EFFECTS OF THE
DAIRYLAND POWER COOPERATIVE ELECTRICAL GENERATING FACILITY
ON THE PHYCOPERIPHYTON IN NAVIGATION POOL NO. 9,
UPPER MISSISSIPPI RIVER

A Thesis
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by

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ABSTRACT

A study was conducted in Navigation Pool No. 9 of the Upper Mississippi River to determine the impact of the thermal effluent from Dairyland Power Cooperative's Genoa, Wisconsin electric generating facility on the phycoperiphyton. The objectives of this study were: 1) to compare the taxonomic composition, density, biomass, and pigment concentration of the phycoperiphyton community upstream and downstream from the thermal effluent; 2) to monitor the physical and chemical characteristics of the upper portion of Navigation Pool 9; and 3) to establish baseline data for phycoperiphyton in channel areas of Navigation Pool No. 9 of the Mississippi River.

Sampling was conducted from 3 June 1980 to 1 June 1981. Phycoperiphyton samples were collected from artificial and natural substrates. Field determinations of temperature, dissolved oxygen, and current velocity were made at each sampling site. Water samples were collected and analyzed for turbidity, conductivity, pH, total hardness, total phosphorus, orthophosphorus, nitrate + nitrite-N, nitrite-N, ammonia-N, and silica.

The electric generating facility effluent increased the temperature of the Mississippi River in the vicinity of the discharge during the entire year. The temperature of the receiving water was elevated 4.3°C to 11°C above the ambient temperature. Increases in temperature were minimal at downstream sampling sites. Dissolved oxygen concentrations were similar to those recorded for other reaches of the Upper Mississippi River and were always >51% of saturation. Current velocity was low and mostly affected by local river morphometry and manmade structures. The chemical character of the water was similar among the four sites sampled. The water could be classified as hard and alkaline with sufficient nitrogen and phosphorus to support high rates of primary production.

A total of 259 species representing 52 genera were identified. Both green algae and blue-green algae were common but not abundant. The most common green algae were *Stigeoclonium lubricum*, an unidentified species of green algae, and several species of *Scenedesmus*. *Oscillatoria* sp. was the most prevalent blue-green alga and was observed at all sampling sites during most of the year.

Three major diatom assemblages were recognized: 1) a summer/autumn assemblage, 2) late autumn assemblage, and 3) a thermally influenced winter assemblage at the discharge. The dominant species in the summer/autumn assemblage was *Cocconeis placentula* var. *euglypta* and *Navicula tripunctata* var. *schizonemoides*. These species had an inverse dominance relationship at all the sampling sites except the site located at the discharge. The summer/autumn assemblage at the discharge site was dominated by *Navicula tripunctata* var. *schizonemoides* and several *Cyclotella* species. The late autumn assemblage persisted for less time than the summer/ autumn assemblage. *Melosira varians* was the most common species observed. *Stephanodiscus rotula* dominated at the discharge during the late autumn assemblage.

The thermal discharge was the only site sampled during the winter, and a thermally influenced witner assemblage was observed. *Stephanodiscus rotula* accounted for at least 70% of the phycoperiphyton density in January and early February. The density of *Stephanodiscus rotula* declined, but it remained dominant during the entire winter. Density was low in summer but increased during late autumn at the sites upstream and downstream of the discharge. In contrast, species diversity was lower in January and February but again increased in the spring.

The greatest total phycoperiphyton densities were observed during September and October. *Cocconeis placentula* var. *euglypta* was the most common alga observed during this time. The greatest density at the discharge site occurred in January and February and was associated with the high relative numbers of *S. rotula*.

The accumulation of chlorophyll *a* varied substantially, both temporally and spatially. In general, accumulation rates were low in the summer, increased in autumn, and declined in late autumn. Chlorophyll at the thermal discharge site accumlated more rapidly than at the other sites; the higest rates in the discharge occurred during the winter.

Accumulation of ash-free dry-weight was greatest in the summer and autumn, and declined in late autumn. The greatest production of organic matter was observed at the discharge site in January and February. This coincided with the greater densities of phycoperphyton.

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INTRODUCTION

Increasing demands for electrical energy have led to the proposal and construction of numerous electrical generating facilities that use water from lakes, oceans, and rivers for cooling of steam condensers (Klarer and Hickman 1975). Inputs of heated water into aquatic ecosystems have caused changes in the biota of these systems (Cairns 1956, Patrick et al. 1969, Morgan and Stross 1969). Because of these changes, research on the effects of thermal effluents on the phycoperiphyton community has increased considerably during the past two decades. Phycoperiphyton is an important component of the ecosystems of major rivers such as the Mississippi (Weitzel 1979). Unlike phytoplankton these sessile algal communities can not be transported from the heated effluent and are therefore good indicators of the effects of point discharges on the algal communities in aquatic systems (Weitzel 1979).

Thermal loadings to surface waters can alter the community composition and standing crops of algae. Seasonal temperature changes may cause shifts in species composition. Cairns (1956) found that diatoms and green algae usually grow best at cool (18-30°C) and at moderate temperatures (30-35°C), respectively, and that several species of blue-green algae are among the most heat tolerant algae (35-40°C). Some species of diatoms, however, have different temperature optima and tolerance ranges than those reported by Cairns (Wallace 1955). For example, *Gomphonema parvulum*, several *Achnanthes* species, and *Nitzschia palea* were abundant at temperatures exceeding 15°C. In contrast, several species of *Synedra* and *Gomphonema angustatum* were more abundant at cooler temperatures (Duke Power 1978). Artificial increases in temperature often exclude all except the most adaptable species from growing. A sequential shift in community composition from diatoms to green algae to blue-green algae was observed in the Green River Reservoir where maximum seasonal temperatures plus thermal loading by power stations increased water temperatures to >38°C (Churchill and Wojlalik 1969). Blue-green algae can remain dominant if warm temperatures are maintained for long periods of time. Consequently, damage to the structure and stability of the ecosystem can occur if one or a few taxa unnaturally remain dominant for prolonged periods (Patrick 1969).

Lakes and rivers in the northern temperate zone do not usually experience complete compositional shifts of phycoperiphyton to blue-green algae. Temperatures rarely exceed 30°C in northern lakes and rivers even with thermal additions by power plants or other industries; therefore, phytoplankton and zooplankton are not usually killed by the increased temperatures. Shifts from diatom dominated communities to ones dominated by the green algae, however, have been observed (Hickman and Klarer 1975).

Thermal effluents may affect phycoperiphyton communities by changing the timing of spring growth and autumn senescence (Moore 1978). For example, _Ulothrix_ growth is active in the spring up to 11°C. In the autumn, active growth usually resumes at 8°C. _Cladophora_ often becomes dominant in late spring and early summer when it coexists with _Ulothrix_. With the addition of heated water from a power station, areas within the thermal plume were found to experience spring succession from _Ulothrix_ to _Cladophora_ in February. This succession occurred almost three months earlier than observed in the reference areas (Moore 1978).

Warinner and Brehmer (1966) observed that temperature may stimulate or inhibit rates of carbon uptake. An 8°C rise inhibited carbon uptake at ambient temperatures of 23°C or warmer. The same input of heat stimulated carbon uptake if receivng waters were 16°C or cooler. Rodgers and Dillion (1974) observed similar increases in a man-made impoundment cooling water from a nuclear power plant. Kevern and Ball (1965) demonstrated that elevated temperatures not only stimulated production in some instances but also stimulated respiration. In such cases, increases in gross primary productivity were usually counterbalanced by increases in respiration; consequently, significant increases in net productivity were not observed.

The present study was conducted near Dairyland Power Cooperative's generating facility at Genoa, Wisconsin. Two plants were in operation during this study. Genoa-3 (G-3) is a 350 megawatt coal fired steam generating plant, and the La Crosse Area Boiling Water Reactor (LACBWR) is a 52 megawatt nuclear generating facility. This study was conducted to evaluate the effects of these power plants on phycoperiphyton of Navigation Pool No. 9. Specific objectives were:

1) to compare the taxanomic composition, density, biomass, and pigment concentration of the phycoperiphyton community upstream and downstream from the thermal effluent;

2) to monitor the physical and chemical characteristics of the upper portion of Navigation Pool 9 of the Upper Mississippi River; and

3) to establish baseline data for phycoperiphyton in channel areas of Navigation Pool No. 9 of the Mississippi River.

DESCRIPTION OF STUDY AREA

Navigation Pool No. 9 of the Upper Mississippi is formed from water impounded by Lock and Dam No. 9 located at River Mile (RM) 648 (43° 12' N, 91° 6' E). The upper boundary of Pool No. 9 is Lock and Dam No. 8 at Genoa, Wisconsin (RM 679.2; 43° 34' N, 91° 14' E). Pool length is 39.9 km and maximum width is approximately 6.4 km. The bed of the Mississippi River in Wisconsin has an average slope of 0.006%; (Martin 1965). Discharges ranged from less than 10,000 cfs to greater than 80,000 cfs from June through September 1980 (Rada et al. 1980).

Dairyland Power Cooperative's power generating complex is located at RM 678.5 (Fig. 1); its thermal effluent enters the river at this point. Site 1 was located 230 m upstream of the thermal effluent and served as the reference site in this study. Samplers for Site 2 were placed in the thermal plume. The exact location of the samplers varied depending on water elevation. Site 3 was located 210 m downstream from the outflow. The samplers were secured to a barge mooring cell at this location. A large eddy resulted in a northward flow at Site 3. This was probably due to the position of the barge mooring cells, the location of the coal unloading facility, and the river morphometry. Site 4 was 870 m downstream from the outflow. The samplers were secured to a tree that had fallen into the river. The tree was large enough to serve as a relatively permanent sampling site. Samplers were, however, periodically subjected to shading by riparian vegetation, wave action, and occasional stranding during low pool elevations.

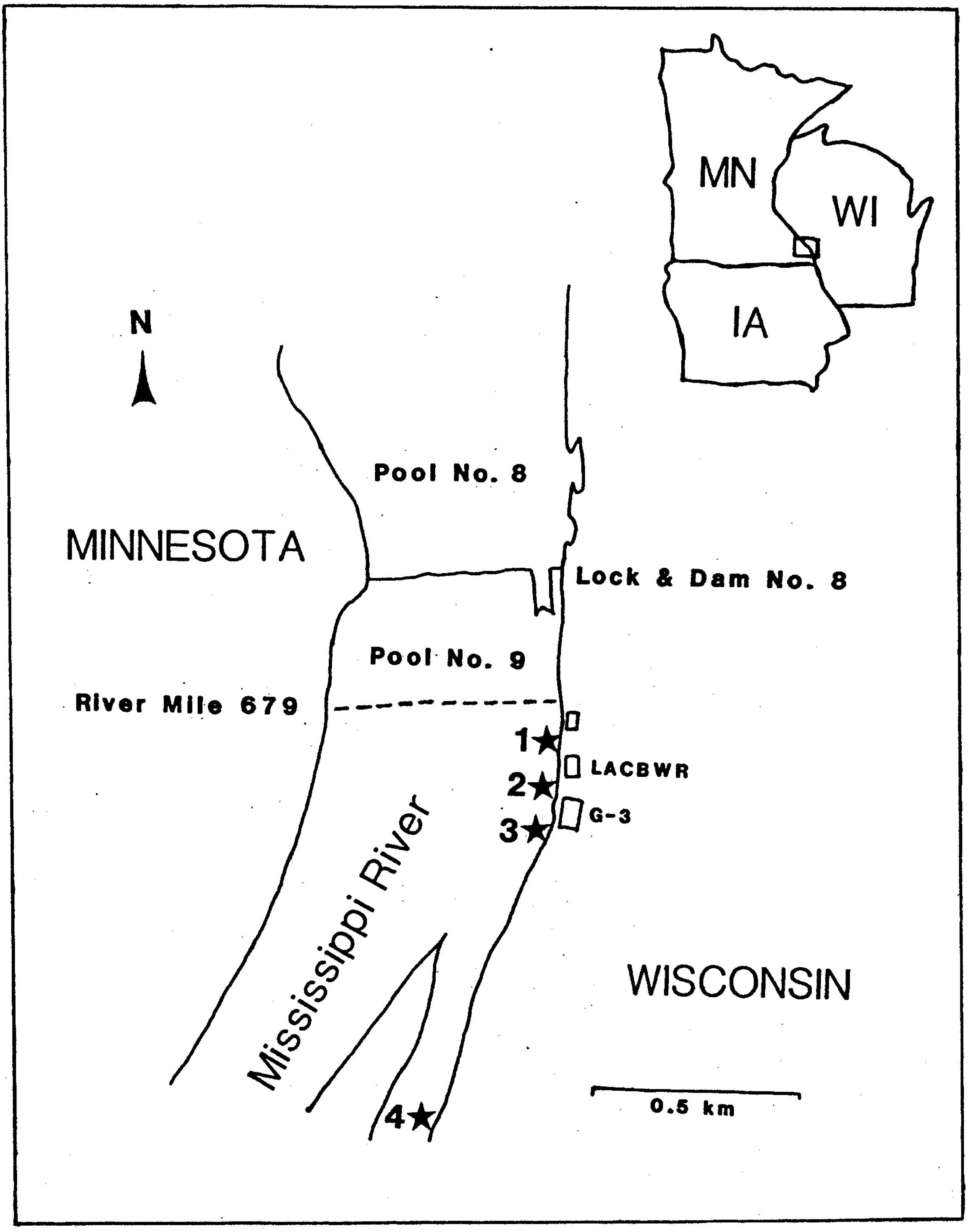

Fig. 1. Map of the study area in Navigation Pool No. 9, Upper Mississippi River (Sampling sites = *).

MATERIALS AND METHODS

Physical and Chemical Analyses

Physical and chemical variables analyzed during this study are presented in Table 1. Field determinations of temperature, dissolved oxygen, and current velocity were made at each sampling site. All measurements were made in the upper 0.5m of water. Water samples were collected in acid-washed bottles that were rinsed on site with river water. Turbidity, conductivity, pH, total hardness, and total phosphorus were determined on unfiltered water. Approximately 500 mL of sample were filtered through a glass fiber filter (Type A/E, Gelman) and analyzed for orthophosphorus, nitrite-N, nitrate + nitrite-N, ammonia-N, and silica. All analyses were conducted within 24 hours after collection.

Phycoperiphyton Analyses

Periphytometer

Phycoperiphyton samplers were constructed by cutting the tops and bottoms out of plastic microscope slide boxes, leaving enough of an edge to retain the glass microscope slides. Slides were held in the boxes with insulated wire. Floats were attached to one side and nylon line was attached to the bottom of the sampler (Fig. 2). The slides were suspended at a uniform depth in the water with the long axis of the slides perpendicular to the water surface.

Sampling Period

Phycoperiphyton samples were collected during ice-free periods from Sites 1, 3, and 4. Site 2, which was located in the thermal plume, was sampled during the entire year. Sampling was conducted from 6 May 1980

Table 1. Variables, reporting units, and methods for the chemical analysis performed on water samples collected from Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981.

Variable(abbrev.)	Units	Method	References
Temperature	°C	Mercury Thermometer	
Turbidity (Turb)	NTU	Nephelometric	EPA 1979
Current Velocity (CV)	m/sec	Current Velocity Meter	USGS 1969
Specific Conductance (K_{sp})	umhos	Conductivity meter	EPA 1979
pH		Electrometric	EPA 1979
Dissolved Oxygen (DO)	mg/L	Dissolved Oxygen Meter	APHA 1976
Total Hardness (T Hdn)	mg/L $CaCO_3$	Titrimetric--CDTA	APHA 1976
Ammonia (NH_3-N)	mg/L	Colorimetric--Indophenol; Colorimetric--Sodium Salicylate	Liddicoat et al. 1974; Verdouw et al. 1979
Nitrate + Nitrite (NO_3 +NO_2-N)	mg/L	Colorimetric--hydrazine reduction	Barnes 1959
Nitrite (NO_2-N)	mg/L	Colorimetric--buffer color reagent	EPA 1969
Total Phosphorus (Total-P)	mg/L	Colorimetric--persulfate digestion, ascorbic acid, two reagents.	EPA 1979
Orthophosphorus (Ortho-P)	mg/L	Colorimetric--ascorbic acid, two reagents	EPA 1979
Silica (SiO_2)	mg/L	Colorimetric-molybdosilicate	EPA 1979

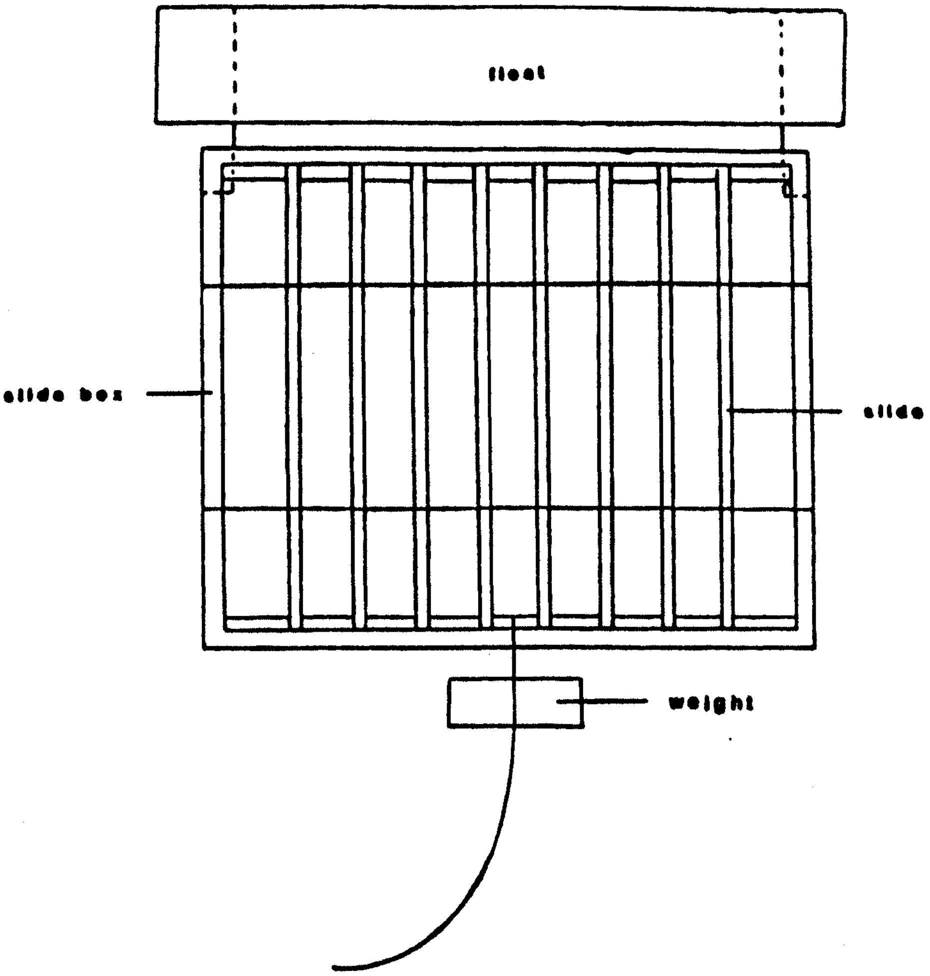

Fig. 2. Periphytometer used during the phycoperiphyton study of Pool No. 9, Upper Mississippi River (Approx. 3/4 scale).

to 1 June 1981. Duplicate samplers were exposed at each site at the beginning of each four-week sampling period. Two more samplers were placed at each site 14 days later. Slides remained in place for 28 days. Four samplers were in place at all times with sampling periods overlapping by 14 days. If the samplers were missing or destroyed, phycoperiphyton was collected from natural substrate.

Pigment Analyses

Algal material for chlorophyll analysis was obtained by scraping both surfaces of one to three slides. The number of slides analyzed depended on the number recovered from samplers. Scrapings were washed onto glass fiber filters (Gelman Type A/E). The filters were placed in tubes wrapped in aluminum foil and stored in a freezer. Phycoperiphyton pigments were extracted by grinding the filters in 90% acetone to which 0.5 g of magnesium carbonate had been added (APHA 1976). Absorbances of the pigment extracts were determined with a narrow slit-width spectrophotometer. Chlorophyll a concentrations and the OD $_{663}$ Before:OD $_{663}$ After acidification ratios and pheophytin a correction were determined according to APHA (1976). Chlorophyll samples with a before:after acidification ratio of 1.7 were considered to be indicative of an algal community with mostly viable, non-decaying organisms (Weber 1973). If pheophytin concentrations are high, however, ratios approach 1.0. Both pigments are present in natural communities and ratios range between 1.0 (all pheophytin a) and 1.7 (all chlorophyll a).

Dry and Ash-Free Weight

One to three slides, depending on the number of slides recovered, were removed from each sampler and were air dried. Attached material was scraped into a crucible and dried to a constant weight at 105°C to determine dry weight. The samples were ignited at 500°C for one hour (APHA 1976). The remaining ash was wetted and dried at 105°C to a constant weight to determine ash-free dry weight.

Autotrophic Index

The autotrophic index, which is the ratio of total biomass to chlorophyll *a* (Weber 1973), was computed for each sample. Autotrophic index values provide a means of assessing the trophic structure of the periphyton community or the autotrophic or heterotrophic condition of the community. Normal A.I. values range from 50 to 200; however, numbers as high as 300 are not uncommon for autotrophic communities. Autotrophic indexes of $\geq$800 usually represent heterotrophic communities and are therefore indicative of organic enrichment.

Phycoperiphyton Identification and Enumeration

Phycoperiphyton was preserved by scraping live material from the surfaces of one or two slides into a solution of "M^3" preservative (APHA 1976). Some natural substrate scrapings were also collected when the glass slides were either broken or missing. A Palmer-Maloney cell (Palmer and Maloney 1954) was used as a counting chamber to enumerate the absolute density of all living cells (diatoms and non-diatoms) and to identify non-diatoms. Identifications of non-diatom algae were made using a bright field microscopy at a magnification of 450X with the following keys: Smith (1950), Tiffany and Britton (1952), and Prescott (1962).

A minimum of 500 cells per sample were counted, providng a 95% confidence interval of $\leq$10% (Lund et al. 1958). Phycoperiphyton densities (cells/m^2) were estimated from these counts using the following equation:

$$\text{Cells/m}^2 = \frac{C}{T} \times \frac{\dfrac{A_{P-M}}{A_t} \times 10 \times V}{\text{Area Scraped}}$$

where:

C = number of cells counted
T = number of transects
A_{P-M} = area of the Palmer-Maloney cell
A_t = area of one transect
10 equates volume of Palmer-Maloney cell to 1 mL
V = volume of the concentrated sample

Enumeration of individual cells of colonial and filamentous algae would have caused an error in estimating total phycoperiphyton density as well as being very time consuming. Therefore, a method of counting using predetermined standard sizes for algal units was used. Filaments were counted as the number of units of a standard length, and colonies were enumerated as the number of units of a standard area (APHA 1976). Standard units are listed in Appendix IV.

Diatom samples were cleared by the nitric acid-potassium dichromate method (Patrick and Reimer 1966). A high refractive index mounting media (Hyrax^R, Custom Research and Development Inc., Auburn, CA) was used for permanent mounts. Diatom identification and species proportional counts were made at a magnification of 1200X by bright field microscopy (APHA 1976). A minimum of 500 valves were counted per slide. Data were reported as means of duplicate samples. Taxonomic keys used for identification were Bourrelly (1968), Cleve-Euler (1955), Huber-Pestalozzi (1942), Hustedt (1930a and b), Patrick and Reimer (1966, 1975), and Weber (1971). All taxa were identified to the lowest taxon practicable, and taxa that were not positively identified were assigned an identification number. *Stephanodiscus rotula* is synonomous with *S. astrea* which is the former taxonomic designation for this species. Voucher specimens were retained for all taxa.

RESULTS AND DISCUSSION

Physical Variables

The most significant impact of Dairyland Power Cooperative's Genoa generating facility observed in this investigation was caused by its thermal effluent in Pool 9. Seasonal differences in temperature between Sites 1 and 2 were greater during winter than in the summer because of higher temperatures of the thermal effluent from the power plant (Fig. 3). In November one of two intake pumps was shut down, resulting in an increase in effluent temperature. The pump was put back into operation in April (McInery 1980). On 2 December 1980, the temperature at Site 2 was 12°C compared to 1°C at Site 1. In contrast, the temperature at Site 2 was only 5°C higher than at Site 1 on 15 July 1980. On 10 March 1981, the generating station was partly shut down, which decreased the need for cooling. Consequently, the temperature at Site 2 decreased to the lowest recorded value (6.8°C) of this study. This was an increase of only 4.3°C above the ambient river temperature. Water temperature was warmer at Sites 2, 3, and 4 than at Site 1, which was located upstream of the discharge (Table 2, Appendix I). The highest temperature (33°c) was recorded at Site 2, which also had the highest mean temperature (18°C). Site 3 had a lower mean temperature when compared to the mean temperatures of Sites 1 and 4. This, however, was due to an artifact of sampling procedures in which more temperature readings were taken during cold weather at Site 3 than Sites 1 and 4. The unsafe condition of the river ice made it hazardous to obtain temperature readings at Sites 1 and 4 from 17 December 1980 through 14 January 1981. A similar situation occurred on 10 February 1981. The values listed in Appendix I demonstrate that the temperature at Site 3 and Site 4 were only slightly elevated above the ambient temperature when compared to the increase in

Table 2. Means and ranges for selected physical and chemical variables in Navigation Pool No. 9 near Genoa, Wisconsin, Upper Mississippi River, June 1980 to June 1981.

Variables	Site 1	Site 2	Site 3	Site 4
Conductivity	323	322	331	332
mhos/cm	230 - 450	220 - 450	230 - 460	220 - 490
Turbidity	24	23	25	23
NTU	3 - 89	4 - 90	4 - 87	4 - 92
pH	6.6-8.8	6.6-8.8	6.5-8.9	6.6-9.0
Total Hardness	145	144	147	148
mg/L as $CaCO_3$	100 - 200	102 - 196	100 - 204	108 - 208
NO_3+NO_2-N	0.765	0.752	0.783	0.778
mg/L	0.210-1.57	0.240-1.57	0.240-1.94	0.220-1.57
NO_2-N	0.019	0.019	0.020	0.020
mg/L	0.004-0.040	0.004-0.040	0.004-0.042	0.005-0.041
NH_3-N	0.065	0.064	0.116	0.076
mg/L	0.005-0.272	0.004-0.272	0.005-0.280	0.005-0.287
Total -P	0.193	0.184	0.205	0.201
mg/L	0.080-0.345	0.080-0.340	0.085-0.425	0.085-0.360
Ortho -P	0.095	0.105	0.092	0.098
mg/L	0.010-0.225	0.010-0.220	0.010-0.255	0.010-0.315
Silica as	10.0	9.7	10.2	10.2
mg/L SiO_2	2.0-16.2	2.0-15.2	1.7-17.0	2-17.0
Temperature	14.1	18.0	12.9	14.7
°C	0-28.0	6.8-33.0	1-29.5	1-29.0
D.O.	9.8	10.6	10.7	10.0
mg/L	4-13.5	6-20.0	4.7-20.0	5-17.5
Current Vel	0.04[a]	0.17[a]	0.05[a]	0.14[a]
m/s	<0.01-0.20	<0.01-0.40	<0.01-0.18	<0.01-0.29

[a] <0.010 entered as 0.005 to compute means.

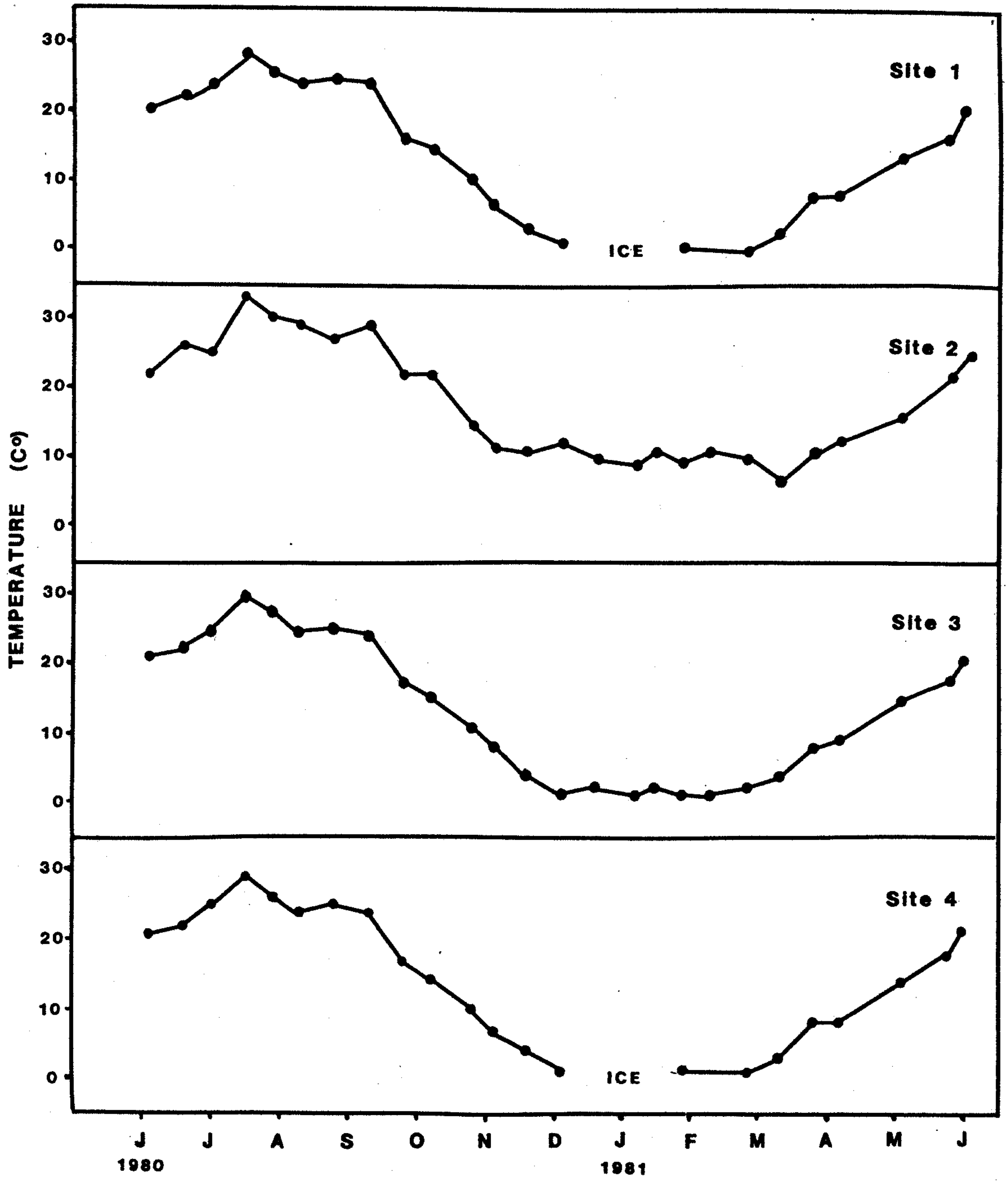

Fig. 3. Seasonal temperatures (C°) at the four sites near the Dairyland Power Generating Station, Genoa, Wisconsin, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981.

river temperature at Site 2. Temperature was one of the most important variables that caused changes in production and community composition. Biological changes will be discusssed later in the phycoperiphyton section.

Mean current velocities for Sites 1 and 3 were similar (Table 2). The samplers at these two sites were secured to the south side of barge mooring cells. This was done to reduce shading, but it also prevented exposure to direct current from the navigation channel. Sites 2 and 4 were located where the current had a more direct effect. The greatest mean current velocity was observed at Site 2 because of its exposure to the thermal plume. The plume flowed over the retaining wall and samplers during spring when river stages were high or when the river stage was artificially elevated (Appendix I).

Chemical Variables

Dissolved oxygen concentrations remained relatively constant among the four sites on each sampling date (Appendix I). During the winter months, the DO data were unreliable. Dissolved oxygen concentrations during the spring, summer, and autumn were similar to concentrations in Navigation Pool 5 (Luttenton 1982). The percent saturation of O_2 was always >51%, and was usually 90-100%. The greatest percentage of saturation was 165% observed at Site 2 on 9 September 1980.

Means and ranges of turbidity were similar among the four sites (Table 2). The lowest levels, 3 to 4 NTU, were recorded on 14 January 1981 during ice cover, and the greatest levels, 87 to 92 NTU, were recorded on 23 September 1980. The greater turbidity levels may have been due to regular barge activity in the vicinity of the sampling locations. Runoff may also have had an effect on turbidity.

Hardness varied from 100 to 208 mg/L (as $CaCO_3$) at all four sites (Appendix I). Means and ranges for hardness were almost identical among locations (Table 2), the greatest difference in mean values was only 4 mg/L $CaCO_3$ and occurred between Sites 2 and 4. The greatest hardness values were recorded in mid-summer. Hardness decreased in the autumn, increased again in the winter, and declined in the spring. Dilution from runoff was most likely the cause of seasonal variation during spring and autumn. This stretch of the Mississippi River would be classified as having hard water based on mean hardness values (Hem 1970).

Conductivity differed only slightly among the four sites (Table 2). The greatest individual value (490 μmhos) and the greatest mean value (332 μmhos) were observed at Site 4. The lowest individual conductances (220 μmhos) occurred at Sites 2 and 4. Conductivity data were similar to those in other pools of the Upper Mississippi River (Rada et al. 1980, Luttenton 1982, Dawson et al. In press).

Ammonia concentrations in this study (Table 2) were less than those determined by Luttenton (1982) for Pool 5. The greatest mean concentration in Pool No. 9 was 0.29 mg/L compared to 0.59 mg/L in Pool 5. Luttenton reported that Pool 5 values were lower than those of Pool No. 3 (Hestick 1978). These data suggest that a reduction in ammonia concentration with distance downstream between Pools 3 and 9 in the Upper Mississippi. Despite the differences in absolute concentration seasonal trends were similar among pools. The greatest mean concentration of ammonia in this study was observed at Site 3 (Table 2). Sites 1, 2, and 4 all had similar mean concentrations. The current at Site 3 flowed upstream along the shoreline due to structures in the river and the river morphometry. This change in current direction may have resulted in an increase in the amount of organic matter in the area. The decomposition of this material may have been responsible for the higher ammonia values. No other localized influence was observed that would have accounted for the increased ammonia concentration.

Means and ranges of NO_3 + NO_2-N were similar for all four sites in Pool 9 (Table 2). Nitrate + Nitrite was slightly higher at Sites 3 and 4 compared to 1 and 2. Nitrate + Nitrite concentrations were near 1.0 mg/L at all sites on 17 June and then declined until 26 August (Appendix I). Seasonal concentrations then increased through autumn and winter until 10 March when the mean value for the four sites was 1.57 mg/L (Fig. 4). The average NO_3 + NO_2-N concentration then declined until the sampling ended.

Total phosphorus concentrations were greater than 0.20 mg/L from 3 June until 8 October 1980 (Appendix I). In contrast, Total-P fluctuated between 0.08 and 0.20 mg/L from 8 October until 24 February 1981. On 24 February Total-P increased to a mean value of 0.36 mg/L. Concentrations ranged between 0.10 and 0.20 from 10 March until 1 June. Ortho-phosphate concentrations followed the same general trend as Total-P (Table 2, Fig. 4). Phosphorus levels were similar to those seen by Rada et al. (1980) for Pool 9. The phosphorus concentration generally exceeded the critical concentration levels which may lead to eutrophic conditions. Critical concentrations in lakes were established at 0.01 to 0.02 mg/L of phosphorus (Vollenweider 1968, Bachmann and Jones 1974).

The mean concentration of silica for Pool 9 was 10 mg/L SiO_2 (Table 2). The world average for silica in surface waters is about 13 mg/L SiO_2 (Wetzel 1975). Maximal concentrations of 17 mg/L SiO_2 were observed on 18 November (Appendix I). The lowest concentration was seen on 5 May 1981 when SiO_2 dropped to a mean of 1.9 mg/L (Fig. 4). Spring blooms of diatoms have been responsible for similar decreases in silica concentration of other waters (Wetzel 1975). In general, the concentration of silica did not decrease enough to limit productivity. However, some diatom species grow better in lower concentrations of silica than do others (Patrick 1977).

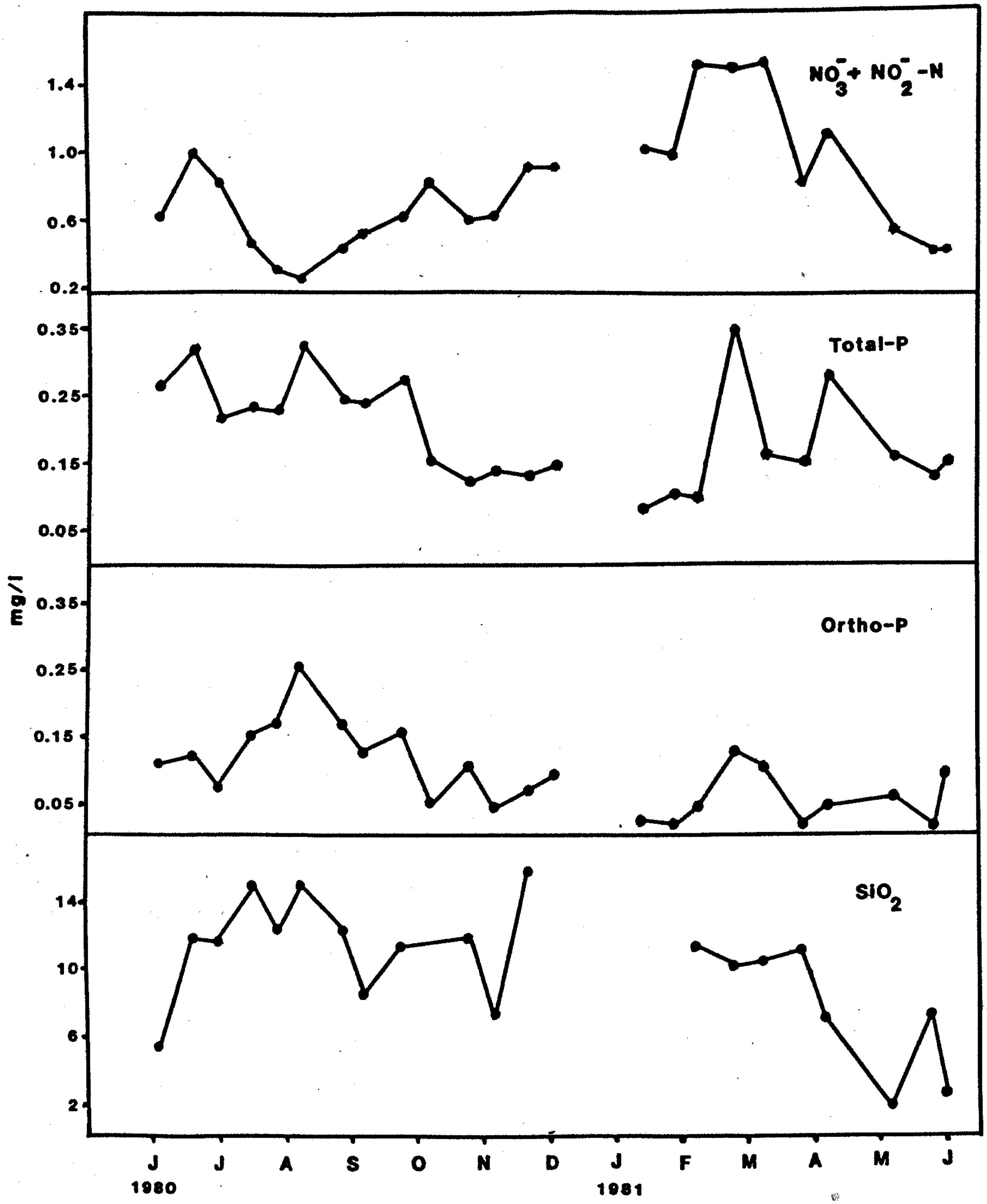

Fig. 4. Seasonal concentrations of nitrate + nitrite-N, total phosphorus, orthophosphorus, and silica in Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981. Values represent mean concentrations for all stations on each date.

Phycoperiphyton

General Taxonomic Composition

One hundred thirty-three samples were collected for taxonomic and quantitative analyses. One hundred and thirteen of the samples were collected from glass substrates; the remainder were collected from natural substrates such as rocks and logs.

Three major taxonomic groups were observed in the phycoperiphyton (Appendix III). These groups were the diatoms (Bacillariophyceae), green algae (Chlorophyta), and blue-green algae (Cyanophyta). A total of 259 species that represented 52 genera were identified during the study. Green algae were represented by 17 species from 13 genera. The blue-green algal flora was less diverse, with 6 species from 6 genera. The diatoms were the most abundant with 33 genera and 236 species. When identification to the species level was not possible, taxa were assigned identification numbers to provide a means to compute densities and relative community composition.

Species Composition

Green Algae. Green algae were observed at all sites on artificial and natural substrates. Green algae were never abundant, but several species consistently occurred in the samples. *Stigeoclonium lubricum* was commonly observed at all sampling sites during the summer and autumn. *Stigeoclonium lubricum* was collected from artificial substrates at Site 2 on 17 December 1980. Samples were not collected at Site 1 this date; however, *S. lubricum* had not been observed in any samples collected from Site 1 after 21 October. Its occurrance at Site 2 may have been related to the elevated temperatures at this site. Several species of *Scenedesmus* were also regularly observed from samples collected at the four sampling sites. *Scenedesmus quadricauda* was the most commonly encountered member of the genus. Luttenton (1982) collected an algal species that was identified as green alga No. 268. The same species was found in Pool No. 9 and was similarly reported in this study. Green alga No. 268 occurred at all four sites and was collected at Site 3 as late as 17 December 1980 and at Site 2 on 14 January 1981. Both *S. lubricum* and green alga No. 268 were well adapted for the smooth surfaces of the artificial substrates. The samplers were located near the surface of the water and were consequently exposed to a substantial amount of wave action. Both algal types were compressed and prostrate, which aids their adnate tendencies (Luttenton 1982).

Blue-Green Algae. A narrow trichome form of *Oscillatoria* was the most prevalent blue-green algae observed in this study. A species of *Oscillatoria* similar to *O. tenuis* Agardh. was observed, but a positive identification was not made. *Oscillatoria* sp. occurred at all sites thoughout most of the year. Several other species of blue-green algae had large standing crops in individual samples but were not abundant nor present in the subsequent sampling period. *Aphanizomenon flos-aquae* accounted for 34% of the phycoperiphyton on artificial substrate samples collected on 17 June 1980 at Site 3. At this time, however, *A. flos-aquae* was undergoing an extensive bloom in the plankton and most likely adhered to the substrate during sampling. *Lyngbya* sp. was common in trace amounts through the summer but was only occasionally collected in the autumn. *Anacystis cyanea* was also observed in the summer sampling period.

Diatoms. Diatoms were the most numerous and most diverse (Appendix III) group of algae collected from artificial and natural substrates in Pool No. 9 of the Upper Mississippi River. Three major community assemblages were evident during this study period. The summer/autumn assemblage persisted for the longest period. This community was composed of the same major taxa from June 1980 until the first week of November 1980. By the middle of November, a major compositional shift had occurred and resulted in a recognizable late autumn assemblage. It was not possible to collect samples from the refernce site during the winter months (Site 1). In contrast, ice cover did not form at Site 2, which was influenced by heat loading from the thermal effluent. Therefore, a thermally influenced winter assemblage was observed at Site 2. Evaluations of the spring diatom communities at Sites 1, 3, and 4 were not possible because many samples were lost during the incubation period.

Seasonal Assemblages of Diatoms

Summer/Autumn Assemblage. The summer/autumn assemblage consisted of *Cocconeis placentula* var. *euglypta*, which was the dominant species at Site 1 during the month of June (Fig 5.) *Stephanodiscus rotula* was dominant at Site 3 during the first part of June but declined rapidly by the end of the month (Fig. 6). *Cocconeis placentula* var. *euglypta* increased during June and July. Sites 1 and 3 were similar in most variables including species composition. *Cocconeis placentula* var. *euglypta* remained dominant at both sites through the summer and autumn periods (Figs. 5, 6). *Navicula tripunctata* var. *schizonemoides* became a codominate with *C. placentula* var. *euglypta* during this period at Sites 1 and 3. The relative densities of these two species, however, were not parallel. For example, the density of *C. placentula* var. *euglypta* was increasing while relative density of *N. tripunctata* var. *schizonemoides* was decreasing (Figs. 5, 6). Conversely, when *N. tripunctata* var. *schizonemoides* was increasing *C. placentula* var.

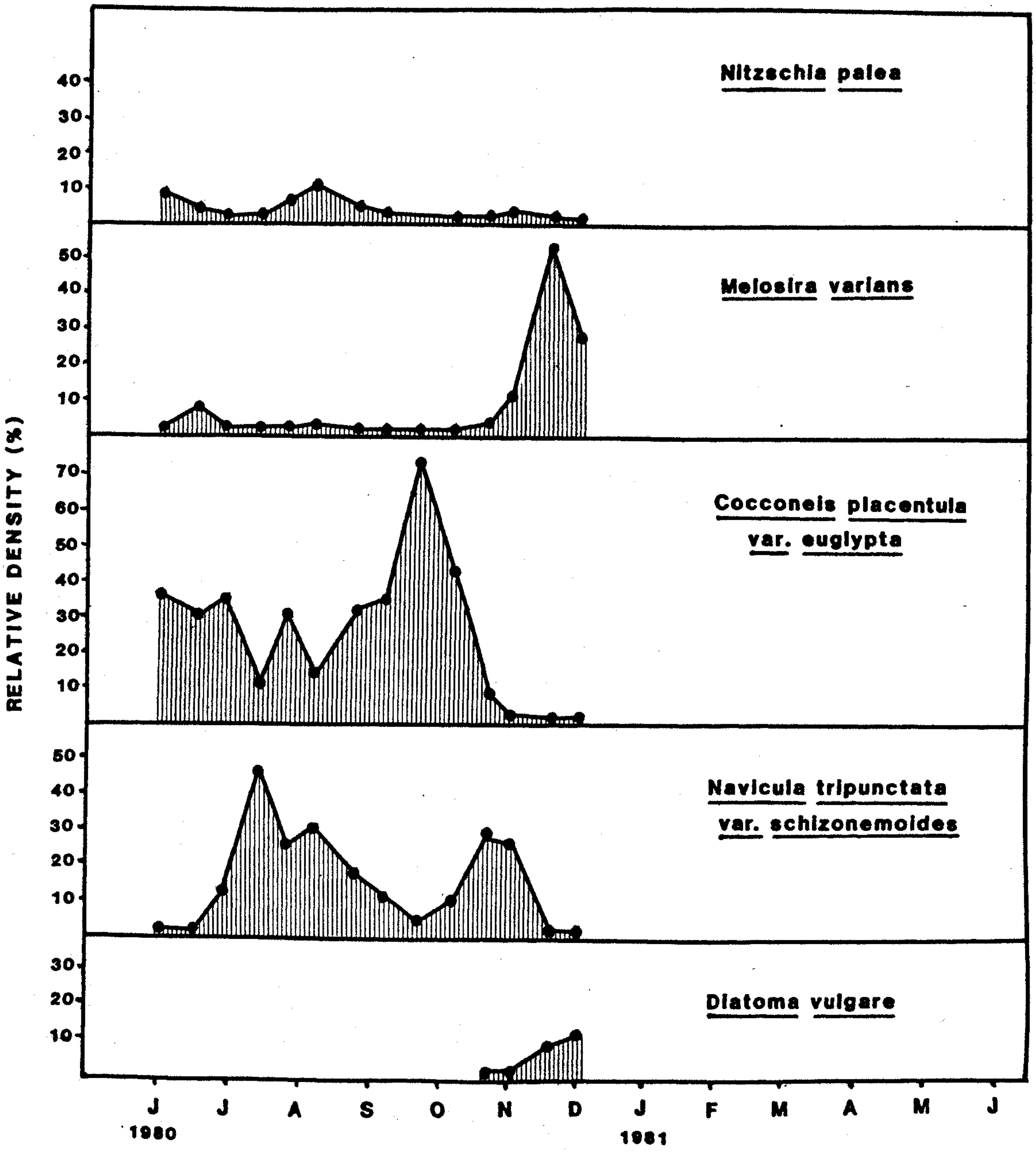

Fig. 5. Relative densities (%) of some dominant diatom taxa in phycoperiphyton samples collected from Site 1, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 2 December 1980.

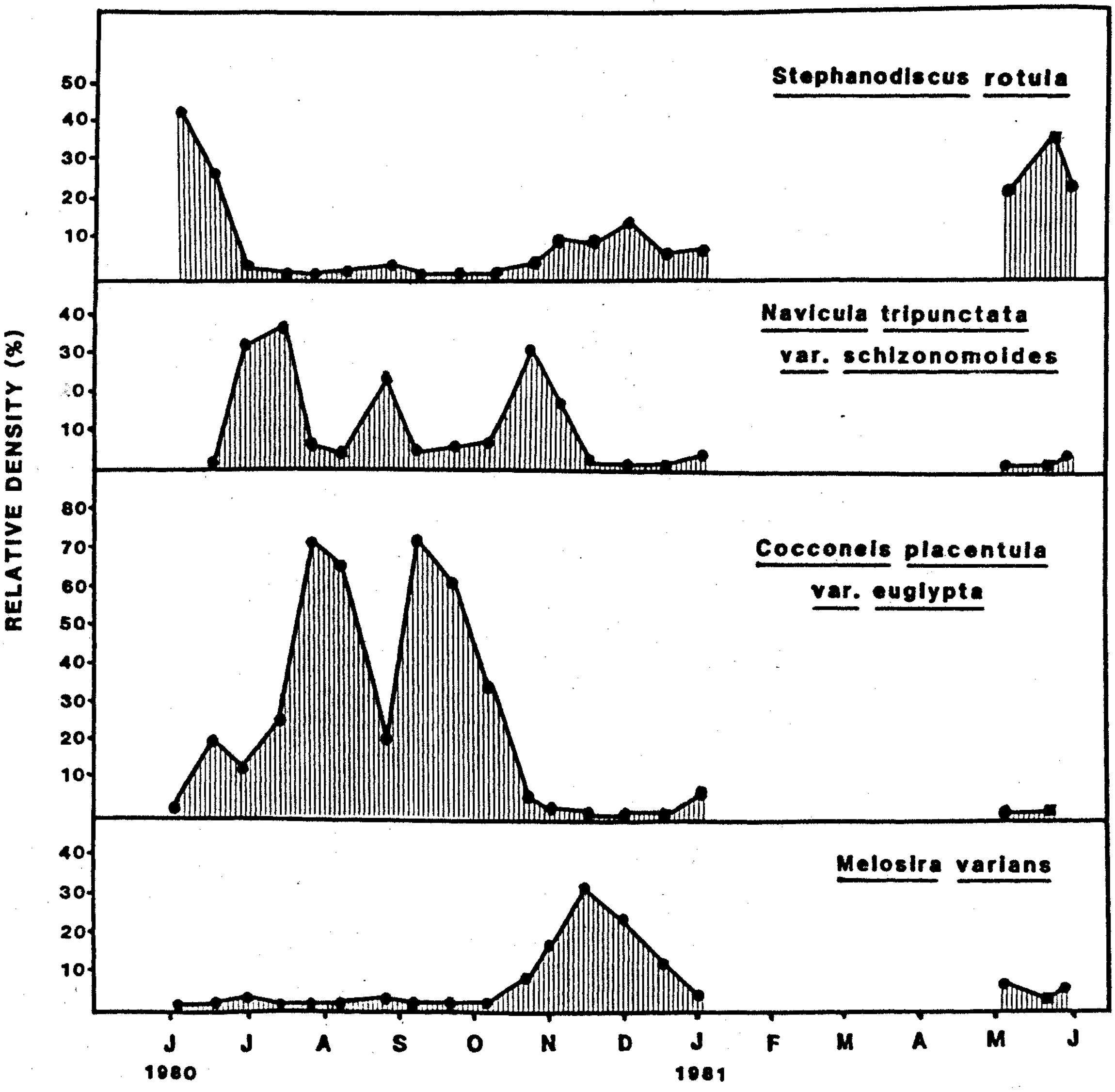

Fig. 6. Relative densities (%) of some dominant diatom taxa in phycoperiphyton samples collected from Site 3, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981. Artifical substrate =●, natural substrate =■.

euglypta was decreasing. Brown and Austin (1973) observed a similar occurrance in their studies of littoral periphyton and plankton relationships. They observed an inverse relationship between standing crops of *Cocconeis placentula* and *Achnanthes minutissima* in the periphyton. The two diatoms were competing for colonization space on the available substrate. Densities of those two taxa did not become equal until winter when the standing crops were reduced to low levels. Luttenton (1982) found *C. placentula* var. *euglypta* to be dominant in summer/autumn samples and stated that this species was successful due to its ability to adhere to glass slides. The greater than normal barge activity also may have produced turbulence in which nonstalked forms such as *C. placentula* var. *euglypta* could have remained attached while less adnate species may have been removed by the stronger current and abrasion. The same situation observed by Luttenton may have occurred in Pool No. 9. *Navicula tripunctata* var. *schizonemoides*, a gelatinous tube-dwelling species (Millie and Wee 1981), was probably competing for the same colonization space as *C. placentula* var. *euglypta* in Pool No. 9. The gelatinous tube of *N. tripunctata* var. *schizonemoides* was most likely arranged parallel to the surface of the substrate, which allowed it to remain attached in greater current velocities. Examination of the chemical and physical data did not reveal any other factor investigated that would explain the alternating dominance of *C. placentula* var. *euglypta* and *N. tripunctata* var. *schizonemoides*. Studies by Brown and Austin (1973) support the hypothesis that differences in species composition on glass slides may be due to species competition for a colonization substrate and not some physical or chemical difference in the water.

Artificial substrate samples from Site 4 (Fig. 7) were not as complete as Sites 1 and 3; however, an alternating density relationship between *C. placentula* var. *euglypta* and *N. tripunctata* var. *schizonemoides* also seemed to occur at this site. The artificial substrates were not recovered at Site 4 during September, but natural substrate (submerged tree) scrapings were collected from Site 4 during the month. In contrast to the artificial substrate samples at Sites 1 and 3 where *C. placentula* var. *euglypta* was dominant, *N. tripunctata* var. *schizonemoides* was the dominant species in these natural substrate samples (Fig. 7). These data indicate that *C. placentula* var. *euglypta* may be better suited than *N. tripunctata* var. *schizonemoides* for attachment to glass slides. Samples from Site 4 were collected from a submerged tree. The surface of the submerged tree was rougher than glass, consquently *N. tripunctata* var. *schizonemoides* was able to remain dominant during the period in September when *C. placentula* var. *euglypta* was dominant on the glass slides. *Cocconeis placentula* var. *euglypta* is a low profile species that does well on smooth surfaces and creates an environment suitable for community succession to begin. Hoagland et al. (1982) observed this phenonomon on artificial substrates. They compared periphyton succession to succession of higher plants, i.e. the change in community structure proceeds from low to high physical stature. Patrick (1976) referred to early stages of colonization as a two-dimension community (composed of low profile species). In contrast, she categorized the more advanced stages of colonization as a three-dimension community with stalked and rosette species. This successional process may explain the alternating dominance of *C. placentula* var. *euglypta* and *N. tripunctata* var. *schizonemoides*. The mechanism may explained as follows. *Cocconeis placentula* var. *euglypta* colonizes the bare glass slides and increases in density. *Navicula tripunctata* var.

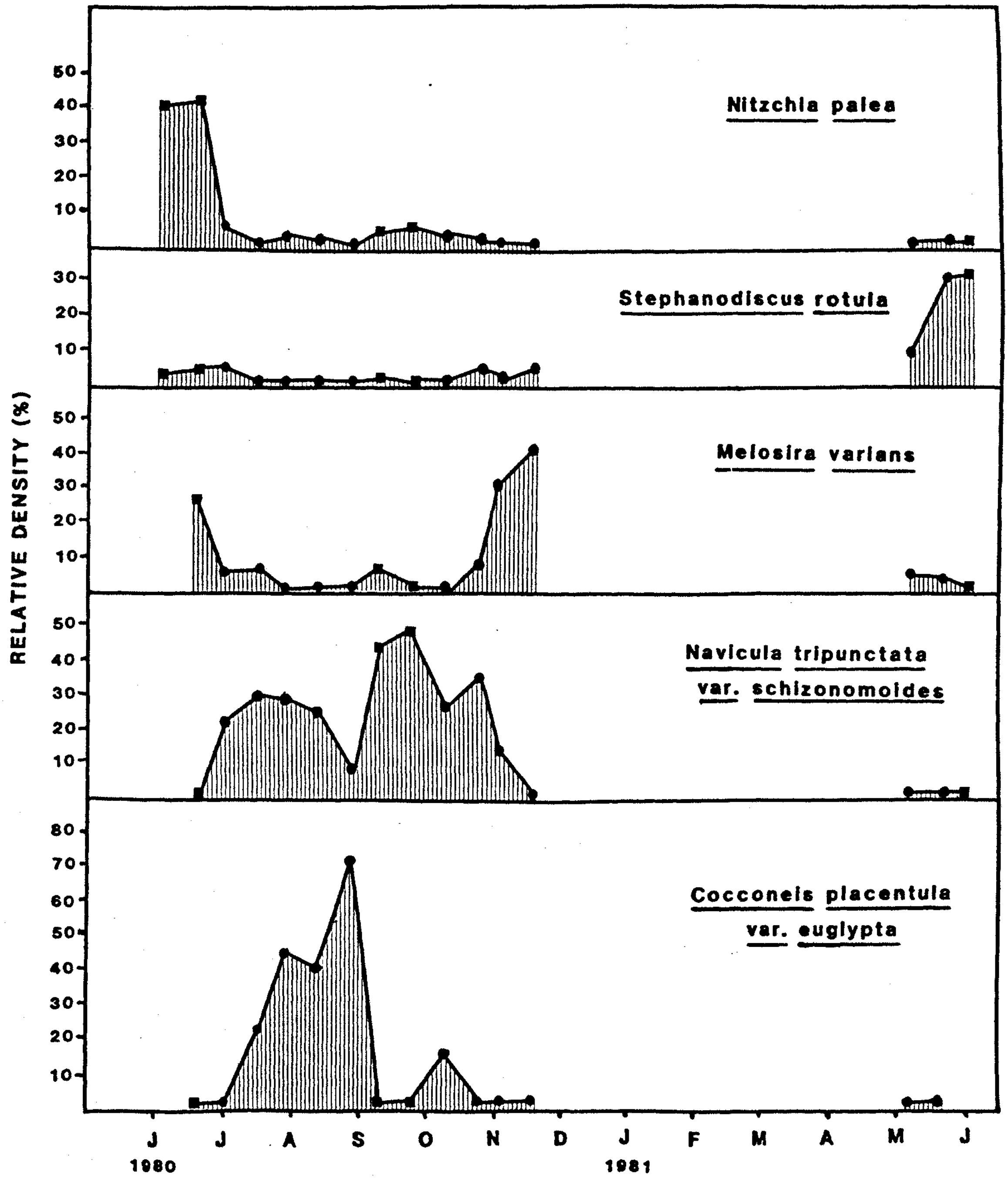

Fig. 7. Relative densities (%) of some dominant diatom taxa in phyco-periphyton samples collected from Site 4, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981. Artifical substrate =● , natural substrate=■ .

schizonemoides may then begin to colonize the altered substrate created by *C. placentula* var. *euglypta*. *Navicula tripunctata* var. *schizonemoides* can then become dominant until abrasion from wave action impedes the successional process and colonization on a two-dimension scale begins again. A different experimental design must be used to determine the mechanism responsible for the species succession observed in this study.

Community structure was similar for Sites 1, 3, and 4 during the summer/autumn period. Table 3 shows the similarities in species composition for representive samples from that period. The species composition at Site 2, which received the thermal effluent, was different in comparison to the other three sites. *Cocconeis placentula* var. *euglypta*, which was a major constituent in the 15 July samples at Sites 1, 3, and 4, composed less the 1% of the community density at Site 2 (Table 3, Fig. 8). *Navicula vaucheriae* accounted for a much larger proportion of the community on this date at Site 2 at than the other three study sites. *Navicula tripunctata* var. *schizonemoides* was still a major constituent of the community at Site 2 and the other sites. Several species of *Cyclotella* were also more prevalent at Site 2 than at the other three sites (Table 3).

The samples collected during the summer/autumn period were often dominated by one or a few species. The community structure of the summer/autumn assemblage at the four sites may have been under some environmental stress due to factors other than the thermal effluent. A harsh environment may exclude species that are unable to tolerate the existing conditions. In the case of Pool No. 9, the naturally high current velocities, the close proximity of the samplers to the surface and the direct sunlight and wave action from navigational activities

Table 3. The ten most commonly encountered diatom taxa based on mean relative density (%) of the total diatom community. Samples were collected from Sites 1, 2, 3, and 4 on artificial substrates 15 July 1980, Pool No. 9, Upper Mississippi River.

Taxa	Site 1	Site 2	Site 3	Site 4
Navicula tripunctata var. schizonemoides	48.6	28.6	37.6	30.0
Cocconeis placentula var. euglypta	11.5		25.5	23.6
Navicula vaucheriae	7.3	28.0	2.8	5.1
Achnanthes lanceolata	3.4			2.4
Gomphonema parvulum	2.9	2.8	1.3	3.1
Navicula capitata	2.5			
Nitzschia palea	2.1	6.8	2.9	
Achnanthes lanceolata var. dubia	1.9		1.8	2.6
Melosira granulata	1.9	9.7	8.0	3.7
Gomphonema subclavatum var. mexicanum	1.9			
Stephanodiscus rotula		2.7		
Cyclotella sp. 32		2.3		
Nitzschia amphibia		2.0		
Cyclotella striata		1.9		
Cyclotella atomus		1.5		
Cocconeis placentula var. lineata			3.0	7.3
Melosira italica			3.0	
Melosira varians			1.9	6.7
Navicula salinarum var. intermedia				2.0

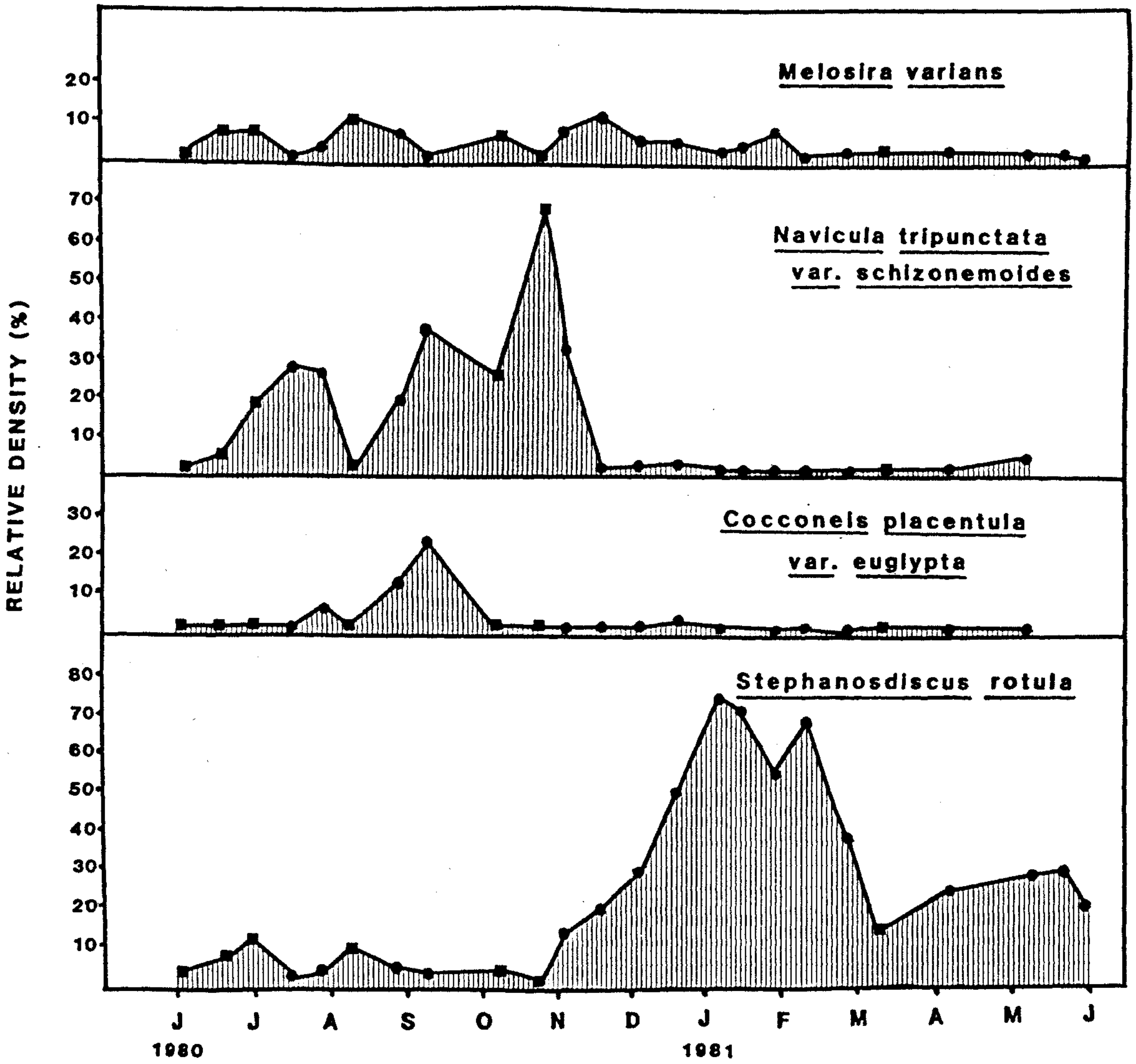

Fig. 8. Relative densities (%) of some dominant diatom taxa in phycoperiphyton samples collected from Site 2, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981. Artifical substrate = ● , natural substrate = ■

may have affected community composition.

Late Autumn Assemblage. The late autumn community assemblage was short lived than compared to the summer/autumn group (Figs. 5, 6, 7, 8). The late autumn assemblage was only observed from the middle of November until the middle of December. *Melosira varians* was the most abundant diatom at Sites 1, 3, and 4 (Table 4). In contrast, several species that had similar densities were observed at Site 2. *Stephanodiscus rotula* (formerly known as *Stephanodiscus astrea*) was the most abundant taxon at Site 2. *Diatoma vulgare* densities accounted for during this period at all sites except Site 3. *Diatoma vulgare* composed less than 2% at of relative density at Site 3 on 18 November, but it increased to 8.0% of the relative density by 17 December. It appears that the density of diatoms was more evenly distributed at Site 2 than at the other two sites (Table 4). The high percentage of *M. varians*, however, declined after 18 November, when greater diversities were observed at Sites 1 and 3 (Figs. 5, 6). Diversity at Site 4 cannot be discussed because of sampler loss (Fig. 7).

Winter Assemblage at Site 2. Sampling continued in the winter months only at Site 2. The observations made at Site 2 cannot be considered as representative of the typical winter phycoperiphyton community in channel areas of Pool No. 9. Instead, the data collected were used to address an artificial environment created by the thermal effluent. *Stephanodiscus rotula* dominated the community at Site 2 during most of the winter months (Fig. 8). *Stephanodiscus rotula* was dominant in January and February, but its relative species density began to decrease at the end of February. The relative density of *Stephanodiscus rotula* was between 20 and 30% through April and May. The species composition for Site 2 on 14 January 1981 is illustrated in

Table 4. The ten most commonly encountered diatom taxa based on mean relative density (%) of the total diatom community. Samples were collected from Sites 1, 2, 3 and 4 on artificial substrates 18 November 1980, Pool No. 9, Upper Mississippi River.

Taxa	Site 1	Site 2	Site 3	Site 4
Melosira varians	53.3	10.8	32.2	41.7
Diatoma vulgare	8.8	11.8		6.3
Synedra ulna	4.7	13.4	5.1	5.3
Stephonodiscus rotula	4.4	19.6	9.5	6.3
Synedra ulna var. *contracta*	3.2	8.4		
Synedra rumpens var. *familiaris*	3.2	2.6	3.4	3.4
Fragilaria capucina var. *mesolepta*	3.0		7.8	4.5
Melosira granulata	1.9	2.7	3.4	
Melosira italica	1.9		4.0	
Navicula tripunctata var. *schizonemoides*	1.3	1.7	2.9	
Navicula salinarum var. *intermedia*		2.6	3.6	2.2
Navicula tripunctata		2.1		
Synedra pulchella		2.0		
Nitzschia dissipata			1.9	
Cocconeis placentula var. *euglypta*				2.4

Table 5. Densities of *S. rotula* were near their maximum at this time. It is possible that the late fall assemblage would have continued into the winter months in the absence of the thermal effluent. Conditions apparently provided *S. rotula* competitive advantage over the other species. This advantage may have been lacking under normal winter conditions, and the large *S. rotula* production may not have been observed.

Seasonal Trends in Diversity

The total number of species were compared to evaluate diversity for samples collected from 15 July 1980 to 18 November 1980 for Sites 1 through 4. The mean numbers of species for all stations combined on 15 July was 33 while the mean on 18 November was 51. These diversities were generally indicative of the summer/autumn and late autumn assemblages, respectively. Diversity increased substantially from the summer to late autumn (Fig. 9). A major shift in species composition and an increase in diversity was observed in the late autumn assemblage at all sites. A different trend was found at Site 2, i.e. *M. varians* was not dominant and the relative density was more evenly distributed among the diatom species.

The greater density of *S. rotula* in January and the first half of February was probably responsible for the decline in the species diversity (Fig. 10). In late February when *S. rotula* density declined (Fig. 8) the number of species increased at Site 2 to levels comparable to those seen in the late autumn for the four sites combined.

A few samples were collected from sites other than Site 2 in May. *Stephanodiscus rotula* was among the more common diatoms in these samples but was not as abundant as during the winter at Site 2 (Figs. 6, 7, 8). The diversities in the May and June 1981 samples were high; the average number of species number was greater than 50 for samples

Table 5. The seven most commonly encountered diatom taxa based on mean relative density (%) of the total diatom community. Samples were collected from Site 2 on artificial substrates 14 January 1981, Pool No. 9, Upper Mississippi River.

Taxa	Site 2
Stephanodiscus rotula	71.8
Melosira varians	3.9
Cyclotella striata	2.8
Asterionella formosa	2.7
Fragilaria vaucheriae	2.4
Synedra ulna	2.2
Fragilaria capucina var. *mesolepta*	1.5

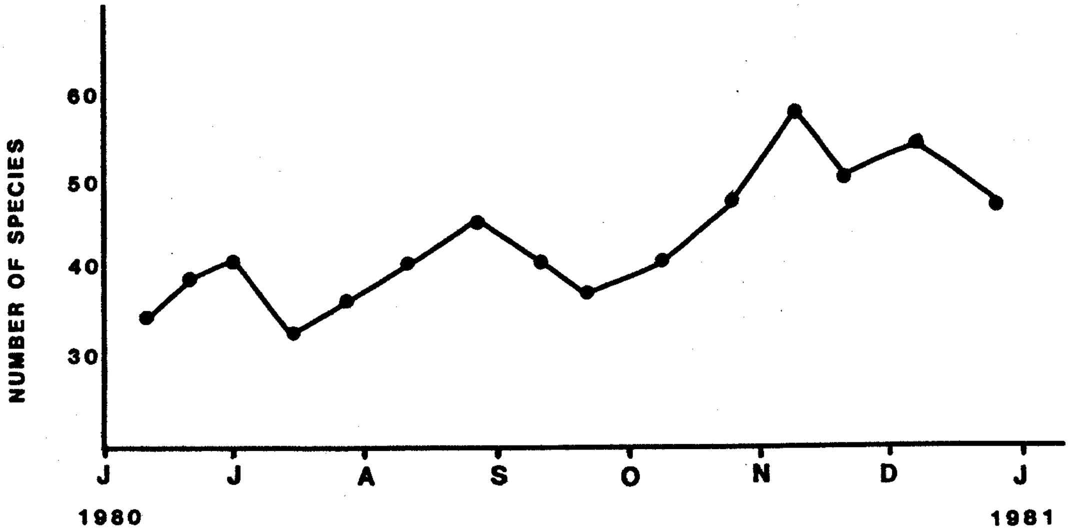

Fig. 9. Mean number of diatom species for Site 1-4 collected from artificial and natural substrates, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 17 December 1980.

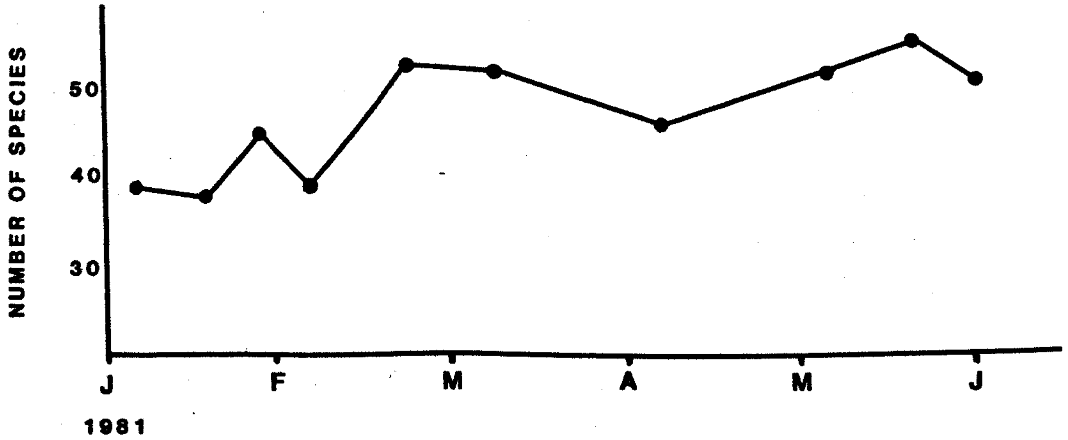

Fig. 10. Number of diatom species for Site 2 collected from artificial and natural substrates, Navigation Pool No. 9, Upper Mississippi River, 17 January 1981 to 1 June 1981.

collected from all sites.

Seasonal Trends in Cell Density

Diatoms accounted for at least 93% of the average algal density at Site 1. Sites 2, 3, and 4 were similar except in a few samples where diatoms composed as little as 65% of the total community density. There were differences in total density among the four stations (Table 6), but statistical comparisons of the sites were not possible because of sample loss.

Cell density increased sharply in mid June at Site 1 and continued to rise to its highest levels between 26 August and 8 October (Fig. 11). *Cocconeis placentula* var. *euglypta* composed over 70% of the mean density of diatoms during this period (Fig. 5). There was a large fluctuation in densities between sampling dates, which was probably a result of the relatively long exposure time of samplers (Tilley and Haushild 1975).

The greatest cell density at Site 2 was observed in February (Table 6 and Fig. 11). Samples were lost in late September and October; however, the samples collected on 26 August and 9 September had lower densities than samples collected at Site 1 on the same dates. The thermal effluent may have inhibited production at Site 2 during this period. In contrast, the phycoperiphyton cell density appears to have been enhanced by the thermal effluent in February (Table 6 and Fig. 11). A similar occurrance was reported for water 16°C or cooler by Warinner and Brehmer (1966).

A sharp increase in the relative density of *Stephanodiscus rotula* during January and February (Fig. 8) coincided with the large cell density (Fig. 11). In January and most of February, *S. rotula* composed 50% to 73% of the diatom community collected from artificial substrates.

Table 6. Diatom and total phycoperiphyton cell density for Sites 1, 2, 3, and 4 collected from artificial substrates 3 June 1980 to 1 June 1981, Navigation Pool No. 9, Upper Mississippi River.

Date of Collection	Site 1		Site 2		Site 3		Site 4	
	Diatom	Total	Diatom	Total	Diatom	Total	Diatom	Total
06-03-80	1.51[a]	1.58	--[b]	--	1.36	1.77	--	--
06-17-80	8.45	8.62	--	--	4.34	5.49	--	--
07-01-80	7.13	7.34	--	--	6.63	5.49	5.46	5.71
07-15-80	7.98	8.08	2.91	3.11	2.46	2.70	4.63	4.80
07-29-80	12.6	13.2	3.37	3.57	1.18	1.22	10.2	10.6
08-12-80	8.06	8.10	--	--	13.2	13.5	12.3	12.5
08-26-80	18.2	18.8	5.26	5.45	17.5	17.7	16.7	17.1
09-09-80	11.3	11.8	2.42	2.53	21.2	21.3	--	--
09-23-80	17.0	17.3	--	--	26.8	27.2	--	--
10-08-80	21.9	22.0	--	--	24.8	24.8	1.77	1.88
10-21-80	6.68	6.74	--	--	8.62	8.74	1.34	1.36
11-04-80	11.6	11.6	5.50	5.50	13.6	13.7	5.39	5.44
11-18-80	3.38	3.39	4.38	4.38	10.3	10.3	1.74	1.77
12-02-80	8.53	8.58	14.3	14.4	6.33	6.35	--	--
12-17-80	--	--	1.80	1.82	5.69	5.74	--	--
01-07-81	--	--	29.7	29.8	3.41	3.42	--	--
01-14-81	--	--	31.1	31.1	--	--	--	--
01-27-81	--	--	14.8	14.8	--	--	--	--
02-10-81	--	--	39.7	39.8	--	--	--	--
02-24-81	--	--	47.3	50.2	--	--	--	--
03-10-81	--	--	--	--	--	--	--	--
03-24-81	--	--	--	--	--	--	--	--
04-07-81	--	--	17.0	17.0	--	--	--	--
05-05-81	--	--	8.30	8.34	17.6	17.6	20.5	20.6
05-20-81	--	--	10.3	10.3	--	--	19.0	19.1
06-01-81	--	--	6.33	6.45	7.01	7.06	--	--

[a] (cells x $10^8/m^2$)

[b] -- indicates no data collected

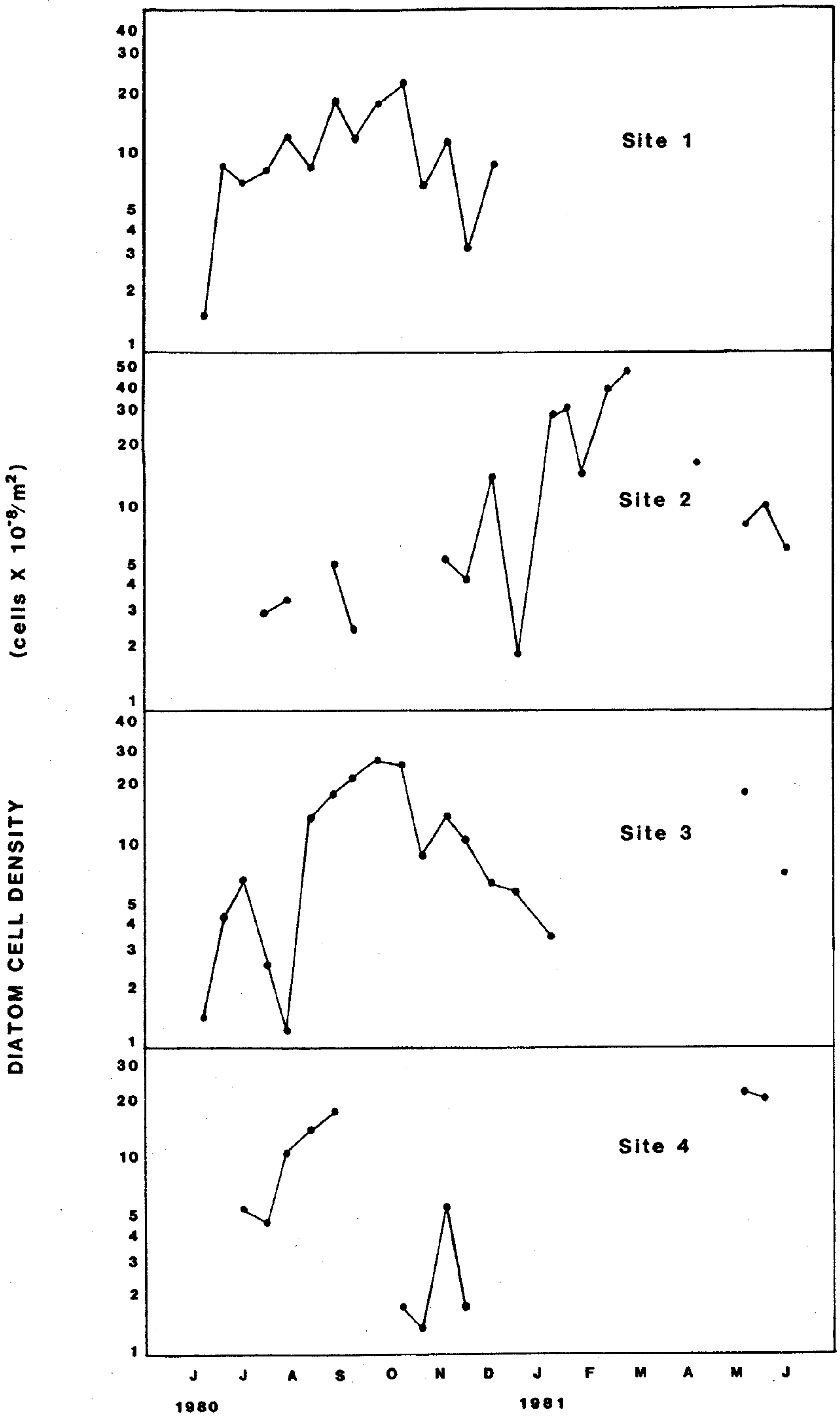

Fig. 11. Diatom cell density for Sites 1 through 4 collected from artificial substrates, Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981.

Cell densities at Site 3 (Table 6) were similar to those at Site 1. The greatest numbers of cells were observed from 12 August to 8 October. *Cocconeis placentula* var. *euglypta* accounted for most of the high density of cells observed in August and September (Fig. 6). The lack of recognizable trends was due to the considerable sample loss experienced at Site 4 (Table 6). Cell densities in August samples were much greater than those of the previous month and were similar to the densities at Sites 1 and 3. *Cocconeis placentula* var. *euglypta* again was an important part of the community during peak cell numbers.

Productivity: Accumulation of Pigments and Total Organic Matter

Pigments. The accumulation of chlorophyll *a* varied temporally and spatially. Comparisons among sites for all seasons were not done because of sampler loss. A complete set of samples, however, was collected at Sites 1 and 3 from June 1980 until December 1980. Samples were collected at Site 2 from November 1980 until March 1981 (Appendix II). The greatest sampler losses occurred at Site 4; consequently, samples were only collected in July, August, October, and November of 1980. Only isolated samples were recovered at Sites 2, 3, and 4 between March 1981 and June 1981. Concentrations reported in this section represent production or accumulation during the 28-day exposure period.

A general trend in chlorophyll accumulation was apparent for Sites 1 and 3 (Fig. 12). The rates at both sites were $\leq$ 5 mg/m^2 during June and July 1980. Accumulation of chlorophyll a increased at both sites in August 1980. The maximum chlorophyll *a* accumulations was observed at Site 1 on September 9 (9.79 mg/m^2). In contrast, the greatest chlorophyll *a* productivity (15.38 mg/m^2) was not observed at Site 3 until 21 October 1980.

Some of the variation among sampling periods may have been related to the exposure period of the substrates. Tilley and Haushild (1975) found that amounts of chlorophyll increased with increasing exposure time. However, variablility between duplicate samples also increased. A three-week exposure period resulted in variability of up to 21% among replicates. The substrates for my study were exposed for 28 days which may have increased the variations in chlorophyll a.

Low summer chlorophyll a concentrations may be due to the high light intensities experienced during these months. Jorgensen (1964) demonstrated that some algae adapt to low light intensities by increasing chlorophyll levels. Conversly, high light intensities inhibit production and/or cause photodestruction of chlorophyll in some species of algae (Prezelin 1981). The substrates for this study were floating near the surface. Different trends in chlorophyll concentration may have occurred in samples taken from greater depths.

Chlorophyll a data are incomplete from June 1980 to November 1980, but data are complete from 4 November 1980 to 24 February 1981. The mean concentration for Site 2 from 2 December 1980 to 24 February 1981 was 5.94 mg/m^2 Chl a. This concentration was greater than the amounts expected on glass slide substrates at normal winter temperatures (Hohn and Hellerman 1963). This elevated level of chlorophyll was likely the result of the heated effluent discharged during the observed period. The phycoperiphyton at Site 2 may have produced more chlorophyll in response to the higher than normal temperatures. Phinney and McIntire (1965) observed similar results when as light and CO_2 were not limiting.

The seasonal patterns of pheophytin a and its relation to chlorophyll a can best be analyzed from the B/A acidification ratios. The median B/A ratio for Site 1 was 1.60 for samples collected between 3

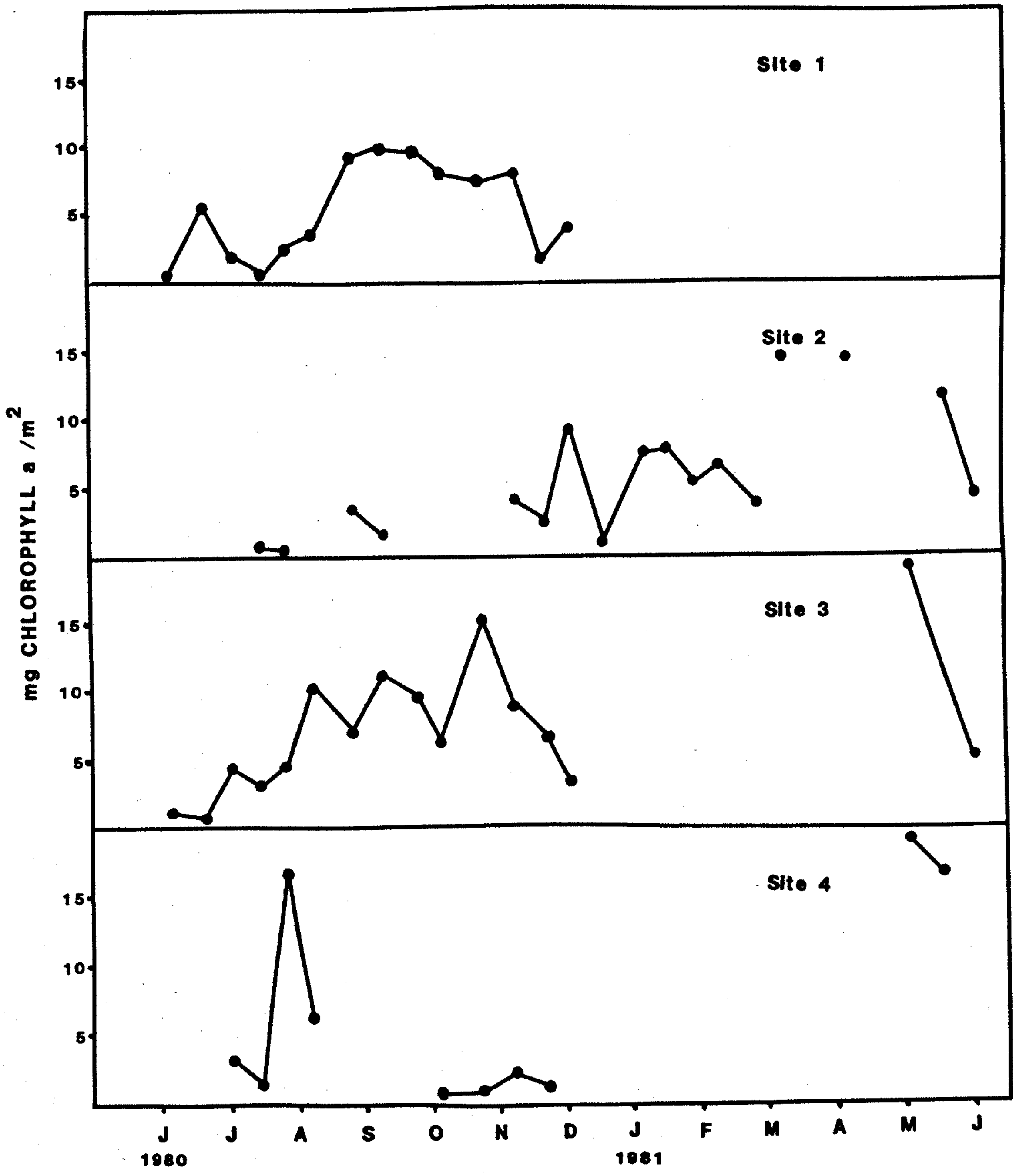

Fig. 12. Seasonal accumulation of chlorophyll a (mg/m^2) for phycoperiphyton from Navigation Pool No. 9, Upper Mississippi River, 3 June 1980 to 1 June 1981.

June 1980 to 2 December 1980. The mean for Site 3 for the same period was 1.55. The B/A ratio at Site 3 was lower than at Site 1 but neither value is considered indicative of physiological stress (Weber 1973). Site 2 had a median B/A ratio of 1.49 for the period 4 November 1980 to 24 February 1981. Median B/A ratios were lowest at Site 2, but significant differences of B/A ratios were not observed ($p>0.05$) among the four stations when analyzed by the Kruskal-Wallis nonparametric test. Based on this criterion, the physiologic health of the algal community was generally good; only a few isolated low values were observed (Appendix II).

Total Organic Matter. Mean accumulation of ash-free dry weight and dry weight and autotrophic indices for the study are presented in Appendix II. Sampling success for biomass analysis was similar to that for pigment analysis. Concentrations reported in this section represent production or accumulation during the 28-day exposure period. Seasonal trends for accumulation of ash-free dry weight were similar at Sites 1 and 3 (Fig. 13). The greatest ash-free dry weights occurred in June, July, and August 1980. Ash-free dry weights decreased at Sites 1 and 3 from September to December. The decrease in accumulation of ash-free dry weights coincided with the decreasing water temperatures (Fig. 3).

The accumulation of ash-free dry weights at Site 2 began to increase in December 1980, and the greatest level was observed on 10 February 1981 (Fig. 13). Warinner and Brehmer (1966) in studies of the York River in Virginia demonstrated that inputs of heated water caused increased carbon uptake and increased production when the ambient temperature was below 16°C. This phenomonon appears to have occurred at Site 2 from December 1980 to February 1981. Ash-free dry weights fluc-

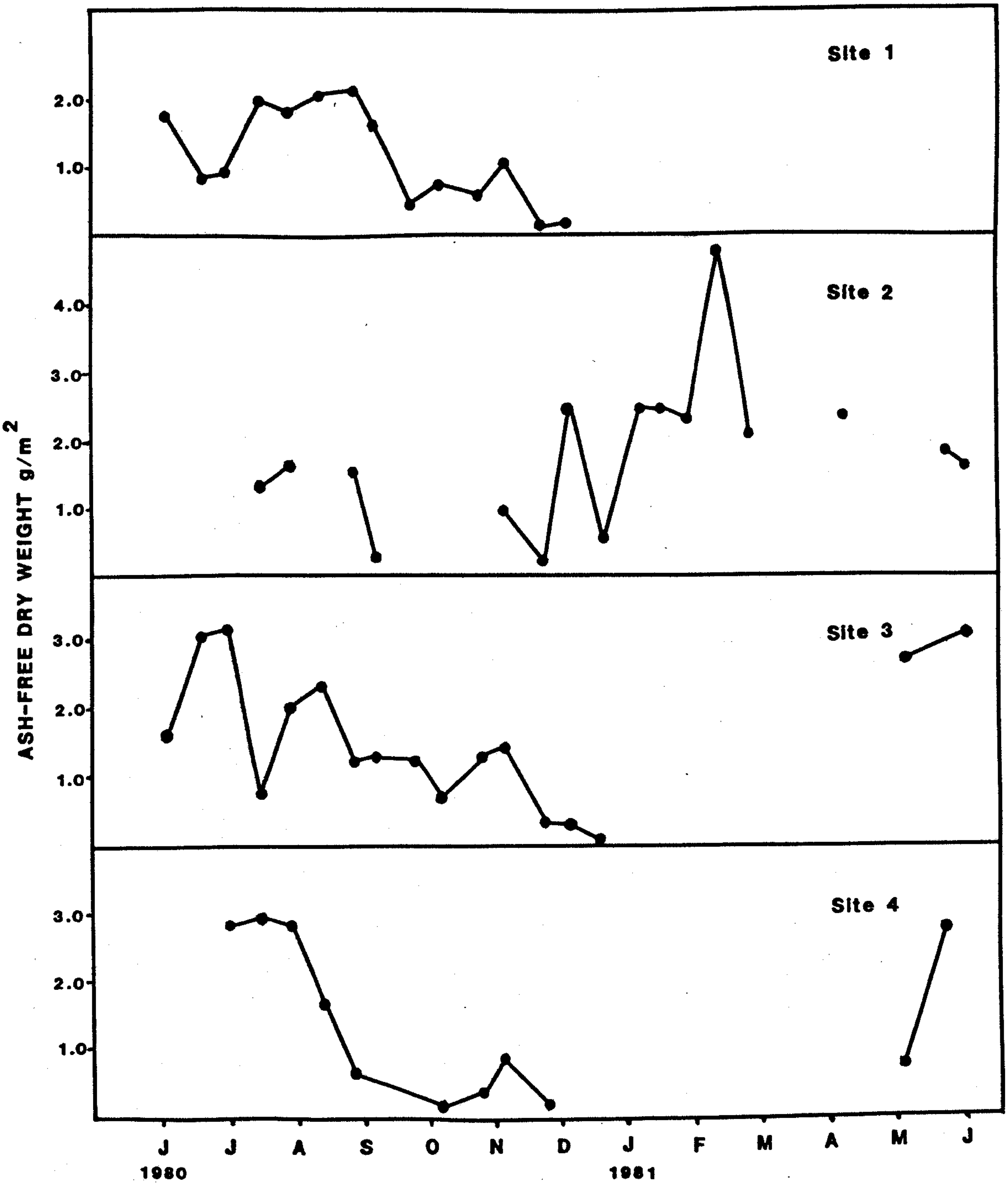

Fig. 13. Seasonal accumulation of ash-free dry weights (g/m^2) for phycoperiphyton from Navigation Pool No. 9, Upper Mississippi River, 2 June 1980 to 1 June 1981.

tuated during December 1980 at Site 2. Ash-free dry weight accumulation rates were compared for the months of June, July, and August to those observed by Luttenton (1982) for Pool 5. During June, July, and August of 1979 in Pool 5, the mean accumulation rate for four sampling sites was 0.095 $g/m^2 \cdot da$ (Luttenton 1980). The mean for four sites from Pool 9 for the same period of 1980 was 0.066 $g/m^2 \cdot da$. Because of the variability of ash-free dry weight results, the rates for the two pools appear similar. Farrell and Tesar (1982) reported an accumulation rate of 0.241 $mg/m^2 \cdot da$ for samples collected over a seven-year period from the Missouri River near the Cooper Nuclear Station (RM 534). Other Missouri River sites sampled in that area were similar. Those rates were greater than the accumulation rates for ash-free dry weight observed in my study of Pool No. 9 of the Upper Mississippi River. Ash-free dry weight accrual rates are listed in Appendix II.

Autotrophic indices varied among sites as well as through time (Appendix II). The data suggest that the periphyton at all four sites consisted largely of heterotrophic organisms. However, examination of the artificial substrates did not reveal this type of community structure. Large numbers of heterotrophs were not observed in the Palmer-Maloney cell counts. The artificial substrates often had chironomid and tricopteran larvae and cases attached to their surfaces at times of collection. This material was included in the ash-free weight determination and would have increased the organic matter. This extra material resulted in abnormally high autotrophic index values. These problems are major disadvantages of autotrophic and trophic indices (Weitzel et al. 1979).

SUMMARY AND CONCLUSIONS

A study was conducted in Navigation Pool No. 9 of the Upper Mississippi River to determine the impact of the thermal effluent from Dairyland Power Cooperative's Genoa, Wisconsin electric generating facility on the phycoperiphyton.

Periphytometers with glass slide substrates provided quantitative and qualitative data, and natural substrates were analyzed for qualitative purposes. Water samples for physical and chemical analyses were collected concomitantly with the phycoperiphyton.

The power plant effluent elevated the temperature of the Mississippi River in the vicinity of the discharge (Site 2) during the entire year. The temperature in the plume of the receiving water was increased 4.3°C to 11°C above the ambient temperatures (Site 1). Great increases in temperature were not observed at Sites 3 and 4, which were downstream of the discharge. The dissolved oxygen concentrations were similar to those recorded for other reaches of the Upper Mississippi River and were always greater than 51 percent of saturation. Dissoved oxygen saturation was generally 90 to 100% of saturation. Current velocity was low and was mostly affected by local river morphometry and manmade structures such as mooring cells. Chemical characteristics of the water were very similar among the four sites. The water could be classified as hard and alkaline with sufficient nitrogen and phosphorus to support high rates of primary production.

A total of 259 species representing 52 genera were identified from the samples. Green algae were common but not abundant. The most common green alga were _Stigeoclonium_ _lubricum_, green algae No. 268, and several species of _Scenedesmus_. _Oscillatoria_ sp. was the most prevalent blue-green alga and was observed at all four sites during most of the year. Three major diatom assemblages were recognized: 1) a summer/autumn assemblage, 2) late autumn assemblage, and 3) a thermally influenced winter assemblage at Site 2. The dominant species in the summer/autumn assemblage were *Cocconeis placentula* var. *euglypta* and *Navicula tripunctata* var. *schizonemoides*. These two species had an inverse dominance relationship at Sites 1, 3, and 4. Competition for available substrate and abrasion due to various types of turbulence may have been the cause of this phenomenon. A different summer/autumn assemblage was observed at Site 2. *Navicula tripunctata* var. *schizonemoides* and several *Cyclotella* sp. were the most prevalent taxa and *Cocconeis placentula* var. *euglypta* never became dominant. The late autumn assemblage persisted for less time that the summer/autumn assemblage. During this period *Melosira varians* was the most common species observed at Sites 1, 3, and 4, whereas *Stephanodiscus rotula* dominated the phycoperiphyton at Site 2.

Site 2 was the only site sampled during the winter, and a thermally influenced winter assemblage was observed. *Stephanodiscus rotula* accounted for at least 70% of the phycoperiphyton density in January and early February. The density of *Stepanodiscus rotula* declined, but it remained dominant during the entire winter.

Diversity was lower in summer but increased during the late autumn at Sites 1,3, and 4. In contrast, species diversity was lower in January and February but increased during the spring at Site 2. This site was influenced by the thermal effluent.

The greatest total phycoperiphyton densities for Sites 1 and 3 were observed in the autumn during September and October. *Cocconeis placentula* var. *euglypta* was associated with the maximal densities. The greatest density at Site 2 occurred in January and February and was associated with the high relative numbers of S. rotula.

The accrual of chlorophyll a varied substantially temporally and spatially. In general, accumulation rates were low in the summer, increased in the autumn, and declined in the late autumn. Sites 1 and 3 were similar, and their greatest rates were observed in September and October. Chlorophyll a accumulated more rapidly at Site 2 than the other sites; the highest rates occurred during the winter.

Accumulation of ash-free dry weight was greatest in the summer and autumn, and declined in the late autumn and winter for Sites 1, 3, and 4. The greatest production of organic matter was observed at Site 2 in January and February. This coincided with the greater densities of phycoperiphyton.

The thermal effluent affected the phycoperiphyton community in various ways during different seasons, e.g. changes in species composition, densities, and biomass. The data from this study indicate that the impact of the thermal effluent on the attached algal community of Pool No. 9 was minimal. Values of $663_b/663_a$ acidification ratios were similar for all four sites and indicated physiologically healthy phycoperiphyton communities at all sites. Significant changes in the phycoperiphyton were not observed in the downstream sampling sites when compared to the upstream reference site. The effect of the electrical power generating facility as determined by this study was confined to the area in close proximity to the thermal effluent outfall i.e. Site 2.

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Appendix I. Values of physical and chemical variables determined on water samples collected from Navigation Pool No. 9, Upper Mississippi River during 3 June 1980 to 1 June 1981.

Site	Conductivity µmhos	Turbidity NTU	pH	T Hdn mg/L $CaCO_3$	NO_3+NO_2-N mg/L	NO_2-N mg/L	NH_3-N mg/L	Total P mg/L	Ortho-P mg/L	Silica mg/L SiO_2	Temp °C	DO mg/L	CV m/sec
1980													
<u>3 June</u>													
Site 1	303	44	8.3	146	0.675	0.021	0.180	0.310	0.110	5.7	20.0	—[a]	0.08
Site 2	300	35	8.3	148	0.588	0.020	0.190	0.250	0.115	5.7	22.0	—	0.12
Site 3	300	40	8.4	158	0.588	0.020	0.225	0.250	0.110	5.5	21.0	—	0.18
Site 4	340	39	8.5	160	0.625	0.021	0.220	0.240	0.115	5.5	21.0	—	0.29
<u>17 June</u>													
Site 1	345	—	8.0	156	1.000	0.040	0.175	0.345	0.126	10.7	22.0	—	<0.01
Site 2	330	—	8.1	152	0.960	0.039	0.155	0.320	0.126	10.7	26.0	—	0.08
Site 3	330	—	8.2	156	0.960	0.042	0.150	0.320	0.126	13.0	22.0	—	<0.01
Site 4	330	—	8.2	152	0.960	0.148	0.280	0.280	0.126	13.0	22.0	—	0.18
<u>1 July</u>													
Site 1	440	—	7.4	194	0.900	0.033	0.070	0.210	0.092	12.3	23.5	—	<0.01
Site 2	430	—	7.3	196	0.900	0.035	0.060	0.183	0.083	12.2	25.0	—	0.01
Site 3	460	—	7.3	204	0.900	0.034	1.000	0.235	0.077	11.0	24.5	—	<0.01
Site 4	490	—	7.2	208	0.630	0.029	0.080	0.225	0.061	11.0	24.5	—	0.01
<u>15 July</u>													
Site 1	450	14	7.8	200	0.500	0.021	0.160	0.245	0.185	15.2	28.0	4.0	<0.01
Site 2	450	10	8.0	196	0.400	0.021	0.165	0.240	0.170	15.2	33.0	6.0	0.29
Site 3	440	10	8.1	193	0.500	0.020	0.130	0.215	0.140	15.0	29.5	4.7	<0.01
Site 4	440	10	8.2	195	0.415	0.021	0.085	0.225	0.135	15.0	29.0	5.0	0.17
<u>29 July</u>													
Site 1	410	41	7.9	190	0.300	0.011	—	0.218	0.185	12.4	25.5	7.3	<0.01
Site 2	400	18	7.9	190	0.300	0.011	—	0.228	0.170	12.4	30.0	8.0	0.13
Site 3	415	16	8.1	194	0.300	0.012	—	0.228	0.150	12.4	27.5	7.0	0.05
Site 4	410	12	8.1	196	0.340	0.012	—	0.233	0.185	12.4	26.0	7.5	0.07
<u>12 Aug</u>													
Site 1	358	23	8.2	172	0.210	0.004	0.005	0.315	0.225	14.0	24.0	7.0	<0.01
Site 2	338	32	8.2	172	0.240	0.004	0.004	0.340	0.220	13.4	29.0	6.0	0.33
Site 3	360	23	8.2	182	0.240	0.004	0.005	0.325	0.255	16.4	24.5	6.5	0.08
Site 4	359	23	8.2	196	0.220	0.005	—	0.315	0.315	16.4	24.0	6.0	0.22

[a] — denotes that data were not collected

Appendix I. Con't

Site	Conductivity µmhos	Turbidity NTU	pH	T Hdn mg/L $CaCO_3$	NO_3+NO_2-N mg/L	NO_2-N mg/L	NH_3-N mg/L	Total P mg/L	Ortho-P mg/L	Silica mg/L SiO_2	Temp °C	DO mg/L	CV m/sec
1980 (con't)													
<u>26 August</u>													
Site 1	335	12	8.2	154	0.420	0.014	0.042	0.235	0.168	12.4	24.5	5.5	<0.01
Site 2	360	13	8.2	154	0.430	0.014	0.026	0.235	0.168	12.0	27.0	6.5	0.08
Site 3	385	14	8.3	162	0.430	0.014	0.015	0.245	0.173	12.4	25.0	5.5	0.05
Site 4	380	16	8.3	160	0.430	0.016	0.015	0.260	0.169	12.4	25.0	6.0	0.07
<u>9 September</u>													
Site 1	255	43	—	116	0.320	0.013	0.005	0.235	0.128	10.8	24.0	9.0	0.08
Site 2	250	44	—	114	0.285	0.013	0.005	0.200	0.120	7.4	29.0	12.5	0.06
Site 3	260	38	—	112	0.255	0.012	0.005	0.250	0.135	7.8	24.0	8.5	0.06
Site 4	245	36	—	112	0.440	0.014	0.005	0.264	0.128	7.8	24.0	9.0	0.18
<u>23 September</u>													
Site 1	250	89	6.8	106	0.650	0.040	—	0.245	0.145	11.2	16.0	11.8	0.08
Site 2	255	90	6.6	108	0.600	0.040	—	0.265	0.160	11.0	22.0	12.2	0.40
Site 3	260	87	6.5	108	0.525	0.041	—	0.315	0.160	11.6	17.0	11.5	0.07
Site 4	260	92	6.6	122	0.635	0.041	—	0.265	0.170	11.6	17.0	10.2	0.14
<u>8 October</u>													
Site 1	270	30	—	128	0.875	—	0.010	0.165	—	—	14.5	8.2	0.01
Site 2	280	32	—	120	0.800	—	0.007	0.135	—	—	22.0	12.5	0.14
Site 3	285	27	—	134	0.710	—	0.005	0.160	0.050	—	15.0	9.5	0.04
Site 4	285	29	—	126	0.850	—	0.009	0.150	—	—	14.5	9.5	0.08
<u>21 October</u>													
Site 1	240	21	7.7	128	0.606	0.013	0.019	0.117	0.105	11.6	10.0	11.2	0.20
Site 2	245	20	7.9	130	0.535	0.015	0.035	0.117	0.110	11.2	14.8	10.8	0.13
Site 3	255	22	7.9	130	0.600	0.015	0.035	0.127	0.105	12.2	10.5	10.6	0.03
Site 4	250	20	7.9	144	0.615	0.016	0.031	0.120	0.090	12.2	10.0	11.0	0.13
<u>4 November</u>													
Site 1	230	19	7.4	104	0.630	0.013	0.025	0.140	0.050	6.5	6.5	9.9	0.08
Site 2	220	13	7.5	108	0.615	0.012	0.031	0.135	0.045	7.5	11.5	9.7	0.33
Site 3	230	13	7.6	100	0.535	0.012	0.057	0.135	0.045	7.5	8.0	9.2	0.07
Site 4	240	14	7.6	108	0.650	0.012	0.030	0.145	0.050	7.5	7.0	9.2	0.10

Appendix I. (Con't)

Site	Conductivity µmhos	Turbidity NTU	pH	T Hdn mg/L CaCO$_3$	NO$_3$+NO$_2$-N mg/L	NO$_2$-N mg/L	NH$_3$-N mg/L	Total P mg/L	Ortho-P mg/L	Silica mg/L SiO$_2$	Temp °C	DO mg/L	CV m/sec
1980 (con't)													
<u>18 November</u>													
Site 1	330	14	7.4	136	0.940	0.014	0.023	0.125	0.075	16.2	3.0	13.2	0.06
Site 2	315	13	7.8	136	0.910	0.012	0.018	0.125	0.075	13.2	11.0	11.4	0.20
Site 3	310	12	7.7	140	0.910	0.009	0.123	0.135	0.075	17.0	4.0	12.6	0.07
Site 4	340	14	7.8	138	0.885	0.010	0.023	0.137	0.067	17.0	4.0	12.2	0.08
<u>2 December</u>													
Site 1	310	14	7.3	144	0.855	0.010	0.023	0.195	0.095	—	1.0	10.0	0.05
Site 2	330	13	7.4	134	0.955	0.010	0.019	0.150	0.095	—	12.0	10.5	0.13
Site 3	330	13	7.5	136	0.930	0.011	0.023	0.120	—	—	1.0	10.9	0.04
Site 4	330	16	7.6	116	0.930	0.009	0.028	0.125	0.077	—	1.0	10.0	0.06
<u>17 December</u>													
Site 1	—	—	—	—	—	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—	—	—	10.0	11.9	<0.01
Site 3	—	—	—	—	—	—	—	—	—	—	2.0	13.8	0.05
Site 4	—	—	—	—	—	—	—	—	—	—	—	—	—
1981													
<u>7 January</u>													
Site 1	—	—	—	—	—	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—	—	—	9.0	11.5	<0.01
Site 3	—	—	—	—	—	—	—	—	—	—	1.0	18.0	0.03
Site 4	—	—	—	—	—	—	—	—	—	—	—	—	—
<u>14 January</u>													
Site 1	375	3	8.0	170	1.030	—	—	0.080	0.020	—	—	—	—
Site 2	380	4	8.1	166	0.925	—	—	0.080	0.020	—	11.0	12.0	<0.01
Site 3	410	4	8.1	172	1.030	—	—	0.085	0.025	—	2.0	12.5	—
Site 4	380	4	8.1	168	1.030	—	—	0.085	0.020	—	—	—	—
<u>27 January</u>													
Site 1	350	4	7.9	154	0.975	0.009	0.043	0.105	0.015	—	0.5	11.5	0.04
Site 2	350	4	7.9	160	1.000	0.013	0.043	0.110	0.020	—	9.5	10.4	<0.01
Site 3	360	4	7.8	158	1.000	0.014	0.043	0.110	0.020	—	1.0	12.5	0.03
Site 4	360	4	7.5	162	1.000	0.018	0.043	0.100	0.020	—	1.0	12.0	—

Appendix I. (Con't)

Site	Conductivity µmhos	Turbidity NTU	pH	T Hdn mg/L $CaCO_3$	NO_3+NO_2-N mg/L	NO_2-N mg/L	NH_3-N mg/L	Total P mg/L	Ortho-P mg/L	Silica mg/L SiO_2	Temp °C	DO mg/L	CV m/sec
1981 (con't)													
10 February													
Site 1	370	10	7.5	176	1.570	0.018	0.033	0.095	0.035	11.4	—	—	—
Site 2	380	7	7.6	176	1.570	0.018	0.033	0.085	0.045	11.8	11.0	11.0	<0.01
Site 3	410	7	7.6	176	1.520	0.018	0.053	0.085	0.045	11.0	1.0	12.5	0.03
Site 4	375	11	7.7	176	1.570	0.018	0.043	0.130	0.045	11.0	—	—	—
24 February													
Site 1	320	33	7.4	134	1.450	0.034	0.272	0.370	0.120	9.7	0.0	11.0	0.03
Site 2	320	31	7.4	134	1.450	0.034	0.272	0.320	0.115	11.0	10.0	10.0	0.40
Site 3	315	52	7.5	134	1.580	0.034	0.280	0.425	0.130	10.0	2.0	11.0	0.03
Site 4	330	44	7.4	136	1.530	0.034	0.287	0.320	0.130	10.0	1.0	11.5	—
10 March													
Site 1	350	10	6.6	144	1.510	0.021	0.171	0.155	0.120	10.4	2.5	11.5	<0.01
Site 2	350	10	6.8	144	1.470	0.020	0.180	0.180	0.130	10.4	6.8	12.2	<0.01
Site 3	355	11	6.7	150	1.940	0.023	0.270	0.155	0.130	10.4	3.5	12.2	<0.01
Site 4	345	11	7.0	144	1.350	0.018	0.270	0.175	0.018	10.4	3.0	13.8	<0.01
24 March													
Site 1	330	13	7.6	140	0.770	0.020	0.018	0.160	0.020	11.0	7.5	13.5	<0.01
Site 2	335	16	7.7	142	0.850	0.023	0.018	0.155	0.015	11.0	11.0	20.0	<0.01
Site 3	330	14	7.6	154	0.770	0.023	0.036	0.125	0.015	11.0	8.0	20.0	0.07
Site 4	330	16	7.6	148	0.810	0.024	0.018	0.170	0.015	11.0	8.0	17.5	<0.01
7 April													
Site 1	260	38	7.5	100	0.970	0.028	0.024	0.190	0.035	8.0	8.0	9.0	0.04
Site 2	275	44	7.7	102	1.060	0.025	0.013	0.175	0.040	5.7	12.5	9.3	0.40
Site 3	280	51	7.6	102	1.120	0.025	0.065	0.400	0.040	2.0	9.0	10.1	0.08
Site 4	285	27	7.7	114	1.290	0.029	0.074	0.360	0.050	7.5	8.0	10.2	0.22
5 May													
Site 1	290	26	8.8	120	0.380	0.014	0.016	0.155	0.115	2.0	13.5	11.0	0.04
Site 2	290	23	8.5	118	0.420	0.015	0.012	0.125	0.075	2.0	16.0	9.7	0.29
Site 3	295	45	8.6	118	0.650	0.020	0.016	0.170	0.015	1.7	14.4	9.0	0.06
Site 4	295	29	8.7	118	0.650	0.022	0.011	0.190	0.016	2.0	14.0	9.2	0.25

Appendix I. (Con't)

Site	Conductivity µmhos	Turbidity NTU	pH	T Hdn mg/L $CaCO_3$	NO_3+NO_2-N mg/L	NO_2-N mg/L	NH_3-N mg/L	Total P mg/L	Ortho-P mg/L	Silica mg/L SiO_2	Temp °C	DO mg/L	CV m/sec
1981 (con't)													
20 May													
Site 1	250	17	8.8	115	0.410	0.010	0.043	0.110	0.010	7.0	16.0	10.0	<0.01
Site 2	220	16	8.8	115	0.410	0.010	0.043	0.130	0.010	7.0	22.0	10.8	0.25
Site 3	240	15	8.9	120	0.390	0.010	0.010	0.155	0.010	7.5	17.5	9.8	<0.01
Site 4	220	17	9.0	118	0.400	0.010	0.095	0.140	0.010	7.8	17.5	11.0	0.19
1 June													
Site 1	—	—	8.6	—	0.430	—	0.010	0.154	0.016	2.0	20.0	10.6	<0.01
Site 2	—	—	8.7	—	0.410	—	0.005	0.130	0.102	3.8	25.0	8.9	0.33
Site 3	—	—	8.7	—	0.420	—	0.010	0.160	0.076	2.0	20.5	9.5	0.13
Site 4	—	—	8.7	—	0.410	—	0.005	0.174	0.156	2.0	21.0	9.7	0.21

Appendix II. Mean pigment concentrations, biomasses, and autotrophic indices determined for phycoperiphyton samples collected from Navigation Pool No. 9 Upper Mississippi River during 6 May 1980 to 1 June 1981.

Site	[a] Chl a (mg/m^2)	[a] Pheo a (mg/m^2)	$663_b/663_a$ Ratio	Chl a Accumulation Rate (mg/m^2·da)	[a]Dry Weight (g/m^2)	[a]Ash-free Dry Weight (g/m^2)	Ash-free Dry Weight Accumulation Rate (g/m^2·da)	Autotrophic Index
1980								
6 May–3 June								
Site 1	0.64	0.26	1.54	0.023	10.86	1.78	0.064	2770
Site 2	—[b]	—	—	—	—	—	—	—
Site 3	1.02	1.42	1.29	0.037	13.68	1.66	0.059	1822
Site 4	—	—	—	—	—	—	—	—
20 May–17 June								
Site 1	5.85	4.22	1.40	0.209	1.82	0.85	0.031	157
Site 2	—	—	—	—	—	—	—	—
Site 3	4.59	0.78	1.30	0.021	13.30	3.11	0.111	5237
Site 4	—	—	—	—	—	—	—	—
3 June–1 July								
Site 1	1.96	0.54	1.56	0.070	3.80	0.97	0.035	535
Site 2	—	—	—	—	—	—	—	—
Site 3	4.34	2.22	1.46	0.155	9.23	3.21	0.115	754
Site 4	3.00	1.93	1.38	0.107	9.73	2.85	0.102	2091
17 June–15 July								
Site 1	0.51	1.65	1.29	0.018	8.23	1.99	0.054	12119
Site 2	0.64	0.67	1.36	0.023	4.38	1.35	0.049	2183
Site 3	3.20	0.71	1.56	0.114	3.00	0.80	0.029	267
Site 4	1.32	0.67	1.47	0.047	13.05	2.90	0.104	2202
1 July–29 July								
Site 1	2.23	1.12	1.47	0.080	7.61	1.83	0.065	1053
Site 2	0.20	1.28	1.29	0.007	6.57	1.63	0.058	8193
Site 3	4.53	2.51	1.41	0.161	9.47	2.07	0.074	781
Site 4	16.82	2.56	1.56	0.601	31.12	2.80	0.100	229

[a] Denotes amount accumulated during the 28-day exposure period.
[b] A hyphen (-) denotes that data were not collected.
[c] An asterisk (*) denotes concentrations <0.01 mg/m^2.

Appendix II. (con't)

Site	[a] Chl a (mg/m^2)	[a] Pheo a (mg/m^2)	$663_b/663_a$ Ratio	Chl a Accumulation Rate (mg/m^2·da)	[a]Dry Weight (g/m^2)	[a]Ash-free Dry Weight (g/m^2)	Ash-free Dry Weight Accumulation Rate (g/m^2·da)	Autotrophic Index
1980 (con't)								
15 July-12 August								
Site 1	3.63	0.01	1.70	0.130	11.22	2.02	0.060	561
Site 2	—	—	—	—	—	—	—	—
Site 3	10.02	2.14	1.58	0.358	15.61	2.37	0.085	236
Site 4	6.24	0.03	1.70	0.223	12.04	1.66	0.060	276
29 July-26 August								
Site 1	9.33	0.22	1.68	0.333	9.06	2.13	0.076	230
Site 2	3.42	1.19	1.53	0.122	10.64	1.56	0.056	460
Site 3	6.97	0.35	1.67	0.249	8.16	1.24	0.045	180
Site 4	—	—	—	—	5.28	0.69	0.025	—
12 August-9 Sept								
Site 1	9.79	*[c]	1.70	0.314	17.05	1.62	0.058	184
Site 2	1.79	0.05	1.65	0.064	1.55	0.29	0.011	366
Site 3	11.13	0.56	1.67	0.398	8.28	1.32	0.048	119
Site 4	—	—	—	—	—	—	—	—
26 August-23 Sept								
Site 1	9.43	*	1.70	0.337	5.16	0.49	0.018	52
Site 2	—	—	—	—	—	—	—	—
Site 3	9.52	*	1.70	0.340	12.95	1.27	0.046	141
Site 4	—	—	—	—	—	—	—	—
9 Sept-8 Oct								
Site 1	8.02	0.27	1.68	0.277	6.41	0.72	0.025	84
Site 2	—	—	—	—	—	—	—	—
Site 3	6.32	2.21	1.52	0.219	4.28	0.73	0.025	122
Site 4	0.56	0.02	1.68	0.020	1.18	0.12	0.005	220
23 Sept-21 Oct								
Site 1	7.75	0.18	1.65	0.277	2.56	0.66	0.024	176
Site 2	—	—	—	—	—	—	—	—
Site 3	5.38	1.23	1.65	0.549	19.58	1.32	0.047	86
Site 4	0.70	0.03	1.67	0.025	1.68	0.35	0.013	435

Appendix II. (con't)

Site	[a] Chl a (mg/m^2)	[a] Pheo a (mg/m^2)	$663_b/663_a$ Ratio	Chl a Accumulation Rate (mg/m^2•da)	[a]Dry Weight (g/m^2)	[a]Ash-free Dry Weight (g/m^2)	Ash-free Dry Weight Accumulation Rate (g/m^2•da)	Autotrophic Index
1980 (con't)								
8 Oct-4 November								
Site 1	8.10	0.66	1.66	0.300	15.47	1.04	0.039	131
Site 2	4.30	0.27	1.66	0.159	7.58	0.97	0.036	226
Site 3	9.01	1.34	1.61	0.334	16.79	1.49	0.056	169
Site 4	2.07	0.35	1.60	0.077	1.75	0.68	0.032	438
21 Oct-18 November								
Site 1	1.75	0.08	1.68	0.062	0.39	0.13	0.005	77
Site 2	2.50	0.47	1.60	0.090	2.14	0.23	0.009	107
Site 3	6.63	0.33	1.67	0.237	3.36	0.37	0.014	56
Site 4	1.07	0.54	1.46	0.038	0.87	0.17	0.006	146
4 Nov-2 December								
Site 1	4.28	*	1.70	0.153	0.93	0.24	0.009	54
Site 2	9.37	2.44	1.54	0.335	24.45	2.46	0.088	343
Site 3	3.32	0.19	1.66	0.119	2.81	0.35	0.013	104
Site 4	—	—	—	—	—	—	—	—
18 Nov-17 December								
Site 1	—	—	—	—	—	—	—	—
Site 2	0.85	0.34	1.50	0.029	2.82	0.53	0.019	566
Site 3	—	—	—	—	0.51	0.11	0.004	—
Site 4	—	—	—	—	—	—	—	—
2 Dec-7 January								
Site 1	—	—	—	—	—	—	—	—
Site 2	7.87	3.36	1.49	0.225	9.08	2.47	0.071	313
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
17 Dec-14 January								
Site 1	—	—	—	—	—	—	—	—
Site 2	7.78	5.75	1.40	0.278	9.72	2.45	0.086	310
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—

Appendix II. (con't)

Site	^{a} Chl a (mg/m^2)	^{a} Pheo a (mg/m^2)	$663_b/663_a$ Ratio	Chl a Accumulation Rate (mg/m^2•da)	^{a}Dry Weight (g/m^2)	^{a}Ash-free Dry Weight (g/m^2)	Ash-free Dry Weight Accumulation Rate (g/m^2•da)	Autotrophic Index
1981 (con't)								
7 Jan–27 January								
Site 1	—	—	—	—	—	—	—	—
Site 2	5.25	4.77	1.37	0.251	5.29	2.30	0.110	441
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
14 Jan–10 February								
Site 1	—	—	—	—	—	—	—	—
Site 2	6.71	7.10	1.34	0.249	14.02	4.81	0.178	718
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
17 Jan–24 February								
Site 1	—	—	—	—	—	—	—	—
Site 2	3.78	1.40	1.51	0.135	8.87	2.04	0.073	541
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
10 Feb–10 March								
Site 1	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
24 Feb–24 March								
Site 1	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
10 March–7 April								
Site 1	—	—	—	—	—	—	—	—
Site 2	14.51	1.33	1.60	0.519	20.62	2.31	0.083	270
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—

Appendix II. (con't)

Site	[a] Chl a (mg/m²)	[a] Pheo a (mg/m²)	$663_b/663_a$ Ratio	Chl a Accumulation Rate (mg/m²•da)	[a]Dry Weight (g/m²)	[a]Ash-free Dry Weight (g/m²)	Ash-free Dry Weight Accumulation Rate (g/m²•da)	Autotrophic Index
1981 (con't)								
<u>24 March-21 April</u>								
Site 1	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—
Site 3	—	—	—	—	—	—	—	—
Site 4	—	—	—	—	—	—	—	—
<u>7 April-5 May</u>								
Site 1	—	—	—	—	—	—	—	—
Site 2	—	—	—	—	—	—	—	—
Site 3	22.62	*	1.70	0.780	9.05	2.73	0.094	119
Site 4	22.17	*	1.70	0.765	5.58	0.78	0.027	35
<u>21 April-20 May</u>								
Site 1	—	—	—	—	—	—	—	—
Site 2	11.78	*	1.70	0.393	14.00	1.86	0.062	156
Site 3	—	—	—	—	—	—	—	—
Site 4	16.80	5.48	1.53	0.560	16.66	2.74	0.092	166
<u>5 May-3 June</u>								
Site 1	—	—	—	—	—	—	—	—
Site 2	4.50	3.26	1.41	0.167	8.04	1.61	0.060	357
Site 3	5.13	0.79	1.61	0.190	9.09	3.10	0.115	605
Site 4	—	—	—	—	—	—	—	—

Appendix III. A list of phycoperiphyton taxa collected from Navigation Pool No. 9, Upper Mississippi River during 6 May 1980 to 1 June 1981

Chrysophyta
Bacillariophyceae
Centrales
Coscinodiscaceae

Coscinodiscus sp.

Cyclotella atomus Hust.
C. comta (Ehr.) Kutz.
C. kutzingiana Thwaites
C. meneghiniana Kutz.
C. michiganiana Skv.
C. pseudostelligera Hust.
C. stelligera Cl. and Grun. var. *stelligera*
C. striata (Kutz.) Grun. var. *striata*
C. No. 32
C. No. 40

Melosira distans (Ehr.) Kutz.
M. granulata (Ehr.) Rolfs var. *granulata*
M. italica (Ehr.) Kutz. var. *italica*
M. varians Ag.
M. No. 41

Stephanodiscus rotula (Kutz.) Hendy
S. dubia (Fricke) Hust.
S. hantzschii Grun.
S. invisitatus Hohn. and Hellerman
S. niagarae Ehr. var. *niagarae*
S. tenius Hust.

Pennales
Fragilarineae
Eunotiaceae

Eunotia arcus Ehr. var. *arcus*
E. arcus var. *bidens* Grun.
E. curvata (Kutz.) Lagerst. var. *curvata*
E. exigua (Breb. ex Kutz.) Rabh. var. *exigua*
E. monodon Ehr.
E. pectinalis (O.Mull.) Rabh.

Fragilariaceae

Asterionella formosa Hassall

Diatoma anceps (Ehr.) Kirchn. var. *anceps*
D. tenue var. *elongatum* Lyngb.
D. vulgare Bory

Fragilaria capucina Desmae. var. *capucina*
F. capucina var. *mesolepta* Rabh.
F. construens (Ehr.) Grun. var. *construens*
F. construens var. *pumila* Grun.
F. construens var. *venter* (Ehr.) Grun.
F. crotonensis Kitton
F. crotonensis var. *oregona* Sov.
F. leptostauron (Ehr.) Hust. var. *leptostauron*
F. [*leptostauron* var. *dubia*] (Grun.) Hust.
F. pinnata Ehr. var. *pinnata*
F. pinnata var. *intercedens* (Grun.) Hust.
F. vaucheria (Kutz.) Peters

Meridion circulare (Grev.) Ag. var. *circulare*

Opephora martyi Herib.

Synedra acus Kutz.
S. *cyclopum* var. *robustum* Schulz.
S. *delicatissima* W. Sm. var. *delicatissima*
S. delicatissima var. *angustissima* Grun.
S. minuscula Grun. var. *minuscula*
S. parasitica (W. Sm.) Hust.
S. parasitica var. *subconstricta* (Grun.) Hust.
S. pulchella Ralfs. ex Hust.
S. radians Kutz.
S. rumpens var. *rumpens* Kutz.
S. rumpens var. *familiaris* (Kutz.) Hust.
S. rumpens var. *fragilarioides* Grun.
S. rumpens var. *meneghiniana* Grun.
S. socia Wallace
S. ulna (Nitz.) Ehr. var. *ulna*
S. ulna var. *amphirhynchus* (Ehr.) Grun.
S. ulna var. *contracta* Ostra.
S. ulna var. *oxyrhynchus* (Kutz.) V.H.
S. No. 61
S. No. 71

Tabellaria fenestrata (Lyngb.) Kutz.
T. floculosa (Roth.) Kutz.

Achnanthineae
Achnanthaceae

Achnanthes exigua Grun. var. *exigua*
A. exigua var. *constricta* (Grun.) Hust.
A. haukianna Schultz
A. hungarica Hust.
A. lanceolata Breb. ex Kutz. var. *lanceolata*
A. lanceolata var. *apiculata* Patr.
A. lanceolata var. *dubia* Grun.
A. lanceolata var. *omissa* Reimer
A. linearis (W.Sm.) Grun.
A. No. 38
A. No. 55

Cocconeis pediculus Ehr.
C. placentula var. *euglypta* (Ehr.) Cl.
C. placentula var. *lineata* (Ehr.) V.H.

Rhoicosphenia curvata (Kutz.) Grun. ex Rabh.

Naviculineae
Naviculaceae

Amphora ovalis (Kutz.) Kutz. var. *ovalis*
A. ovalis var. *pediculus* (Kutz.) ex DeT.
A. perpusilla (Grun.) Grun. var. *perpusilla*
A. veneta Kutz.

Caloneis bacillum (Grun.) Cl. var. *bacillum*
C. lewisii Patr. var. *lewisii*
C. No. 78

Capartogramma crucicula (Grun. ex Cl.) Ross

Cymbella minuta Hilse ex Rabh. var. *minuta*
C. minuta var. *pseudogracilus* (Choln.) Reim. comb Nov.
C. minuta var. *silesiaca* (Bleisch ex Rabh.) Reim.
C. naviculaformis Averswald
C. prostrata (Berk.) Cl.
C. tumida (Breb. ex Kutz.) V.H.
C. triangulum (Ehr.) Cl.

Diploneis oculata (Breb.) Cl.

Entomoneis ornata (J.W. Bail.) Reim. comb Nov., var. *ornata*

Gomphonema affine Kutz. var. *affine*
G. angustatum (Kutz.) Rabh. var. *angustatum*
G. angustatum var. *obtusatum* (Kutz.) Grun.

G. *angustatum* var. *sacrophagus* (Greg.) Grun.
G. *constrictum* var. *capitatum* (Ehr.) Cl.
G. *dichotomum* Kutz.
G. *gracile* Ehr. emend. V.H.
G. *intricatum* Kutz. var. *intricatum*
G. *intricatum* var. *pulvinatum* (Braun) Grun.
G. *olivaceum* (Lyngb.) Kutz.
G. *olivaceum* var. *calcarea* (Cl.) Cl.
G. *parvulum* (Kutz.)
G. *simus* Hohn & Hellerm. var. *simus*
G. *subclavatum* (Grun.) var. *subclavatum*
G. *subclavatum* var. *commutatum* (Grun.) A. Mayer
G. *subclavatum* var. *mexicanum* (Grun.) Patr.
G. *tenellum* Kutz.
G. *ventricosum* Greg. var. *ventricosum*
G. No. 47
G. No. 59

Gyrosigma *obtusatum* (Sulliv. & Wormly) Boyer
G. *scalproides* (Rabh.) Cl.
G. *sciotense* (Sulliv. & Wormly) Cl.
G. *spencerii* (W.Sm.) Cleve.

Navicula [c.f. *accomoda*] Hust.
N. *anglica* Rahfs.
N. [c.f. *anglica* var. *subsalsa*] (Grun.) Cl.
N. *arvenis* Hust.
N. *capitata* Ehr. var. *capitata*
N. *capitata* var. *hungarica* (Grun.) Ross
N. *cincta* (Ehr.) Ralfs var. *cincta*
N. *cryptocephala* Kutz. var. *cryptocephala*
N. *cryptocephla* var. *veneta* (Kutz.) Rabh.
N. *cuspidata* (Kutz.) Kutz.
N. *cuspidata* var. *major* Meist.
N. *decussis* Ostr. var. *decussis*
N. *dicephala* W.Sm.
N. *elginensis* (Greg.) Ralfs.
N. *elginensis* var. *lata* (M. Perag.) Patr. comb. nov.
N. *elginensis* var. *rostrata* (A. Mayer) Patr. comb. nov.
N. *exigua* var. *capitata* Patr.
N. *festiva* Krasske var. *festiva*
N. *gastrum* Ehr.
N. *ingrata* Krasska
N. *integra* (W.Sm.) Ralfs. var. *integra*
N. *lanceolata* (Ag.) Ag.
N. *menisculus* Schum.
N. *menisculus* var. *upsaliensis* (Grun.) Grun.
N. *minima* Grun.
N. *mutica* Kutz.
N. *mutica* var. *stigma* Patr.

N. pelliculosa (Breb ex Kutz.) Hilse var. *pelliculosa*
N. protracta Grun. var. *protracta*
N. pseudoreinhardtii Patr.
N. pupula Kutz. var. *pupula*
N. pupula var. *rectangularis* (Greg.) Grun.
N. radiosa Kutz. var. *radiosa*
N. radiosa var. *tenella* (Breb. ex Kutz.) Grun.
N. reinhardtii (Grun.) Grun.
N. reinhardtii var. *elliptica* Herib.
N. rhyncocephala Kutz. var. *rhyncocephala*
N. rhyncocephala var. *amphiceros* (Kutz.) Grun.
N. rhyncocephala var. *germainii* (Wallace) Patr.
N. salinarum var. *intermedia* (Grun.) Cl.
N. schroeteri var. *escambia* Patr.
N. secura Patr. var. *secura*
N. seminulum Grun.
N. symmetrica Patr.
N. tenera Hust.
N. terminata Hust.
N. tripunctata (O.F. Mull.) Bory var. *tripunctata*
N. tripunctata var. *schizonemoides* (V.H.) Patr.
N. vaucheriae Peterson
N. viridula (Kutz.) Kutz. var. *viridula*
N. viridula var. *avenacea* (Brib ex. Grun.) V.H.
N. viridula var. *linearis* Hust.
N. viridula var. *rostellata* (Kutz.) Cl.
N. No. 31
N. No. 33
N. No. 44
N. No. 45
N. No. 51
N. No. 56
N. No. 77

Neidium affine (Ehr.) Pfitz.

Pinnularia biceps Greg.
P. dactylus A.V.
P. subcapitata Greg. var. *subcapitata*

Pleurosigma delicatulum W.Sm.

Stauroneis anceps Ehr. var. *anceps*
Stauroneis sp.

Epithemiaceae

Epithemia adnata (Kutz.) Breb. var. *adnata*
E. argus (Ehr.) Kutz.
E. turgida (Ehr.) Kutz. var. *turgida*

Rhopalodia gibba (Ehr.) O. Mull.

Surirellaceae

Cymatopleura *solea* (Breb.) W.Sm.

Surirella *angustata* Kutz.
S. *multiplicata* Cleve. ender.
S. *ovata* Kutz.
S. *robusta* Ehr.

Nitzschia *acicularis* W.Sm.
N. *acicularis* var. *closterioides* Grun.
N. *acuta* Hantzsch
N. *adamata* Hust.
N. *affinis* Grun.
N. *amphibia* Grun.
N. *amphibia* var. *acutiuscula* Grun.
N. *angustata* Hust.
N. *capitellata* Hust.
N. *dissipata* (Dutz.) Grun.
N. *filiformis* (W.Sm.) Hust.
N. *fonticola* Grun.
N. *gandersheimiensis* Krasske
N. *gracilis* Hantzsch
N. *holsatica* Hust.
N. *hungarica* Grun.
N. *lacunarum* Hust.
N. *laevissima* Grun.
N. *linearis* W.Sm.
N. *obtusa* var. *scalpelliformis* Grun.
N. *palea* (Kutz.) W.Sm.
N. *paradoxa* (Gmelin) Grun.
N. *parvula* Lewis
N. [c.f. *pseudoamphioxys*] Hust.
N. *sigma*
N. *sigmoidea* (Nitz.) W. Sm.
N. *subcapitellata* Hust.
N. *tryblionella* Hantzsch.
N. (Nos. 34, 50, 54, 73)
N. No. 35
N. No. 48
N. No. 49
N. No. 52
N. No. 58

Chlorophyta
  Chlorophyceae
    Volvacales

Green Algae No. 268

Ulotricales
  Stigeoclonium *lubricum* (Dillw.) Kutz.
  Ulothrix sp.

Cladophorales
  Cladophora sp.

Chlorococcales
  Ankistrodesmus falcatus (Corda) Ralfs.
  Ankistrodesmus sp.

  Characium sp.

  Chlorella sp.

  Pediastrum duplex var. *gracilimum* West & West

  Scenedesmus abundans var. *brevicauda* Smith
  S. acuminatus (Lag.) Chodat.
  S. quadricauda (Tup.) de Brebisson
  S. quadricauda var. *quadrispina* (Chod.) Smith

  Selenastrum westii G.M. Smith

Zygnematales
  Closterium moniliferum (Bory) Ehr.

  Cosmarium formosulum Hoffman

  Spirogyra gratiana Transeau.

Cyanophyta
  Myxophyceae
    Chroococcales
      Anacystis cyanea (Kutz.) Dr. & Daily

      Merismopedia sp.

    Oscilliaoriales
      Anabaena flos-aquae (L.) Ralfs.

      Chamaesiphon incrustans Grun.

      Lyngbya sp.

      Oscillatoria sp.

Appendix IV. A list of the number of cells designated as one unit for the enumeration of colonial and filamentous algae.

TAXA	CELLS/UNIT
Chlorophyta	
Stigeoclonium lubricum	10
Ulothrix sp.	5
Cladophora sp.	3
Green Algae No. 268	4
Cyanophyta	
Anacystis cyanea	15
Anabaena flos-aquae	5
Lyngbya sp.	8
Oscillatoria sp.	12