenced conditions in the lake, the four southeastern transects were the only ones at which there were obvious inshore-offshore differences in the major phytoplankton dominants. The nearshore assemblage appeared to be dominated by *Stephanodiscus minutus* which comprised more than 50% of the assemblage at many stations on the Kalamazoo River and Muskegon River

TABLE 11. Comparison of river and lake data on phytoplankton at 2 meters on transects off Lake Michigan rivers, April 1972.

Transect	Species		Cells/ml		Diversity		% Diatoms	
	River	Lake	River	Lake	River	Lake	River	Lake
Manistique	34	44	122	1378	3.29	2.70	86.2	90.4
Betsie	76	28	966	894	3.62	2.25	97.2	80.8
Manistee	67	37	513	842	3.57	2.72	100.0	89.8
Pere Marquette	68	35	1047	1007	3.46	2.56	99.2	84.6
Muskegon	61	33	11748	890	1.07	2.56	99.0	91.3
Grand	76	36	3556	1110	2.87	2.63	99.6	91.7
Kalamazoo	64	36	8409	1845	1.70	2.53	98.9	94.5
St. Joseph	74	32	14506	1141	1.65	2.68	99.9	82.9
Milwaukee	48	33	2897	1068	2.75	2.56	99.1	98.2
Manitowoc	54	29	3171	1089	2.65	2.39	95.6	87.3
Sturgeon Bay	42	34	1290	1093	2.97	2.46	93.5	93.1

transects which had no significant tributary influence (Figs. 4b, 6b). *S. minutus* also comprised more than 20% of the assemblage at stations ranging from .4 to 6.4 km offshore on the Grand River and St. Joseph River transects where river species dominated the assemblage at stations closer to shore (Figs. 3b, 5b).

At the Grand River, stations close to the river mouth were dominated by typical river species including *Stephanodiscus subtilis, S. tenuis, Cyclotella meneghiniana* v. *plana,* and *Melosira granulata* v. *angustissima* (Fig. 5b). In the St. Joseph River, *M. granulata* dominated the stations closest to the river and *Stephanodiscus tenuis* was also common (Fig. 3b).

Neither the transects located in the northern half of the lake along the eastern shoreline (Figs. 7b–9b) nor those along the western shoreline in Wisconsin (Figs. 11b–13b) had inshore-offshore differences in species composition of the major phytoplankton dominants. The Wisconsin transects, particularly the one off the Milwaukee River, differed from the northern Michigan transects in that there were larger nearshore than offshore standing crops on the Wisconsin transects. On the Milwaukee River transect more than 2000 cells/ml were found as far offshore as 6.4 km; this density of cells was not present at any station on the northern Michigan transects.

Environmental parameters were more homogeneous on the transects sampled on the western (Wisconsin) side of the lake than on the eastern side. Given the fact that water temperatures on the western side were also homogeneous and $<2°C$ indicates that this condition resulted from upwelling and lakeward spreading of upwelled water. The Wisconsin transects were sampled after a storm period during which seas were too large for sampling causing us to remain in port at Milwaukee for two days.

Offshore phytoplankton assemblages in all areas were dominated by diatoms; the only non-diatom entity present was undetermined flagellates. Only two species, *Cyclotella stelligera* and *Synedra filiformis,* were present as major dominants on every transect and these species were either the most abundant species or among the three or four most abundant species. Only four other species ranked among the most abundant and included *Rhizosolenia gracilis, R. eriensis, Melosira islandica,* and *Fragilaria crotonensis;* all but *R. gracilis* were found as major dominants on the atypical Manistique River transect. A list of dominant species found as offshore dominants on the transects follows:

Species	Transects: St. Joseph Kalamazoo Grand Muskegon	Pere Marquette Manistee Betsie	Sturgeon Bay Manitowoc Milwaukee	Manistique
Cyclotella stelligera	XXX	XXX	XXX	XXX
Synedra filiformis	XXX	XXX	XXX	XXX
Rhizosolenia gracilis	XXX	XXX	XX	–
R. eriensis	–	–	XX	XXX
Melosira islandica	X	X	XX	XXX
M. italica	X	XX	X	–
Asterionella formosa	X	X	XX	–
Tabellaria fenestrata	X	X	X	X
Nitzschia acicularis	–	X	X	X
Fragilaria crotonensis	X	X	XX	XXX
F. pinnata	–	–	X	–
Stephanodiscus minutus	XX	XX	X	–
S. tenuis	X	–	X	–
Undetermined flagellates	X	XX	X	XX

– Not a major dominant.
X Low relative abundance on all transects or not among dominants on all transects.
XX Smaller relative abundance than the three to five most abundant species on transects.
XXX One of three to five most abundant species on transects.

On the eleven transects, there were three patterns of species diversity (Shannon-Wiener information index) which seemed to be related to the location of the transect within the lake. In the southeastern part of the lake diversities appeared to increase slightly from the river mouth out to the offshore stations; this pattern occurred at the St. Joseph River, Kalamazoo River, and the Muskegon River. The Grand River was an exception where diversity was relatively constant along the transect. The three northern rivers, Manistee, Pere Marquette, and Betsie, on the east side of northern Lake Michigan had diversities which were largest at the river mouth and then were relatively constant at the stations on the remainder of the transect. On the western side of the lake, diversities were fairly constant over the length of the three transects with some indication of smaller diversities at the stations located 13 to 52 km offshore on the Sturgeon Bay and Manitowoc River transects, but not on the Milwaukee transect.

A wide range of species diversities was found for the different stations sampled in April. Diversities in general ranged from 2.5–3.0 at offshore stations. Values >3.0 were found only for rivermouth samples and were about 3.5 at the Pere Marquette River, Manistee River, Betsie River, and Manistique River in the northern part of the lake. Diversities <2.0 were found at the mouth of the St. Joseph River, out to a distance 3.2 km offshore from the Muskegon River, and to a distance of .4 km offshore from the Kalamazoo River. An explanation for the low diversity on the Muskegon River transect is not obvious, but since several of these values ranged between 1.0 and 1.5 they are obviously quite different from diversities in other areas sampled.

The nutrient load of the rivers had an obvious effect on the nearshore zone. Only loadings from two rivers, the Grand and St. Joseph, produced large enough nearshore zones to be detected at distances >1.6 km from the river mouth with the methods employed in our sampling. Our sampling design utilized stations on transects perpendicular to shore. This strategy is not ideally suited to delineate the extent of river plumes as water transport is usually longshore (Mortimer 1975). Under some conditions plumes of river water are distinct for distances of ten or more km along shore. Intuitively one would expect the effect of tributary loading on phytoplankton to be manifested in the nearshore zone because nutrients discharged by tributaries to the nearshore can be processed by phytoplankton prior to being diluted or being transported offshore (see Schelske 1978a).

One important chemical factor needed to determine the effect of nutrients on phytoplankton is nutrient availability, particularly availability of phosphorus. Our data are for total phosphorus, which give no information on availability. Large standing crops of chlorophyll *a*, 15 to 20 mg/m^3 (Table 8), were associated with phosphorus concentrations ranging from 20 to 175 μg/liter (Table 7). This broad range of phosphorus concentrations indicates either that much of the phosphorus is not available or that some of the total phosphorus has not been utilized by phytoplankton. Large supplies of phosphorus may be present in the environment and may not be immediately reflected in large standing crops of phytoplankton. Although no data were obtained on reactive phosphate, our data do show that large standing crops of phytoplankton did not develop in the absence of elevated levels of phosphorus.

Differences in the distribution of some species can be related to species trophic preference. It seems apparent that *Cyclotella stelligera, Synedra filiformis,* and *Rhizosolenia gracilis,* which occurred in the greatest relative abundance at the offshore stations, represented populations associated with the most oligotrophic waters that we sampled. According to Tarapchak and Stoermer (1976), *Cyclotella stelligera* and *Synedra filiformis* are characteristic of mesotrophic conditions; *S. filiformis* is tolerant of moderate nutrient enrichment but *Cyclotella stelligera* is intolerant of nutrient enrichment, possibly explaining why *C. stelligera* tended to increase in relative abundance with distance offshore on most transects. At the opposite extreme of trophic conditions, *Stephanodiscus minutus* and *S. tenuis,* which were most abundant in the phosphorus enriched nearshore zone in the southeastern area, are classified by Tarapchak and Stoermer as species attaining maximum abundance under eutrophic conditions. Two other eutrophic species that were present in the southeastern area in high relative abundance were *Melosira granulata* (St. Joseph River and adjacent stations) and *Stephanodiscus subtilis* (Grand River and adjacent stations).

CONDITIONS IN JULY

In July 1972, three rivers and their corresponding transects were sampled intensively over an 11-day period. This sampling was done in conjunction with a nutrient perturbation experiment being conducted in the same area (Schelske *et al.* 1975). The areas sampled were transects off the Grand, Kalamazoo and St. Joseph rivers. For the three transects 309 phytoplankton taxa were identified, of which 209 were diatoms. There were 232 taxa including 149 diatoms on the St. Joseph transect, 175 taxa including 135 diatoms on the Kalamazoo transect, and 194 taxa including 143 diatoms on the Grand River transect.

One factor in common for the three tributary inputs of phytoplankton in July was the large cell densities, ranging to more than 30000 cells/ml at the Kalamazoo and Grand Rivers. Standing crops in the St. Joseph River were smaller but were >10000 cells/ml on eight of the ten days of sampling. Standing crops in the rivers were not directly related to total phosphorus concentrations, which were greatest in the Grand River ranging from 90–190 μg/liter and least in the Kalamazoo River ranging from 50–120 μg/liter. Total phosphorus is not a good variable to use to predict standing crops in river water, because some of the phosphorus may not be available and because phosphorus was probably present in surplus concentrations. Other nutrients measured with the exception of silica were not present in growth-limiting quantities in any of the rivers.

Dominant species among the three river inputs varied greatly. In the Grand River, more than 40% of the cell counts on all dates were due to one species, *Cyclotella atomus.* Smaller relative abundances were due to *C. meneghiniana* v. *plana, C. cryptica,* and *Stephanodiscus subtilis.* In the St. Joseph River there were two major dominants, *S. tenuis* and *Melosira granulata,* with *Cyclotella atomus* occurring in much smaller percentages only during the last half of the experiment. Patterns of relative abundance at the Kalamazoo River were more complex than at the other rivers. *C. cryptica* became the dominant species at the end of the experiment when its relative abundance increased to more than 80% and cell densities in the assemblage increased to a maximum of 37600 cells/ml. At the beginning of the experiment, *C. meneghiniana* was the most dominant species but it decreased in relative abundance during the sampling period. On day 3, the relative abundance of *C. atomus* was 40%. *Melosira granulata* and *M. granulata* v. *angustissima* were also present throughout the experiment but in smaller relative abundances than the three species of *Cyclotella* which dominated the assemblage at different times during the experiment.

Offshore dominants at 3.2 and 6.4 km were variable from day to day and from transect to transect, possibly because these stations were not in the true offshore zone which has been defined by Mortimer (1975) as starting at roughly 10 km from shore. *Cyclotella stelligera, Rhizosolenia gracilis,* and undetermined flagellates were found at every station during July, but these species could not be considered as the only dominants. The extreme variability in species composition can be illustrated best from the changes in relative abundance of *Fragilaria crotonensis,* which was more than 90% on one date, and *Tabellaria fenestrata* which was nearly 50% on one date. Relative abundances of both species ranged to less than one per cent.

Total standing crops at the 3.2 and 6.4 km stations ranged generally from 100 to 500 cells/ml except at the Grand River transect where cell counts ranged from 1500 to 2000 cells/ml during the first part of the experiment. The larger standing crop at the beginning of the sampling period may have been due to upwelling events. This variability in cell counts offshore from the Grand River is additional evidence that offshore waters were not present consistently at distances as near as 6.4 km from shore.

Variability on the transects was also apparent from the patterns of species diversity which were observed. In general species diversity ranged from 1.0 to 2.5 with values at both extremes being found in river samples and in offshore samples.

St. Joseph River

Over the course of the experiment, water temperature in the river increased from <20 to >24° C (Fig. 29). Specific conductance and pH were relatively constant with specific conductance being greater and pH being smaller at the end of the experiment than at the beginning (Fig. 29). The increase in specific conductance and the decrease in pH can both be attributed to variability in river discharge, because specific conductance would be <300 μmhos/cm and pH would be >8.4 in open lake water (Fig. 14).

Nutrient concentrations were not strongly related to water temperature (only four samples were available for nitrate so no trend would be expected). Silica concentra-

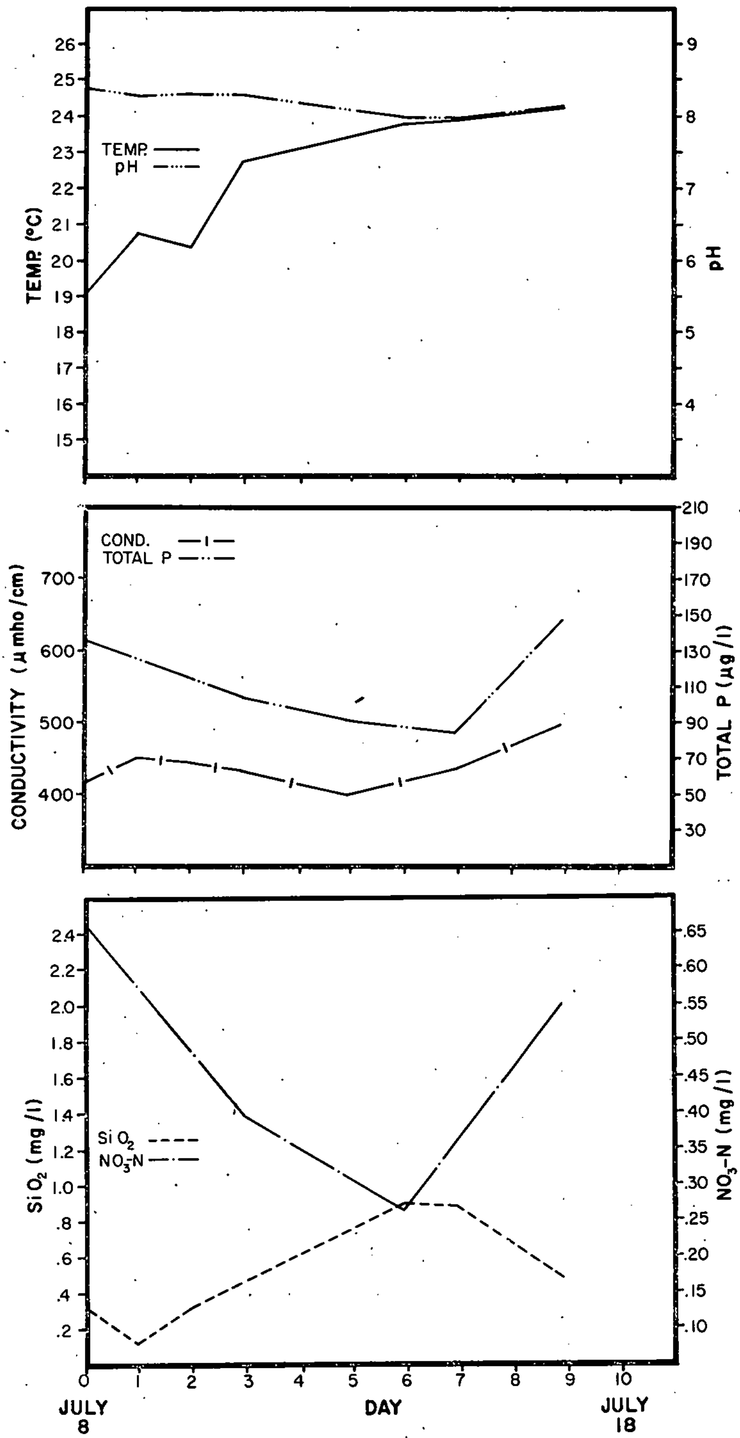

FIG. 29. Variations in physical-chemical conditions at the mouth of the St. Joseph River, July 8–18, 1972. Values plotted are the average of all depths sampled on each date.

tions were least at the beginning of the experiment, largest on days 6 and 7, and then decreased on the last two days of sampling (Fig. 29). The largest values for silica, .9 mg/liter, were two or three times larger than concentrations found in lake water (Fig. 14) and the smallest concentrations <.2 mg/liter were roughly equal to those in lake water. Total phosphorus concentrations, ranging from 90 to 150 μg/liter, were much greater in the river water than concentrations <10 μg/liter found in lake water. Nitrate concentrations were also greater in river water than in lake water.

Kalamazoo River

Temperature in the Kalamazoo River, like that in the St. Joseph River, also increased over the course of the experiment ranging from 17 to 23° C. Unlike the St. Joseph River, specific conductance was lower at the end of the experiment than at the beginning and pH was nearly constant during the experiment (Fig. 30).

Nutrient concentrations appeared to be not strongly related to water temperature. Concentrations of total phosphorus appeared to increase during the period of sampling. The range in concentrations was 50 to 120 μg/liter (Fig. 30). Concentrations of silica and nitrate were quite variable with time, both being generally greater than concentrations in the lake (Fig. 18); silica concentrations ranged from .65 to 2.0 mg/liter and nitrate concentrations ranged from .30 to .75 mg/liter.

Grand River

Like the other two rivers sampled in July, water temperature in the Grand River increased during the period of sampling and ranged from a low of 16° C to a high of 24° C. Like the St. Joseph River, pH tended to be lower at the end of the experiment than at the beginning and specific conductance, although quite variable, tended to be greater at the end of the experiment than at the beginning (Fig. 31).

Nutrient concentrations like water temperature were greater at the end of the experiment than at the beginning (Fig. 31), but the range in concentrations was smaller than that found at the other rivers (Figs. 29, 30). With the exception of day 0, total phosphorus concentrations, ranging from 100 to 190 μg/liter, were much larger than those found in the lake (Fig. 22). Variations of concentrations of silica and nitrate were within those found in the lake. Silica concentrations ranged from .1 to .6 mg/liter whereas nitrate concentrations only ranged from .15 to .25 mg/liter.

CONDITIONS IN SEPTEMBER

Three rivers on the Michigan shoreline were sampled in September 1972. Two of these, Betsie and Pere Marquette, as pointed out above, are relatively unpolluted rivers draining into the northern basin and the Grand River carries a large nutrient load to the southern basin (Table 2).

Temperature

Surface water temperatures in September on the three transects sampled ranged from about 15 to 16° C with little horizontal variation from the river mouth out to

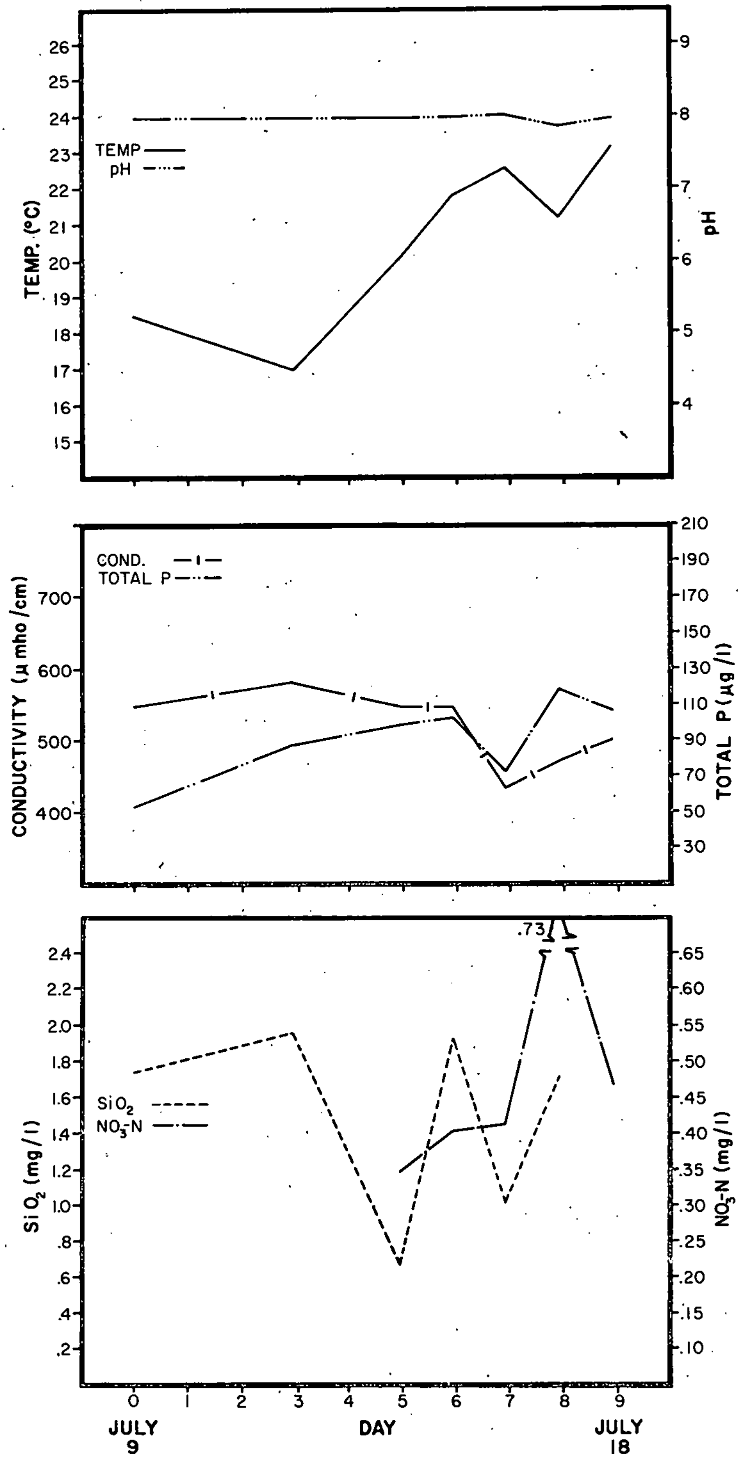

FIG. 30. Variations in physical-chemical conditions at the mouth of the Kalamazoo River, July 9–18, 1972. Values plotted are the averages of all depths sampled on each date.

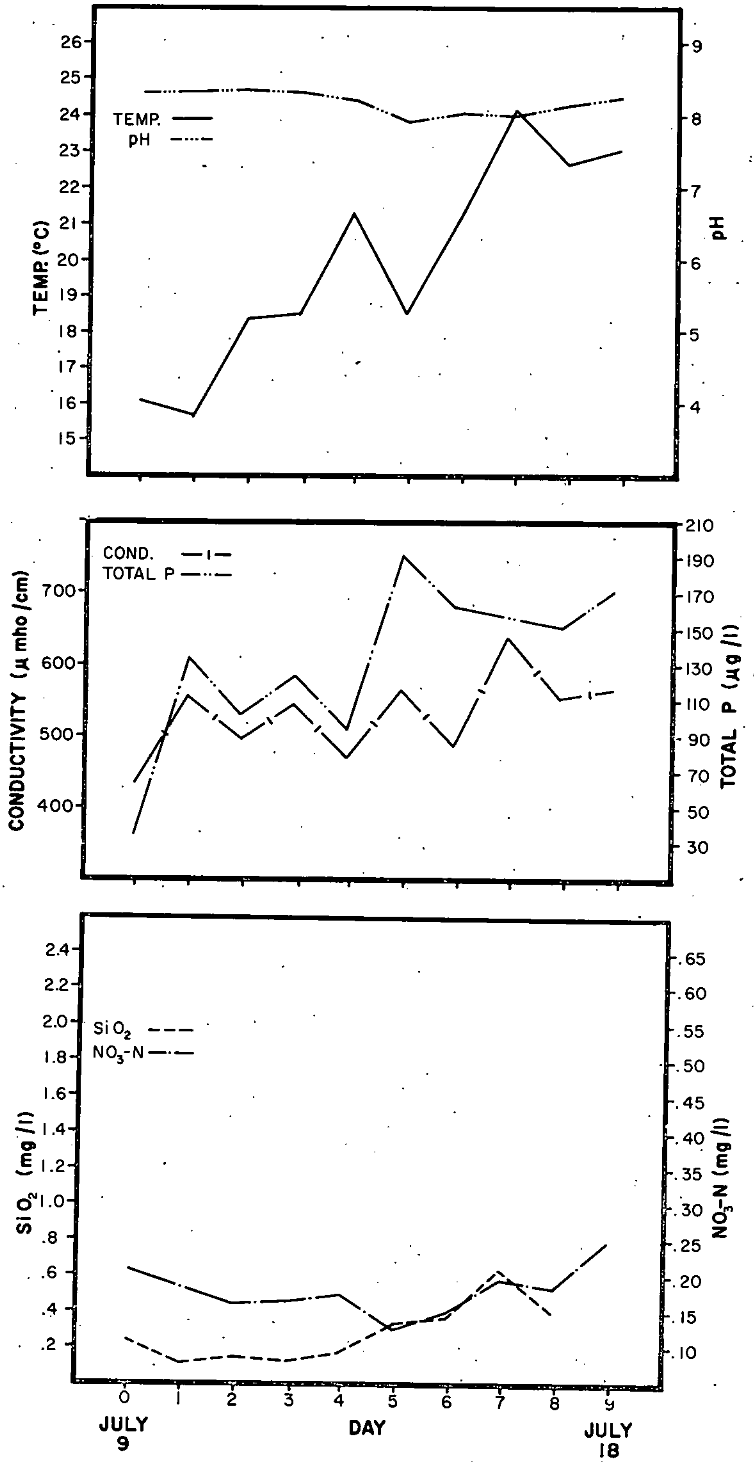

FIG. 31. Variations in physical-chemical conditions at the mouth of the Grand River, July 9–18, 1972. Values plotted are the averages of all depths sampled on each date.

stations 26 km offshore (Table 12). Thermal stratification was present offshore on the Grand River and Betsie River transects, but was not found on the Pere Marquette transect where no samples were collected more than 6.4 km offshore.

TABLE 12. Physical-chemical conditions in the Betsie, Pere Marquette, and Grand Rivers at 2 m September 1972.

Distance offshore (km)	Transects			Distance offshore (km)	Transects		
	Betsie	Pere Marquette	Grand		Betsie	Pere Marquette	Grand
		Temp. °C				Chloride (mg/l)	
0	–	16.1	16.3	0		22.7	16.0
.2	15.8	16.1	–	.2	8.6	8.7	
.4	–	16.0	16.4	.4		8.9	10.1
.8	15.0	16.0	16.5	.8	9.3	8.3	8.7
1.6	–	16.0	16.2	1.6		8.1	9.2
3.2	15.5	15.5	16.0	3.2	7.1	7.8	8.0
6.4	15.1	15.6	16.0	6.4	8.0	7.4	7.5
13	15.0		15.5	13	7.8		7.6
26	–		14.9	26			8.0
		pH				Specific Conductance (μmho/cm)	
0	–	8.31	8.49	0		401	416
.2	8.52	8.56	–	.2	292	288	
.4	–	8.55	8.59	.4		287	321
.8	8.53	8.56	8.59	.8	291	285	321
1.6	–	8.57	8.56	1.6		285	290
3.2	8.54	8.57	8.52	3.2	285	286	284
6.4	8.55	8.56	8.53	6.4	282	283	284
13	8.54	–	8.55	13	275		283
26			8.54	26			283

Hydrogen Ion Concentration

Except at the rivermouth stations of the Grand and Pere Marquette, pH generally was 8.55 with values ranging from 8.52 to 8.59 (Table 12).

Chloride

Concentrations of chloride reflected the patterns of specific conductance discussed above. The Pere Marquette River had a greater chloride concentration than the Grand River (Table 12), but a lower specific conductance, indicating ions in addition to chloride contributed relatively more to the specific conductance of the Grand River.

Physical-chemical conditions in September were less variable than in April due to two factors. Fewer transects were sampled in September and the river temperatures in September varied less from the lake temperatures than in April. Major phytoplankton nutrients were also less variable in September than in April.

Specific Conductance

Water at the mouth of the Grand and Pere Marquette rivers with low pH values had elevated specific conductance (Table 12) with only slightly higher values near the mouth of the Betsie River. On the Grand River transect, high specific conductance was evident at least out to .8 km and possibly to 1.6 km offshore.

Total Phosphorus

Total phosphorus concentration in the Grand River (110 μg/liter) was much greater than in the other two rivers (Table 13). Total phosphorus concentrations on the Grand River transect indicated that the influence of the tributary extended to 1.6 km where the concentration was greater than that in the open lake.

The total phosphorus concentration in the Pere Marquette was also greater than in the open lake, but the one large concentration was restricted to the river mouth.

TABLE 13. Nutrients and chlorophyll in the Betsie, Pere Marquette, and Grand Rivers at 2 m September 1972.

Distance offshore (km)	Transects			Distance offshore (km)	Transects		
	Betsie	Pere Marquette	Grand		Betsie	Pere Marquette	Grand
	Chlorophyll *a* (mg/m^3)				Nitrate Nitrogen (μg/l)		
0	–	13.40	12.77	0	–	.175	.488
.2	2.08	2.22	–	.2	.184	.167	–
.4	–	1.70	8.93	.4	–	.157	.285
.8	1.16	1.88	7.44	.8	.117	.303	.234
1.6	–	1.91	3.32	1.6	–	.159	.185
3.2	1.00	0.51	1.85	3.2	.148	.160	.171
6.4	1.31	1.35	1.31	6.4	.192	.401	.170
13	1.44		1.31	13	.130		.194
26			0.95	26			.186
	Silica (mg/l)				Total Phosphorus (μg/l)		
0	–	1.99	2.56	0		28.9	110.7
.2	0.48	0.44	–	.2	5.7	8.9	
.4	–	0.42	1.01	.4		7.3	25.0
.8	0.30	0.42	1.04	.8	5.4	6.0	27.8
1.6	–	0.40	0.58	1.6		7.2	12.0
3.2	0.27	0.33	0.52	3.2	2.9	8.3	6.9
6.4	0.26	0.29	0.47	6.4	4.5	8.7	5.2
13	0.28		0.31	13	5.6		4.0
26			0.30	26			4.4

Chlorophyll *a*

Chlorophyll *a* concentrations at stations removed from the influence of tributary inputs ranged from 1.0 to 1.9 mg/m^3 (Table 13). Concentrations greater than 3.0

mg/m^3 were associated with total phosphorus concentrations greater than 9.0 mg/m^3 at nearshore stations. On the Grand River transect, higher chlorophyll *a* concentrations could be detected at least 1.6 km offshore.

Nitrate Nitrogen

In the Grand River nitrate nitrogen was 0.5 mg/liter, more than twice as large as concentrations at offshore stations (Table 13) but much less than the concentration of 1.5 mg/liter found in April (Table 9). The Pere Marquette and Betsie rivers had nitrate concentrations similar to those found offshore or about .18 mg/liter.

Silica

Offshore silica values were <0.3 mg/liter (Table 13). These concentrations were greater than the summer minimum which is 0.1 mg/liter or less, probably indicating replenishment of silica during the fall from entrainment of deep water in the surface waters as the thermocline deepens. The concentration of silica in the Grand River was 2.5 mg/liter with greater concentrations than those in the open lake being present out to 6.4 km offshore.

Phytoplankton Standing Crop and Species Composition

Standing crops of phytoplankton were small at the offshore stations, ranging from 200 to 300 cells/ml. Cell counts were largest near the river mouths for all three transects (Figs. 22–24). Samples from September yielded 184 taxa with 133 of these being diatoms.

The Betsie and Pere Marquette Rivers had similar phytoplankton assemblages in that the dominant species was *Fragilaria crotonensis* with *Melosira granulata* forming an important component nearshore. At the offshore stations where silica was reduced, undetermined flagellates and blue-green and green algae (particularly *Anacystis thermalis* and *Oocystis* spp.) comprised more than 25% of the assemblage (Figs. 27–28).

In contrast to the two northern rivers, the influence of the large flow of the Grand River was evident in the phytoplankton composition on the Grand River transect. The river-borne species, *Melosira granulata, Cyclotella atomus, C. cryptica,* and *Melosira distans* v. *alpigena* persisted at stations 3.2 and 6.4 km offshore (Fig. 26). *Asterionella formosa, Fragilaria crotonensis,* and *Cyclotella stelligera* were also common in nearshore samples.

At the offshore stations blue-green algae and undetermined flagellates comprised nearly half the phytoplankton assemblage. *Anacystis thermalis* and *Oocystis* spp. were the dominant blue-green and green algae and *Fragilaria crotonensis* was the dominant diatom.

A similar trend in the phytoplankton data was observed for the three transects in that larger numbers of species were found at stations in the river mouth and in the river plume than were found at the offshore stations. At offshore stations, about 20 species were identified per sample whereas the rivermouth sample for the Grand River contained 97 species (Table 14). Phytoplankton assemblages at the river stations that had adequate quantities of silica were more than 90% diatoms, while the offshore

TABLE 14. Phytoplankton assemblage composition and standing crop at 2 meters, September 1972.

	Distance offshore (kilometers)								
Transect	0	.2	.4	.8	1.6	3.2	6.4	13	26
Betsie									
Per Cent Diatoms		95.8	–	95.1	–	89.2	58.4	76.0	45.1
Per Cent Blue-greens		0.5	–	1.0	–	3.3	5.9	4.5	8.5
Number of species		55		20		17	17	22	22
Total cells/ml		1194		865		448	211	322	297
Pere Marquette									
Per Cent Diatoms	98.9	84.3	81.2	78.8	80.6	68	64		
Per Cent Blue-greens	0.5	7.1	6.0	6.6	3.8	6.6	7.9		
Number of species	68	40	42	27	24	23	22		
Total cells/ml	3776	561	557	574	725	383	395		
Grand									
Per Cent Diatoms	95		91	92	86.3	70.0	63.8	29.1	58
Per Cent Blue-greens	1		1.3	1.1	3.1	10.0	5.4	31.4	15
Number of species	97		78	63	69	47	30	16	21
Total cells/ml	5586		2957	3313	1131	566	312	180	191

assemblages included several dominants that were not diatoms. The percentage of diatoms at offshore stations ranged from 29 to 76 with the smaller percentages being related to silica values of about 0.3 mg/liter (Table 15). It should be noted that the standing crops at the offshore stations were small so that in absolute terms the populations of blue-greens, greens and undetermined flagellates are not in the category that could be called nuisance blooms. In addition, it has been pointed out by Stoermer (1978) that the shift in phytoplankton in Lake Michigan from assemblages dominated by diatoms to those dominated by species not requiring silica occurs in the fall and not during the summer when nuisance blooms might be expected. Presumably greater nutrient enrichment than that which has occurred in Lake Michigan is needed to develop summer blooms.

As in April, the largest numbers of species on the three transects sampled were found at the nearshore stations; numbers ranged from 55 at the Betsie River to 97 at the rivermouth station in the Grand River. Numbers of species decreased with distance

TABLE 15. Comparison of phytoplankton composition, chlorophyll *a* (mg/m^3) and silica (mg/liter) conditions for river and open lake stations, September 1972.

	% Composition									
	Diatoms		Greens		Blue-greens		Chl *a*		SiO_2	
Transect	River	Lake	River	Lake	River	Lake	River	Lake	River	Lake
Grand	95.3	29.1	2.0	23.3	0.9	31.4	12.8	1.3	2.56	0.31
Pere Marquette	98.9	64.0	0.4	13.8	0.46	7.9	13.4	1.4	1.99	0.29
Betsie	95.8	76.0	3.5	13.0	0.5	4.5	2.1	1.2	0.48	0.29

offshore, ranging as low as 16 or 17 species on the Grand River and Betsie River transects to 22 species on the Pere Marquette River transect. The large flow of the Grand River obviously influenced the number of species at offshore stations: at the station 3.2 km from shore more than 45 species were found whereas on the other transects only about 20 species were present at this distance from shore.

The pattern for diversities in September was different on each of the three transects. In the Grand River the high diversity of about 3.0 was maintained out to a distance 3.2 km offshore (Fig. 26). Beyond this point where the number of species decreased drastically (Table 14) the diversity also decreased, being in the range of 2.1–2.7. The range of diversities on the Betsie River transect was relatively small, ranging from 1.3–2.4 (Fig. 28) over the transect with the lowest diversities being found at the stations .8 and 3.2 km from shore. Even though the number of species at the river mouth in the Pere Marquette River was large the diversity at this station was only 1.5 (Fig. 27). The diversity did, however, increase at stations located .2 and .4 km from shore. At the offshore stations 3.2 and 6.4 km from shore the diversity ranged from 2.1–2.5, a range found also at the offshore stations on the other two transects.

REPRESENTATIVE VALUES FOR PHYSICAL-CHEMICAL VARIABLES

Students of the Great Lakes often search for representative values for different environmental variables, but obtaining such data from the diverse literature sources on Lake Michigan is somewhat difficult. There are two basic problems. First, many data are not correct due to any one of several problems which can be grouped under faulty analytical procedures. These data then in fact have no useful purpose and should not be considered as being representative of conditions in the lake. Second, many variables, particularly conservative substances, have changed with time which has been convincingly documented by Beeton's studies (Beeton 1965, 1969). Representative values for these variables and others therefore also have changed with time. It should be obvious to the researcher interested in analyzing historical data that the major problem is to separate the data into two categories, those data which are accurate and those which are not. The serious student will quickly discover that there is a paucity of accurate chemical data for many variables.

Historical chemical data for Lake Michigan have been compiled by Torrey (1976), but unfortunately not enough attention was given in this important work to evaluating the quality of data nor in determining which data were actually representative of conditions in the lake. Beeton's papers are still the only ones to deal with the questions: have chemical conditions changed? and what are or were the concentrations of different substances? Recently, Schelske (1978c) analyzed the historical data on silica and concluded that this nutrient, required for diatom growth, decreased in concentration by a factor of two or three in 15 years to levels which as early as 1969 limited diatom growth during the summer (Schelske and Stoermer 1971).

In this paper we have compiled representative values for selected physical-chemical variables in Lake Michigan. Values for offshore waters were obtained mainly from Rousar (1973) because they represent the best set of published seasonal data and they compare well with other data available (Schelske 1977). A large but to date unpublished data set was obtained during 1976 as part of the U.S. Environmental Protection Agency study of Lake Michigan. Data are presented as ranges which with the exception of total phosphorus and total alkalinity are extremes resulting from seasonal cycles. Nearshore data are included to illustrate inshore-offshore differences and to represent extreme conditions that occur near major nutrient inputs. Some of these data are obviously biased toward the most enriched nearshore zones and would represent only selected nearshore areas, particularly those in the southern half of the lake.

Data collected in this study support the conclusion that phosphorus supplies to the lake control the growth of phytoplankton (Schelske and Stoermer 1971). In addition the data also confirm the hypothesis that silica depletion resulting from increased diatom growth in the lake would affect the species composition by reducing the proportion of diatoms and increasing the proportion of green and blue-green algae in the assemblage. On the transect off the St. Joseph River in April, silica concentrations that are limiting to diatoms were present in the nearshore waters .4 and .8 km from shore (Table 10). This condition developed even though the offshore water temperature was <4° C (Table 3). In addition, proportions of diatoms in offshore waters in September were less than those at the nearshore and river stations where silica concentrations were more than adequate for diatom growth in contrast to concentrations at the lake stations which were approaching levels that are physiologically limiting for diatom growth.

Reliable historical data on nutrients in offshore waters are very limited for Lake Michigan (Beeton 1969), and we believe that most of the reliable data have been published since 1970. Some silica data are available dating back to 1954 (Schelske 1978c); the winter maximum, 1.4 mg/liter in 1972 (Table 16), was probably>4.0 mg/liter in 1954. No attempt has been made to analyze data on the different forms of inorganic nitrogen, but a seasonal cycle in net rate concentration does occur (Table 16), and the degree of summer nitrate depletion has been related to phosphorus loading (Schelske 1975). Reliable phosphorus data appear to be quite limited; the average concentration of total phosphorus based on seasonal data collected between 1970 and 1972 and in 1976 was 8 μg/liter and does not appear to vary greatly over the lake basin (Schelske 1977, Bartone and Schelske in prep.). An obvious seasonal trend is not apparent, but detecting changes in concentration of a nutrient like phosphorus which is present in small and variable concentrations is extremely difficult in a system as physically complex as Lake Michigan (Schelske 1978b).

Due to the large thermal inertia in the system, lake temperatures lag considerably behind those in the atmosphere. Minimum temperatures occur in late February and

TABLE 16. Representative values for physical-chemical variables in offshore and nearshore waters of Lake Michigan. Range with the exception of data for total phosphorus and total alkalinity is due to seasonal cycles. See text for additional explanation of data.

	Offshore	Nearshore
Temperature (°C)	0.1-24	0.1-24
pH	8.1-9.0	7.9-9.1
Total alkalinity (meq/liter)	2.04-2.17	2.06-2.23
NO_3-N (mg/liter)	0.10-0.28	0.010-1.0
NH_3-N (mg/liter)	<0.025	
SiO_2 (mg/liter)	<0.1-1.4	<0.1-3.0
Total P (μg/liter)	5-10	15-150
Chlorophyll *a*, (mg/m^3)	0.7-2.7*, 1.0-4.5**	2->20

*Ladewski and Stoermer (1973).
**Rousar (1973).

March in the open lake and occur earlier in shallow waters than in deep offshore waters. Maximum temperatures are found during August and early September. Roüsar (1973) reported minimum temperatures in offshore waters during March. Values were as low as 0.1°C for samples collected from 4 m at three offshore stations between Ludington and Milwaukee. Mortimer (1975) concluded from the few offshore winter observations available that the waters are probably mixed to the bottom in the southern half of the basin, with some evidence (Verber 1963) that inverse stratification may persist in the deepest part of the northern basin. Verber found temperatures close to that of maximum density below 600 ft. (183 m), but <2.0°C in the upper 300 ft. (91 m). It appears likely therefore that the entire lake, except perhaps for the deepest trough, may cool to temperatures <2.0°C in some years.

More detailed data on the thermal cycle and stratification as well as other information on physical limnology are available in Mortimer (1975).

Hydrogen-ion concentration or pH in Lake Michigan is considerably larger than 8.0, the value frequently cited from Beeton and Chandler (1963). This fact was pointed out by Schelske and Roth (1973) from data collected in 1970; more extensive data collected since 1970 have confirmed that fact. The difference may be due in part to earlier measurement and analytical errors (pH now is routinely measured on shipboard with sensitive electrodes), but part of the change must be attributable to increased photosynthetic activity and eutrophication that have been reflected in widespread occurrences of milky water, precipitation of calcium carbonate (Ayers *et al.* 1967, Ladewski and Stoermer 1973, Schelske and Callender 1970).

A trend of increasing values for pH in Lake Michigan in the last 20 years at first may appear to contradict the rather widespread acidification of many lakes due to the input of acid rain. Murphy (1978), however, has shown that one would not expect acidification of Lake Michigan due to its high alkalinity, which is adequate to neutralize projected inputs of atmospheric H_2SO_4. In addition, carbonate rocks in the drainage basin provide additional buffering to counteract increased acidic inputs.

Two sets of seasonal chlorophyll data are available for the years 1970 and 1971 (Rousar 1973, Ladewski and Stoermer 1973). Both data sets show a relatively low midsummer concentration of chlorophyll *a* with average values ranging from 0.7–1.0 (Table 16). Values for the spring bloom from the two studies would appear to be quite different with the mean for Ladewski and Stoermer's data being 2.7 in 1971 compared to a mean of 4.5 for Rousar's data from 1970 and 1971. Ladewski and Stoermer's earliest samples were from April and as a consequence the spring bloom in the southern basin may have occurred earlier. Rousar's higher values came from two cruises, one in late May and the following one in early June when water temperatures were in the 6 to 8°C range, creating physical conditions ideally suited for the spring bloom. In addition, data from Ladewski and Stoermer are averages of several stations and not the seasonal extremes.

Chlorophyll *a* concentrations in nearshore waters are much larger than those in the offshore waters reflecting larger inputs of nutrients, particularly phosphorus (Table 16). In our study the largest concentrations of chlorophyll *a*, exceeding 20 mg/m^3, were found offshore from the St. Joseph River, Grand River, and Muskegon River transects (Table 8), and probably represent some of the largest concentrations that have been found in Lake Michigan, excluding Green Bay. Maximum concentrations of 15 mg/m^3 were found by Rousar (1973) and Ladewski and Stoermer (1973) during the spring.

The large nutrient input from the Fox River creates highly eutrophied conditions in southern Green Bay. Chlorophyll *a* concentrations in the Fox River as it enters Green Bay averaged more than 40 mg/m^3 during the summer (Sager and Wiersma 1972, Patterson *et al.* 1975): In July 1971, Rousar and Beeton (1973) found chlorophyll *a* concentrations >120 mg/m^3 in southern Green Bay near the mouth of the Fox River and concentrations >20 mg/m^3 at stations located as far as 25 km from the mouth of the Fox River. Concentrations of total phosphorus 25 km from the Fox River ranged from 50 to 60 μg/liter, but nearer the Fox River concentrations were much greater, ranging from 350 to 430 μg/liter.

Nearshore data are highly variable for any given site and between sites for most periods of the year. It is therefore definitely beyond the scope of this paper to analyze or describe seasonal dynamics of the nearshore zone. Data presented in this report serve to document, and a number of references have been cited to confirm, the presence of nearshore variability. For the person interested in this type of data or research, large amounts of information exist in the records maintained at municipal water intakes and from environmental studies conducted in relation to siting and operation of large electrical power generating facilities. The researcher who is unaware should be cautioned that these data may not be representative of the open lake. Such sources of data could be used to describe the nearshore zone, but due to the presence of inshore-offshore differences in environmental variables (Beeton and Edmondson 1972) this analysis would not necessarily be applicable to the description of the major mass of open lake water.

SUMMARY

A very large data set was obtained on the nearshore environment of Lake Michigan during 1972. The data set is probably unique in that samples were collected and analyzed for a number of physical-chemical parameters and for phytoplankton standing crop and species composition. Phytoplankton identified during the study totaled 431 taxa of which 306 were diatoms, which serves to illustrate the magnitude of available data.

Results are presented for eleven different transects sampled in April and for three of these transects which were sampled in September. In addition, transects for the St. Joseph, Kalamazoo, and Grand Rivers were sampled four or five times and each of these rivers were sampled from seven to eleven times in July. Data collected with depth presented in this report include water temperature, Secchi disc transparency, pH, specific conductance, dissolved reactive silica, nitrate nitrogen, and total phosphorus as physical-chemical variables. On transects samples with depth were obtained at stations 0, .2, .8, 1.6, 3.2, 6.4, 13, 26, and 52 km from shore, although the stations from 13 to 52 km were not sampled on every transect. Data related to phytoplankton include species composition and abundance, species diversity, chlorophyll *a*, and rates of carbon fixation. All these data were obtained only at 2 meters.

CONDITIONS IN APRIL

Data collected in the spring of 1972 show a large amount of variability among the rivers sampled and the nearshore areas influenced by the rivers. The Manistique River differed greatly from the other rivers sampled. It differed chemically with a pH of 7.4 (Table 4), low specific conductance (Table 6), and low chloride (Table 5). Although not measured directly, it was obvious that the river carried a greater organic load than any of the other rivers sampled. The water was foamy and contained wood chips and fibers from pulp and paper production. These polluted conditions contributed to a low standing crop of phytoplankton with a small number of species (Table 11). Even though total phosphorus and other nutrients were present in the Manistique River in concentrations similar to some of the other rivers, cell counts and chlorophyll were comparatively low.

Offshore temperatures at stations >3.2 km from shore generally fell in the range of 1-2° C with some being $<1^\circ$ C (Table 3). Although these temperatures would appear to be quite low, they are certainly not unrealistic. Rousar (1973) found surface temperatures $<1^\circ$ C in mid lake during winter and also found that in general water temperatures in the lake decreased through the month of March. These low offshore temperatures in April then reflect the large thermal inertia of a deep, large body of water.

In the open lake pH ranged from >8.55 at the stations off the St. Joseph River to <8.5 or 8.45 on many of the other transects. In general, pH on the Michigan side of the lake appeared to be highest at the south end of the lake and lowest at the north end of the lake, a trend probably related to slightly higher temperatures (faster warming) and to earlier and greater phytoplankton activity in the southern end of the lake.

Chloride concentrations offshore approached 8 mg/liter at most stations. Although in general these concentrations were <8 mg/liter they were all generally >7.8 mg/liter, indicating that chloride in offshore waters was still increasing from earlier surveys and results obtained by Beeton (1965). The trend of increasing chloride concentration in offshore water continued at least through 1976 when chloride concentrations over most of the lake were probably 8 mg/liter or possibly slightly greater (Schelske 1978b).

Although concentrations on some transects were about 1.0 mg/liter, silica concentrations in the open lake were for the most part in the range of 1.2–1.4 mg/liter. All samples from transects on the western side of the lake had silica concentrations at the low end of the range.

Open lake values for nitrate appeared to range from .25–.30 mg/liter with many of the values being in the range of .27–.30 mg/liter. Patterns in these data were more difficult to discern than those for silica, possibly either due to more variability in the data or to the fact that phytoplankton utilize the available pools of nitrogen less rapidly than the available silica (Schelske 1975).

Total phosphorus at all the offshore stations was <10 μg/liter. These data indicate that the total phosphorus concentrations are small. Although concentrations change seasonally and spatially, Schelske (1977) concluded that an average of 8 μg/liter was representative of the open lake.

The largest chlorophyll *a* concentrations, ranging from 10 to >20 mg/m^3, were found at the river mouth and at stations as far offshore as 3.2 km on the Muskegon River, Grand River, and St. Joseph River transects. Chlorophyll *a* concentrations several times larger than the offshore concentrations were also found at the nearshore stations on the Kalamazoo River and Milwaukee River transects. In the offshore waters, chlorophyll *a* concentrations were generally <2 mg/m^3: on most transects these concentrations were found either 6.4 or 13 km from shore.

Standing crops of phytoplankton in the open lake, measured by cell counts, were similar over all transects. Cell counts ranged from 800 to 1800 cells/ml with most of the counts ranging between 800 to 1100 cells/ml. Cell counts higher than 1100 cells/ml were found only off the Manistique transect and the Kalamazoo transect. The Manistique area was not typical of the rest of the lake so this deviation is probably not important.

The species composition of the offshore phytoplankton was similar for all areas of the lake. On the transects from the eastern shore, *Cyclotella stelligera, Rhizosolenia gracilis,* and *Synedra filiformis* were the most dominant species. In addition *Stephanodiscus minutus* was present in varying relative abundances. *Melosira italica* was a dominant species on the northeastern transects but not on the southeastern. *Tabellaria fenestrata, Asterionella formosa,* and *Melosira islandica* were dominant species on some of the southeastern transects. One outstanding feature on the Kalamazoo and Muskegon transects was the dominance of *Stephanodiscus minutus* over the entire transect. On the Wisconsin transects, there were no new offshore dominants, but *Fragilaria pinnata,* a benthic species, was abundant in the nearshore waters of the Manitowoc transect and was found also in smaller relative abundances on the Milwaukee transect.

Largest numbers of algal species generally were found nearshore and at the river mouth; however, the largest number of species, 96, was found at the station 1.6 km offshore on the Grand River transect. On this transect, all stations <1.6 km from shore had larger numbers of species than the rivermouth station, which had 76 species. At nearshore stations on the east side of the lake, at least 60 species were found; whereas on the west side of the lake all the nearshore stations had <60 species each. In general, the number of species decreased with distance offshore. At the open lake stations located >1.6 to 3.2 km offshore, numbers ranged generally from 30–50 species. Numbers of species at the open lake stations 6.4 km or more offshore ranged generally from 28 to 37.

CONDITIONS IN JULY

In July, transects off the St. Joseph, Kalamazoo, and Grand Rivers were sampled. River water was characterized by larger standing crops of phytoplankton and greater concentrations of total phosphorus than the lake waters. Standing crops in river water ranged to a maximum of 37600 cells/ml (80% were *Cyclotella cryptica*) in the Kalamazoo River compared to standing crops at 3.2 and 6.4 km from shore which were generally in the range of 100 to 500 cells/ml. Total phosphorus concentrations in river water ranged as large as 190 μg/liter compared to lake concentrations which were <10 μg/liter.

River inputs of phytoplankton for each river were fairly consistent in terms of species composition. In the Grand River, *Cyclotella atomus* comprised more than 40% of the cell counts on all dates. In the St. Joseph River there were two dominants, *Stephanodiscus tenuis* and *Melosira granulata.* At the end of the sampling period, *Cyclotella cryptica* dominated the assemblage at the Kalamazoo River, but *C. meneghiniana, C. atomus, Melosira granulata,* and *M. granulata* v. *angustissima* were dominant species at other times.

Upwelling of deep waters occurred during the sampling as evidenced by surface water temperatures which ranged from 11 to 23°C on the Grand River transect. Possibly as the result of upwelling and the nearshore location of stations, considerable variability in species composition and to a lesser extent in standing crop occurred between the 3.2 and 6.4 km stations. *Cyclotella stelligera, Rhizosolenia gracilis,* and undetermined flagellates were present at all stations, but in varying relative abundances, and could be considered as only some of the dominant entities. Species diversity was also variable, ranging generally from 1.0 to 2.5 with no apparent pattern in space or time.

Physical-chemical conditions on the transects were also variable during the July experiment. Surface water temperatures ranged from 11–23°C at the Grand River transect with smaller ranges at the other transects indicating that upwelling occurred during the experiment. Values for pH were generally in the range of 8.5 to 8.65 with values >8.7 occurring on the Grand River transect. Surface silica concentrations were low on all transects, ranging generally from .2 to .5 mg/liter. Surface nitrate concentrations were variable, ranging from .12 to .22 mg/liter with the larger values probably reflecting inputs from upwelling.

CONDITIONS IN SEPTEMBER

Three transects sampled in September were the Grand River, Pere Marquette River, and Betsie River. Temperature and pH at the lake stations were quite uniform, water temperature ranged from 15 to 16°C, and pH ranged from 8.55 to 8.59 at most stations.

River inputs affected conditions in the lake only on the Grand River transect. Chlorophyll concentrations in the Grand River and Pere Marquette River were 13 mg/m^3 compared to a range of 1–2 mg/m^3 at the offshore stations. *Melosira granulata* and to a lesser extent *Fragilaria crotonensis* and *Asterionella formosa* were major components in the phytoplankton assemblages in the Pere Marquette and Betsie Rivers. These three species and several others were dominants in the Grand River. Standing crops in the rivers ranged from 1000 to 5000 cells/ml.

Standing crops of phytoplankton at the offshore stations generally ranged from 300 to 800 cells/ml, but were 200 cells/ml at the 13 and 26 km stations on the Grand River transect. Silica concentrations decreased slightly with distance offshore to a minimum of .3 mg/liter. Where silica concentrations were lowest, the phytoplankton assemblage contained larger proportions of *Anacystis thermalis* and *Oocystis* spp. than at the stations closer to shore. *Cyclotella stelligera* and undetermined flagellates were dominants at the offshore stations. *Fragilaria crotonensis* was the dominant species at all stations on the Betsie River and Pere Marquette River transects.

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