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Spatial and Temporal Variation of Diatom Community Structure in Two East-Central Illinois Streams

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ABSTRACT

Much attention has been given to macroinvertebrate and fish communities of the Embarras River Basin. In contrast, algal communities have been ignored, even though algae are potentially more sensitive as monitors of environmental change. Recent industrialization in the watershed could negatively impact water quality of the Embarras River and Brushy Fork - streams already subject to agricultural runoff, wastewater plant effluent, and landfill leachate. Our purpose was to describe attached diatom communities in order to establish a baseline for future comparisons. Artificial substrates were deployed in the Embarras River and in Brushy Fork for successive two-week intervals from 30 May 1990 through 22 September 1990. While seventy species of diatoms were identified, seventy to ninety-nine percent of all communities were comprised of only eleven species. These dominant species are recommended as potential biological monitors, while community level parameters such as species richness, diversity, and evenness are believed to be insensitive to environmental perturbation.
Key Words: stream ecology, periphyton, algae, diatoms, biological monitoring

INTRODUCTION

The degradation of streams worldwide is partially the result of industrialization, energy production, modern agricultural practices, land development and deforestation. These activities generally increase burdens of heavy metals, pesticides, herbicides, industrial chemicals, and sediment in aquatic systems. Such perturbations often produce streams and lakes which are low in productivity and species diversity (Takamura et. al., 1989), and which have reduced economic and aesthetic value.

Techniques have been developed for utilizing organisms to monitor the effects of environmental perturbations on aquatic ecosystems. Methods of biological assessment range from floristic and faunistic studies to complex community analyses and lengthy *in situ* bioassays (Friant and Koerner, 1981). Use of specific organisms in natural communities as indicators of pollution was proposed as early as 1913 (Wilhmin, 1975). Algae and aquatic macrophytes are especially useful as biomonitors because they vary in their sensitivities to pollutants (Friant and Koerner, 1981; Bailey and Stokes, 1985;

Smith and Kwan, 1989). Diatom communities on artificial substrates are one of the more widely used biomonitors in the United States (Whitton, 1975).

The Embarras River receives largely agricultural runoff along with municipal and industrial waste effluents, as well as other miscellaneous urban and highway runoff. Continued industrialization, including the citing of a heavy metal recycling facility near Newman, IL, could potentially impact aquatic communities in Brushy Fork and the Embarras River. In 1987 the Illinois Environmental Protection Agency conducted an intensive study of the Embarras River basin in effort to ascertain the condition of the various reaches of the river (Ettinger, 1989). While data were obtained on macroinvertebrate and fish community structures, no data were collected on algal communities. Therefore, this study was initiated to obtain baseline data on the community structure of attached algae (periphyton), specifically that of diatoms.

MATERIALS AND METHODS

Study Site

The Embarras River originates south of Champaign, Illinois (Fig. 1) and flows approximately 310 km to its confluence with the Wabash River near Vincennes, Indiana. The Embarras drains an area of approximately 4500 km^2 in eleven east-central Illinois counties (Ettinger, 1989). Brushy Fork, a tributary of the Embarras, originates northeast of Newman, Illinois and enters the Embarras in Douglas County. Preliminary field investigations and studies of United States Geological Survey topographic maps led to the selection of four sample sites (Fig. 1). Site selection was based on two criteria: i) ease of access to the site (i.e., sites selected were located near roadway bridges) and ii) proximity to the mouths of Brushy Fork and Newman Drain #2. Sampling sites were established in the Embarras River 4.7 km downstream (DNEMB) and 3.7 km upstream (UPEMB) of the mouth of Brushy Fork, and in Brushy Fork 3.0 km upstream (UPBFK) and 1.1 km downstream (DNBFK) of the mouth of Newman Drain #2 (Fig. 1).

Sampling Regime

Artificial substrates were continuously exposed for 2-week intervals from 30 May 1990 to 22 September 1990. Substrates (35.5 cm X 24.4 cm plexiglas sheets) were attached to flotation devices consisting of styrofoam blocks attached at either end of a 71 cm X 15 cm X 1.5 cm PVC pipe frame. Floats were anchored to cement blocks with ample rope to compensate for depth fluctuations. Substrates were recovered at the end of each sampling interval and replaced with clean substrates. Stream flow, conductivity, dissolved oxygen, pH, and temperature were determined on each sample collection date.

Laboratory Analyses

Air-dried periphyton (i.e., primarily diatoms, but also including other algae, insect larvae, invertebrate eggs, and trapped sediment) was removed from a 185 cm^2 area of the upper surface of each substrate and placed into separate, acid-washed, preweighed glass vials. Samples were dried for 24 hours in a convection oven at 103-105 °C, cooled in a desiccator and weighed to the nearest 0.1 mg. Net mass of the periphyton was determined by subtraction of tare mass.

Approximately 60 ± 0.1 mg of each periphyton sample were digested in clean Pyrex centrifuge tubes with 1 mL of concentrated sulfuric acid and a few crystals of potassium dichromate (Patrick and Reimer, 1966). Digestion was continued for a 48-hr period, during which samples were agitated occasionally with subsequent rinsing of centrifuge tube walls with deionized water. After digestion, tubes were filled to 10 mL, shaken vigorously to suspend the digested material and centrifuged at 1,750 revolutions min^{-1} for 10 minutes. Following aspiration of the supernatant, tubes were again filled to 10 mL, shaken and centrifuged. This rinsing procedure was repeated a third time to insure removal of all acid and tubes were filled to 10 mL in preparation for mounting. Dilutions of 1:2, 1:5 and 1:10 were prepared from the original suspension. Fifty µL of the original suspension and of each dilution were evenly distributed on separate circular (d = 1.2 cm) coverslips and dried on a hot plate. Coverslips were inverted and mounted on a glass microscope slide using Permount.

Coverslips were scanned at 1000x using a Bausch and Lomb phase-contrast microscope equipped with a Whipple grid and the number of each species observed in each scan was recorded. Species were identified according to Wolle (1894), Tiffany and Britton (1952), Patrick and Reimer (1966, 1975) and Dodd (1987). Diatom frustules were counted if they were at least half intact and if they i) were completely contained within the optical grid but did not touch or extend past the bottom line of the grid or, ii) if they touched the top line of the optical grid or extended into the grid from the top. Successive scans were observed until a minimum of 500 frustules had been enumerated. The area of each scan was determined and the total area scanned was recorded. Total and individual species densities were calculated from data on relative abundance as follows:

$$\text{Density (no. cm-2)} = N \frac{(A_t)}{(A_s)} (F_d) \frac{(V_o)}{(M_d)} \frac{(M_t)}{(A_p)} \frac{1}{}$$

where:
- N = number of frustules observed,
- A_t = total area of coverslip (cm^2),
- A_s = area scanned (cm^2),
- F_d = dilution factor (mL^{-1}); (200 for 1:10 dilution, 100 for 1:5 dilution, 40 for 1:2 dilution, 20 for no dilution)
- V_o = original volume of suspension (mL),
- M_t = mass scraped from substrates (mg),
- M_d = mass digested (mg),
- A_p = area of plexiglas scraped (cm^2).

Diversity (Shannon and Weaver, 1963) was calculated as:

$$H' = -\sum_{i=1}^{s} p_i(\log p_i)$$

where:
- s = number of species present in a sample,
- p_i = proportion of community represented by species i.

Evenness (J), which is the ratio of observed diversity to maximum diversity (Pielou, 1969), was calculated based on the formula:

$$J = H' / H'_{max}$$

where: H' = observed diversity index,
H'_{max} = maximum diversity, (= log s).

Statistical Analyses

Substrates were not replicated at sampling sites. Therefore, two-way analysis of variance (ANOVA) without replication (Sokal and Rohlf, 1981) was used to determine significant ($p < 0.05$) differences for characteristics of the physical/chemical environment and the diatom community with sample date and site as independent variables. Because observations were not replicated, it was not possible to test for interaction between independent variables. Characteristics which differed significantly between sites or over time were subjected to correlation analysis (Sokal and Rohlf, 1981). For characteristics which did not differ significantly by site, a single factor (sample date) ANOVA was performed utilizing the Scheffé method to identify significant differences between means, with sites as replicates (Sokal and Rohlf, 1981).

RESULTS

The physical and chemical environments of the four sampling sites proved to be quite variable. Dissolved oxygen was the only measured characteristic for which significant differences were not detected, while stream flow, temperature, conductivity, and pH all varied significantly ($p < 0.05$) between sampling sites and over time. Stream flow tended to be higher early in the study period, with a general decline at all four sites through August and September (Fig. 2a). Water temperature increased from May through August before declining again in September (Fig. 2b). Conductivity appeared to decline over the course of the study at all sites except UPBFK (Fig. 3a) and pH was relatively higher in May and September with lower values being observed during mid-summer (Fig. 3b).

Neither diversity nor evenness varied significantly ($p < 0.05$) by date or site, thus overall means ($n = 28$) were calculated and are reported as 0.77 (H') and 0.58 (J). However, variation in diatom density and species richness was significant ($p < 0.05$) for sampling date. Total diatom density appeared to decrease over the course of the study, with significant differences detected between mean diatom densities for sampling periods one and six as well as for periods one and seven (Table 1). No readily discernible trend was apparent for species richness, with only sampling periods two and six differing significantly (Table 1). Significant correlations ($p < 0.05$) were not observed between any environmental variable (stream flow, temperature, conductivity, pH) and either diatom density or species richness.

Seventy different diatom species were identified (Table 2). Major community dominants, i.e., those species which comprised ten percent or more of the total individuals observed on at least one sampling date, accounted for seventy to ninety-nine percent of the total diatom community at all four sites. Dominant species included *Achnanthes lanceolata lanceolata*, *Cocconeis placentula euglypta*, *Cocconeis placentula placentula*, *Cyclotella*

meneghiniana meneghiniana, *Gomphonema angustatum angustatum*, *Gomphonema olivaceum olivaceum*, *Navicula lanceolata lanceolata*, *Navicula seminulum seminulum*, *Navicula subarvensis subarvensis*, *Navicula viridula viridula*, and *Nitszchia amphibia amphibia*.

Four species were regular community dominants throughout the study period (Figs. 4a, 4b, 5a, 5b). *Achnanthes lanceolata lanceolata* was a major constituent of the diatom community at all sites from June through September with peaks in relative abundance generally occurring prior to the end of July. *Cocconeis placentula euglypta* and *C. placentula placentula* generally replaced *A. lanceolata lanceolata* as dominants during August but declined in September. Although *N. seminulum seminulum* was relatively abundant from early June through early September at DNBFK, it was never an important component of the Embarras River and UPBFK communities.

Early season communities were characterized by the presence of three species (Figs. 6a, 6b, 7a, 7b). *Navicula subarvensis subarvensis* was abundant on 13 June at all four sites but was virtually absent in all communities from July through September. While *G. angustatum angustatum* and *G. olivaceum olivaceum* were abundant at UPEMB and DNEMB on 13 June, neither achieved high densities at the Brushy Fork sites. Both species of *Gomphonema* were minor components of Embarras River communities for the remainder of the study period except for a peak in relative abundance observed for *G. angustatum angustatum* on 8 August.

Four species occurred in higher relative abundance later in the study period (Figs. 8a, 8b, 9a, 9b). *Nitzschia amphibia amphibia*, never present in high numbers at UPEMB and a major component of the DNEMB community only on 8 August, was an important component of the Brushy Fork communities during August and September. *Cyclotella meneghiniana meneghiniana* was rare or absent at all four sites through July, and never attained high relative abundance at DNEMB. This typically planktonic species was an important constituent at UPEMB and the Brushy Fork sites on 22 September, at which time it composed eighty-seven percent of all individuals at DNBFK. Relative abundance of *N. lanceolata lanceolata* peaked on 22 September at the Embarras River sites, on 25 August at UPBFK, and on 8 September at DNBFK. *Navicula viridula viridula* was abundant only at UPBFK during September.

DISCUSSION

Our main goal was to provide a basis of comparison for future studies regarding changes in water quality within the Embarras River drainage. One would expect species richness, diversity, and evenness to reflect variation in the physical and chemical characteristics of the Embarras River and Brushy Fork if community level parameters are to serve as indicators of water quality. Seasonal variation in species richness in the Embarras River and Brushy Fork was not remarkable since the only observed significant difference was between means for sampling periods two and six. Krebs (1985) points out that even stable communities are in a constant state of flux, with some species becoming less abundant while others increase in number. Furthermore, diversity and evenness did not vary significantly over time or between sites in spite of the temporal and spatial differences which were observed for stream flow, temperature, conductivity, and pH.

Thus, we concur with Sullivan (1986) and Round (1991) that diversity indices fail as indicators of water quality.

The temporal decline in diatom density which we observed may have resulted directly or indirectly from the general decrease in stream flow over the course of our study, even though a significant correlation was not detected. Douglas (1958) and Jones (1978) observed similar relationships between stream flow and diatom density for communities (including species of *Achnanthes* and *Cocconeis*) occurring on natural substrates in streams. Possible explanations for this observed pattern include depletion of available nutrients at low flow (Douglas, 1958), increased herbivore activity (Jones, 1978), or decreased metabolic activity due to "suffocation" by silt or detritus deposited on the algae (Jones, 1978).

Sullivan (1986) suggested that the identity and autecology of the constituent species are paramount for assessing water quality through use of diatom communities. Diatom species encountered during this investigation possess a variety of ecologies (Patrick and Reimer, 1966; 1975) which are potentially responsible for the fluctuations in community structure that were observed. If diatom communities along with associated abiotic factors are monitored in the same locations for several seasons it could be possible to verify patterns of seasonal succession for these locations and ultimately develop an index for use in identifying the onset of acute or chronic pollution. For example, metal-tolerant species are able to survive in waters enriched with heavy metals while species which are sensitive to heavy metals or other pollutants may be eliminated from the community as a result of toxic conditions (Stokes, 1983).

Information on community structure obtained during this study provides a foundation for further research into the relative sensitivity of diatoms to heavy metals or other pollutants which may be introduced into the Embarras River and Brushy Fork. Laboratory determinations of differential sensitivities of species are required in order to establish a causal relationship between any form of pollution and changes in the diatom community. Furthermore, it will be necessary to establish the relative importance of pollutants versus naturally occurring perturbations (variations in flow, water temperature, etc.) with regard to success of any given species. Research efforts should focus initially on those species which were found to be dominant at different times of year (e.g., *Achnanthes lanceolata lanceolata*, *Cocconeis placentula euglypta*, *Cyclotella meneghiniana meneghiniana*, *Navicula subarvensis subarvensis*) since it is their disappearance which would be most readily detectible in the event of any environmental perturbation.

ACKNOWLEDGEMENTS

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Table 1. Mean density (millions per square centimeter) and species richness of diatom communities occurring on artificial substrates from 14 June 1990 through 22 September 1990 in the Embarras River and Brushy Fork. Mean values for exposure periods which differ significantly ($p < .05$) from a given value are shown in parentheses.

Exposure (Period) Date	Density	Species Richness
(1) 5/30-6/13	1.144 (6,7)	22.25
(2) 6/27-7/11	0.557	13.25 (6)
(3) 7/11-7/25	0.487	17.00
(4) 7/25-8/08	0.638	21.75
(5) 8/08-8/25	0.346	17.50
(6) 8/25-9/08	0.153 (1)	26.50 (2)
(7) 9/08-9/22	0.071 (1)	25.00

Table 2. Species of diatoms collected from sites in the Embarras River, upstream (UPEMB) and downstream (DNEMB) of the mouth of Brushy Fork, and in Brushy Fork, upstream (UPBFK) and downstream (DNBFK) of the mouth of Newman Drain #2. The following categories of occurrence at each sampling site are recorded for each species: rare (+), common (++), uncommon dominant (+++), common dominant (++++).

	Sample Collection Site			
Species	UPEMB	DNEMB	UPBFK	DNBFK
Achnanthes exigua var. *heterovalva* Krasske			+	+
Achnanthes hauckiana Grun. var. *hauckiana*			+	+
Achnanthes lanceolata (Breb.) Grun. var. *lanceolata*	++++	++++	++++	++++
Amphora ovalis var. *affinis* (Kuetz.) V.H. ex De T.	+	+	+	+
Amphora ovalis (Kuetz.) Kuetz. var. *ovalis*				+
Amphora perpusilla (Grun.) Grun. var. *perpusilla*	++	++	++	++
Amphora submontana Hust. var. *submontana*	++	++	++	++
Amphora veneta Kuetz. var. *veneta*	+			
Caloneis lagerstedtii Choln. var. *lagerstedtii*	+			
Caloneis lewisii var. *inflata* (Shultze) Patr.		+	+	++
Caloneis ventricosa var. *minuta* (Grun.) Patr.		++		++
Cocconeis pediculus Ehr. var. *pediculus*			+	
Cocconeis placentula var. *euglypta* (Ehr.) Cl.	++++	++++	++++	++++
Cocconeis placentula var. *lineata* (Ehr.)	++	++	++	++
Cocconeis placentula Ehr. var. *placentula*	++++	++++	++++	++++
Cyclotella meneghiniana Kuetz. var. *meneghiniana*	+++	++	++++	++++
Cymatopleura solea (Breb.) W. Sm. var. *solea*	++	+		
Cymbella affinis Kuetz. var. *affinis*	+	++	++	++
Cymbella sinuata Greg. var. *sinuata*				+
Cymbella tumida (Breb. ex Kuetz.) V.H. var *tumida*				+
Diatoma vulgare Bory var. *vulgare*	+	+		
Diploneis oblongella (Nage. ex Kuetz.) *oblongella*			+	++
Fragilaria capucina Desmaz. var. *capucina*	+			
Fragilaria vaucheriae (Kuetz.) Peters. var. *vaucheriae*	+	+		
Gomphonema acuminatum Ehr. var. *acuminatum*	+		++	+
Gomphonema affine Kuetz. var. *affine*	++	++	++	
Gomphonema angustatum (Kuetz.) Rabh. var. *angustatum*	++	+++	++	++
Gomphonema olivaceum (Lyngb.) Kuetz. var. *olivaceum*	+++	+++	++	++
Gomphonema truncatum Ehr. var. *truncatum*			+	
Gyrosigma acuminatum (Kuetz.) Rabh. var. *acuminatum*	++	++	++	++
Hantschia amphioxys (Ehr.) Grun. var. *amphioxys*		+	++	+
Melosira varians C.A. Ag. var. *varians*	+	++	++	++
Meridion circulare (Grev.) Ag. var. *circulare*	+	+		
Navicula capitata Ehr. var. *capitata*	+	++	++	++
Navicula circumtexta Meist. ex Hust. var. *circumtexta*		+		
Navicula cuspidata (Kuetz.) Kuetz. var. *cuspidata*	+		++	++
Navicula decussis Oestr. var. *decussis*	+	+		+
Navicula exigua Greg. ex Frun. var. *exigua*	++	++	++	++
Navicula fluens Hust. var. *fluens*	++	++	++	++

Table 2. (continued)

Species	Sample Collection Site UPEMB	DNEMB	UPBFK	DNBFK
Navicula gysingensis Foged var. *gysingensis*		+		
Navicula lanceolata (Ag.) Kuetz. var. *lanceolata*	++++	++++	+++	+++
Navicula placentula (Ehr.) Kuetz. var. *placentula* **	+	+		
Navicula pupula var. *elliptica* Hust.	+	+		
Navicula pupula var. *mutata* (Krasske) Hust. **	+			
Navicula pupula Kuetz. var. *pupula*	+		++	+
Navicula pygmaea Kuetz. var. *pygmaea*		+		
Navicula seminulum Grun. var. *seminulum*	++	++	++	++++
Navicula subarvensis Hust. var. *subarvensis*	+++	+++	+++	+++
Navicula tenera Hust. var. *tenera*	++	++	++	
Navicula viridula (Kuetz.) Kuetz. emend. V.H. var. *viridula*	++	++	++++	++
Neidium dubium f. *constrictum* Hust. **	++	++	+	
Nitzschia acicularis (Kuetz.) W. Sm. var. *acicularis*		+	++	+
Nitzschia amphibia Grun. var. *amphibia*	++	+++	++++	+++
Nitzschia angustata (W. Sm.) Grun. var. *angustata*	+		+	
Nitzschia hungarica Grun. var. *hungarica*		++	+	+
Nitzschia intermedia Hantzch var. *intermedia*			+	
Nitzschia tryblionella var. *victoriae* Grun.		+		
Nitzschia umblicata Hust. var. *umblicata*	++		++	
Nitzschia valdestriata Aleem & Hust. var. *valdestriata*	++	++	++	++
Pinnularia abaujensis (Pant.) Ross var. *abaujensis*	+			
Rhoicosphenia curvata (Kuetz.) Grun, var. *curvata*	++	++		
Surirella angusta Kuetz. var. *angusta*		+	+	+
Surirella linearis var. *constricta* Grun.	+			
Surirella ovata var. *crumena* (Breb.) V.H.		+	+	+
Surirella ovata Kuetz. var. *ovata*	++	++	++	++
Surirella ovata var. *pinnata* (W. Sm.) Hust.		+		
Synedra acus Kuetz. var. *acus*		+		
Synedra rumpens var. *meneginiana* Grun.	+	+	+	+
Synedra ulna (Nitz.) Ehr. var. *ulna*	+	+	+	
Tabellaria flocculosa (Roth) Kutz. var. *flocculosa*		+		

(**) - not previously reported in Illinois

(+) - present on one sampling date, but not in significant numbers

(++) - present on more than one sampling date, but never constituting greater than 10% of the total individuals observed

(+++) - comprising greater than 10% of the total individuals in the community on one sampling date

(++++) - comprising greater than 10% of the total individuals in the community on two or more sampling dates

Figure 1. Embarras River and Brushy Fork drainage in Champaign, Edgar and Douglas Counties showing the locations of sampling sites in the Embarras River, upstream (UPEMB) and downstream (DNEMB) of the mouth of Brushy Fork, and in Brushy Fork, upstream (UPBFK) and downstream (DNBFK) of the mouth of Newman Drain #2.

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Figure 2. Stream flow (a) and temperature (b) observed at four sites in the Embarras River and Brushy Fork from 13 June 1990 through 22 September 1990.

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Figure 3. Conductivity (a) and pH (b) observed at four sites in the Embarras River and Brushy Fork from 13 June 1990 through 22 September 1990.

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Figure 4. Relative abundance of *A. lanceolata lanceolata, C. placentula euglypta*, and *C. placentula placentula* from 13 June 1990 through 22 September 1990 at UPEMB (a) and DNEMB (b).

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Figure 5. Relative abundance of *A. lanceolata lanceolata, C. placentula eugylpta, C. placentula placentula*, and *N. seminulum seminulum* from 13 June 1990 through 22 September 1990 an UPBFK (a) and DNBFK (b).

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Figure 6. Relative abundance of *G. angustatum angustatum, G. olivaceum olivaceum*, and *N. subarvensis subarvensis* from 13 June 1990 through 22 September 1990 at UPEMB (a) and DNEMB (b).

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Figure 7. Relative abundance of *N. subarvensis subarvensis* from 13 June 1990 through 22 September 1990 at UPBFK (a) and DNBFK (b).

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Figure 8. Relative abundance of *C. meneghiniana meneghiniana, N. lanceolata lanceolata*, and *N. amphibia amphibia* from 13 June 1990 through 22 September 1990 at UPEMB (a) and DNEMB (b).

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Figure 9. Relative abundance of *C. meneghiniana meneghiniana, N. lanceolata lanceolata, N. viridula viridula*, and *N. amphibia amphibia* from 13 June 1990 through 22 September 1990 at UPBFK (a) and DNBFK (b).

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