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Community Dynamics of Phytoplankton in a Typical Navigation Pool in the Upper Mississippi River

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In 1986 we studied phytoplankton in the mid-reaches of Pool 8, which is a typical navigation pool of the Upper Mississippi River. During years of normal discharge, the areas studied usually become distinctly different from each other (ranging from free-flowing river to stagnant marsh) as the ice-free season progresses. These differences among sites did not occur during our study because the discharge into Pool 8 during 1986 was about 85% greater than the 10-yr mean discharge (1972-1982). Moreover, differences among areas were not observed with respect to physical and chemical characteristics such as photic zone depth, temperature, dissolved nitrogen and phosphorus, and silica. Accordingly, the phytoplankton assemblages and standing crops, which were characteristic of eutrophic waters, remained similar for all study areas. The phytoplankton was dominated by centric diatoms (*Melosira granulata, M. italica, Stephanodiscus astrea,* and *Cyclotella meneghiniana*), which comprised about 70% of the total cell volume. *Aphanizomenon flos-aquae, Cryptomonas ovata,* and *Ulothrix subconstricta* were the most abundant non-diatoms; however, dense blooms of *Aphanizomenon* that normally occur in the Upper Mississippi River did not occur during the summer of 1986. Of the physical and chemical characteristics studied, discharge and temperature were most highly correlated with phytoplankton cell volume and chlorophyll a. In contrast, phosphorus and nitrogen were not correlated with phytoplankton standing crop.

INDEX DESCRIPTORS: Phytoplankton, Mississippi River, Discharge, Nutrients, Chlorophyll

The Mississippi River drains approximately 41% of the contiguous United States and is the largest river in North America. The Upper Mississippi River is defined as the ecological reach extending northward from its confluence with the Missouri River near Alton, Illinois, to the head of commercial navigation at St. Anthony Falls in the Twin Cities of Minneapolis-St. Paul, Minnesota (Fremling *et al.*, 1989). The U.S. Army Corps of Engineers modified the Upper Mississippi River in the 1930s by the construction of 29 locks and dams as part of a 2.74-m (9-ft) navigation channel project. The locks and dams transformed the previously free-flowing river into a series of shallow navigation pools that occupy most of the original floodplain. Typical navigation pools on the Upper Mississippi River consist of three distinct ecological areas (Fremling and Claflin, 1984). Tailwaters immediately downstream of the locks and dams are characterized by braided channels with high current velocities and represent the river in a relatively unmodified form. Mid-pool areas consist of numerous side channels and backwater lakes. The flooded prairie meadows in the mid-pool areas are high quality marshes of great productivity. Downstream reaches are deeper, open-water expanses that cover nearly the entire floodplain. The backwater lakes and open-water downstream areas trap and accumulate sediments (Nielson *et al.*, 1984), thereby reducing the storage capacity of the pools (Chen and Simons, 1986) and elevating river stages (Grubaugh and Anderson, 1989). Emergent vegetation and ultimately terrestrial vegetation of upstream reaches are encroaching upon the downstream areas as sediments accumulate (Eckblad *et al.*, 1977; Bhowmik *et al.*, 1986). The Upper Mississippi is a vast, diverse riverine system that contains three national wildlife and fish refuges and is presently being managed as a multiple-use resource, e.g., for commercial and recreational navigation, commercial and sport fishing, and recreation.

Early ecological investigations of the phytoplankton in the Upper Mississippi River were performed by Bailey (1848), Tilden (1895), and Reinhardt (1931); however, these studies occurred prior to impoundment of the river. Only a few studies of phytoplankton have been conducted since impoundment, e.g., Williams and Scott (1962), Baker and Baker (1979, 1981) in Pool 3, and Huff (1986) in Pool 7. Jackson *et al.* (1981) reviewed literature on the Upper Mississippi River and identified large gaps in the data base for phytoplankton.

In this paper, we compare seasonal trends in the phytoplankton composition and standing crops in three different areas of Pool 8, evaluate which physical and chemical factors most influence phytoplankton within the pool, and expand the phytoplankton data base for the Upper Mississippi River.

DESCRIPTION OF THE STUDY AREA

Navigation Pool 8 was formed by impoundment of the river at Lock and Dam 8 near River Mile 679 and extends upstream 37 km to Lock and Dam 7 at River Mile 702. Pool 8 has an average pool elevation of 192 m (above mean sea level) and a mean annual discharge of 875 $m^3 \cdot s^{-1}$ (Dawson *et al.*, 1984). The surface areas of the water and floodplain of the pool are 5586 ha and 4161 ha, respectively. The locks and dams on the river are regulated to maintain a 2.7-m commercial navigation channel within the pools. Consequently, retention times of water vary greatly within navigation pools depending on discharge (Grubaugh and Anderson, 1989).

Three sampling stations were established in the mid-reaches of Pool 8 (Fig. 1). During years of normal discharge, the stations represent distinctly different habitat types, which range from free-flowing river to stagnant marsh (Claflin, 1976). Station 1 was located in a side channel of similar current velocity and depth as the main channel. Station 2 was located in a bay adjacent to a slough that normally has a low current velocity except during spring runoff. Station 3 was in a shallow, marshy backwater area that has minimal to undetectable current velocities under normal summer river discharges.

METHODS

All samples and *in situ* measurements were taken at approximately 2-week intervals during the ice-free period of 14 June to 15 November 1986. A vertical profile of light extinction in the water column at each station was obtained with an underwater irradiameter at each sampling date. The depth to which 1% of the incident light penetrated was defined as the bottom of the photic zone (American Public Health Association *et al.*, 1985). Samples for water chemistry and phytoplankton were then collected with a Kemmerer sampler from each of four equally-spaced depths within the photic zone (surface, two intermediate depths, and bottom). In addition, water temperature and transparency were measured at these depths at the time of sample collection.

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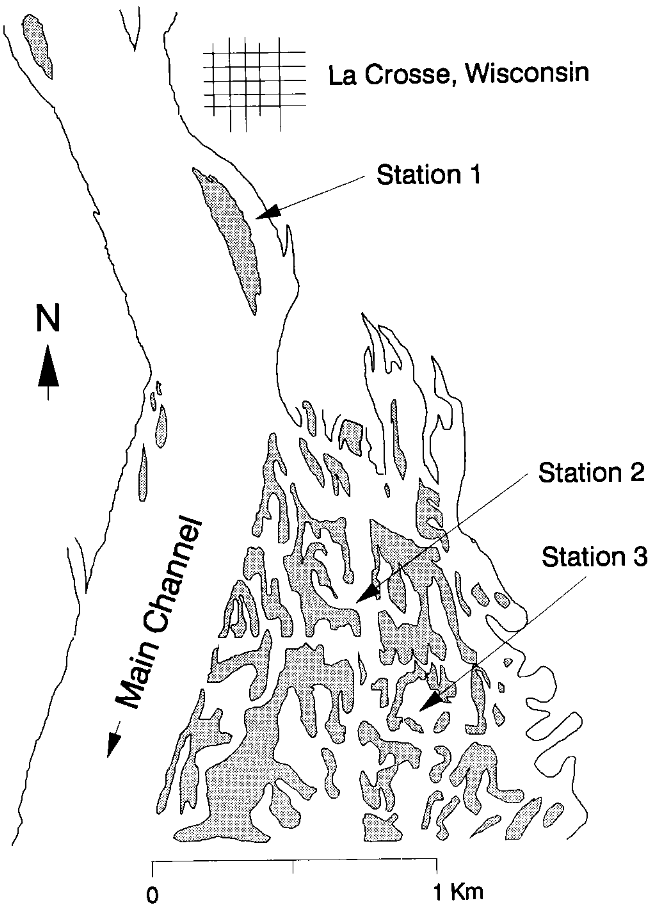

Fig. 1. Map of study area.

Water Chemistry

Water for analyses of physical and chemical properties was placed in two 1-L polyethylene bottles and kept on ice in the dark for transport to the laboratory. One liter of each sample was filtered through a glass fiber filter (Gelman, Type A/E) for analyses of soluble reactive phosphorus, nitrate + nitrite-nitrogen (hereafter referred to as nitrate-N), ammonia-nitrogen, total hardness, and silica. The remaining liter of unfiltered water was used for analyses of turbidity, pH, alkalinity, specific conductance, total Kjeldahl-nitrogen (TKN), and total-phosphorus. All analyses were performed according to standard methods (U.S. Environmental Protection Agency, 1979).

Phytoplankton

Water for phytoplankton pigment analyses was filtered through glass fiber filters (Whatman, Type C) in the field immediately after sample collection. Filters were placed in opaque test tubes and held on ice for transport to the laboratory. The filters were ground in 90% acetone, and the concentrations of extracted pigments (chlorophyll *a* and pheophytin *a*) were determined with a 0.5-nm band width spectrophotometer (American Public Health Association *et al.*, 1985).

Water for phytoplankton identification and enumeration was fixed in "M^3" preservative and stored for subsequent microscopic analysis with the membrane filtration technique (American Public Health Association *et al.*, 1985). The phytoplankton were examined with a bright field microscope fitted with a whipple ocular micrometer. Enumeration of taxa was accomplished by making strip counts of membrane mounts at a magnification of 500X until at least 450 organisms were counted. Organisms were measured and appropriate geometric formulae were used to calculate cell volumes (Wetzel and Likens, 1979). Phytoplankton were identified to the species level when possible with the following keys: Prescott 1961, 1978; Hustedt 1959, 1961, 1962; Patrick and Reimer 1966, 1975; Smith 1950; and Taft and Taft, 1971. A magnification of 1250X was used for identification of small taxa.

Statistics and Data Presentation

Statistical analyses were conducted with the Systat® Statistics Package (Wilkinson, 1988). All correlations and regressions used were linear. A significance-level of ≤ 0.05 was used to judge significance for all statistical tests. Data for all physical, chemical, and biological constituents for all four photic zone depths were similar; therefore, only the means of these four values for each station on each date are presented here. The term "dissolved inorganic nitrogen" is defined here as the sum of nitrate-N, nitrite-N, and ammonia-N.

RESULTS

Discharge and Water Chemistry

The discharge of water through Lock and Dam 7 into Pool 8 during 1986 was about 85% greater than the 10-year mean discharge (1972-1982); moreover, the discharge during September and October of 1986 was 166% to 230% greater than the 10-year mean (Fig. 2).

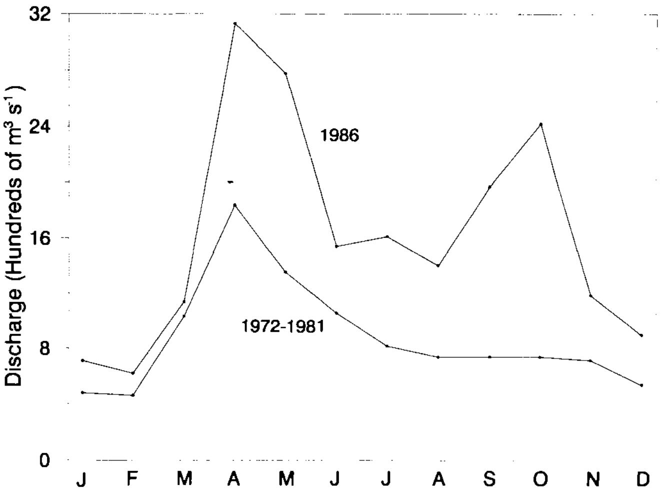

Fig. 2. Discharge into Navigation Pool 8, Upper Mississippi River during 1986 and the 10-yr period of 1972-1981 (monthly mean).

General physical and chemical characteristics of water at all stations were very similar during our study (Table 1). Likewise, no differences were observed among stations for silica, phosphorus, and nitrogen. Seasonal trends for conductance, total alkalinity, and total hardness were negatively correlated to discharge ($P < 0.001$). Concentrations of TKN and nitrate-N were relatively high in late June and early July, decreased through September, and began to increase again in October and November (Fig. 3). Ammonia concentrations remained relatively low during the entire study. Seasonal trends for soluble reactive-P and total-P were similar to those for species of nitrogen, except the autumnal increase in phosphorus concentration was not as great as for nitrogen.

Phytoplankton Taxonomic Composition

The phytoplankton of Pool 8 was represented by five divisions of algae (classification of Prescott, 1961): Chlorophyta (green algae), Chrysophyta (diatoms), Cyanophyta (blue-green algae—cyanobac-

Table 1. Means and ranges (in parentheses) of selected water quality characteristics at three stations in Pool 8, Upper Mississippi River, 14 June to 1 November 1986.

Station	Temp (°C)	Photic zone depth (cm)	Conductance ($\mu S \cdot cm^{-1}$)	pH	Hardness ($meq \cdot L^{-1}$)	Silica ($mg \cdot L^{-1}$)	Soluble reactive phosphorus ($mg \cdot L^{-1}$)	Dissolved inorganic nitrogen ($mg \cdot L^{-1}$)
1	19.0	132	308	7.9	3.3	13.3	0.12	0.44
	(8.0-28.0)	(70-166)	(153-371)	(7.6-8.2)	(2.2-4.4)	(6.4-19.4)	(0.08-0.18)	(0.03-0.86)
2	19.3	126	333	8.1	3.6	13.5	0.13	0.48
	(7.5-28.3)	(65-150)	(246-373)	(7.7-8.5)	(2.6-4.7)	(5.7-19.8)	(0.07-0.27)	(0.07-0.91)
3	19.3	116	325	8.1	3.5	13.3	0.11	0.49
	(7.5-27.1)	(45-145)	(235-366)	(7.7-8.4)	(2.4-4.7)	(5.9-19.8)	(0.08-0.17)	(0.07-1.04)

teria), Euglenophyta (euglenoids), and Pyrrophyta (dinoflagellates and cryptomonads). Of the 90 taxa identified, the following were observed in at least one sample on each sampling date: *Melosira granulata, M. italica, Cyclotella meneghiniana, C.* spp. *Synedra ulna, Cocconeis placentula, Stephanodiscus hantzschii, Scenedesmus quadricauda, Ulothrix subconstricta, Actinastrum hantzschii, Aphanizomenon flos-aquae, Cryptomonas ovata,* and an unidentified small, green coccoid alga. Approximately 95% of the total phytoplankton cell volume was accounted for by 23 taxa with three or fewer taxa accounting for >75% of the cell volume of each of the five divisions (Table 2).

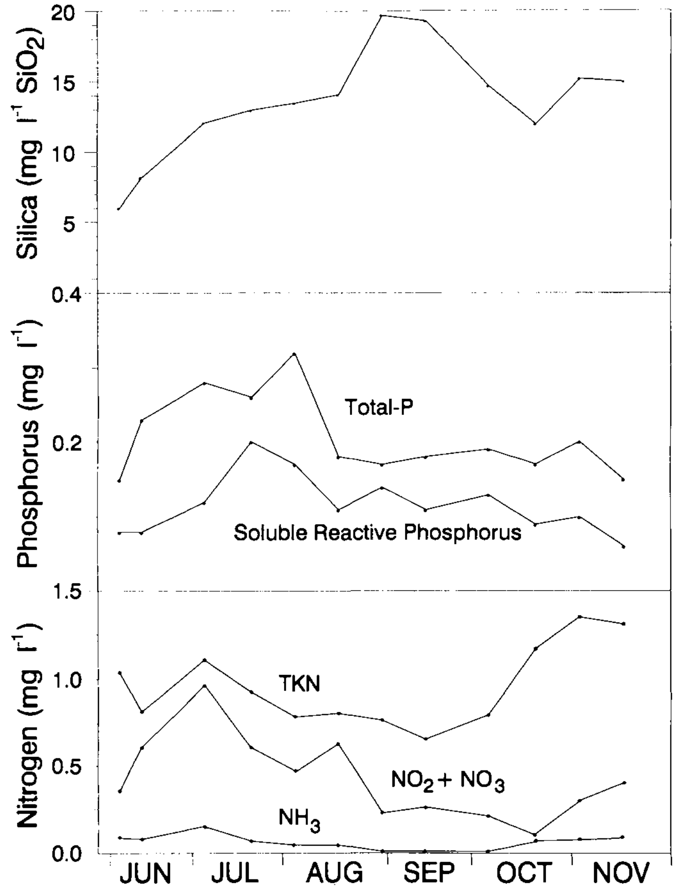

Fig. 3. Seasonal distributions of nitrogen, phosphorus, and silica in Navigation Pool 8, Upper Mississippi River, 14 June to 1 November 1986. Concentrations are mean values for the three stations combined.

Phytoplankton Seasonal Trends

Mean total cell volumes and pigment concentrations of phytoplankton were similar among the three sampling stations (Table 3).

Table 2. Contribution of individual taxa (%) relative to divisional and total cell volumes of phytoplankton in Pool 8, Upper Mississippi River, 14 June to 1 November 1986. Data are mean standing crops for all stations combined.

	Relative Cell Volume (%)	
Division and Taxa	Divisional	Total
Chrysophyta		
Melosira granulata (Ehr.) Ralfs.	39	29
Melosira italica (Ehr.) Kutz.	20	15
Stephanodiscus niagarae Ehr.	12	9
Cyclotella meneghiniana Ehr.	9	7
Cyclotella sp.	5	4
Stephanodiscus astrea (Ehr.) Grun.	5	4
Stephanodiscus hantzschii Grun.	4	3
Nitzschia sp.	1	1
Synedra ulna (Kutz.) Ehr.	1	1
Fragilaria crotonensis Kitton.	1	1
	97	74
Chlorophyta		
unidentified green coccoid	47	3
Ulothrix subconstricta G.S. West	22	2
Scenedesmus quadricauda (Turp.) Deb.	3	<0.5
Acktinastrum hantzschii (Lager.)	1	<0.5
	73	5
Cyanophyta		
Aphanizomenon flos-aquae (L.) Ralfs.	61	5
Microcystis aeruginosa Keutz. emend Elekin	14	1
Anabaena spiroides Kleb. var *crassa* Lemm.	6	1
Microcystis inserta Lemm.	4	<0.5
Anabaena flos-aquae (Lyng.) DeB.	1	<0.5
	86	7
Pyrrophyta		
Cryptomonas ovata Ehr.	87	7
Glenodinium pulvisculus (Ehr.) Stein.	13	1
	100	8
Euglenophyta		
Euglena sp.	48	<0.5
Phacus sp.	52	<0.5
	100	<0.5

Table 3. Means and ranges (in parentheses) of phytoplankton cell volume, chlorophyll *a*, and pheophytin *a* at three stations in Pool 8, Upper Mississippi River, 14 June to 1 November 1986.

Station	Cell Volume ($mm^3 \cdot L^{-1}$)	Chlorophyll *a* ($mg \cdot m^{-3}$)	Pheophytin *a* ($mg \cdot m^{-3}$)
1	4.4	14.8	6.4
	(1.7-7.9)	(2.8-27.2)	(2.2-20.0)
2	4.1	18.8	4.4
	(0.9-7.9)	(3.4-43.7)	(1.9-6.7)
3	4.8	14.5	4.6
	(0.8-11.8)	(3.2-28.7)	(2.2-9.1)

Mean chlorophyll *a* concentrations were substantially greater than concentrations of its breakdown product pheophytin *a* at all stations. Seasonal patterns of the main phytoplankton divisions were essentially the same for all three stations (Fig. 4). Mean chlorophyll *a* concentrations and cell volumes followed the same seasonal trends (data for the three stations were averaged for each date), as evidenced by the strong correlation between these variables ($r = 0.93$, $P < 0.001$). Another set of correlations were conducted with phytoplankton cell volume and chlorophyll *a* as dependent variables and discharge, temperature, photic depth, turbidity, secchi depth, pH, soluble reactive phosphorus, TKN, nitrate, ammonia, and SiO_2 as independent variables.

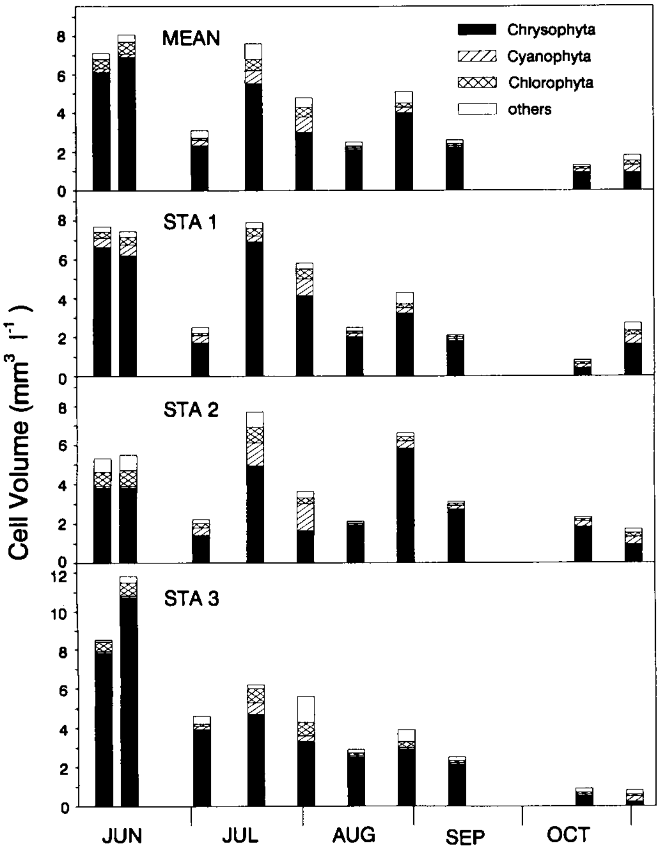

Fig. 4. Seasonal standing crops of phytoplankton divisions in Navigation Pool 8, Upper Mississippi River, 14 June to 1 November 1986.

Chlorophyll *a* was negatively correlated with discharge ($r = -0.60$, $P < 0.001$) and positively correlated with temperature ($r = 0.67$, $P < 0.001$). Moreover, a stepwise regression analysis revealed the following highly significant ($P < 0.01$) two-variable multiple regression model in which temperature (T) and discharge (Q) accounted for 57% of the variation in chlorophyll a concentration (adjusted $R^2 = 0.57$):

$$\text{Chl a } (mg \cdot m^{-3}) = 14.2 - 0.0001\ Q\ (m^3 \cdot s^{-1}) + 0.587\ T\ (^\circ C)$$

Cell volume was significantly correlated with discharge ($r = -0.50$, $P < 0.005$), temperature ($r = 0.54$, $P < 0.005$), and alkalinity ($R = 0.45$, $P < 0.005$); however, no multiple regression models were significant.

Diatoms dominated the phytoplankton during the entire study, with maximal mean cell volumes occurring in mid-June (6.8 $mm^3 \cdot L^{-1}$), mid-July (5.5 $mm^3 \cdot L^{-1}$), and late August (4.0 $mm^3 \cdot L^{-1}$) (Fig. 4). *Melosira granulata* was commonly the dominant diatom followed by *M. italica*, *Stephanodiscus nigarae*, and *Cyclotella meneghiniana* (Table 2; Fig. 5). On a cell volume basis, the green algae never became dominant nor exceeded a cell volume of 0.6 $mm^3 \cdot L^{-1}$ during the study (Fig. 4). The unidentified, green coccoid alga had the greatest standing crop of any green algae (Table 2; Fig. 5). Cyanobacteria were observed throughout the study; however, their maximal cell volume never exceeded 0.8 $mm^3 \cdot L^{-1}$ at any time. *Aphanizomenon flos-aquae* was the only cyanobacterium to be among the most important species on a cell volume basis — Stations 1 and 2 (Fig. 5). The only important representative of the Pyrrophyta was *Cryptomonas ovata*; it was always present, with maximal cell volumes occurring in mid to late summer (Table 2; Fig. 5).

DISCUSSION

Physical and Chemical Characteristics

The large discharges observed during this study were due to rapid runoff after snowmelt in the spring and greater than normal precipitation within the watershed, particularly during late summer and early autumn. The main effects of the abnormally large discharge were the dilution of dissolved substances in the water column (as evidenced by the negative correlation between discharge and conductance), higher than normal pool elevations, and reduced water retention times within the navigation pool — e.g., very little if any water exchange occurs at Station 3 under normal, summer flow conditions; however, the retention time of water at this station in 1986 would likely have been only a few minutes (T.O. Claflin, pers. com., University of Wisconsin-LaCrosse, LaCrosse, WI, USA, 54601). Consequently, our study sites, which normally range from lotic habitat (Station 1) to relatively isolated, stagnant, backwater marsh (Station 3), all remained lotic in nature during this study.

The concentrations of dissolved inorganic nitrogen and TKN observed during this study in Pool 8 were similar to those observed in other pools of the Upper Mississippi River (Baker and Baker, 1981; Dawson *et al.*, 1984; Huff, 1986); however, the concentrations of dissolved inorganic nitrogen, soluble reactive phosphorus, and total-P were substantially lower than the 10-yr means (1972-1981) for Pool 8 reported by Dawson *et al.* (1984). The total-P concentrations we observed suggest that this reach of the river is meso-eutrophic and moderately enriched with phosphorus (Wetzel, 1983), but the 10-yr mean concentration reported by Dawson *et al.* (1984) indicates that this reach is more highly enriched and eutrophic. The comparatively low concentrations of phosphorus we observed were likely the result of dilution by the abnormally high discharges during our study. Seasonal trends for nitrogen were similar to those reported for Pool 7 just upstream of our study area (Smart, 1980; Dawson *et al.*, 1984; Huff, 1986).

Phytoplankton

The seasonal patterns of phytoplankton we observed in Pool 8 were similar to those described for many temperate rivers and stratified

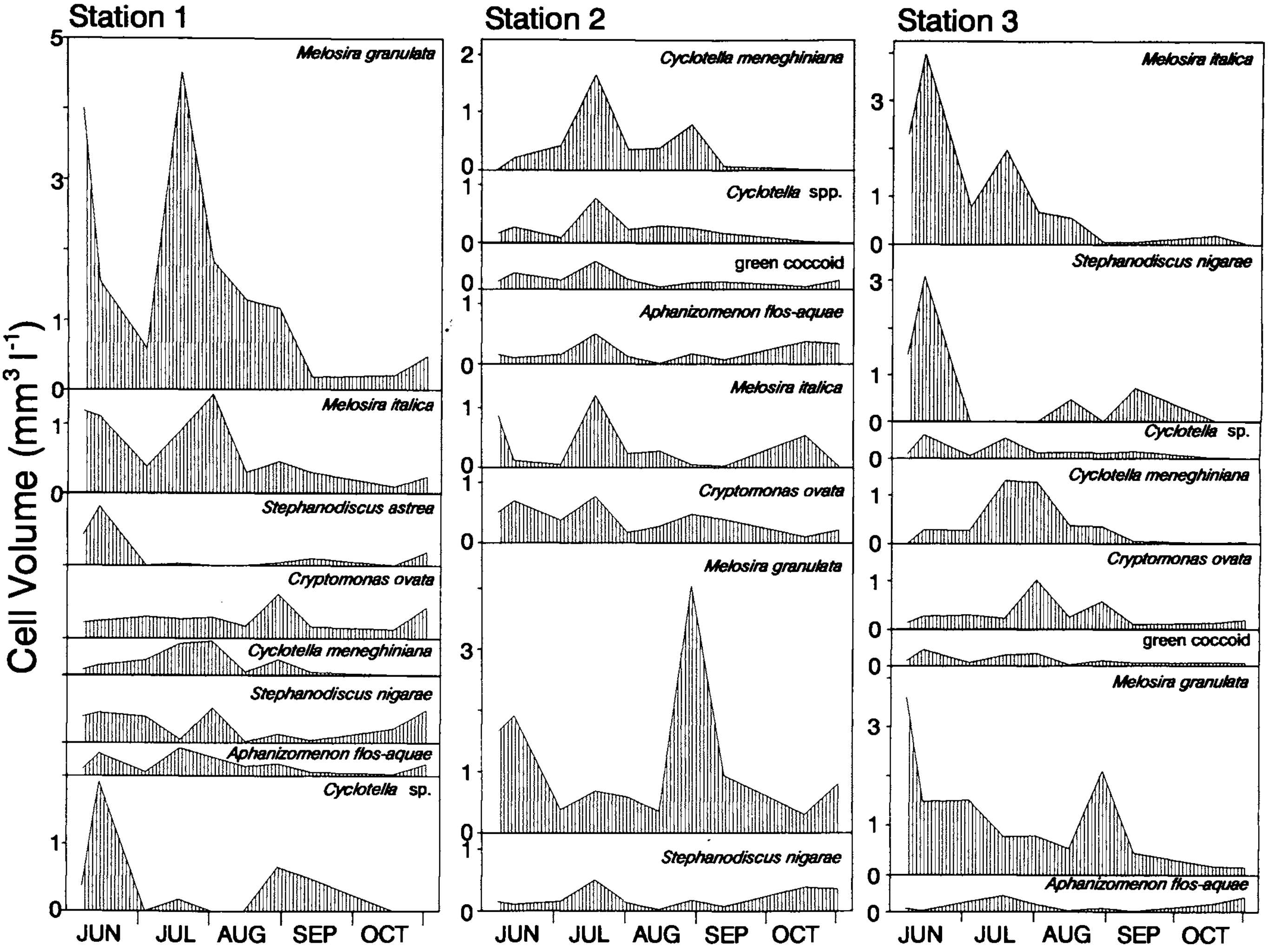

Fig. 5. Seasonal standing crops of the eight most abundant phytoplankton species in Navigation Pool No. 8, Upper Mississippi River, 14 June to 1 November 1986.

lakes, i.e., spring and autumnal dominance by diatoms and elevated populations of green, cyanobacterial, and cryptomonad algae during the summer (Hutchinson, 1967; Hynes, 1970; Wetzel, 1975; Reynolds, 1984). The most unexpected result was the absence of large cyanobacterial blooms (mainly *Aphanizomenon flos-aquae*), which commonly occur during the summer in the Upper Mississippi River (Reinhartdt, 1931; Baker and Baker, 1981; Engman, 1984; Huff, 1986). During 1987-1989, low water years on the Upper Mississippi River, large blooms of *Aphanizomenon* were observed in Pools 4 through 8 (J. Sullivan, pers. com., Wisconsin Department of Natural Resources, LaCrosse, WI, USA, 54601; W. Maurer, pers. com., University of Wisconsin-LaCrosse, LaCrosse, WI, USA, 54601). *Aphanizomenon* was usually present but never became dominant during our study. The heavy-celled centric diatoms (*Melosira, Cyclotella,* and *Stephanodiscus*), being tolerant of high washout (Moss and Balls, 1989), were probably kept suspended in the water column by turbulence from high discharge in Pool 8 during our study rather than settling to the bottom, as occurs during summer stratification in temperate lakes (Reynolds, 1973; Davey, 1987). In general, the phytoplanktonic community we observed was euplanktonic with little tychoplanktonic recruitment from the periphyton community, which in the Upper Mississippi River is dominated by pennate diatoms (Vansteenburg *et al.,* 1984). Under the calm conditions characteristic of backwaters of the river, the periphyton of the Upper Mississippi River usually develops a three-dimensional architecture that is susceptible to scouring under episodes of turbulence (Luttenton and Rada, 1986). However, the high discharges and associated physical turbulence in the river during the summer of 1986 probably prevented the development of a 3-dimensional architecture in periphyton community that otherwise could have contributed to the phytoplankton under conditions of episodic turbulence, e.g., wave action due to wind and navigation. Overall, the community assemblage of phytoplankton in Pool 8 was indicative of eutrophic waters (Hutchinson, 1967; Wetzel, 1983) and was relatively healthy, as evidenced by the large amount of chlorophyll *a* compared to pheophytin *a*.

The lack of heterogeneity among our three stations with regard to taxonomic composition, seasonal trends, and standing crops of phytoplankton reflects similarity of the physical and chemical characteristics of water at the three stations. The abnormally high river discharge in 1986 resulted in high pool elevations and relatively short retention times (likely only a few minutes in duration; T.O. Claflin, pers. com., University of Wisconsin-LaCrosse, LaCrosse, WI, USA, 54601) in much of Pool 8. These conditions maintained the backwater areas as flowing, riverine habitats rather than allowing these areas (especially

Station 3) to become lacustrine habitats as spring runoff subsided. Consequently, much of Pool 8 did not develop the diversity of habitats that Fremling and Claflin (1984) described as being characteristic of typical navigation pools in the Upper Mississippi River. In contrast to our findings, Baker and Baker (1979, 1981) did observe greater standing crops in backwaters than in the main channel of Pool 3 of the Upper Mississippi River and attributed those differences to longer retention times in the backwaters. They also encountered greater standing crops during a relatively dry, low discharge year compared to a wet year.

Although we observed distinct seasonal trends for nitrogen, phosphorus, and silica, no significant correlations were observed between these nutrients and phytoplankton standing crop (cell volume and chlorophyll *a*). The lack of correlation between nitrogen or phosphorus and chlorophyll *a* in these reaches of Pool 8, which have short retention times, is supported by the work of Soballe and Bachmann (1984) who demonstrated that algal biomass in Des Moines River impoundments is uncoupled from the chlorophyll-phosphorus/nitrogen relationships found in most natural lakes. It appears that the same situation also exists in the Pool 3 (Baker and Baker, 1979, 1981), Pool 7 (Huff, 1986), and Pool 21 (Dorris *et al.,* 1963) of the Upper Mississippi River. Multiple regressions with our data indicated that discharge and temperature had the greatest influence of any variables we studied over seasonal succession of phytoplankton standing crops (chlorophyll *a*). Temperature and discharge have been shown to similarly affect standing crops of phytoplankton in Pool 21 of the Upper Mississippi River (Dorris *et al.,* 1963) and in selected reaches of the Ohio River and its tributaries (Peterson and Stevenson, 1989).

The standing crops of phytoplankton (cell volume and chlorophyll *a*) we encountered were similar to those observed under conditions of normal discharge in Pool 7 about 20 km upstream of our stations (Huff, 1986) and were of the same magnitude as those found in other eutrophic waters (Hutchinson, 1967; Wetzel, 1983).

SUMMARY

The abnormally large discharges in the summer of 1986 resulted in sustained high pool elevations and maintained all three stations as lotic habitats rather than allowing Station 3 to become an isolated backwater marsh, which occurs under normal discharges. Therefore, species composition and standing crops of phytoplankton remained similar among the study sites throughout the study. The phytoplankton assemblages and standing crops were characteristic of eutrophic waters and were dominated by the centric diatoms. Dense blooms of *Aphanizomenon* that normally occur in the Upper Mississippi River did not occur during our study, probably because of the abnormally large discharges. Of the abiotic characteristics studied, discharge and temperature were the factors most highly correlated with seasonal phytoplankton cell voume and chlorophyll *a*. Phosphorus and nitrogen were not correlated with phytoplankton standing crop.

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