THE INFLUENCE OF A POWER PLANT'S COOLING WATER EFFLUENT ON THE PHYTOPLANKTON POPULATIONS AND CORRESPONDING PRIMARY PRODUCTIVITY NEAR THE WESTERN SHORE OF LAKE ERIE

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ABSTRACT

THE INFLUENCE OF A POWER PLANT'S COOLING WATER EFFLUENT ON THE PHYTOPLANKTON POPULATIONS AND CORRESPONDING PRIMARY PRODUCTIVITY NEAR THE WESTERN SHORE OF LAKE ERIE

By

Thomas Vern Kreh

Phytoplankton populations near the western shore of Lake Erie were studied at one-month intervals from 16 April to 12 November 1971 in conjunction with the first year operation of a steam-electric generating facility. Estimates of phytoplankton numbers, volumes and species composition were made from samples collected in cooling water sources which included the Raisin River and Lake Erie (three stations) as well as the plant discharge canal. Gross primary productivity (GPP) was examined approximately twice per month using the light-dark bottle oxygen method from 21 May 1971 to 14 June 1972. Also experiments were conducted to determine the effects of transferring water samples in various parts of the cooling system on GPP.

During the study period, algal concentrations near the Monroe fossil fuel plant varied from 1,791 X 10^3 counts/liter to 23,289 X 10^3 counts/liter. There was no statistically significant difference between pre-operational densities (1970) and post-operational densities (1971) for the spring, summer and fall growing seasons. In addition, no yearly statistical differences in total algal cell volume were evident among the three seasons.

Among the three major algal classes, diatoms were most abundant in April, May and November; green algae predominated in June and July; and blue-green algae dominated in August. No differences in class volumes

could be detected for 1970 and 1971 except in the case of higher summer diatom volumes during 1971.

A total of 184 phytoplankton species were observed during the study period in 1971. More species comprised a significant percentage of the total volume in 1971. The river and discharge stations consistently contained higher numbers of species and greater species diversity than lake stations.

At the lake station, higher GPP at all measured depths below the surface occurred in 1971 compared to 1970, independent of plant operation. This was probably caused by greater light penetration in 1971. Average midday hourly GPP was highest at the discharge site and lowest in the river. Community respiration was lowest at the lake station and highest at the river station. Ratios of daily GPP and community respiration were lower at the discharge site during summer and fall 1971 relative to 1970 ratios. Cooling water use appeared to directly affect these ratios.

Cooling system experiments indicated that stimulation of intake GPP occurred at ambient temperatures of 16 C (Δ t = 9 C) but at intake temperatures of 26 C (Δ t = 9 C), inhibition of GPP resulted. In both experiments, cooling water returned to the lake environment exhibited a GPP similar to the lake GPP which indicated rapid community recovery. Community respiration of intake water was generally higher at temperatures of the discharge canal but decreased when incubation of discharge water occurred at the lake station.

GPP was slightly stimulated in the discharge canal and community respiration was stimulated even more so. Most of the community respiration appears to be heterotrophic rather than of phytoplanktonic origin because algal biomass accumulations occured in discharge water comcomitant with higher than expected respiration. Apparently the cooling system acted to stimulate GPP and even more so the heterotrophic consumption of organic detritus so the net effect on the lake was to decrease organic input without effectively altering GPP in the lake proper.

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A THESIS

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in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

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1973

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To all my fellow graduate students I will always recall the enlightening discussions in which we engaged, and especially to T. J. Edwards and J. D. Lu for their willing assistance in the field work. I would also like to thank J. Ashley and R. Freeman for their field support. I wish to thank K. Hunter for diatom slide examinations as well as T. Ecker and C. Annett for providing chemical data.

Support was made possible through the Detroit Edison Company by way of a contract with the Institute of Water Research to whom I am indebted for the study opportunity. Partial support of the Michigan State University computer laboratory use time was made possible by the National Science Foundation.

And to my wife, Kathleen, for her constant encouragement and inspiration for her ceaseless perseverance in typing the manuscript, I am deeply indebted. Appreciation is also extended to my relatives and friends for their interest and concern.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This paper focuses on the effects of a steam-electric generating facility's heated effluent on phytoplankton populations and corresponding primary productivity in waters near the western shore of Lake Erie. The post-operational data presented in this report is compared to pre-operational data gathered during 1970 studies (Marcus, 1972). This report is one in a series of terrestrial and aquatic impact studies embarked upon to assess the influence of a fossil-fuel plant on the physical, chemical, and biological limnology of the study area.

In recent accounts, western Lake Erie has been described as highly enriched and photosynthetically very productive. Davis (1964) reported a consistent increase in phytoplankton numbers off Cleveland, Ohio, between 1920 and 1963 and associated this change with increased nutrient additions. Although no comparable data has been reported for the western basin, some reports have suggested that standing crops have also increased there during the past century. Abundances of phytoplankton are presently concentrated enough to cause periodic nuisances (FWPCA, 1968) at beaches, marinas, etc. Recent (1969) summer beach samples from the western shore of Lake Erie averaged 4,000 counts of algae/ml of water (Mich. DNR, 1970). Further alteration of the phytoplankton community may occur at least locally in the vicinity of a large steam-electric station. Particularly in eutrophied environments the potential changes may aggravate nuisance algal growths. Given a man-made temperature increase, biologists have predicted potential changes in: (1) species composition, (2) average cell size, (3) biomass, (4) species diversity, (5) gross primary productivity (GPP), and (6) respiration (R).

All biological processes involve complex temperature-dependent physical and chemical activities. Photosynthetic rates are controlled by two physiological processes, i.e.: photochemical and thermochemical (Giese, 1962; cited in Hoar, 1966). Light absorption by photosynthetic pigments (photochemical) is limited at lower temperatures while enzymatic reactions (thermochemical) are controlled at relatively high temperatures when the chlorophyll mechanisms are saturated with light energy. Within the algal species' tolerance limits, metabolic rates nearly double with temperature increases of 10 C (the Q_{10} value). Patrick (1969) has proposed that as upper limits of temperature tolerance for an algal species are approached, cellular respiration will comprise most of the metabolism. With increases in temperature, the respiration by the whole community (R) should increase more than gross primary productivity (GPP) because respiration is a characteristic of all life whereas GPP is only a function of plants.

A considerable body of data is now accumulating on thermal effects in once-through cooling systems; particularly in marine environments. Generally, thermal wasting stimulates primary productivity until some upper ambient temperature is reached. The point at which temperature rise becomes inhibitory depends at least on the thermal history of the environment, the change in temperature across the condenser and the kinds of organisms present in that aquatic system. Warinner and Brehmer (1966) examined temperature changes (Δ t) as related to primary productivity. At ambient water temperatures of 10 C and in the presence of a Δ t of 5.4 C, carbon-14 uptake rates increased over controls but at ambient temperatures of 15 C and given the same Δ t, photosynthetic rates

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decreased. Morgan and Stross (1969) reported that stimulation of carbon uptake (C-14) occurred at or below ambient temperatures of 16 C but uptake was inhibited at temperatures of 20 C or greater (given a Δ t of 8 C). An estimate of the recovery ability of enclosed communities when transferring post-condenser water to pre-condenser conditions (Δ t = 15 C) was reported by Suchanek (1971). Essentially no differences in oxygen evolution occurred between discharge water incubated at the intake compared to discharge water incubated in the discharge canal.

Changes in community structure as measured by species composition and diversity indices are also useful indicators of the degree of stress induced in phytoplankton populations subjected to condenser passage. It is assumed that an unstressed environment will support the largest number of species. Few field studies have dealt with direct influences of heated effluents on community composition. Gebelein (1971) followed the trend in the number of phytoplanktonic diatom species collected in both intake and discharge samples at Northport, New York (Δ t = 15 C) and reported no significant differences between stations throughout the year. More studies have emphasized thermal effects on periphyton communities in lotic systems with the temperature appearing to be the controlling factor. Patrick, et al. (1969) found that diatom species of White Clay Creek artificially exposed in situ to temperatures averaging 34.2 C or above were eventually replaced by blue-green algae in a few days time. Other authors have described the species composition of thermally adapted algae in hot springs but these exceptional environments (60 C) are unlike those found in the vicinity of power stations releasing heated effluents having maximum temperatures of 35-40 C.

Morphological changes, such as decreased cell size, may be effected when the upper temperature limit for a species is exceeded (Patrick, 1969). This may be particularly important to algae taxonomy in a given study area.

Generally, the question to be addressed is whether the intermittent operation of a 3,200 megawatt (MW) fossil fuel plant has influenced the phytoplankton populations in a stimulatory or inhibitory manner. But specifically the following hypotheses will be tested and are discussed herein: (1) numbers of algae will increase, (2) cell biomass (volume) will increase, (3) species composition will change from diatoms to green and blue-green algae, (4) the number of species will decrease, (5) the species diversity will decrease, (6) gross primary productivity will increase, (7) community respiration will increase even more than gross primary productivity, and therefore, (8) GPP/R ratios will decrease.

DESCRIPTION OF THE STUDY AREA

Previous reports have described the study area in detail (Cole, 1972; Marcus, 1972; Nalepa, 1972; Parkhurst, 1971) regarding the physical, chemical and biological character determined in a comprehensive survey at the Monroe Power Plant site. The study area has a variety of habitats that could be affected by the discharge of cooling water. The power plant is situated on the filled-over, former Raisin River delta on western Lake Erie near Monroe, Michigan (Figures 1 and 2). The intake of the once-through cooling system is designed to take all river water available along with supplementary lake water which is drawn through the old river mouth. A dredged discharge channel, 2.5 km long, 150 m wide and having a mean water depth of 7 m, was constructed in 1970 to receive the cooling water once it passes through the condensers.

The Raisin River receives municipal wastes and reprocessed paper wastes from the city of Monroe less than 2 km upstream from the intake for the cooling system. A yearly dredging schedule is maintained in the last 2 km of river to remove organic sludge buildups and permit the passage of large vessels into a small harbor near Monroe. An industrial plating operation discharges wastewater 1 km above the plant intake where it is mixed with river water. All of these river disturbances cause a distinct difference in the quality of the water between the river and the lake. The quality of water masses in the western basin of Lake Erie are probably most influenced by inflows from the Detroit River (95%) and the Maumee River (2%). Wind-induced currents most frequently move

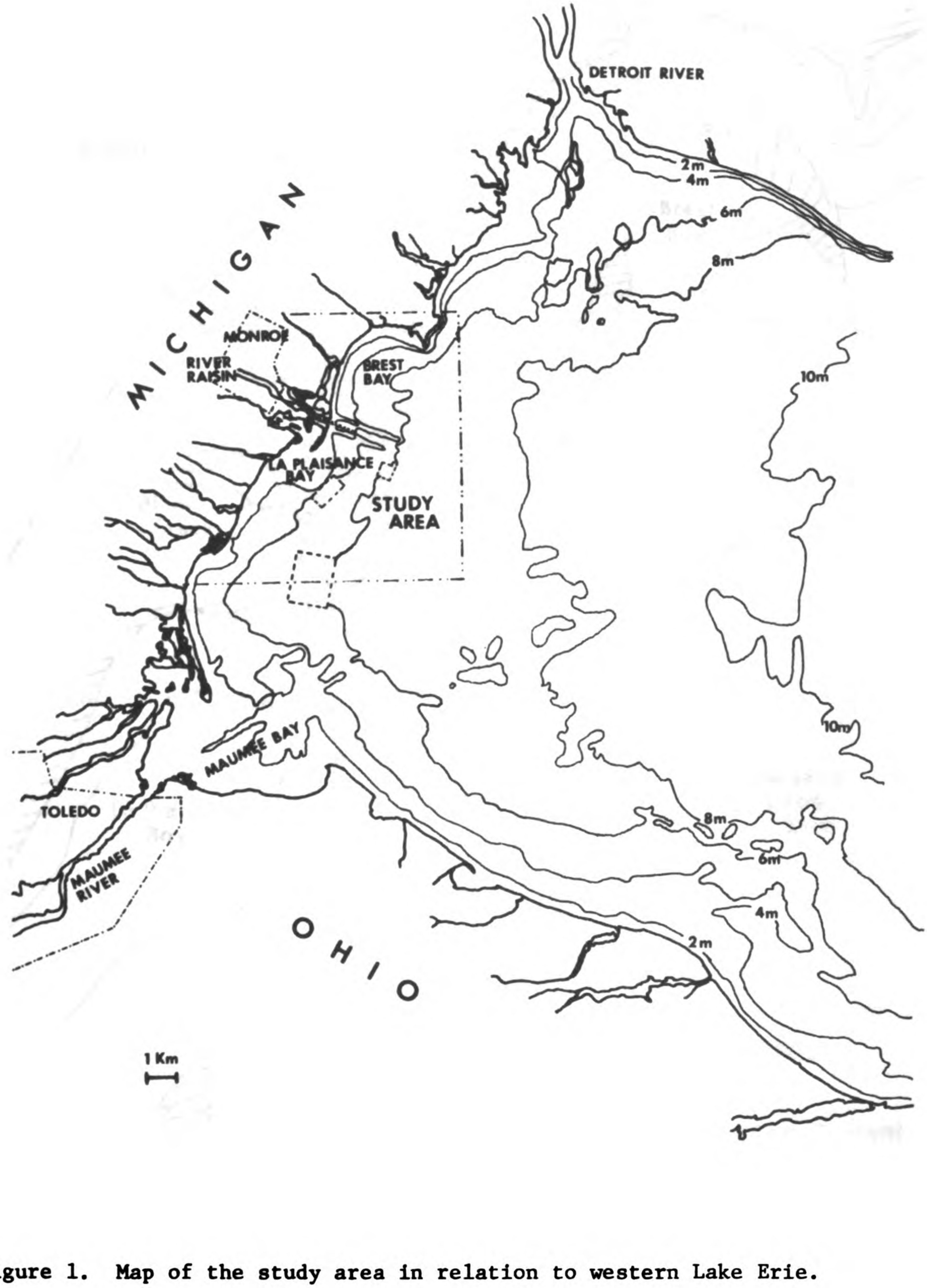


Figure 1. Map of the study area in relation to western Lake Erie.

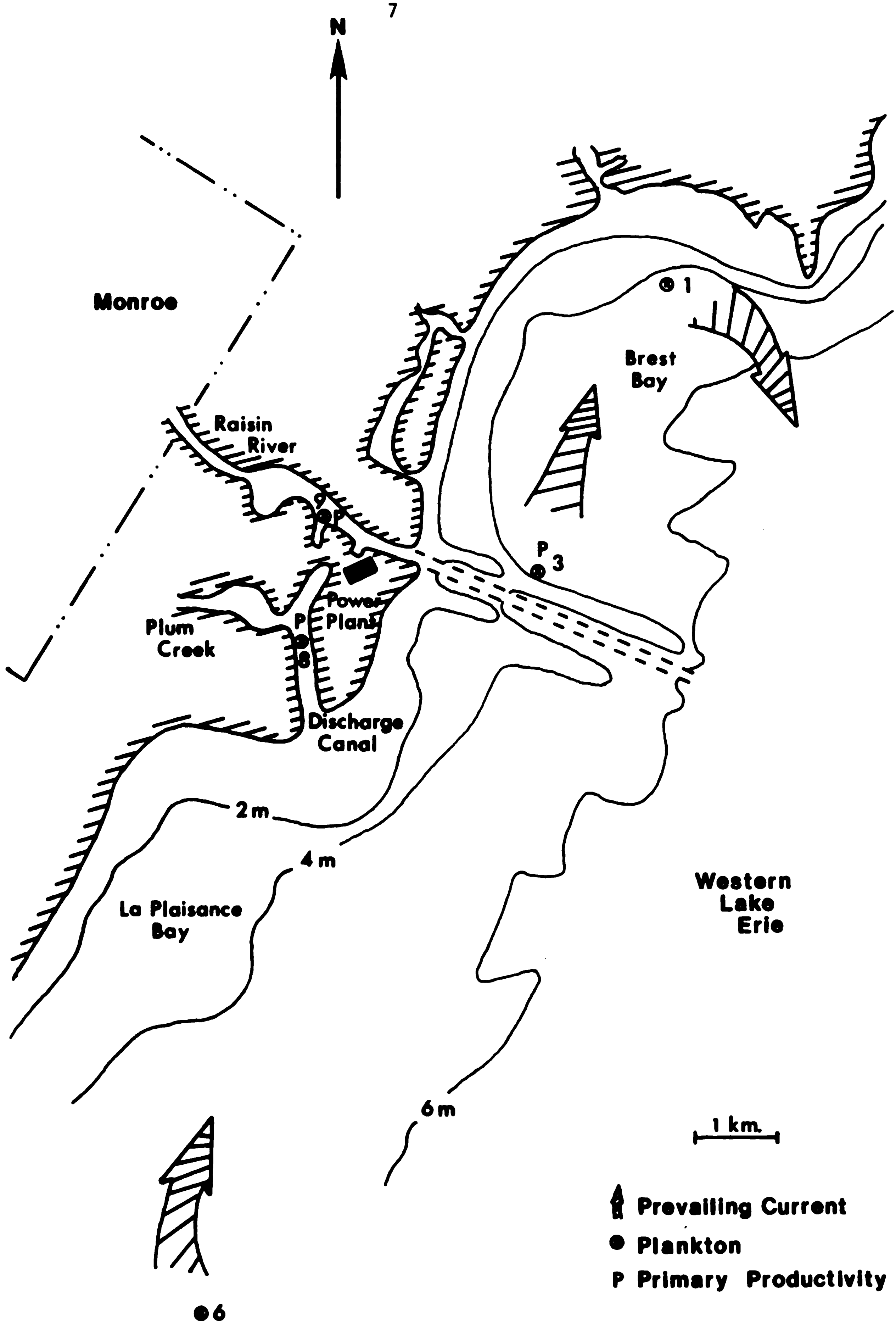


Figure 2. Map of the study area including positions of the sampling stations.

northward along the west shore and through the study area. This produces uniform vertical mixing of various parameters in the study area.

The Monroe Power Plant first began operating on May 3, 1971, but intermittent operation of Unit I (the plant is composed of 4 separate units) was a common occurrence in 1971. Ranges in electrical output from 0 to 830 MW of electricity were primarily a function of the frequency of repairs. On five study dates in 1971 and 1972, the plant was not generating electricity but cooling water was continuously pumped despite the fluctuations in electrical output. Each unit has a set of three intake pumps which are activated as electrical units are put into operation. Temperature changes across the condenser during the study period varied from 0 to 10 C while mechanical effects in the cooling system remained the same except on the last few sampling dates when the pumping rate was doubled from 23 m^3/sec to 46 m^3/sec (Appendix A1). A Δ t of 10 C was approximately the highest temperature change and this corresponds to maximum electrical output. The discharge canal was not subject to flowing conditions in 1970 as it was in 1971. Exchange with lake water in 1970 occurred only through wind-generated mixing and no river water entered the discharge canal. The water pumped through the cooling system takes about seven minutes moving at 2 m/sec with a condenser contact time of approximately 12 seconds.

Chlorine is introduced upstream from the condensers to control bacterial and other growth. Chlorine is applied for one-half hour periods twice daily during winter, spring and fall and four times daily in the summer. The desired residual concentration is less than 0.5 mg/liter total residual chlorine at the head of the discharge canal. Total residual chlorine, as indicated by plant records, is normally less than 0.50 mg/liter but has been as high as 0.75 mg/liter (Appendix A2).

Water temperature in the study area increased steadily at all stations from April until July, 1971, and then declined gradually into November, 1971. Inshore stations[1] had higher water temperatures than the lake stations (Figure 3). The river usually had a 1-2 C greater temperature than the lake water at the 1 m depth. The discharge exhibited wide variations in temperature relative to intake waters during the study period (Figure 3; Appendix A1) because of intermittent plant operation. The change in surface water temperature within the discharge canal was minor ($\leq$ 2 C). Heated water from the discharge canal never reached any of the three lake stations sampled for phytoplankton parameters. For the 1971 study period, lake stations never warmed above 26.5 C similar to 1970 temperatures. River temperatures in 1971 were similar to 1970 regimes. Maximum surface temperatures of 25 C were reported for August by Marcus (1972) at the discharge site compared to 34 C on 30 June 1971 (Appendix A3).

Secchi transparency readings were greatest at the lake station, lowest in the river and intermediate in the discharge canal (Appendix A3), but measurements were rarely greater than 1 m at any of the three stations. With the exception of 29 February, 1971, the average reading for the lake station was 0.8 m, 0.5 m for the river and 0.5 m for the discharge canal. Sestonic solids were highest at the inshore sites and varied with wind velocities.

Daily solar radiation was nearly constant from 15 April to 18 August 1971; thereafter, lower radiations reached the lake during 1971 (Appendix A4). Meterological data indicated a corresponding reduction in the

[1] Inshore stations indicates the river (9) and the discharge canal (8) in combination.

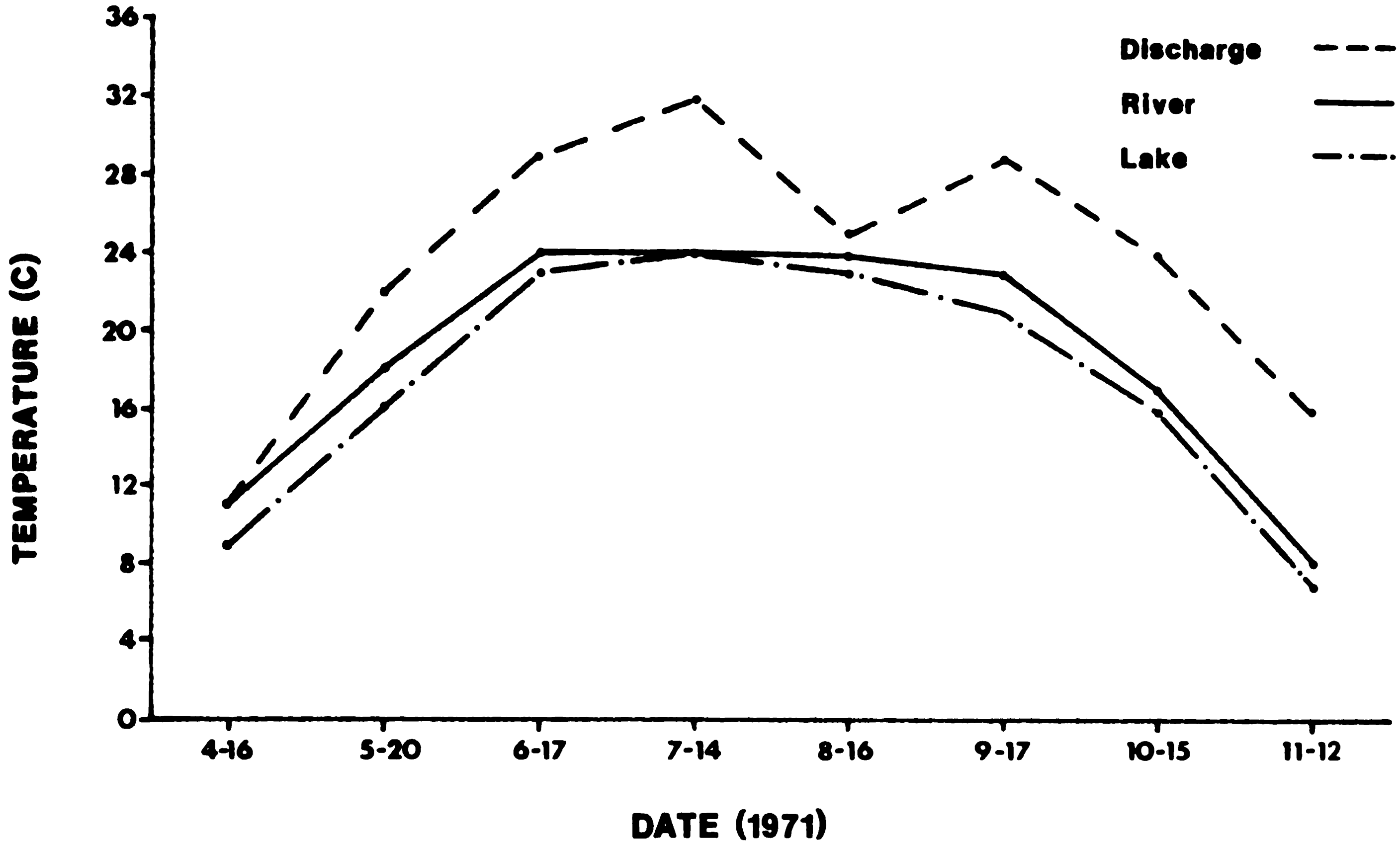


Figure 3. Mean water temperatures at the 1 m depth recorded in conjunction with phytoplankton collections.

percent possible sunshine for the same period (Appendix A5). Daily radiation recorded in the spring of 1972 was like spring and summer radiation in 1971.

Total alkalinity was usually highest in the river; ranging from 120-175 mg/liter $CaCO_3$. The lake water ranged from 90-132 mg/liter, while the discharge had intermediate concentrations of 114-160 mg/liter. Lake water had characteristically higher pH ranges (8.1 - 8.8) than inshore sites (river and discharge canal) with the river most often exhibiting the lowest pH (6.9 - 7.8).

Water at inshore stations contained consistently higher concentrations of total carbon than the lake and concentrations in the river usually exceed concentrations in the discharge. Particulate organic carbon usually comprised not more than 37% of the total carbon. Concentrations of total carbon varied between 22 and 64 mg/liter.

Total phosphorus fluctuated without trend at all stations. Concentrations of total phosphorus varied between 0.07 mg/liter and 0.32 mg/liter in the study area. The lowest concentrations occurred in the lake and highest concentrations occurred in the river.

Mean total nitrogen fluctuated more widely than carbon or phosphorus, with the lowest concentrations (0.6 to 1.2 mg/liter) determined on 17 September 1971 and highest concentrations in April, 1971 (0.5 to 2.7 mg/liter). Inshore stations averaged higher concentrations of nitrogen than the lake sites.

MATERIALS AND METHODS

Field and Laboratory Procedures

Population sampling was completed at four-week intervals from 16 April to 12 November 1971. Water for chemical analyses was obtained at the same time. Standard primary productivity measurements were made approximately every 2 weeks, weather permitting, at three stations during the interval of 15 April 1971 to 14 June 1972.

The stations chosen for phytoplankton analyses (Figure 2) coincided with those selected by Marcus (1972). Sites 1, 3 and 6 are located in the lake proper; station 8 in the discharge canal and station 9 in the river (Figure 2). Each site had two substations where two depths were sampled, i.e.: 0.5 m and 2.5 m. All offshore stations had buoy markers to orient the investigator. Inshore stations were located from shoreline reference points. Water was retrieved using an 8.1 liter VanDorn water sampler (Wildco Co., Saginaw, Mi.) and a subsample was placed in a 500 ml polyethylene bottle. A formalin preservative was used (37% formaldehyde) in a 1:25 solution to arrest biological activity.

Laboratory treatment involved using the membrane filter technique first described by McNabb (1960) and adopted by American Public Health Association (1971). Between 10 and 40 ml of water were filtered through a 0.45 μ "millipore" filter which was placed on a 2 x 3 glass slide and thinly coated with immersion oil. After "cleaning", the filters were subsequently examined at 200X or 450X using a dark phase microscope. Species frequencies in 30 random fields were converted to estimated numbers/ liter by a modified equation applied to this study:

$$\text{no/liter} = \frac{d \times 10^{12}}{(\text{quadrant area in } \mu^2)\ (\text{ml filtered})}$$

where the d value or theoretical density corresponds to a given frequency. A "count" is considered as a cell, colony or filament. Live and preserved wet mounts were qualitatively examined prior to filter enumeration.

Diatoms were identified separately from other algae by performing proportional counts on permanent mounts prepared according to Weber (1971). Total counts of centric or pennate diatoms recorded on the millipore filters were assigned to diatom species on the basis of their relative frequency observed in a permanent "hyrax" mount. Admittedly, the densities are only gross estimates of the existing numbers per unit volume of water.

Phytoplankton taxonomy was based on keys of Hustedt (1930), Patrick and Reimer (1966), Prescott (1962), Taft (1945), Taft and Taft (1971), Tiffany (1934) and Weber (1971). Taxonomic revisions of blue-green algae were applied according to Drouet (1968) and Drouet and Daily (1956).

Volumetric estimates were derived from random measurements of cell volume and total counts/liter for each species during the study period. The mean species volume was calculated using average dimensions of the regular geometric configuration most closely resembling the cell. Mean cell size was obtained from the quotient of total algal cell volume and total counts/liter.

Primary productivity was measured at three stations (Figure 2) from water samples obtained with a 4.1 PVC VanDorn water bottle. Duplicate clear and darkened pyrex borosilicate glass bottles were filled with water obtained at the surface, 0.5 m, 1.5 m, and 2.5 m and placed *in situ* at the corresponding depth of collection. One initial water sample was taken for each set of four exposure bottles to determine the original oxygen concentration. Suspension systems consisted of an anchored styrofoam float, clipped iron rods, and hanger ropes.

Incubations were performed as near the midday period as possible and spaced over 3-4 hours. All _in situ_ intervals were between the times of 0900 and 1600 hours with the majority of times between 1000 to 1400 hours. Sample fixation and titrametric determination followed using the modified Winkler method (A.P.H.A., 1971). Gross primary productivity and respiration values were obtained by oxygen changes (Strickland, 1960).

Comparative cooling system experiments were executed on 18 August and 14 October 1971 in order to discern the effect of plant operation on photosynthetic activities of phytoplankton communities. Surface water, delivered to two light and two dark bottles, was collected at five stations (Figure 4). The combined influences of heat and mechanical disruption were incorporated into the design. Control and transported water was placed at prescribed locations to test the cooling system effects at: (1) river, (2) intake, (3) lake, (4) upper discharge canal and (5) mouth of the discharge canal (plume). Changes in oxygen concentrations within the 300 ml bottles were used to describe stimulatory or inhibitory effects.

Diurnal gross primary productivity was estimated at the surface and 0.5 m depth on 26 August 1971 and 1 June 1972. Four incubation periods comprised the first diurnal study and three were used in the second study. Midpoints of the time interval were used to position the data points.

Secchi transparency data were obtained using a 20 cm disc (Wildco Co., Saginaw, Mi.). A YSI model 51A combination oxygen-thermistor meter was used for temperature measurements. Diel pH ranges were based on a standardized Instrumentation Laboratories porto-matic pH meter, model 175. Total alkalinity measurements were performed as described in A.P.H.A. (1971).

Daily solar radiation was measured during the study period by two instruments: (1) Eppley pyrheliometer (Eppley Lab., Inc., Newport, R.I.), beginning 15 April 1971 and ending 29 February 1972; (2) Belfort

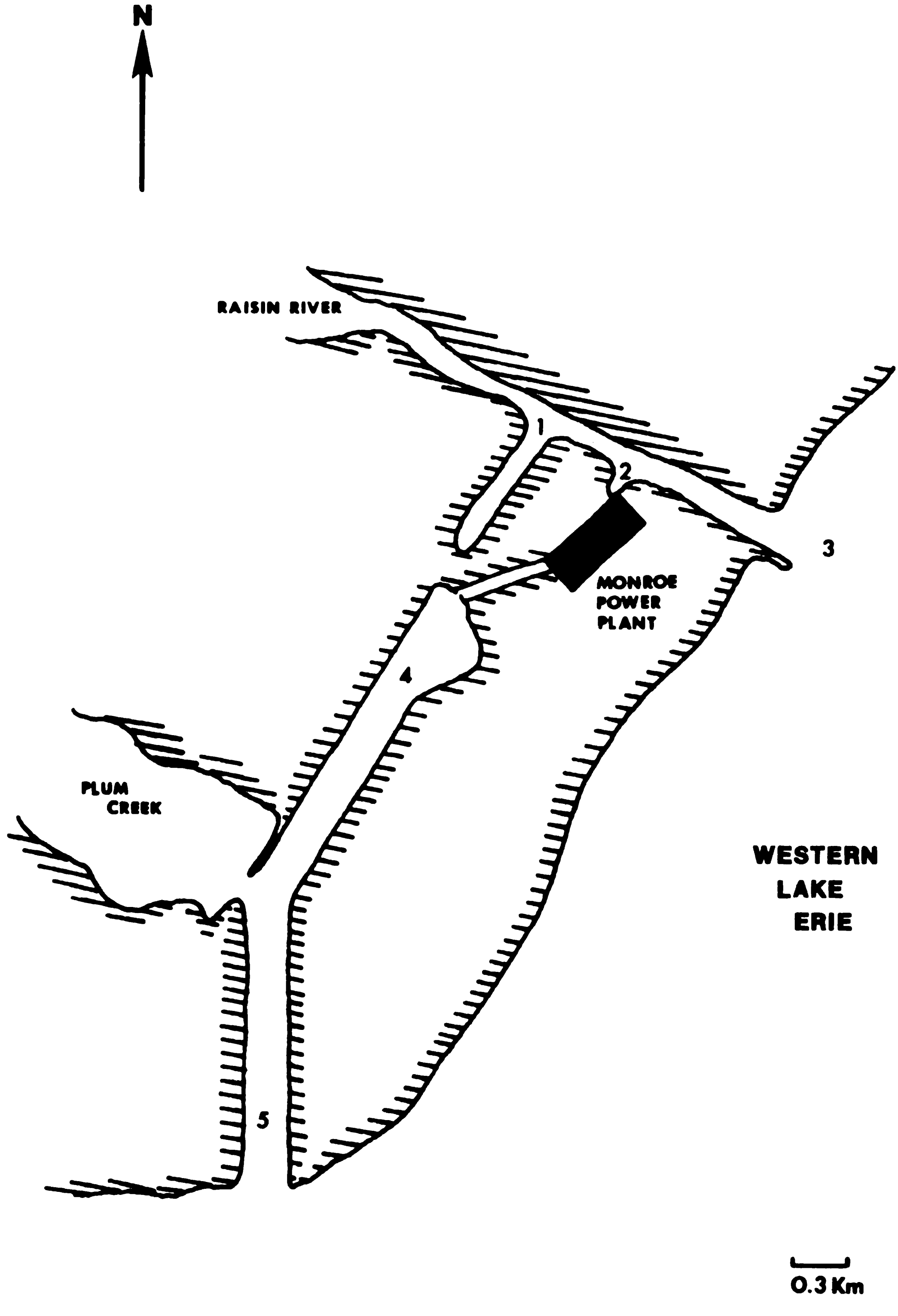


Figure 4. Location of <u>in situ</u> sites in the study area used for the cooling system experiments of 18 August 1971 and 14 October 1971.

pyrheliometer (Belfort Instrument Co., Baltimore, Md.), from 12 May to 14 June 1972. A polar planimeter was used to convert from area to total langleys (g cal/cm^2) per day.

Meteorological information was condensed from U.S. Dept. of Commerce records taken at the Detroit City Airport (Appendix A5). River discharge was obtained from U.S.G.S. guaging station records.

Data Analyses

Raw data were transposed to a computer program summarizing parameters from the four replicates for each station. Average values were compiled for number of counts/liter, percent of total counts, average estimated volume per species and percent of total cell volume for each species. That information was the basis for determining the relative rarity or commonness of species.

A two-way analysis of variance was applied to test for vertical (depth) and horizontal (station) differences in the numbers of observed species, numerical diversity, numerical equitability, total phytoplankton numbers, total cell volume, blue-green algal volume (Cyanophyceae), green algal volume (Chlorophyceae), diatom algal volume (Bacillariophyceae). Preliminary comparisons indicated no significant differences between depths, therefore, all replicates were pooled for testing station differences. Multiple comparison tests using Tukey's method (Steele and Torrie, 1960) were applied to estimated means for each station using an $\alpha = .05$ level of significance. Logarithmic transformations on total numbers, total volumes, and all class volumes were used to reduce heterogeneity among variances. Tukey's value was based on the error mean square produced in the factorial analysis. Range tests were completed using the appropriate mean, whether arithmetic or geometric, but arithmetic means are presented in all cases. Using formulae from Strathmann (1967) total carbon content was estimated from the phytoplanktonic volume.

The Shannon-Wiener diversity index was used to depict phytoplankton diversity (Pielou, 1969). Equitability (the ratio of observed diversity to maximum diversity for the same number of species) is calculated from the formula: $e = \frac{2^{\bar{H}}}{S}$ where $\bar{H}$ is the sample diversity and S refers to the number of sampled species (MacArthur, 1965). Equitability measures the relative evenness of species abundances. Diversity is determined both by equitability and the number of species.

Gross primary productivity and respiration estimates on a volumetric basis were adjusted to areal units by averaging oxygen production among all depths and applying a depth factor for the respective sites. Oxygen content was transformed to carbon uptake by using the photosynthetic ratio of 0.312 units of carbon fixed/unit oxygen evolved (Westlake, 1969).

RESULTS

Community Structure

Phytoplankton Abundance

Total Numbers: Estimated total number of counts/liter in the study area fluctuated from as low as 1,791 X 10^3 on 16 April to as high as 23,289 X 10^3 on 16 August (Figure 5, Appendix A6), but no vertical differences were ever ascertained. The river and discharge canal produced the highest densities on all occasions except one when the river abundance was less than that at one of the lake stations. The lake stations consistently contained lesser ($p < .05$) algal concentrations than the inshore sites. The north lake station usually yielded higher densities than the two southerly stations and approached the summer numbers recorded at the inshore sites. The southernmost lake station on all dates except one was among the significantly lowest group of stations in the multiple range tests for total numbers/liter.

Total Volumes: Figure 5 indicates that algal volumes consistently show temporal shifts at each station in conjunction with algal numbers but again no vertical differences occurred. Volumetric estimates were more variable than numerical estimates of abundance so the capacity to differentiate stations was reduced. The discharge canal was less frequently among the sites with the greatest volume than when numbers were compared, but the south lake station was again most frequently among the stations with the least volumetric abundance (Appendix A7). Shifts in ranks are undoubtedly due to differences in the mean size of the algal cells at the different sites. The mean cell size of algae was frequently lowest

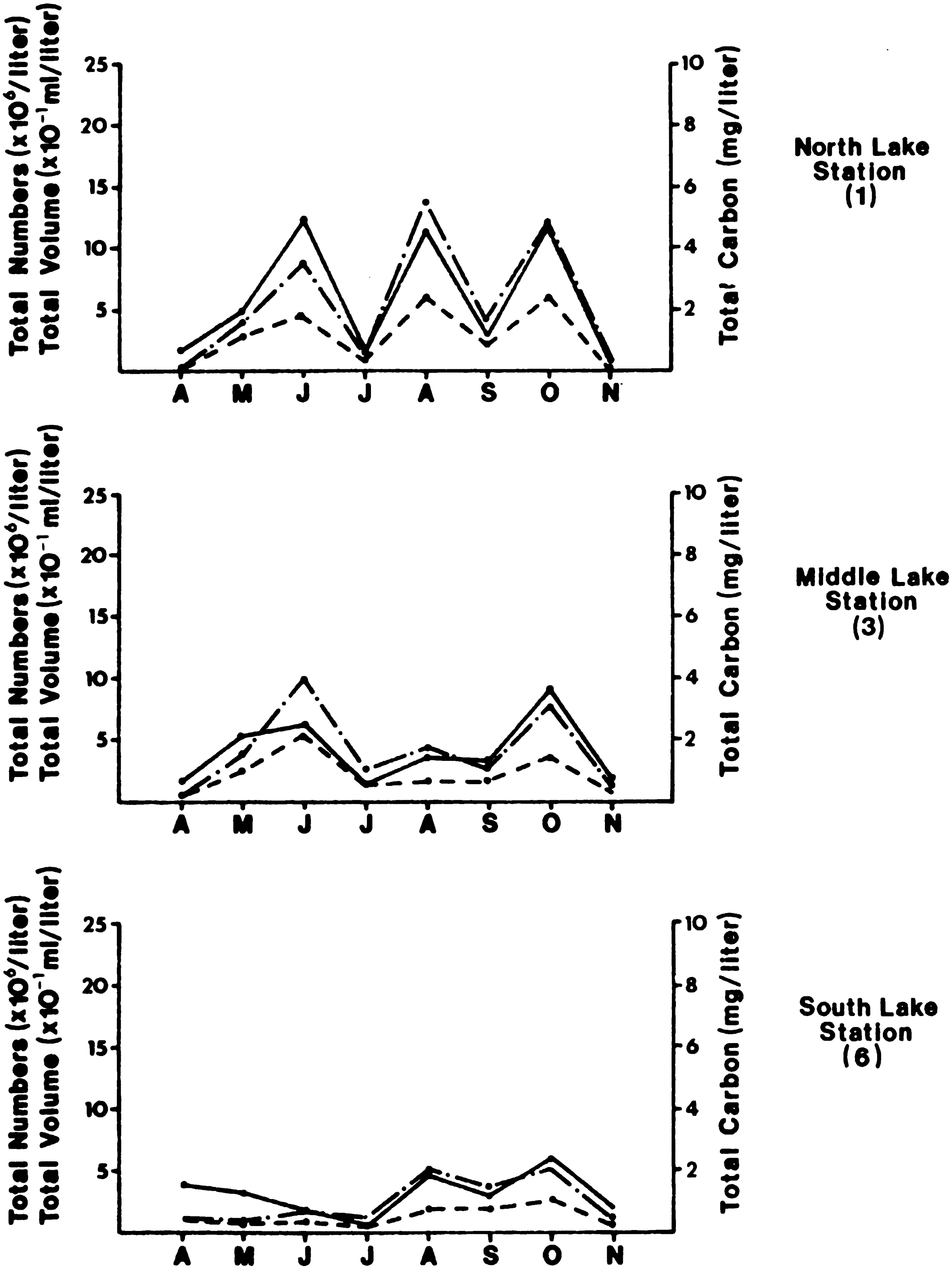
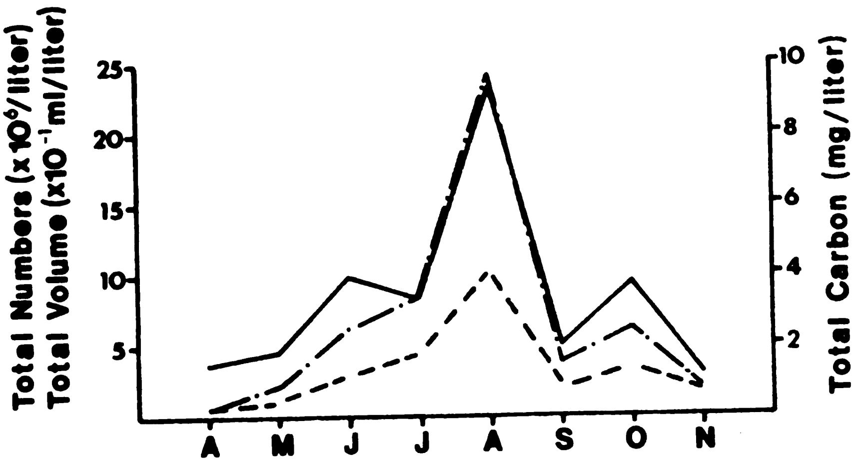
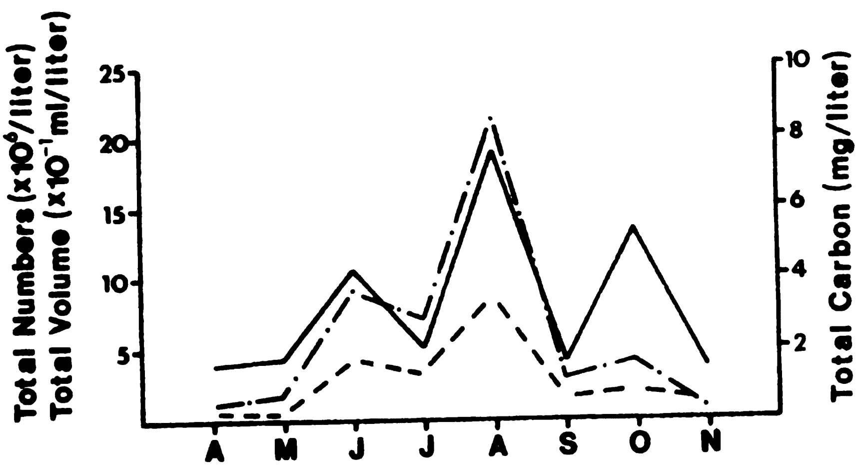


Figure 5. Mean total algal numbers, total algal cell volume and total cell carbon in 1971 by station (total numbers ____; total volume ------; total carbon ___.___).



Discharge
Station
(8)



River
Station
(9)

Figure 5 (con't.)

in the river and discharge canal and grestest among the lake station (Appendix A8).

Total Carbon Content: Conversion of total volume to carbon content (mg/liter) depends on the algal species present in greatest abundance and therefore will vary differently than variation in total volume when the species composition changes. The estimated algal carbon concentration remained below 7 mg/liter at all stations except on 16 August when it reached 8.4 and 9.6 in the river and canal, respectively (Figure 5).

The south lake station produced lower concentrations of carbon compared to the other lake stations. As expected, this appears to be more closely allied to volumetric variation than to total number of individuals per liter.

Class Abundances

A total of six algal classes were represented in the enumeration of western Lake Erie phytoplankton during 1971. Three classes comprised the major percentage of algae volumetrically, i.e.: diatoms (Bacillariophyceae), blue-greens (Cyanophyceae) and greens (Chlorophyceae). Two dinoflagellates, one Cryptophycean and five Euglenophytan species constituted the remaining species in 1971. *Cryptomonas ovata* and *Ceratium hirundinella* were two species which provided a notable portion of the total algal volume from June to September. Otherwise, primary volumetric contributions were from the three classes previously noted (Figure 6).

Mean volumetric composition fluctuated expectedly by station but more so temporally (Figure 6). Although there was considerable overlap in dominance as seasons changed, generally diatoms were most abundant (> 50% of volume) in the cooler months of the year 1971, i.e.: April, May and November. Green algae replaced diatoms as the dominant class in June and

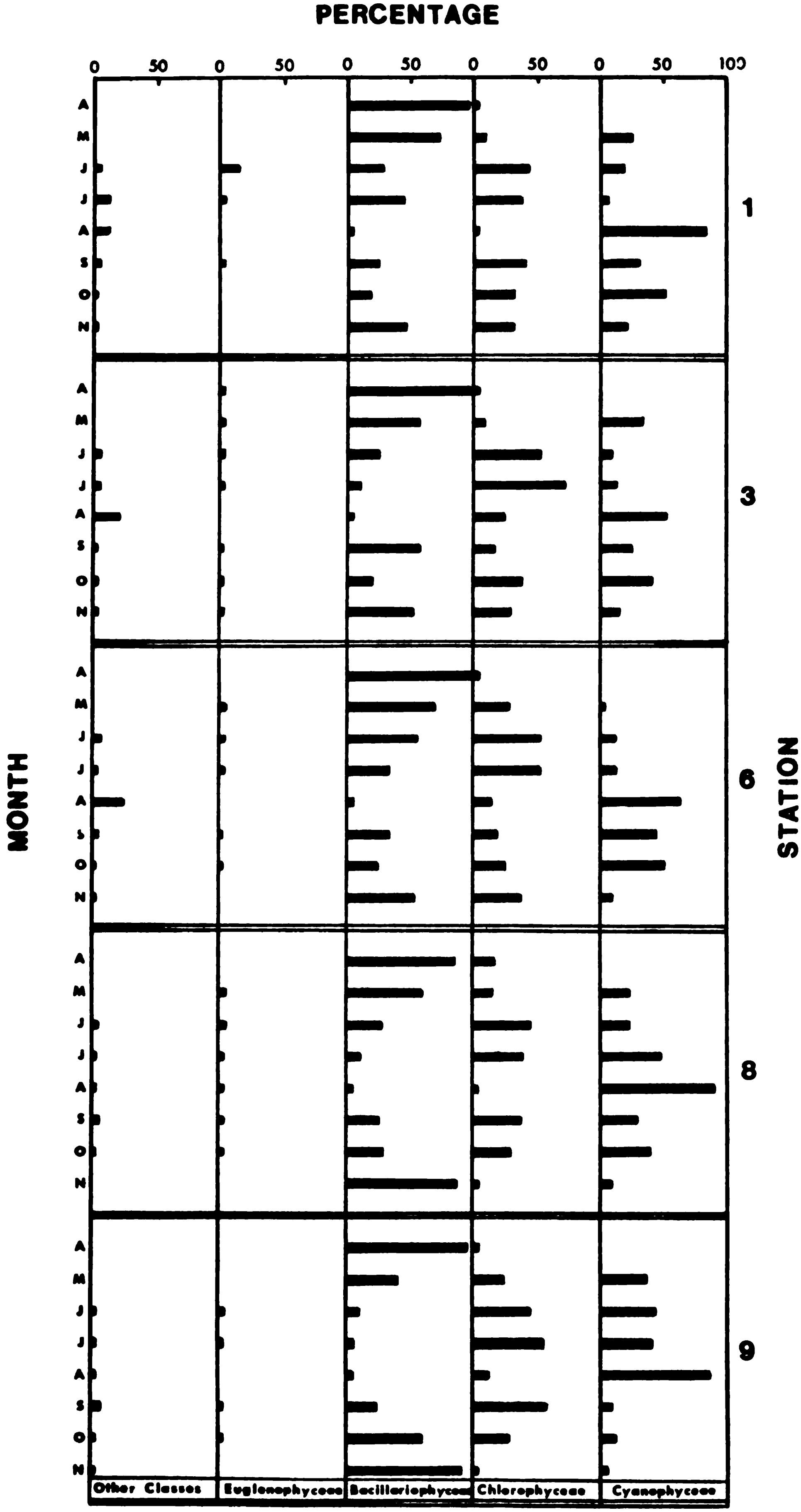


Figure 6. Mean percent composition of algal classes on a volumetric basis for the study period of 16 April to 12 November, 1971.

July. Blue-green algae predominated in August, green algae and diatoms dominated in September while greens and blue-green algae dominated in October.

Species Composition by Class

Blue-green Algae: Strong monthly variation in blue-green algal volumes is apparent (Appendix A9). Highest standing crops existed in the discharge canal (90,836 X 10^{-6} ml/liter) during August when 90% of the algal volume was composed of blue-green algae. But at that time, temperatures in the discharge canal barely exceeded river or lake temperatures (Figure 3). This extraordinary abundance was not caused by a temperature change. A resurgence of cyanophyceans occurred in October when lake stations had larger concentrations than inshore areas. Four blue-green algae exhibited significant volumes during 1971, *Aphanizomenon flos-aquae*, *Anacystis incerta*, *Anacystis thermalis* and *Anacystis cyanae* (Appendices A10 to A13). Of those four, *A. flos-aquae* could be considered the most ubiquitous species, occurring at all stations on seven dates with a maximum concentration observed during the August "bloom" in the discharge canal. *A. incerta* also reached its greatest abundance during that time. Both species were volumetrically most abundant at inshore stations on 16 August 1971. High standing crops of *A. thermalis* were recorded at the inshore sites for the three summer dates. *A. cyanae* occurred in scattered samples but also attained significant volume on 16 August, especially inshore.

Green Algae: Peak volumes of green algae occurred during June to October with the river and discharge canal consistently containing the largest volumes of greens on those dates (Appendix A14). One filamentous green alga, *Mougeotia elegantula*, flourished in the fall period first in the canal and river, then somewhat later in the lake (Appendix A15). Two relatively large coenocytic algae, Pediastrum duplex and P. simplex, produced scattered but relatively great volumes in 1971 (Appendix A16 and A17). P. duplex reached a maximal concentration on 17 June while P. simplex peaked on 16 August. The latter species had a slightly larger mean colonial volume than P. duplex but never became as abundant as P. duplex.

Diatoms: Maximum diatom volumes occurred in the spring and fall months, but the summer levels never decreased below the minimum concentrations that any of the other classes experienced (Appendix A18). Seven species of diatoms were considered dominants during 1971. Coscinodiscus radiatus exhibited no consistent pattern of seasonal fluctuation in abundance but its largest volume was recorded on 17 September. Inshore samples contained lower volumes of this species than the lake sites (Appendix A19). Temporal variation of Melosira granulata followed a sequence of high spring volumes, low summer and slightly higher fall volumes. No evident spatial difference appeared to exist for this species (Appendix A20). The centric diatom, Stephanodiscus astraea, predominated in May samples at all stations (Appendix A21). It usually was higher in abundance volumetrically at the river and discharge stations. Stephanodiscus tenuis also fluctuated but was most prevalent in spring samples (Appendix A22). Fragilaria capucina accentuated itself in the fall chiefly at the lake stations (Appendix A23). During the spring, Fragilaria crotonensis proliferated in larger volumes at the lake stations than inshore (Appendix A24). Tabellaria fenestrata was most abundant in the spring, particularly in May. Its volume was characteristically lower inshore than offshore (Appendix A25).

Other Species: A cryptophycean, *Cryptomonas ovata*, played a minor role volumetrically but was relatively numerous when it occurred. Peak volumes in May occurred at the northern part of the lake study area but otherwise showed little spatial variation (Appendix A26). A dinoflagellate, *Ceratium hirundinella*, occurred in greatest quantities in the lake at the time of an August algal bloom that was otherwise dominated by blue-green algae (Appendix A27).

Comparing volumetrically dominant species common to the 1970 and 1971 study periods (Tables 1 and 2) suggests that most of those species did not comprise nearly the same average yearly percentage of the total cell volume. Also, there appears to be no relation between yearly differences in discharge canal environment and the change in species dominance. Fewer species were volumetrically dominant ($\geq$ 1%) in 1970 than 1971; those important in 1971 but not in 1970 were *F. capucina*, *E. crotonensis*, *T. fenestrata*, *M. elegantula*, *P. simplex* and *C. hirundinella* (Table 2). *P. duplex* is the only species which exhibited a higher percent composition during 1971. Of the species in Table 2, eight averaged a lower percent of the total cell volume in 1971 relative to 1970. This implies that percentages of the total cell volume were more evenly distributed among more species in 1971 samples than in those of 1970.

Variety of Species

Total Number of Species: Table 2 illustrates that in 8 months of water collection, 184 phytoplankton species were observed. Of that number, diatoms were represented by 80 species; green algae, 79 species; blue-green algae, 17 species; euglenoid algae, 5 species, dinoflagellates, 2 species; and cryptophyceans by 1 species.

Table 1. Mean annual percent volumetric composition of dominant species examined from May to November, 1970 (Marcus, 1972; X < 1% of the total algal cell volume).

Species (16)	Percent by Station 1	3	6	8	9
Coscinodiscus radiatus	1.8	2.2	3.4	X	X
Cyclotella meneghiniana	X	1.1	X	2.6	7.1
Melosira granulata	13.7	8.5	12.5	15.3	8.2
Stephanodiscus alpinus	X	1.2	X	X	3.0
S. astraea	7.4	2.3	3.4	5.0	3.9
S. binderanus	13.9	21.6	14.5	9.8	32.1
S. niagarae	1.2	1.1	6.6	4.1	X
S. tenuis	1.2	X	X	X	3.4
Anacystis cyanae	13.0	17.7	16.7	13.8	12.3
A. delicatissima (A. incerta)	10.5	10.7	8.8	13.8	3.0
Aphanizomenon flos-aquae	19.3	12.6	12.2	11.5	5.9
Oscillatoria sp. (Microcoleus vaginatus)	6.7	7.4	10.2	10.3	4.2
Pediastrum duplex	2.1	3.9	3.5	4.7	3.2
A. elachista var. conferta (A. incerta)	1.6	1.4	2.4	2.8	2.0

Table 2. Phytoplankton species enumerated from April to November, 1971 with their mean annual percent composition by station (X < 1% of the total cell volume).

Bacillariophyceae	Station 1	3	6	8	9
Achnanthes lanceolata (Breb.) Grun.	X	X	X	X	X
A. minutissima Kutz.			X	X	
Amphiprora ornata Bailey				X	
Amphora ovalis (Kuta.) Kutz.	X			X	
A. ovalis var. pediculus (Kutz.) V.H.	X				
Asterionella formosa Hass.	X	X	X	X	X
Cocconeis disculus (Schum.) Cleve.	X				X
C. placentula Ehr.	X	X	X	X	X
Coscinodiscus radiatus Ehrenberg	10.7	10.6	14.6	6.9	8.0
Cyclotella bodanica Eulenst.	X	X	X	X	1.4
C. kuetzingiana Thwaites	X	X	X	X	X
C. meneghiniana Kutz.	X	X	X	X	X
C. ocellata Pant.	X	X	X	X	X
C. stelligera (Cleve and Grun.) V. H.	X	X	X	X	X
Cymatopleura solea (Breb. and Godey) Wm. Smith	X	X	X	X	X
Cymbella affinis Kutz.			X	X	X
Diatoma hiemale (Lyngbye) Heiberg			X		X
D. tenue var. elongatum Lyngb.	X	X	X	X	X
D. vulgare Bory.	X				X
Epithemia sorex Kutz.				X	X
Fragilaria brevistriata Grun.	X	X	X	X	X
Fragilaria capucina Desm.	2.5	2.8	2.8	1.1	1.4
F. construens (Ehr.) Grun.		X			X
F. crotenensis Kitton	4.0	1.6	4.8	1.0	X
F. pinnata Ehr.	X	X	X	X	X
Gomphonema olivaceum (Lyngb.) Kutz.	X	X	X	X	X
G. parvulum (Kutz.) Kutz	X		X	X	X
Gyrosigma kutzingii (Grun.) Cleve.			X		
G. scalproides (Rabh.) Cleve.					X
G. spencerii (Quek.) Griff and Renfr.				X	
Hantzschia amphioxys (Ehr.) Grun.	X	X		X	
Melosira ambigua (Grun.) O. Mull.	X	X			X
M. granulata (Ehr.) Ralfs	3.9	7.5	3.9	4.9	3.6
M. islandica O. Mull	1.4	X	X		X
Navicula bacillum (Ehr.)		X		X	X
N. canalis Patr. var. canalis		X		X	X
N. contenta Grun.					X
N. cryptocephala Kutz.		X	X	X	X
N. cuspidata Kutz.				X	
N. exigua (Gregory) O. Mull.	X	X	X	X	X
N. gastrum (Ehr.) Kutz.	X			X	X
N. hungarica Grun.					X
N. hungarica var. capitata (Ehr.) Cleve.		X		X	X

Table 2 (con't.)

Bacillariophyceae	1	3	6	8	9
N. mutica Kutz.	X			X	X
N. reinhardtii (Grun.) Grun.				X	
N. tripunctata (O.F. Mull.) Bery.	X	X	X	X	X
Nitzschia acicularis (Kutz.) Wm. Smith	X	X	X	X	X
N. amphibia Grun.	X	X		X	X
N. angustata (Wm. Smith) Grun.					X
N. apiculata (Greg.) Grun.	X				
N. denticula Grn.	X	X			
N. dissipata (Kutz.) Grun.	X	X	X	X	X
N. filiformis (Wm. Smith) Schutt	X			X	X
N. fonticola Grun.				X	
N. gracilis Hantzsch				X	
Nitzschia holsatica Hust.	X	X	X	X	X
N. hungarica Grun.			X		
N. linearis Wm. Smith				X	
N. lorenziana Grun.	X			X	
N. palea (Kutz.) Wm. Smith	X	X	X	X	X
N. sigma (Kutz.) Wm. Smith	X	X		X	X
Pinnularia borealis Ehr.	X				
Rhoicosphenia curvata (Kutz.) Grun.			X	X	X
Rhopalodia gibba (Ehr.) O. Mull.				X	
Stephanodiscus alpinis Hust.	X	X	X	X	X
S. astraea (Ehr.) Grun.	2.7	4.3	4.7	14.2	13.8
S. binderanus (Kutz.) Krieger	X	X	X	X	X
S. dubius (Fricke) Hust.	X	X	X	X	X
S. niagarae Ehr.	X	X	X		
S. tenuis Hust.	1.5	1.2	X	1.7	2.0
Stephanodiscus sp. #1	X	X			
Surirella angusta Kutz.	X		X	X	X
S. ovalis Breb.		X		X	
S. ovata Kutz.	X	X	X	X	X
Synedra acus Kutz.	X	X		X	
S. nana Meister	X		X	X	X
S. parasitica (Wm. Smith) Hust.	X		X		X
S. ulna (Nitz.) Ehr.	X	X	X	X	X
Tabelleria fenestrata (Lyngb.) Kutz.	10.7	10.4	9.4	3.0	1.3
Centric sp. #1		X			X

Chlorophyceae	1	3	6	8	9
Actinastrum hantzschii Lagerheim	X		X	X	
A. hantzschii Lagerheim var. fluviatile Schroeder	X	X	X	X	X
Ankistrodesmus falcatus (Corda) Ralfs	X	X	X	X	X

Table 2 (con't.)

Chlorophyceae	1	3	6	8	9
A. convolutus Corda					X
Binuclearia eriensis Tiffany	X	X	X	X	X
Botryococcus braunii Kuetzing.	X			X	
B. sudeticus Lemm.			X		
Chlorella ellipsoidea Gerneck					X
Chlorella vulgaris Beyerinck	X	X	X	X	X
C. sp. #1				X	X
Chlorococcum infusionum (Schrank) Meneghini	X	X	X	X	X
Coelastrum microporum Naegeli	X	X	X	X	X
C. sphaericum Naegeli	X	X	X	X	X
Cosmarium bipunctatum Boergesen	X	X	1.1	X	X
C. formulosum Hoffman			X		
C. subcrenatum Hantzsch			X		X
Crucigenia apiculata (Lemm.) Schmidle	X		X	X	X
C. irregularis Wille		X		X	X
C. lauterbornei Schmidle				X	
C. quadrata Morren	X	X		X	X
C. rectangularis (A. Br.) Gay	X			X	X
C. tetrapedia (Kirch.) W. and G. S. West				X	X
Dictyosphaerium ehrenbergianum Naegeli		X	X	X	X
Gloeoactinium limneticum G. M. Smith	X				
Gloeocystis planktonica (W. and G. S. West) Lemm.				X	
Golenkina radiata (Chod.) Wille	X	X	X	X	X
Haematococcus lacustris (Girod.) Wittrock					X
Kirchneriella contorta (Schmidle) Bohlin	X	X	X	X	X
Kirchneriella lunaris (Kirch.) Moebius				X	
K. obesa (W. West) Schmidle	X	X	X	X	X
Lagerheimia genevensis Chodat var. subglobosa (Lemm) Chodat	X			X	X
L. quadriseta (Lemm.) G. M. Smith		X	X	X	X
Micractinium eriense Tiffany and Ahlstrom					X
M. pusillum Fresenius	X	X	X	X	X
Mougeotia elegantula Wittrock	3.9	3.4	2.2	2.7	2.0
Oocystis borgei Snow	X	X	1.0	X	X
O. pusilla Hansgirg					X
O. submarina Lagerheim	X		X	X	
Pandorina morum (Muell.) Bory		X		X	X
Pediastrum boryanum (Turp.) Meneghini	X	X	X	X	1.2
P. duplex Meyen	12.8	20.2	11.8	12.7	13.0

Table 2 (con't.)

Chlorophyceae	1	3	6	8	9
P. simplex (Meyen) Lemm.	3.2	2.0	6.0	1.4	5.5
P. tetras (Ehr.) Ralfs	X	X	X	X	X
Planktosphaeria gelatinosa G.M. Smith	X	X	X	X	X
Polyedriopsis quadrispina G. M. Smith				X	X
P. spinulosa Schmidle				X	X
Quadrigula closterioides (Bohlin) Printz.	X	X	X	X	X
Scenedesmus abundans (Kirch.) Chodat	X	X	X	X	X
S. acuminatus (Lager.) Chodat		X	X	X	
S. anomalus (G. M. Smith) Ahlstrom and Tiffany	X	X		X	X
S. bernardii G. M. Smith	X	X			X
S. bijuga (Turp.) Lagerheim	X	X	X	X	X
S. carinatus (Lemm.) Chodat.			X		
S. denticulatus Lagerheim	X	X	X	X	
S. dimorphus (Turp.) Kuetzing	X	X	X	X	X
S. opliensis P. Richter			X	X	
S. quadricauda (Turp.) de Breb.	X	X	X	X	X
S. quadricauda (Turp.) de Breb. var. *alternans* G. M. Smith	X	X	X	X	X
Schroederia setigera (Schroed.) Lemm.	X	X	X	X	X
Sphaerocystis schroeteri Chodat	X	X	X	X	X
Spondylomorum quaternarium Ehr.				X	X
Staurastrum chaetoceras (Schroeder) G. M. Smith	X	X	X	X	X
Tetraedron arthrodesmiforme (G. S. West) Woloszynska		X		X	X
T. caudatum (Corda) Hansgirg	X				X
T. hastatum (Reinsch) Hansgirg	X	X			
T. incus (Teiling) G. M. Smith	X	X		X	X
T. limneticum Borge	X			X	
T. minimum (A. Br.) Hansgirg	X	X		X	X
T. pentraedricum W. and B. S. West	X	X	X	X	X
T. regulare Kuetzing				X	
T. trigonum (Naeg.) Hansgirg	X	X	X	X	X
Tetrastrum glabrum (Roll) Ahlstrom and Tiffany				X	
T. heteracanthum (Nordst) Chodat	X	X	X	X	X
T. staurogeniaeforme (Schroeder) Lemm.	X	X	X	X	X
Westella botryoides (W. West) de Wildermann	X	X	1.7	1.6	2.2
Green sp. #1		X	X		

Table 2 (con't.)

Cryptophyceae	1	3	6	8	9
Cryptomonas ovata Ehr.	1.1	X	1.1	X	X

Cyanophyceae					
Agmenellum quadriduplicatum Breb.	X	X	X	X	X
Anabaena circinalis Rabenhorst	X	X	X	X	X
Anabaena sp. #1	X	X	X	X	X
Anacystis cyanae Drouet and Daily	1.6	1.6	1.2	2.2	1.3
A. dispersus Meneghini	X	X	X	X	1.5
A. incerta Drouet and Daily	10.3	4.1	8.7	9.0	8.5
A. marina Drouet and Daily		X	X	X	X
A. minutus Meneghini		X		X	
A. montana Drouet and Daily	5.7	5.6	X	3.2	4.0
A. pulchra Meneghini	X	X		X	X
A. thermalis Drouet and Daily	1.9	3.1	2.1	4.8	6.5
Aphanizomenon flos-aquae (L.) Ralfs	7.1	7.0	9.6	6.6	6.2
Coccochloris peniocystis Drouet and Daily				1.0	X
C. stagnina Sprengel		X			X
Gomphosphaeria lacustris Chodat		X		X	X
Marssoniella elegans Lemm.	X	X	X	X	X
Microcoleus vaginatus (Vauch.) Gom.	X	X	X	X	X

Dinophyceae					
Ceratium hirundinella (O. F. Muell.) Dujardin	2.7	2.9	3.2	X	X
Peridinium quadridens Stein	X	X	X	X	X

Euglenophyceae					
Euglena acus Ehr.				X	X
E. gracilis Klebs	X	X	X	X	X
E. minuta Prescott				X	
E. polymorpha Dangeard		X	X	X	X
Trachelomonas pulchella Drezepolski	1.5	X	X	X	X

The mean number of observed species among the four station replicates and the distinctly different species accumulated among those samples indicates the relative commonness of species (Table 3). In all cases, the most abundant species were common to all replicates at a station. The maximum mean number of species recorded for any set of samples amounted to 51 species on 17 September in the discharge canal when the maximum number of distinctly different algal species occurred. There was no statistically significant difference ($p < .05$) between the number of species at the discharge canal and river on that date (Appendix A28). The fewest species samples (19) were collected on 16 April at lake station 3.

Within the total list of species, only twenty three contributed 1% or more of the mean volume at any one of the stations (Table 2). Twenty six occurred only at one station and comprised less than 1% of the total volume collected in 1971. These most abundant and rarest species differed only slightly from rare and abundant species in 1970 collections (Marcus, 1972).

Annual Differences in Species Abundance: The discharge canal had the greatest number of species of any station on 87% of the 1970 dates compared to 75% of the 1971 dates. Apparently, the discharge canal retained its study area dominance in 1971 with respect to species abundance even though major physical changes occurred in the water masses when pumping started in 1971. However, a reduction in the mean number of species identified at the discharge site occurred in 1971 compared to 1970 (Marcus, 1972). The river station consistently was next highest in number of species during 1971 but averaged fewer species per sample in 1971 relative to 1970. Although differences exist in the mean number of species per sample, the species tabulation list of Marcus (1972) numerically approximates

Table 3. Number of distinctly different species accumulated temporarily and spatially with the mean number of species at a station in parentheses.

Date	Station 1	3	6	8	9
4-16-71	25 (23)	21 (19)	23 (23)	40 (37)	41 (39)
5-20	42 (34)	41(35)	28 (24)	54 (47)	44 (38)
6-17	39 (31)	44 (32)	41 (30)	54 (42)	48 (36)
7-14	41 (36)	40 (30)	26 (20)	54 (38)	51 (37)
8-16	34 (23)	29 (22)	28 (21)	56 (43)	45 (36)
9-17	58 (36)	58 (42)	41 (28)	73 (51)	61 (47)
10-15	56 (40)	52 (33)	48 (32)	65 (44)	60 (42)
11-12	53 (38)	54 (39)	43 (29)	41 (40)	49 (41)

(203 sp.) the 1971 list (184 sp.) using an equivalent number of replicates (160). Therefore, it appears that there was slightly more temporal segregation of species in 1971, meaning the average persistence time of each species was shorter than during 1970. Species common to both lists equaled 140. Some of the difference in species lists is undoubtedly due to imperfect identification but much is also caused by annual shifts in the abundance of rare species.

Species Diversity and Equitability

Inshore stations most often were among the stations with the highest phytoplanktonic diversity while the lake stations had consistently lower diversity (Figure 7, Appendix A29). The species equitability, or evenness of species relative abundance, did not regularly vary with diversity, except on one notable occasion during the algal bloom on 16 August when both population parameters were low (Appendix A30). At that time, the lake stations had relatively few total species compared to the remainder of dates but relatively high numbers/liter among a few species. The inshore stations had slightly more species but exhibited the same low equitability on that date. Usually, diversity differences among sites were due more to the equitability component than the number of species but both directly affected variations in diversity.

Monthly diversity and equitability varied erratically at the discharge station as well as at the other stations. The discharge canal had the highest or next to the highest diversity on 87% of the dates in 1971 versus only 38% of the comparisons in 1970. Absolute diversity levels at the canal station in 1971 were higher than 1970 levels 75% of the time. That station also exhibited higher equitability in 1971 on 75% of the dates which coincided with the higher diversity dates. However, the mean

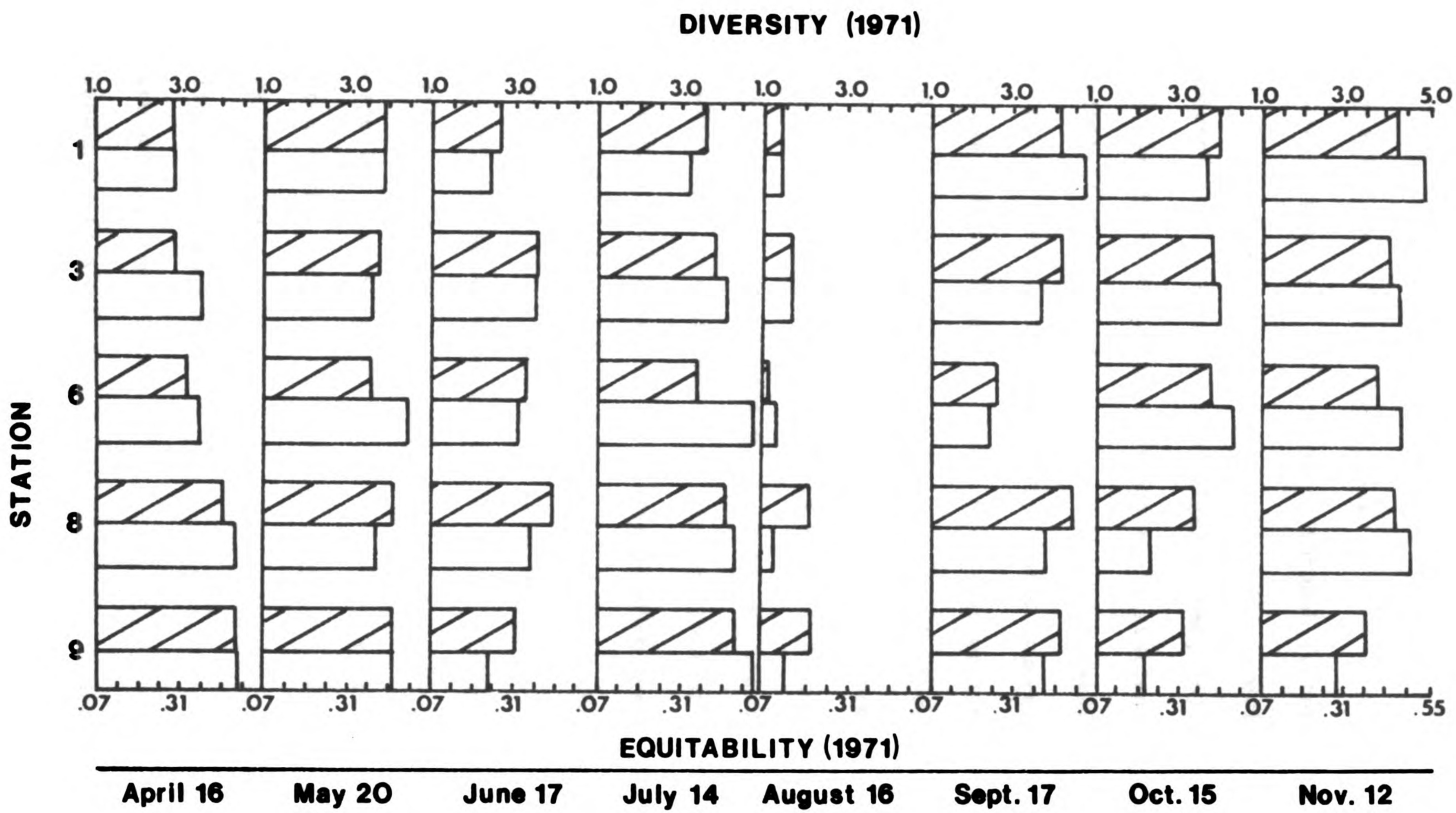


Figure 7. Mean phytoplanktonic diversity and equitability by station on each sampling date (hatched boxes--diversity; clear boxes--equitability).

number of species in discharge samples was higher during 1970 than 1971.

Seasonal and Yearly Statistical Comparisons

The following parameters were compared through factorial analysis: (1) number of species, (2) numerical diversity, (3) numerical equitability, (4) total numbers/liter, (5) blue-green algal volume, (6) green algal volume and (7) diatom volume using year and month station factors. Results indicated a statistically significant two-factor interaction term for all variables except numerical equitability, total counts/liter, and green algal volume (Appendix A31). But a three-factor interaction term was also significant for all factors except green algal volume. Therefore, a year test averaging all months at each station produced inconsistent and non-independent means. This is primarily due to the wide variation in replicates incorporated in the mean and the non-additivity of the model which violates an assumption for analysis of variance. A separation of 1970 and 1971 data by the three growing seasons sampled was performed to ascertain whether real differences existed between years for a given season. Seasonal testing has more biological basis because phytoplankton flourish seasonally in lake systems. It is evident that statistical differences existed in the number of species in the spring and fall, in species diversity during the fall season, and for equitability measured during the fall as well as diatom volume in the summer (Table 4). The reduction in the number of species affected the diversity and equitability comparisons made for the fall season but no effect occurred in the spring comparison. Diatom volume increased in the summer of 1971 independently from non-significant changes in other algal class volumes.

Table 4. Results of a two-way analysis of variance testing various parameters by the year (Y) and station (S) factors with a significance probability of the F-statistic based on the interaction mean square (Y x S).

Parameter	Season[1,2]		
	Spring	Summer	Fall
(1) Number of Species	p = 0.027* (all stations were higher in 1970)	p = 0.986(n.s.)	p = 0.001** (all stations were higher in 1970)
(2) Numerical Diversity	p = 0.058(n.s.)	p = 0.929(n.s.)	p = 0.002* (all stations were higher in 1970 except 8)
(3) Numerical Equitability	p - 0.78(n.s.)	p = 0.915(n.s.)	p = 0.04* (all stations were higher in 1970)
(4) Total counts/liter	p = 0.479(n.s.)	p = 0.40(n.s.)	p = 0.34(n.s.)
(5) Total cell volume/liter	p = 0.122(n.s.)	p = 0.51(n.s.)	p = 0.91(n.s.)
(6) Blue-green algal volume/liter	p = 0.70(n.s.)	p = 0.33(n.s.)	p = 0.907(n.s.)
(7) Green algal volume/liter	p = 0.83(n.s.)	p = 0.53(n.s.)	p = 0.14(n.s.)
(8) Diatom volume/liter	p = 0.15(n.s.)	p = 0.0005** (all stations were higher in 1971 except station 9)	p = 0.67(n.s.)

[1]Stations 1, 3, 6, 8 and 9 were combined in the analysis for a given season between years.

[2]Three dates were used for the spring comparison, three for the summer and two for the fall season.

An appraisal of statistical comparisons indicates that no striking dissimilarities in the phytoplankton population parameters occurred temporally or annually in the study area. Examining the standing crop at monthly intervals without doubt lends itself to wide fluctuations in populations. A look at the physiological responses of the phytoplankton community may illustrate any significant alterations due to plant operation.

Community Metabolism

Effects in Depth

Average depth profiles of gross primary productivity (GPP) indicate a significant reduction in carbon assimilation at approximately the 1.5 m depth for all stations both in 1971 and 1970 (Figure 8). Among the three stations, the river was least productive at all depths. The average GPP for the river surface was almost as great as values for the lake surface during 1971 but not nearly as high as at the surface in the discharge canal.

A higher GPP occurred at the 0.5 m depth relative to the average surface rate in the lake during 1971. This contrasts with the sharp decline from the surface to 0.5 m exhibited in 1970 at the lake station. No apparent yearly change occurred at the canal station in average surface GPP but higher productivity was indicated at the 0.5 and 1.5 m depths in 1971 compared to 1970. Below the surface, average GPP at the discharge station simulated average lake GPP at each measured depth. Average river gross primary productivity was slightly higher during 1971 at the surface and 0.5 m depths but was comparatively reduced below 0.5 m.

A respiratory profile with depth may have indicated slight decreases in carbon release at stations from the surface to 2.5 m but variation was so great that no statistically significant change could be identified.

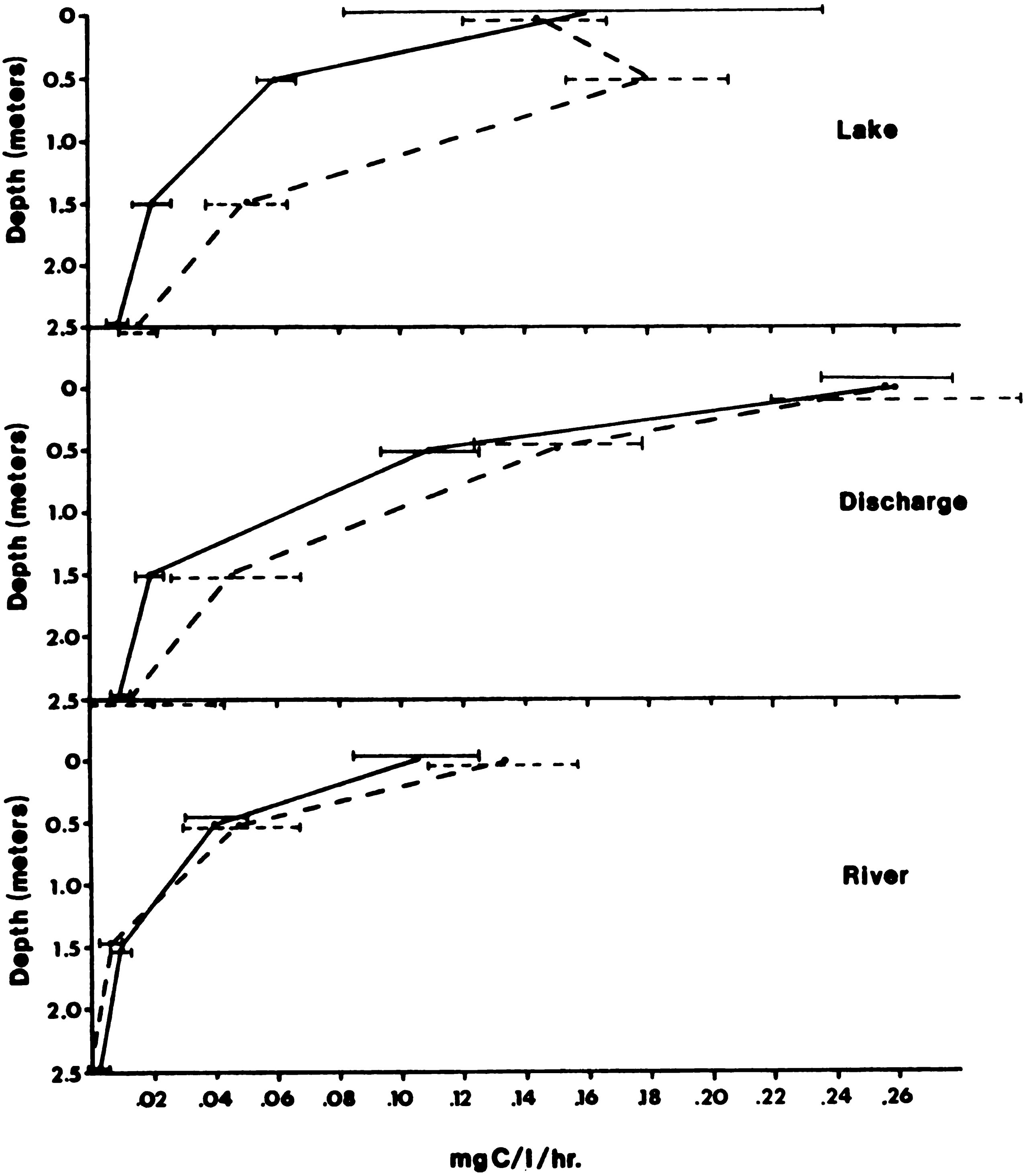


Figure 8. Depth profile of average gross primary productivity measured during the midday interval for the years 1970 (______) and 1971 (-----) at the three stations in the study area ($\bar{X}$ ± 1 S.E.)

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Dark bottle respiration exhibited more temporal deviation from the mean than did light bottle changes, causing wider standard errors. The river experienced a greater average respiratory rate at the surface among the three stations but the average for the discharge canal was greatest at the 0.5 and 1.5 m depths. A significant decrease in average oxygen consumption occurred at 2.5 m in the discharge canal.

Spatial and Temporal Effects

Midday Productivity: Gross primary productivity, as measured by *in situ* light and dark bottles, was lower in the river than in the lake or discharge on all but one occasion (Table 5). The discharge canal had the highest midday GPP on six of the study dates when complete sets were made. On the remaining five dates the lake environment evolved more oxygen. Maximum GPP of 498 ± 9 mg $C/m^2/hr$ occurred on 16 July in the discharge canal. Heating of intake water reached a Δ t of 8 C in that exposure. Highest GPP for the lake was recorded on 18 June and for the river on 2 October. Mean midday rates for 1971 were similar to spring 1972 mean rates (Table 5) at the lake but higher in the discharge and river during 1971.

Midday Respriation: Community respiration includes total chemical and biological oxygen demand but the chemical demand is assumed to be negligible. The enclosed biological community contains heterotrophic fungi, bacteria and zooplankton as well as autotrophic phytoplankton. Each component contributes an unknown amount to the total oxygen consumption. Respiration was consistently lowest in the lake (Table 5), except on two extraordinary occasions which may have been influenced by river water due to westerly winds on those dates. Most of the time lake respiration averaged about one-half that in the river and discharge canal.

Table 5. Mean gross primary productivity (GPP) and community respiration rates (R) estimated during the midday interval in $mgC/m^2/hr$ ($\bar{X} \pm 1$ S.E.).

		Stations					
		Lake		Discharge		River	
Date	Δ t[1]	GPP	R	GPP	R	GPP	R
5-21-71	4	348 ± 12	132 ± 22	272 ± 3	232 ± 21	122 ± 2	480 ± 99
6-3	1	263 ± 48	368 ± 58	137 ± 12	206 ± 26	24 ± 8	78 ± 18
6-18	8	448 ± 33	140 ± 42	266 ± 4	398 ± 31	66 ± 16	536 ± 6
6-30	7	184 ± 2	114 ± 4	236 ± 5	373 ± 21	98 ± 1	51 ± 2
7-16	8	280 ± 16	466 ± 4	498 ± 9	299 ± 15	108 ± 6	176 ± 4
7-29	9	252 ± 1	147 ± 10	324 ± 7	378 ± 22	95 ± 1	210 ± 0.0
9-15	8	375 ± 0	178 ± 3	362 ± 18	604 ± 38	104 ± 0.5	538 ± 10
10-2	4	354 ± 13	26 ± 1	473 ± 25	193 ± 4	245 ± 2	109 ± 6
10-16	5	103 ± 14	22 ± 10	272 ± 1	284 ± 14	120 ± 2	287 ± 6
10-30	4	181 ± 4	42 ± 8	242 ± 8	272 ± 8	147 ± 21	191 ± 4
11-13	7	62 ± 11	41 ± 3	---	---	---	---
Yearly Mean		259.1	152.3	308.2	314.4	112.9	265.6
2-29-72	1	38 ± 8	57 ± 42	-11 ± 4	22 ± 4	---	---
5-12	8	---	---	88 ± 2	173 ± 8	---	---
6-1	4	117 ± 3	70 ± 1	102 ± 7	136 ± 12	101 ± 6	208 ± 10
6-14	5	428 ± 7	59 ± 5	150 ± 4	232 ± 21	0 ±	354 ± 0
Spring Mean		272.5	64.5	113.3	180.3	50.5	281.0
Grand Mean		261.2	138.8	263.2	283.5	102.5	268.2

[1]The Δ t corresponds to the difference between intake and discharge temperatures.

Respiratory rates were similar in magnitude for both years at the lake station, i.e.: 1971 yearly averages and 1972 spring averages were nearly alike. Hourly respiration rates in the discharge canal during 1971 relative to 1970 averaged (by season): (1) spring, 23% lower; (2) summer, 166% higher; and (3) fall, 134% higher.

Diurnal Gross Primary Productivity: The diurnal change in GPP, measured on one occasion each in the summer of 1971 and late spring 1972, indicates peak photosynthesis in the early afternoon (Figure 9), close to the time that midday productivity was normally estimated.

Midday GPP peaks at the lake station were not much greater than mid-morning rates. Lowest secchi transparencies during the study period were recorded at the lake on those dates. The magnitude of diurnal productivity appeared to vary as much spatially as it did temporally. Real mean differences in respiratory rates for 26 August were evident: (1) the discharge averaged 54 mg C m^3/hr, (2) the lake averaged 18 mg C/m^3/hr, and (3) the river averaged 6 mg C/m^3/hr. Temperature differences were minor for that date (1C). Respiratory estimates on 1 June 1972 were similar for all stations with a Δ t = 4C recorded on that date.

Daily and Seasonal Gross Primary Productivity: To obtain daily estimates of GPP, the two sets of diurnal data were combined with the midday productivity measurements by proportioning the midday estimates to the average diurnal change in GPP (based on the two diurnal studies) measured over the rest of the day (Table 6). This procedure is of course subject to error since a constant proportion of total daily GPP is assumed to exist outside the midday *in situ* period. Another technique suggested by Schindler (1971) revealed similar daily and seasonal GPP to that obtained by the proportional method in Table 6. Schindler's technique incorporates the ratio of total daily solar radiation (I_t)

Figure 9.

mgC/m³/hr In upper m³

mgC/m³/hr In upper m³

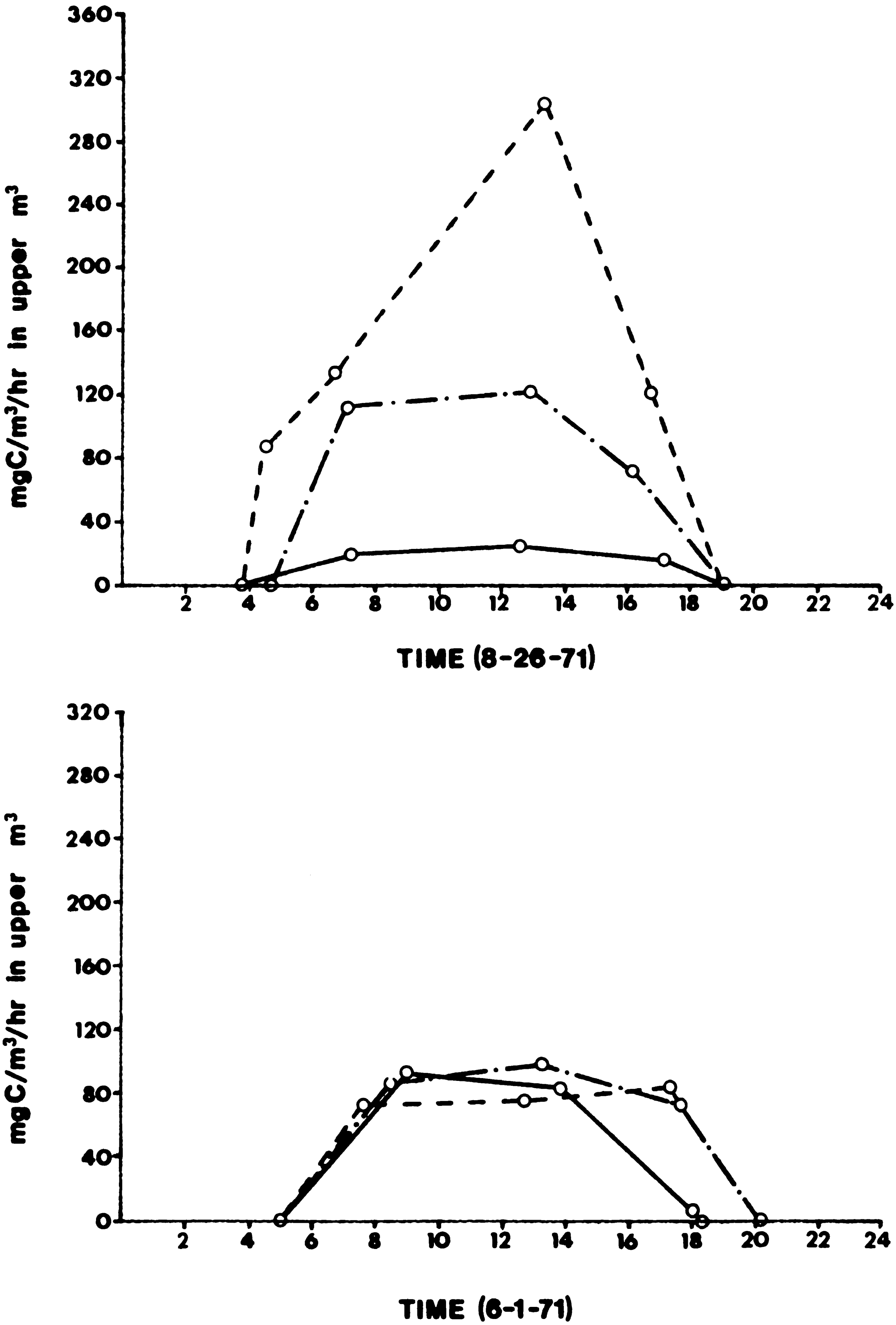

Figure 9. Average gross primary productivity estimated during the diurnal period on two study dates (lake ___.___; discharge -----; river _____).

Table 6. Mean daily and seasonal gross primary productivity during 1971 and 1972 (gC/m^2/day and season) compared to 1970 means (Marcus, 1972).

	Station					
Date	Lake	Marcus (1972)	Discharge	Marcus (1972)	River	Marcus (1972)
5-21-71	3.8		2.8		1.3	
6-3	3.0		1.4		0.3	
6-18	5.1		2.8		0.7	
$\bar{x}$ daily	4.0	0.9	2.3	2.0	0.8	0.8
$\bar{x}$ seasonal	361.0	78.3	212.3	185.8	68.7	71.0
6-30	2.1		2.6		1.1	
7-16	3.2		5.2		1.2	
7-29	2.7		3.2		1.0	
9-15	3.5		3.2		0.9	
$\bar{x}$ daily	2.9	1.7	3.6	2.7	1.0	1.5
$\bar{x}$ seasonal	261.6	159.2	323.1	250.7	94.4	141.2
10-2	3.1		3.9		2.1	
10-16	0.9		2.1		0.1	
10-30	1.4		1.8		1.1	
11-13	0.5		---		---	
$\bar{x}$ daily	1.5	0.7	2.6	2.2	1.4	0.7
$\bar{x}$ seasonal	135.7	62.9	239.2	204.6	124.7	63.7
Total gC/m^2 for three seasons	758.3	300.4	774.6	641.0	287.8	275.9
2-29-72	0.3		-0.1		---	
$\bar{x}$ daily	0.3		-0.1		---	
$\bar{x}$ seasonal	30.0		-6.8		---	
5-12	---		1.0		---	
6-1	1.3		1.1		1.1	
6-14	4.9		1.6		0.0	
$\bar{x}$ daily	3.1		1.2		0.6	
$\bar{x}$ seasonal	285.2		113.5		50.2	

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to partial daily radiation during the bottle incubation interval (I_p) (See Appendix A4). This method assumes a linear response of photosynthesis to light energy incident at the water's surface but it takes into account definite changes in the percentage of total daily GPP that the midday value comprises, regardless of the study day.

Seasonal summaries of GPP indicate no obvious relation between time of year and GPP except that GPP was lowest during the late fall (13 November) and winter (29 February) sampling (Table 6). The lake usually had the highest productivity during the spring of 1971 and 1972 while the discharge productivity was usually greatest in the summer and fall of 1971. Based on 1971 seasonal estimates, the river GPP was at most slightly more than one-half the GPP recorded at the other sites. During 1971, the growing season GPP for the lake station was slightly lower than the discharge GPP during the same period. Spring data from 1972 suggests a reduced seasonal GPP at the discharge and lake sites from the previous spring. Winter GPP in the study area appears relatively low based on limited sampling.

Seasonal average hourly GPP at the discharge canal in 1971 was consistently higher than GPP that Marcus (1972) reported, i.e.: a 15% spring increase, a 33% summer increase and an 18% fall increase (Table 6). Average hourly GPP in the discharge canal during the spring of 1972 was lower than the two previous spring GPP's. Lake hourly GPP in 1971 greatly exceeded 1970 rates but differences at the river station were minor.

GPP/R Ratios: Ratios of diurnal GPP and daily respiration (GPP/R) reveal whether or not the community is autotrophic (producing more than is consumed) or heterotrophic (producing less than is consumed). In no instance during the study period was GPP/R > 1 in the river or discharge canal, indicating heterotrophy (Table 7). This contrasted the lake site

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Table 7. Ratios of gross primary productivity/community respiration at the sampling stations (based on $gC/m^2/day$) with seasonal and yearly averages for the years 1970 and 1971.

Date	Lake	Marcus (1972)	Discharge	Marcus (1972)	River	Marcus (1972)
5-21-71	1.20		0.53		0.11	
6-3	0.34		0.28		0.16	
6-18	1.52		0.29		0.05	
Spring Mean	1.02	0.38	0.32	0.24	0.11	0.12
6-30	0.77		0.29		0.91	
7-16	0.29		0.72		0.28	
7-29	0.76		0.35		0.20	
9-15	0.82		0.22		0.07	
Summer Mean	0.66	0.66	0.40	0.56	0.36	0.32
10-2	4.84		0.84		0.80	
10-16	1.73		0.31		0.01	
10-30	1.37		0.28		0.24	
11-13	0.51		----		----	
Fall Mean	2.11	1.23	0.48	1.64	0.35	0.13
2-29-72	0.22		0.19		0.19[1]	
Winter Mean	0.22	----	0.19	----	0.19	----
Yearly Mean	1.0	0.76	0.36	0.81	0.25	0.19
5-12-72	----		0.24		----	
6-1	0.78		0.34		0.22	
6-14	3.45		0.29		----	
Spring Mean	2.12		0.29		0.22	

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which exhibited autotrophy (GPP/R > 1) on several occasions. Estimated annual averages, although far from precise because of great variability within seasons and inadequate cold weather sampling, indicate that the lake most often is near an autotrophic condition during the year. But removing the two relatively high ratios for the lake station would reduce the yearly mean ratio below 1.0, i.e.: heterotrophy would occur. However, the inshore sites are markedly heterotrophic. Daily respiratory rates incorporated in the ratios are based on the assumption that metabolic oxygen loss remains constant over the 24 hour period when R is probably a little higher during the day than it is at night. This could create over-estimates in respiration which would reduce the GPP/R ratios but relative comparisons are not likely to be as greatly affected.

Yearly variations in average seasonal GPP/R ratios suggests significant differences in the productive and consumptive capacity of the sampled water masses (Table 7). The lake exhibited a higher ratio in the spring and fall of 1971 as well as during the spring of 1972 compared to 1970 ratios. Lower ratios at the discharge canal during the summer and fall of 1971 contrasts the changes at the lake station in 1971. River ratios were characteristically low and similar during all three years. Slightly higher yearly ratios were obtained for the lake and river site in 1971, but a much reduced ratio was recorded at the canal site. Marcus (1972) lacked any winter sampling which likely would have reduced his yearly ratios even more than the tabulated values.

Sources of Power Plant Effects

On 18 August 1971 (D-1) and 14 October 1971 (D-2) experimental cooling system studies were completed to test the effect of various sources of potential alteration to *in situ* community metabolism as water

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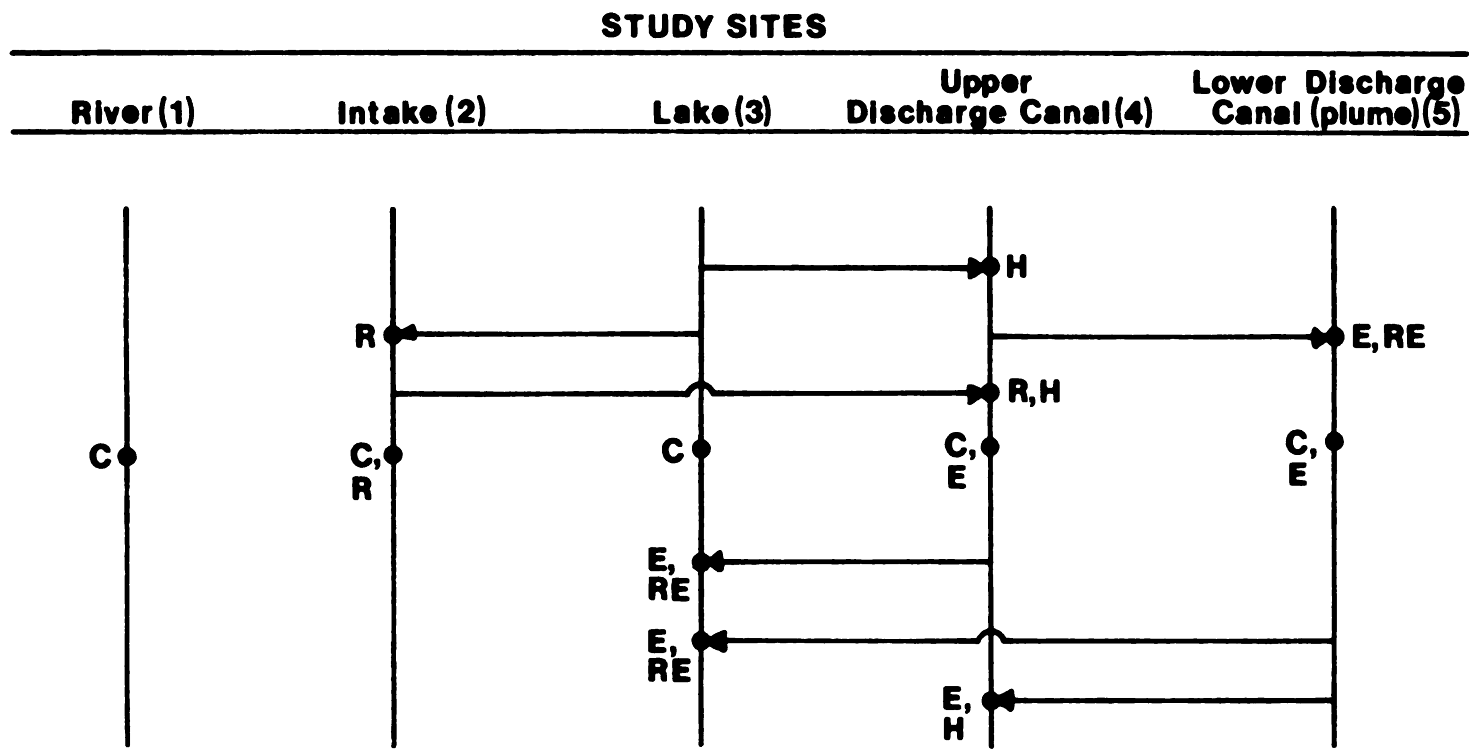
is used for cooling (Figure 10, Table 8). Potential sources of effects on ambient metabolism included: (1) mixing of river and lake water, (2) temperature alteration, (3) length of exposure to increased temperature, (4) mechanical damage and temperature alteration combined. An estimate of the ability of the community to recover after exposure to the cooling system was also included. Discharge samples were obtained twice during times when chlorine effects should have been minimal and once when chlorine was likely present (0825) according to plant operational schedules but this was not validated by direct measurement.

The effects of the cooling system were in some ways very consistent on both dates and in other respects much less consistent. On D-1 and D-2, all water returned to ambient temperatures of the lake showed relatively lower GPP and respiration rates. The temperature alteration accompanying those shifts was about a 10 C decrease. Uniform recovery in GPP to that of the lake suggests only temporary changes in community metabolism.

In August, water from the lake (22 C) and intake (25 C) incubated in the discharge canal (33 C) either maintained or exhibited lower GPP than control samples at those sites. Discharge water had a slightly lower GPP than intake water on that date but intake water transferred to discharge conditions was inhibited (+ 8 C change). In October, the GPP of intake water was apparently stimulated by exposure to discharge temperatures (+ 9 C). Plume origin water (lower discharge canal) was also stimulated by exposure at the discharge temperatures (+ 2 C change). Ambient temperature appears to govern the different responses between dates.

Mechanical effects appeared to be inhibitory in October but stimulative in August. In addition, length of exposure to heated water has little influence on the maintenance of GPP which was as high in the plume as in the discharge on both dates.

STUDY SITES



Key: C – Control, R – River and Lake mixing H – Warming, E – Multiple effects (heat, mechanical, river), RE – Recovery from multiple effects.

Figure 10. Schematic diagram of control and transfer light-dark bottle combinations used to measure effects of the power plant cooling system on In situ gross primary productivity and respiration.

Table 8. Comparative cooling system, gross primary productivity (GPP) and respiration (R) in the upper cubic meter on two dates (X ± 1S.E.).

Table 8. Comparative cooling system, gross primary productivity (GPP) and respiration (R) in the upper cubic meter on two dates (X ± 1S.E.).

Date 1 (8-18-71)[1]

Sample Treatment	Test Effects	Δ t (C)[2]	In situ times	GPP $mgO_2/l/hr$ ($\bar{X}$ + 1 S.E.)	GPP Mean $mgC/m^3/hr.$	R $mgO_2/l/hr$ ($\bar{X}$ + 1 S.E.)	R Mean $mgC/m^3/hr.$
River - River	C	0	11:20-2:30	0.32 ± 0.01	100	0.31 ± 0.02	96
Intake - Intake	C, R	0	11:40-2:35	0.47 ± 0.01	147	0.20 ± 0.01	61
Intake - Discharge	H, R	+8	11:40-4:25	0.27 ± 0.04	86	0.22 ± 0.03	69
Lake - Lake	C	0	11:55-4:05	0.25 ± 0.01	78	0.11 ± 0.01	33
Lake - Intake	R	+2	11:55-3:50	0.30 ± 0.04	93	0.18 ± 0.00	56
Lake - Discharge	H	+10	12:40-4:25	0.25 ± 0.01	79	0.20 ± 0.01	62
Discharge - Discharge	E, C	0	1:15-4:25	0.41 ± 0.0	128	0.27 ± 0.02	84
Discharge - Plume	E, Re	-1	1:30-4:50	0.36 ± 0.0	112	0.20 ± 0.02	61
Discharge - Lake	E, Re	-10	1:30-5:15	0.27 ± 0.03	85	0.11 ± 0.03	33
Plume - Plume	C, E	0	1:50-4:50	0.43 ± 0.01	135	0.28 ± 0.02	88
Plume - Lake	E, Re	-9	1:50-5:15	0.28 ± 0.01	86	0.16 ± 0.02	50
Lake - Lake	C	0	7:20-11:50	0.49 ± 0.02	152	0.13 ± 0.0	42
Lake - Discharge	H	+10	7:25- 1:05	0.53 ± 0.0	165	0.12 ± 0.0	38
Discharge - Discharge	E, C	0	8:25- 1:05	0.66 ± 0.02	207	0.32 ± 0.0	100

Table 8 (con't.)

Table 8 (con't.)

[1] The ratio of lake to river water mixed at the intake was approximately 19.2 : 1.

[2] Δt - the change in temperature from sample origin to incubation site.

Key: C - Control sample
R - River influence
H - Warming
E - Multiple exposure (heat, mechanical, river)
Re - Recovery

Table 8 (con't.)

Date 2 (10-14-71)[1]

Sample Treatment	Test Effects	Δ t (C)[2]	In situ times	GPP $mgO_2/l/hr$ ($\bar{X}$ ± 1 S.E.)	GPP Mean $mgC/m^3/hr.$	R $mgO_2/l/hr$ ($\bar{X}$ ± 1 S.E.)	R Mean $mgC/m^3/h4.$
River - River	C	0	9:50-2:00	0.43 ± 0.0	135	0.26 ± 0.0	82
Intake - Intake	C, R	0	10:00-2:05	0.43 ± 0.01	134	0.15 ± 0.0	46
Intake - Discharge	H, R	+9	10:25-2:25	0.61 ± 0.01	189	0.36 ± 0.01	111
Lake - Lake	C	0	10:10-2:45	0.37 ± 0.0	116	0.06 ± 0.01	18
Lake - Intake	R	+1	10:10-2:05	0.42 ± 0.01	131	0.09 ± 0.01	28
Lake - Discharge	H	+10	---	---	---	---	---
Discharge - Discharge	E, C	0	10:40-2:25	0.51 ± 0.001	158	0.23 ± 0.01	70
Discharge - Plume	E, Re	-2	10:50-2:35	0.48 ± 0.0	150	0.13 ± 0.0	42
Discharge - Lake	E, Re	-10	10:55-2:45	0.38 ± 0.01	118	0.13 ± 0.0	40
Plume - Plume	C, E	0	11:00-2:35	0.53 ± 0.0	165	0.17 ± 0.0	52
Plume - Lake	E, Re	-8	11:05-2:50	0.36 ± 0.02	111	0.04 ± 0.01	12
Plume - Discharge	E, H	+2	10:35-2:25	0.60 ± 0.03	188	0.14 ± 0.04	45

[1] The ratio of lake to river water mixed at the intake was approximately 8.5 : 1.

[2] Δ t - the change in temperature from sample origin to incubation site.

Key: C - Control sample
R - River influence
H - Warming
E - Multiple exposure (heat, mechanical, river)
Re - Recovery

Respiration stays the same or is increased whenever a significant temperature elevation occurs whereas respiration significantly decreases when incubation takes place at cooler temperatures. Mixing of lake and river water at the intake decreased respiration over that of the river water by dilution with lake water that has a relatively low oxygen demand.

DISCUSSION

Changes in Community Structure

Algal community composition did not exhibit any significant changes after plant operation. Comparing mean 1970 class volumes (Marcus, 1972) with 1971 class volumes suggests maximal variation was as much as 10 times different between 1970 and 1971 for each class except when blue-green algae were not present in 16 April 1971 samples. This variation could easily lie within experimental chance. Neither did any of the dominant phytoplankton species of pre-operational (1970) studies show pronounced responses to cooling water use during 1971 studies. The number of species was lower in 1971 but this was consistent over the whole study area, nor did species diversity significantly change at the lake and inshore sites between years. Slightly higher than predicated (Table 10), algal biomass (volume) occurred in the discharge canal during 1971 but mean cell size in the discharge canal showed similar fluctuations between the two years.

Annual Variation in Gross Primary Productivity

The most useful tool for discovering short-term integrated physiological shifts in phytoplankton metabolism seems to be their ability to actively fix energy. It was expected that a shift in average daily and seasonal photosynthetic rates at the discharge station would accompany plant operation. Marcus' (1972) measurements of mean daily GPP in the river during 1970, when cooling water was not being pumped, closely approximated measurements made at the river station in 1971 (Table 9).

Table 9. Comparison of various parameters that could potentially influence phytoplankton populations and primary productivity in the study area during 1970 and 1971 (GPP and R means are for the year period).

	1970			1971		
Parameter	Lake[1]	Discharge	River	Lake	Discharge	River
Total Phosphorus (mg/liter)[2]	0.11	0.10	0.25	0.11	0.20	0.28
Total Nitrogen (mg/liter)[3]	1.27	2.01	2.59	1.00	1.74	1.89
Total Carbon (mg/liter)[3]	27.5	41.8	46.9	24	36	40
Total Suspended Solids (mg/liter)[3]	27.2	45.3	43.8	20.4	44.4	35.9
Wind Velocities (km/hr)	------	12.8[4]	------	------	12.6[5]	------
Zooplankton levels (no/liter)[6]	455	931	193	633	492	310
$\bar{x}$ daily GPP ($gC/m^2/day$)	1.1	2.3	1.0	2.8	2.8	1.1
$\bar{x}$ daily R ($gC/m^2/day$)	2.5	6.6	6.2	3.7	7.5	6.4
$\bar{x}$ daily P/R ratios	0.4	0.4	0.2	0.8	0.4	0.2

[1]Means for station 1, 3 and 6 on 8 study dates (April - November) for each year.

[2]From Charles Annett, unpublished data.

[3]From Thomas Ecker, unpublished data.

[4]U.S. Department of Commerce, Toledo Express Airport, Toledo, Ohio.

[5]U.S. Department of Commerce, Detroit City Airport, Detroit, Michigan.

[6]From Thomas Nalepa (1972) and Julin Lu, unpublished data.

But the 1971 mean daily GPP at the lake station increased 155% over the previous year while the daily rate at the discharge site increased only 22% from the 1970 mean GPP.

A list of possible factors which influence the phytoplankton community aid in explaining yearly differences in GPP (Table 9). Average concentrations of important macronutrients were essentially similar in 1970 and 1971 and therefore were probably not limiting algal growth. It is impossible that observed changes in lake GPp were caused by any change in nutrient concentrations. Temperature differences from 1970 to 1971 were negligible so that temperature was not responsible for higher GPP in the lake during 1971. Zooplankton abundances (grazers and non-grazers) may have slightly increased in the lake over 1970, probably as a response to higher GPP in 1971 rather than decreased predation because fish abundances in the lake were similar in 1970 and 1971 (Cole, 1973). Wind velocities on study dates were similar but overall slightly calmer weather occurred in 1971. This may have been partly responsible for reduced suspended solids in the lake during 1971. Suspended solids in western Lake Erie have been demonstrated to affect the variation in light penetration with other factors being equal (Verduin, 1954). Thus, the significant yearly differences in daily GPP at the lake were caused by differences in light penetration. Average depth profiles of GPP in the lake indicated a real light inhibition at the surface during 1971 in contrast with 1970 when surface values were the greatest. Gross primary productivity in the lake was higher in 1971 only at subsurface depths. The fact that other parameters influencing GPP are uniformly distributed with depth except wind disturbances implies that light indeed does control GPP in the lake. Cody (1972) also reported a surface inhibition of primary productivity in western Lake Erie (Bass Island region) with a maximum reached between 1 and 3 meters followed by a rapid decline in O_2 production and carbon assimilation below 3 meters. Similar sharp decreases in GPP with depth were experienced in the study area. The higher GPP/R ratios also reflect the significant increase in yearly GPP at the lake in 1971 because respiration only slightly increased during 1971 (Table 9). But average ratios in 1971 at the discharge site have remained about the same as 1970 values.

Influence of Power Plant Operation on Intake Community Metabolism

Further yearly comparison of the discharge canal is constrained by the fact that in 1971, it was actually a flow-through environment unlike the standing situation of 1970. The effects of strong currents and river mixing were negligible in 1970 as opposed to 1971. Therefore, an analysis of observed vs. expected changes at the site for 1971 seems applicable. Based on the calculated average mixing ratio of lake water to river water (6.7:1), expected values of parameters are compared to observed values in the discharge canal (Table 10). The difference between expected and observed probably indicates the integrated effects of temperature change, river and lake mixing, and mechanical effects. But it should also be remembered that lake values were determined over one kilometer from the intake and considerable differences could occur between the lake water at station 3 and lake water at the intake before it reaches the cooling system. The lake station GPP and respiration must be assumed to represent the lake contribution at the plant intake because GPP measurements were not made near the mixing zone of the intake.

Passage through the cooling system apparently stimulated hourly and daily GPP and respiration in the discharge canal over that expected from the simple mixing proportions. Mechanical and river effects may

Table 10. Mean observed and expected values for parameters associated with the Monroe Power Plant operation in 1971.

Parameter	Lake	River	Discharge (observed)	Discharge (expected)	% Variation
Flow	20 m^3/sec[1]	3 m^3/sec	23 m^3/sec	19.3	---
Mean Temperature (°C)	19.2[1]	20.3	27.1	19.3	
Average Time of Flow	----	----	∿ 4 hours	----	---
GPP : mgC/m^2/hr.	259.1	112.9	308.2	235.7	31
gC/m^2/day	2.8	1.1	2.8	2.6	7
R : mgC/m^2/hr.	152.3	265.6	314.4	167.1	100
gC/m^2/day	3.7	6.4	7.5	4.0	88
Daily P/R ratios	0.8	0.2	0.4	0.7	-77
Algal Cell Carbon (Biomass) (Mg/liter)	1.5[1]	1.6	1.7	1.5	13
Particulate Org. Carbon (mg/liter)	3.4[1]	5.1	6.0	3.6	67
Hourly GPP/carbon (P/B)[2]	176.3	70.1	180.2	158.1	14
Hourly R/carbon[2] (R/B)	103.6	164.9	183.8	112.1	64
Species Diversity ($\bar{H}$)	3.34[1]	3.51	3.67	3.36	12

[1] Based on mean values for stations 1, 3 and 6 from April to November.

[2] Units for this ratio are $\frac{\text{mg C/m}^2\text{/hr.}}{\text{mg C/liter}}$

interact with temperature elevation to produce higher GPP. As indicated by the two entrainment studies, mixing at the intake of lake and river water appeared to stimulate GPP over that which the lake experienced before the in situ community was exposed to a temperature rise. Therefore, the Δ t is probably not the only stimulant. The average decrease in GPP/R ratios suggests more energy is being used to maintain the community than expected. Slightly higher cell carbon (biomass) occurred at the discharge site over expected concentrations which hints of a higher standing crop of phytoplankton. An increase over expected was also experienced in the particulate organic carbon measurements. This may seem contrary to the lower GPP/R ratios but it indicates that the stimulation of respiration is primarily due to increased decomposition of detritus from the river-lake mixture while a relatively high proportion of the GPP was retained in cell biomass. But the GPP/B ratio also was higher than expected which suggests that GPP has increased more than biomass in the discharge canal. Margalef (1968) believes population stability is inversely correlated with the GPP/B ratio and directly correlated with species diversity. A relatively high GPP/B ratio usually is indicative of an unbalanced, productive and eutrophic system where export of organic production predominates. But the discharge water had a comcomitant increase in respiratory consumption that increased at a faster rate than the algal biomass. The source of this community respiration appears to be heterotrophic and undoubtedly must be concentrated on detritus breakdown because the observed algal biomass also was higher in the discharge canal. This sounds completely contradictory to the description of a "eutrophic system" but Marcus (1972) also expressed the importance of organic import (detritus) to the study area. This is particularly emphasized in the low GPP/R ratios common to the study area.

The higher species diversity than expected is usually not characteristic of a system that exhibits high GPP/B ratios but Marcus (1972) also reported a relatively high species diversity in the discharge canal in conjunction with high GPP. The high diversity is probably due to the constant import of rare species to the canal from surrounding marsh habitats.

Any physiological alterations produced in the phytoplankton community from cooling system effects appeared to be only temporary because GPP recovered almost completely when bottles from the discharge canal were returned to ambient lake conditions. This also implies that exposure to river water and mechanical effects had no persistent after-effects on lake phytoplankton metabolism. Temperature seemed to be the major if not the only regulatory factor involved.

The initial ambient water temperature before passage could be involved in determining photosynthetic inhibition or stimulation. At initial temperatures of 26 C, a depression in GPP resulted but at 16 C, an increase in GPP was exhibited. Similar water temperature regimes reported by Morgan and Stross (1969) and Warinner and Brehmer (1966) produced equivalent results in carbon fixation rates of enclosed brackish water and river communities respectively. Heating in cooler seasons to stimulate GPP may be desirable and advantageous.

Chlorine effects probably did not occur on days primary productivity was measured because average hourly GPP rates were stimulated rather than inhibited in the discharge canal during 1971. Recent studies have shown inhibition of photosynthetic capabilities or destruction of algal cells by chlorine (Brook and Baker, 1972; Hirayama and Hirano, 1970).

In general, I suspect that plant activities in 1971 stimulated gross primary productivity of intake water. A localized effect probably occurred from this stimulation because discharge canal GPP recovered to that measured in the lake. The lowered GPP/R ratios appear to be caused by detritus import into the discharge canal followed by heterotrophic respiration rather than algal respiration. Algal cells will eventually become part of this detritus system unless primary consumers ingest the cells to satisfy their energy needs. The characteristically consumptive conditions of the study area would tend towards a more balanced (GPP/R = 1) system if foreign organic import was reduced but may be offset by accumulations of algal biomass in the vicinity of the discharge canal due to stimulated GPP.

Because the Monroe Power Plant produced not more than 25% of its maximum potential electrical output during post-operational studies of 1971 and early 1972, more studies are needed to predict long-term effects of the cooling water discharge on the near-shore environment of western Lake Erie. In particular, an examination of the ability of photosynthetic organisms to recover from cooling system passage might be sought by <u>in situ</u> laboratory culture of post-condenser communities. By exposing these communities to various temperatures over ambient, a time factor for recovery may be obtained as measured by such parameters as oxygen production, carbon fixation or ATP activity in those cultures.

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APPDENICES

Appendix A1. Water temperature elevation in the cooling system at the one meter depth, Raisin River flow, and pumping rate at the Monroe Power Plant site recorded at the time of plankton collections and primary productivity studies.

Date	River flow m^3/sec[1]	Pumping Rate m^3/sec	Δ t (over intake)
4-16	15.4	0	0
5-20	6.3	23	5
5-21	5.9	23	4
6-3	5.5	23	1
6-17	5.6	23	6
6-18	4.9	23	8
6-30	2.6	23	7
7-14	1.9	23	8
7-16	2.0	23	8
7-29	1.9	23	9
8-16	1.6	23	2
8-18	1.2	23	10
8-26	1.1	23	1
9-15	1.2	23	8
9-17	1.4	23	8
10-2	3.0	23	4
10-14	2.7	23	10
10-15	2.6	23	8
10-16	2.3	23	5
10-30	3.7	23	4
11-12	2.8	23	9
11-13	2.7	23	7
2-29-72	5.7	46[2]	1
5-12	25.2	23	8
6-1	9.2	46	4
6-14	5.2	46	5

[1] City of Monroe contributes not more than a 10% additional discharge to river flow before it reaches the plant intake.

[2] Doubled because pumping units doubled.

Appendix A2. Periodic total residual chlorine concentrations (ppm) condensed from plant operational reports of 1971 and 1972.

Date	ppm[1]	Date	ppm	Date	ppm
6-24-71	0.5[2]	10-10	0.05	2-27-72	0.35
6-29	0.4[2]	10-12	0.05	2-28	0.5
7-1	0.5[2]	10-15	0.05	4-11	0.5
7-6	0.4[2]	10-20	0.2	4-20	0.3
7-8	0.7[2]	10-22	0.05	5-2	0.07
7-12	0.5[2]	10-27	0.1	5-4	0.05
7-15	0.15[2]	11-1	0.05	5-9	0.06
7-21	0.15[2]	11-5	0.1	5-11	0.04
7-23	0.15[2]	11-11	0.1	5-16	0.07
7-27	0.2[2]	11-12	0.1	5-18	0.12
8-10	0.2[2]	11-16	0.0	5-25	0.0
8-17	0.15[2]	11-19	---	5-27	0.1
8-20	0.20[2]	11-22	0.05		
9-8	0.15[2]	11-27	0.10		
9-10	0.75[2]	12-7	0.2		
9-11	0.75[2]	12-14	0.25		
9-15	0.1[3]	12-16	0.25		
9-17	0.1[3]	2-1-72	0.35		
9-22	0.1[3]	2-3	0.35		
9-25	0.05[3]	2-8	0.25		
9-28	0.05[3]	2-10	0.25		
9-30	0.05[3]	2-15	0.20		
10-5	0.05	2-17	0.20		
10-8	0.05	2-21	0.30		

[1] All values are average total residual unless indicated otherwise

[2] Maximum total residual chlorine

[3] Free chlorine

Appendix A3. Physical parameters recorded at the time of primary productivity studies.

	STATION					
	LAKE		RIVER		DISCHARGE	
Date	Secchi (m)	Temperature[1]	Secchi	Temperature	Secchi	Temperature
5-21-71	---	17.5-17.5	---	20.5-20.0	---	22-21
6-3	---	22-18.0	---	20-18.5	---	22-19
6-18	---	23.5-22.0	---	25-24	---	32.5-30.0
6-30	0.8	26.5-25	0.4	27.5-26	0.5	34.0-32.5
7-16	1.0	23-23	0.6	25.0-23.5	0.8	32.-29.5
7-29	1.1	22-22	0.6	25-23	0.6	31.5-30.0
8-18	0.9	23.0-22	0.5	26.0-24.0	0.6	33.5-32.0
8-26	0.6(m) 0.5(a)	23.0-22.5	0.5(m) 0.5(a)	24.0-24.0	0.6(m) 0.5(a)	24.0-23.5
9-15	0.8	22.0-22.0	0.5	23.5-23.0	0.6	29.5-29.5
10-2	1.2	21.5-20	0.5	23-21.0	0.4	26-23
10-14	0.6	15.0-15.0	0.5	16.5-16.0	0.5	25.0-25.0
10-16	1.0	14.5-14.0	0.4	15.5-15.0	0.5	19.5-19.0
10-30	0.9	17.-16.5	0.4	18.5-17.0	0.4	22-19
11-13	1.0	7.0-7.0	0.4	7.0-6.5	0.2	14.0-14.0
2-29-72	2.0	1.0-1.0	---	------	1.0	3.0-1.5
5-12	1.2	10.0-10.0	---	11.5-11.0	0.6	19.0-19.0
6-1	0.5	18.5-18.0	0.6	20-19.0	0.4	22-22
6-14	0.4	21.0-19.0	0.4	24.0-21.0	0.3	26.5-26.5

[1]Temperature (°C) range: surface to 3 meters
m - morning
a - afternoon

Appendix A4. Measured daily solar radiation in conjunction with primary productivity studies of 1971 and 1972.

Date	Langleys/day	Langleys/discharge in situ period	I_t/I_p
4-15-71	517	239	---
5-21	565	245	2.33
6-3	604	284	2.13
6-18	626	277	2.27
6-30	534	239	2.22
7-16	581	237	2.44
7-29	582	249	2.33
8-18	510	---	---
8-26	263	---	---
9-15	342	128	2.63
10-2	294	137	2.17
10-14	212	---	---
10-16	231	104	2.22
10-30	198	112	1.79
11-13	200	104	2.22
2-29-72	190	140	1.35
5-12	698	309	2.27
6-1	423	275	1.54
6-14	632	296	2.13

Appendix A5. Meteorological information pertaining to plankton and productivity studies (1971-72).

Date	% Possible Sun-shine for Day	% Sky Cover	Average Wind speed (km/hr.)	Prevailing Wind Direction	Air Tem-perature (°C)
4-16	69	10	7.7	SE	10
5-20	70	70	16.0	W	13
5-21	84	40	15.0	NW	13
6-3	81	30	14.5	W	18
6-17	100	0.0	8.6	SE	21
6-18	95	40	10.2	SE	21
6-30	68	40	14.8	NW	27
7-14	97	20	18.3	NW	21
7-16	95	20	17.6	W	21
7-29	76	60	9.7	W	18
8-16	92	30	11.7	S	20
8-18	100	0.0	9.7	SE	21
8-26	31	70	14.0	SW	23
9-15	57	70	14.8	NW	20
9-17	60	70	17.3	NE	18
10-2	77	20	7.0	SE	22
10-14	59	70	13.3	SW	13
10-15	93	50	8.6	SE	15
10-16	64	70	11.5	NE	17

Appendix A5 (con't.)

10-16	64	70	11.5	NE	17
10-30	83	30	8.9	SE	16
11-12	9	100	10.5	SW	6
11-13	78	60	14.3	NE	7
2-29-72	57	100	14.6	SE	3
5-12	100	70	14.0	E	14
6-1	27	80	13.7	SW	14
6-14	52	80	15.2	SW	18

Appendix A6. Mean total algal numbers (1971) (X 10^3/liter).

Date	Station				
4-16-71	1	3	6	8	9
	1791	1844	3546	3755	4004
5-20-71	6	9	8	1	3
	2808	4462	4618	4926	5348
6-17-71	6	3	8	9	1
	1977	6582	10014	10995	12857
7-14-71	6	3	1	9	8
	889	1628	1827	5265	8537
8-16-71	3	6	1	9	8
	3640	4811	11948	18948	23289
9-17-71	1	6	3	9	8
	2910	3157	3283	4122	5022
10-15-71	6	3	9	1	8
	6238	8536	9312	11998	13636
11-12-71	1	3	6	8	9
	1732	1781	1908	2987	4004

Appendix A7. Mean total algal volume (1971) (X 10^{-4} ml/liter).

Date	Station				
4-16-71	1	3	9	8	6
	488	576	586	645	1528
5-20-71	6	9	8	3	1
	712	942	1171	2730	2992
6-17-71	6	8	9	1	3
	985	2901	4780	4787	5633
7-14-71	6	1	3	9	8
	505	859	1342	3412	4505
8-16-71	3	6	1	9	8
	1851	2059	5922	8877	10222
9-17-71	9	3	8	6	1
	1605	1689	2014	2062	2226
10-15-71	9	6	8	3	1
	2321	2713	3405	3628	5940
11-12-71	9	1	6	3	8
	611	695	733	768	1704

Appendix A8. Mean individual phytoplanktonic volume (1971) in μ^3.

Date	Station				
4-16-71	9	8	1	3	6
	1463	1714	2733	3152	4277
5-20-71	9	6	8	3	1
	2330	2515	2586	5114	5890
6-17-71	8	1	9	6	3
	2952	3928	4308	5069	8538
7-14-71	1	8	6	9	3
	5034	5533	5553	6441	8072
8-16-71	8	6	9	1	3
	4396	4415	4755	5026	5088
9-17-71	9	8	3	6	1
	3926	3946	5072	6207	7524
10-15-71	9	8	6	3	1
	1692	3674	4247	4332	4956
11-12-71	9	6	1	3	8
	1531	3869	4004	4249	5718

Appendix A9. Mean volume of blue-green algae (1971) (X 10^{-6} ml/liter).

Date	Station				
4-16-71	1	3	6	8	9
	0	0	0	0	0
5-20-71	6	8	9	1	3
	40	2687	3461	7464	9170
6-17-71	6	3	8	1	9
	1228	4714	6586	8156	20236
7-14-71	6	1	3	9	8
	541	554	1524	13894	22090
8-16-71	3	6	1	9	8
	9848	12805	49445	74124	90836
9-17-71	9	3	8	1	6
	1536	4257	6072	6807	8876
10-15-71	9	8	6	3	1
	2667	13384	14229	14788	29718
11-12-71	9	6	3	1	8
	326	689	1198	1448	1684

Appendix A10. Volumetric dynamics of *Aphanizomenon flos-aquae* (X 10^{-5} ml/liter).

Date		Station 1	3	6	8	9
4-16-71	(1)[1]	0	0	0	0	0
5-20	(3)	7.5	44.8	4.0	8.8	32.3
6-17	(5)	6.9	3.2	15.5	10.6	0
7-14	(7)	44.8	38.6	19.5	76.3	83.3
8-16	(9)	2112.6	614.7	906.0	3744.4	2867.7
9-17	(11)	53.8	17.7	197.2	30.6	41.7
10-15	(13)	503.4	469.5	305.4	281.0	165.9
11-12	(15)	28.4	25.9	38.3	57.2	13.5

[1]Designates a coded date.

Appendix A11. Volumetric dynamics of _Anacystis incerta_ (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	75.99	75.99	0	0	1114.5
(7)	0	21.2	0	1101.9	227.98
(9)	1773.1	141.2	211.7	3580.0	3039.7
(11)	338.8	183.5	561.2	63.5	63.5
(13)	1891.3	405.3	861.2	296.4	0
(15)	25.4	0	0	0	0

Appendix A12. Volumetric dynamics of _Anacystis thermalis_ (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	10.6
(5)	59.3	29.7	5.3	389.8	779.6
(7)	0	63.8	34.5	635.4	779.6
(9)	144.1	14.1	30.1	508.4	632.7
(11)	106.3	178.8	40.2	124.0	10.6
(13)	259.9	192.1	118.6	0	0
(15)	14.2	24.1	10.6	0	15.9

Appendix A13. Volumetric dynamics of *Anacystis cyanae* (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	0	0	18.6	0	0
(7)	0	28.9	0	12.4	44.5
(9)	593.6	190.2	105.4	949.7	791.4
(11)	24.8	0	61.1	310.1	0
(13)	118.7	0	0	612.2	0
(15)	0	0	0	0	0

Appendix A14. Mean volume of green-algae (1971) (X 10^{-6} ml/liter).

Date	Station				
4-16-71	1	6	3	9	8
	42	49	62	315	1013
5-20-71	8	6	9	1	3
	1707	1905	2026	2356	2481
6-17-71	6	8	1	9	3
	4944	12809	20852	21546	35056
7-14-71	6	1	3	8	9
	2678	3199	9598	17498	18254
8-16-71	1	6	8	3	9
	896	2124	3136	4396	10505
9-17-71	3	6	8	1	9
	2623	3776	7087	8962	9229
10-15-71	9	6	8	3	1
	6363	6829	9922	14010	18234
11-12-71	9	8	3	1	6
	220	440	2218	2251	2683

Appendix A15. Volumetric dynamics of Mougeotia elegantula (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	0	0	0	0	34.0
(7)	0	0	0	0	0
(9)	0	0	0	0	45.4
(11)	240.5	85.4	0	237.3	170.9
(13)	635.9	620.8	238.5	270.5	61.7
(15)	60.8	29.6	33.2	23.7	14.2

Appendix A16. Volumetric dynamics of Pediastrum duplex (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	52.0	103.9	0	0	0
(5)	1885.5	3294.5	415.7	1118.9	1740.5
(7)	215.2	652.4	164.5	1391.2	1409.0
(9)	0	358.0	0	0	165.8
(11)	150.1	34.6	10.0	173.2	277.1
(13)	718.3	331.5	124.3	536.9	155.9
(15)	110.8	159.3	112.6	0	0

Appendix A17. Volumetric dyanmics of Pediastrum simplex (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	0	0	0	0	0
(7)	0	58.8	22.0	0	0
(9)	0	0	146.9	0	656.1
(11)	470.1	58.8	350.4	176.3	381.9
(13)	281.2	281.2	210.9	88.1	293.8
(15)	0	0	88.1	0	0

Appendix A18. Mean diatom volume (1971) (X 10^{-6} ml/liter).

Date	Station				
4-16-71	1 4833	8 5438	9 5544	3 5690	6 15232
5-20-71	9 3805	6 4973	8 7023	3 15392	1 20103
6-17-71	6 2999	9 5111	8 7789	1 12481	3 13879
7-14-71	6 1665	3 1679	9 1722	1 3719	8 5179
8-16-71	3 895	6 1021	1 2068	9 3859	8 5374
9-17-71	9 3755	8 5080	1 5356	6 7042	3 9814
10-15-71	6 5860	3 6980	8 10380	1 10920	9 13927
11-12-71	1 3188	6 3898	3 3992	9 5548	8 14912

Appendix A19. Volumetric dynamics of Coscinodiscus radiatus (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
4-16-71	73.6	68.1	22.7	61.5	109.6
5-20	253.8	77.9	83.3	66.9	10.6
6-17	22.9	470.4	265.9	47.1	28.4
7-14	182.9	89.7	104.1	257.3	82.97
8-16	185.5	82.3	93.4	323.6	271.98
9-17	410.6	524.8	602.6	403.6	269.7
10-15	404.9	174.3	158.3	196.9	196.4
11-12	83.0	113.1	124.5	61.9	77.9

Appendix A20. Volumetric dynamics of Melosira granulata (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	92.1	222.2	222.4	120.4	53.7
(3)	141.98	50.9	0	87.4	41.6
(5)	134.7	49.3	5.4	122.9	0
(7)	4.1	4.8	0	35.98	13.5
(9)	4.2	0	4.2	13.2	14.0
(11)	21.7	192.6	12.6	30.98	31.1
(13)	137.9	85.3	51.7	110.1	96.2
(15)	27.9	34.97	43.0	45.4	50.9

Appendix A21. Volumetric dynamics of Stephanodiscus astraea (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	2.8	18.7	52.1	86.8	120.9
(3)	185.5	357.6	106.1	161.4	142.4
(5)	102.7	80.0	1.0	33.2	10.0
(7)	1.5	0.87	0.4	0	2.4
(9)	3.0	3.2	4.2	9.5	10.1
(11)	15.7	31.8	9.0	11.2	5.6
(13)	416.3	273.0	211.1	585.6	797.4
(15)	35.2	48.3	74.9	1146.1	243.0

Appendix A22 . Volumetric dynamics of Stephanodiscus tenuis (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	50.1	45.0	82.5	47.4	30.2
(3)	0	2.9	4.1	7.4	14.0
(5)	23.6	3.7	0.3	29.4	6.2
(7)	0.9	0.14	0.12	18.2	1.5
(9)	0.24	0.0	0.12	14.1	6.3
(11)	5.5	7.2	0.7	26.1	34.9
(13)	7.7	5.99	7.7	74.3	221.6
(15)	2.9	1.96	0.8	13.6	37.1

Appendix A23. Volumetric dynamics of <u>Fragilaria</u> <u>capucina</u> (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	1.6	0	43.2	0.0	0.0
(3)	29.0	47.6	19.2	15.3	0.0
(5)	38.4	8.2	0.0	0.0	0.0
(7)	15.81	10.4	0.0	0.0	0.0
(9)	0.0	0.0	0.0	0.0	0.0
(11)	0.0	14.6	20.9	6.7	3.0
(13)	39.9	71.6	102.4	34.3	22.1
(15)	113.9	132.4	108.0	86.9	62.8

Appendix A24. Volumetric dynamics of <u>Fragilaria</u> <u>crotonensis</u> (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	78.9	47.1	421.8	18.1	0.0
(3)	321.4	80.4	67.4	40.4	21.5
(5)	74.3	47.3	0	36.6	19.0
(7)	20.8	10.9	0.0	0.0	0.0
(9)	0.0	0.0	0.0	8.3	10.5
(11)	15.3	0.0	0	0.0	0.0
(13)	42.0	16.8	41.97	0.0	0.0
(15)	0.0	0.0	8.1	0.0	0.0

Appendix A25. Volumetric dynamics of <u>Tabellaria fenestrata</u> (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	84.8	121.4	480.9	63.5	40.2
(3)	1004.2	800.4	205.3	227.0	75.7
(5)	823.5	705.4	0.0	343.2	134.0
(7)	122.1	42.7	61.4	46.0	0.0
(9)	0	0	0	0	0
(11)	51.3	171.95	51.6	0	0
(13)	0	19.66	0	0	0
(15)	7.8	54.5	0	21.4	0

Appendix A26. Volumetric dynamics of <u>Cryptomonas ovata</u> (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	121.9	156.3	56.4	64.5	34.1
(7)	23.0	5.2	1.1	1.2	16.7
(9)	14.3	16.3	1.6	55.8	27.9
(11)	30.3	0	77.1	75.4	43.96
(13)	51.0	33.5	10.2	6.92	10.7
(15)	6.8	4.7	6.2	0	1.2

Appendix A27. Volumetric dynamics of Ceratium hirundinella (X 10^{-5} ml/liter).

Date	Station 1	3	6	8	9
(1)	0	0	0	0	0
(3)	0	0	0	0	0
(5)	0	57.1	0	0	0
(7)	80.9	52.99	11.9	0	0
(9)	532.5	296.8	421.3	152.1	0
(11)	74.2	0	47.7	47.7	47.7
(13)	0	0	0	0	0
(15)	0	19.1	0	0	0

Appendix A28. Mean number of species at each station in 1971.

Date	Station				
4-16-71	3	1	6	8	9
	19	23	23	37	39
5-20-71	6	1	3	9	8
	24	34	35	38	47
6-17-71	6	1	3	9	8
	30	31	32	36	42
7-14-71	6	3	1	9	8
	20	30	36	37	38
8-16-71	6	3	1	9	8
	21	22	23	36	43
9-17-71	6	1	3	9	8
	28	36	42	47	51
10-15-71	6	3	1	9	8
	32	33	40	42	44
11-12-71	6	1	3	8	9
	29	38	39	40	41

Appendix A29. Mean phytoplanktonic diversity (1971).

Date	Station				
4-16-71	1	3	6	8	9
	2.73	2.83	3.07	4.04	4.26
5-20-71	6	3	1	9	8
	3.59	3.72	3.79	4.02	4.21
6-17-71	1	9	6	3	8
	2.68	3.15	3.25	3.58	3.93
7-14-71	6	1	3	8	9
	3.38	3.64	3.72	4.17	4.30
8-16-71	6	1	3	8	9
	1.02	1.35	1.63	2.02	2.19
9-17-71	6	3	1	9	8
	2.69	4.05	4.08	4.19	4.36
10-15-71	9	8	3	6	1
	3.16	3.36	3.76	3.88	4.00
11-12-71	9	6	3	8	1
	3.58	3.79	4.16	4.26	4.36

Appendix A30. Mean phytoplanktonic equitability (1971).

Date	Station				
4-16-71	1	6	3	8	9
	.29	.36	.37	.45	.48
5-20-71	3	8	1	9	6
	.38	.39	.41	.43	.49
6-17-71	1	9	6	8	3
	.21	.24	.32	.36	.37
7-14-71	1	3	8	6	9
	.34	.42	.47	.52	.53
8-16-71	6	8	1	9	3
	.10	.10	.11	.12	.14
9-17-71	6	3	9	8	1
	.24	.39	.39	.40	.46
10-15-71	9	8	1	3	6
	.21	.23	.40	.42	.46
11-12-71	9	3	8	6	1
	.30	.46	.47	.47	.53

Appendix A31. Analysis of variance of factorial design comparing year, station and month factors.

(1) Number of Species

Source	df	M.S.	F Stat.
Year (A)	1	4890.63	635.75**
Station (B)	4	2310.22	300.31**
A x B	4	94.21	12.25**
Months (C)	7	644.82	83.82**
AC	7	361.30	46.97**
BC	28	98.54	12.81**
ABC	28	99.18	12.89**
Error	240	7.69	

(2) Phytoplanktonic Numerical Diversity

Source	df	M.S.	F. Stat.
A	1	0.26	3.72*
B	4	4.21	60.18**
AB	4	0.35	4.96**
C	7	10.34	147.96**
AC	7	4.94	70.70**
BC	28	1.61	23.06**
ABC	28	1.18	16.88**
Error	240	0.07	

(3) Phytoplanktonic Numerical Equitability

Source	df	M.S.	F Stat.
A	1	0.41	164.82**
B	4	0.02	9.48**
AB	4	0.003	1.23N.S.
C	7	0.296	118.49**
AC	7	0.079	31.71**
BC	28	0.047	19.01**
ABC	28	0.044	17.81**
Error	240	0.002	

Appendix A31 (con't.)

(4) Total Phytoplanktonic Numbers (Units)

Source	df	M.S.	F. Stat.
A	1	0.227	15.82**
B	4	2.112	147.28**
AB	4	0.011	0.76N.S.
C	7	1.722	120.101**
AC	7	0.764	53.32**
BC	28	0.293	20.46**
ABC	28	0.232	16.24**
Error	240	0.014	

(5) Total Phytoplanktonic Cell Volume

Source	df	M.S.	F. Stat.
A	1	0.007	0.376N.S.
B	4	0.777	39.70**
AB	4	0.072	3.67*
C	7	2.722	139.12**
AC	7	1.231	62.90**
BC	28	0.363	18.53**
ABC	28	0.242	12.39**
Error	240	0.0196	

(6) Blue-green Algal Volume

Source	df	M.S.	F. Stat.
A	1	37.99	49.29**
B	4	1.36	1.77N.S.
A x B	4	2.56	3.32*
C	7	122.12	158.44**
AC	7	19.37	25.14**
BC	28	1.77	2.29**
ABC	28	1.84	2.38**
Within	240	0.77	

Appendix A31(con't.)

(7) Green Algal Volume

Source	df	M.S.	F. Stat.
A	1	32.34	107.51**
B	4	1.76	5.84**
AB	4	0.16	0.52N.S.
C	7	13.75	45.71**
AC	7	4.43	14.74**
BC	28	1.09	3.63**
ABC	28	0.42	1.38N.S.
Within	240	0.30	

(8) Diatom Volume

Source	df	M.S.	F. Stat.
A	1	0.18	9.88**
B	4	0.95	52.29**
AB	4	0.35	19.05**
C	7	5.50	301.17**
AC	7	1.55	84.7**
BC	28	0.35	19.06**
ABC	28	0.22	12.35**
Error	240	0.02	

* - significant at the α = .05 level.

** - significant at the α = .01 level.