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Diatom Assemblages Reflect Environmental Heterogeneity In An Urban Stream

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Diatom Assemblages Reflect Environmental Heterogeneity in an Urban Stream

BY

Kristen M. Thomas

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Master of Science

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2004

I HEREBY RECOMMEND THAT THIS THESIS BE ACCEPTED AS FULFILLING
THIS PART OF THE GRADUATE DEGREE CITED ABOVE

18 May 2004	Charles L Pedersen
DATE	THESIS DIRECTOR
18 May 2004	Andrew S Methven
DATE	DEPARTMENT HEAD

ABSTRACT

Physical habitat (e.g., flow regime, bottom substrate composition, instream cover, etc.) and chemical water quality must be suitable to support individual species and maintain integrity of lotic communities. Reservoir and sanitary discharges can alter the physical and chemical nature of stream systems which, in turn may impact stream biota. Since 1998, spatial and temporal heterogeneity have been examined in an urban reach of the Sangamon River in east central Illinois, USA. This system is appropriate for evaluating the relationship of the physical habitat and chemical water quality as influenced by impoundments as well as point source disharges on benthic algal assemblages. Based on the Stream Habitat Assessment Procedure, this 8.5 km stream reach represents a fair aquatic environment in the context of riparian and bed features. Commonly used measures of fish diversity as well as a fish community based Index of Biotic Integrity failed to detect any habitat heterogeneity. However, according to the Macroinvertebrate Biotic Index, sites downstream from the discharge of the Sanitary District of Decatur (SDD) are of significantly better quality than those in the reach that extends upstream to the dam which impounds Lake Decatur.

My first objective was to evaluate temporal and spatial heterogeneity of the physical and chemical nature of the Sangamon River as influenced by gate management of the Lake Decatur dam and daily discharges from the SDD. Sampling sites were stratified by location, as either upstream (UPS) or downstream (DNS) of the discharge from SDD. Water samples were collected from 10 sites on 10 different sample dates under variable flow conditions between 19 June and 10 December, 2002. Field and laboratory determinations were made of 15 variables, and Principal Components Analysis was used to characterize the two stream reaches. While analysis of variance revealed significant differences between the UPS and DNS reaches. considerable similarity of the two reaches exists during periods of high discharge from Lake Decatur.

During the same time period. I documented diatom community response to the physiochemical condition of the stream and evaluated the utility of diatoms as biological monitors. Diatoms were collected from the stream on six different occassions. Artificial substrates were deployed in the stream during successive, three week exposure periods to allow colonization by benthic diatoms. Diatoms were removed from the substrata and frustules were mounted onto glass microscope slides after being cleared via acid digestion. A minimum of 300 frustules were identified to species (and/or variety) and relative abundances at each sample site were determined for all sample periods from which substrates were recovered. Diversity, taxonomic richness, and evenness of diatom assemblages all increase significantly at DNS sites. Subsequently, I used Nonmetric Multidimensional Scaling (NMDS) based on the Bray-Curtis Index of Dissimilarity to evaluate response of diatom community structure to discontinuity of stream habitat quality. Diatom assemblages at UPS and DNS sites occupied discrete regions of the ordination space created by NMDS. Although periods of high discharge from Lake Decatur precipitate convergence of UPS and DNS diatom assemblages, ordination scores for individual species still permit characterization of discrete stream reaches and confirm the utility of diatoms for biotic assessment of Illinois streams.

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INTRODUCTION

Impoundment of rivers to create reservoirs used for irrigation purposes, as urban water supplies, and recreation is commonplace. However, impoundments may impact downstream aquatic systems and their surrounding terrestrial habitats. Diminished water quality and availability, closures of fisheries, extirpation of species, groundwater depletion, and pronounced hydrologic variability are increasingly distinguished as consequences of current river management associated with impoundments (Naiman *et al.* 1995, Abramovitz 1996, Collier *et al.* 1996). Specifically, dams affect riverine systems by altering flow regime, changing nutrient and sediment loads, and modifying energy flow (Ligon *et al.* 1995). As a result, river reaches downstream from a dam may no longer support intolerant native species, reflected by a reduction in the integrity of biotic communities (NRC 1992, Naiman *et al.* 1995).

A natural flow regime is critical for sustaining ecosystem integrity and native biodiversity in rivers (Poff *et al.* 1997). Dams can have varying effects on downstream aquatic habitats depending on the purpose for which the dam was built. Impoundments used for urban water supplies reduce flow rates below dams throughout the entire year, but increase daily and seasonal variability in flow regime (Finlayson *et al.* 1994, McMahon and Finlayson 2003). Due to the flow regime, abiotic variables including temperature, dissolved oxygen, turbidity, pH, conductivity, and solids concentrations are altered in the downstream river system (e.g., Finlayson *et al.* 1994).

Along with stream impoundments, point source and non-point source pollution can have profound effects on the ecological integrity of riverine systems. Water chemistry is often directly impacted by human disturbance, such as nutrient enrichment resulting from agriculture and wastewater treatment plants (McCormick and O'Dell

1996, Pan *et al.* 1996). Non-point sources of pollution may include agriculture, livestock grazing, and urbanization while sanitary discharge and industrial waste are examples of point source pollution. To reduce point source pollution, the Water Quality Act of 1972 encouraged wastewater treatment plants to upgrade their systems and, as a result, many communities were forced to build advanced tertiary wastewater treatment facilities (Karr *et al.* 1985). Yet these treatment facilities still export high concentrations of nutrients into rivers. Carpenter and Waite (2000) documented that concentrations of phosphorus were highest in streams draining agricultural basins and at sites influenced by wastewater discharges, while Twichell *et al.* (2002) reported that sewage effluent inputs had elevated nitrate levels. These enhanced nutrient inputs can be expected to increase productivity within a river because primary productivity and detrital processing usually are limited by low ambient stream nutrient concentrations (Stockner and Shortreed 1978, Elwood *et al.* 1981, Winterbourn 1990).

Distribution and abundance of individual species and the composition of aquatic communities in lotic systems largely are governed by geographically related physiochemical variables. Desirable physical habitat (e.g., flow, current velocity, bottom substrate composition, cover, etc.) and suitable chemical water quality must exist to meet specific requirements of individual species. While the physical and chemical characteristics of a stream are set by local conditions, human activities alter these components. Routine monitoring of river conditions traditionally incorporates chemical as well as biological analyses. Chemical analyses are essential to ensure that levels of nutrients, metals, pesticides, etc. are kept below recommended levels, whereas biocriteria are necessary to evaluate overall effects of the chemical input on organisms (Round 1991).

Passage of the Clean Water Act of 1977 (PL 95-217) and more recently, the Water Quality Act of 1987 (PL 100-4) has emphasized protection and assessment of biotic integrity in aquatic environments. Assessment of biotic integrity using fish has received increased emphasis in recent years (Stauffer *et al.* 1976, Hocutt 1981, Karr 1981, Karr *et al.* 1986). And the Illinois Environmental Protection Agency has emphasized use of fish communities as an indicator of stream quality for assessment required by Section 305(b) of the Clean Water Act and as the primary biotic metric of the Illinois EPA/IDNR Interagency Biological Stream Characterization (BSC) process (Hite and Bertrand 1989). Water quality conditions that significantly affect lower levels of the food web also may alter the abundance, species composition, and condition of the fish community. Because fish occupy upper trophic levels, they are affected directly and indirectly by physical and chemical changes in the environment. Condition of a fishery is the index of water quality most meaningful to the general public (Weber 1973), however, fish may not be ideal biological monitors because their response to perturbations is predictable due to mobility and their trophic position in the community (Cole 1973).

Benthic macroinvertebrates may be better suited for biomonitoring because they are sensitive and respond quickly to reduced water quality and their use in evaluating aquatic habitat is well established (Cairns and Dickson 1971, Barbour *et al.* 1999). Each macroinvertebrate species is dependent on specific ranges of environmental conditions (e.g., water quality, habitat, flow) throughout its lifespan. Unlike fish they are sessile, and upon collection, macroinvertebrates can be assumed to have integrated information regarding environmental conditions over the preceding weeks and months. This makes the macroinvertebrate community especially useful under conditions of mild or intermittent perturbation when altered water quality is not readily detectable by conventional chemical surveys (Chutter 1972). Good water quality typically supports a diverse community containing largely intolerant taxa, while various types of pollution may increase density of tolerant species and reduce species richness (Keup *et al.* 1967).

Benthic algae are important to riverine ecology when considering their role as primary producers and transformers of inorganic nutrients into organic forms that are ready to be used by other organisms (Lamberti 1996, Mulholland 1996). Algae also stabilize substrate and create mats that may form habitat for fish and invertebrates (Bott 1996). Along with fish and macroinvertebrates, benthic diatoms have been used for biological assessment of rivers (Growns 1999) and may represent the most useful taxonomic group for studying ecosystem perturbation. Although often neglected in monitoring programs due to the lack of available taxonomic expertise in many agencies, diatoms are easily identified due to the unique ornamentation of their frustules (Round 1993). Diatom assemblages are useful for evaluating different forms of pollution, such as organic enrichment downstream of sewage discharges (Cox 1991), and they respond quickly to environmental change due to their relatively short life cycles. Many studies have related changes in diatom assemblages to altered water chemistry, specifically phosphorus, nitrogen, and pH (Carrick *et al.* 1988, Pan *et al.* 1996, Winter and Duthie 2000). Diatom communities vary with substratum type (Leland 1995) and overall habitat heterogeneity (Robinson *et al.* 1994). Diatom community structure likely varies according to reach scale morphological features that coincide with land use and geologic variation among basins (Kutka and Richards 1996).

Physical habitat (e.g., flow regime, bottom substrate composition, instream cover, etc.) and chemical water quality must be suitable to support individual species and maintain integrity of lotic communities. The Sangamon River offers an opportunity to study these relationships influenced by impoundment as well as point source discharges. The Sangamon River Basin is a 14,000 km^2 watershed covering all or portions of eighteen counties in central Illinois. More than 3540 km of streams within the basin course through glacial and alluvial deposits creating typically low gradient streams with sand and gravel substrates (IDNR 1999a). Streams within the basin have been impacted by humans for most of the past century, receiving inputs from both point and non-point sources. Current land use is 80% agricultural of which a majority is corn or soybean production. Native deciduous woodlands now are limited to riparian areas and the expanses of prairie that once existed in Illinois have been reduced to isolated hill and sand prairies coupled with remnants along highway and railroad right-of-ways. Major metropolitan areas associated with the Sangamon River are Bloomington, Decatur, and Springfield representing a combined population of more than 500,000 residents. Impoundments associated with urbanization include Lake Taylorville, Lake Sangchris, and Lake Springfield on the South Fork of the Sangamon; Clinton Lake on Salt Creek; and Lake Decatur on the main stem (IDNR 1999b).

Considerable development and habitat alteration within the watershed may impact biotic integrity of the Sangamon River system. In 1998-1999 and continuing from 2001-2003, an intensive sampling program was initiated to document temporal and spatial heterogeneity of an 8.5 km reach of the Sangamon River beginning just below the Lake Decatur Dam and extending downstream to incorporate discharges from the Sanitary District of Decatur (SDD). This urban reach can be divided into two reaches that have received profoundly different inputs. The upstream reach extends upstream from the SDD to the dam that impounds Lake Decatur and is influenced mainly by reservoir discharge, while sites downstream of the SDD receive treated sanitary effluent from the Sanitary District of Decatur. Based on the Stream Habitat Assessment Procedure, although mean numerical ratings of the upstream and downstream reaches are significantly different, both are categorized as "fair" habitats. The Macroinvertebrate Biotic Index classified both reaches as "good/fair" although conditions are improved significantly downstream of the discharge from the SDD main treatment plant. The Fish Index of Biotic Integrity classified both reaches as "fair", but failed to detect any significant difference between stream reaches (Fischer and Pederson 2003).

I have used a conceptual framework to evaluate the effects of reservoir and sanitary discharges on stream biota. Regardless of source, discharges can alter the physical and chemical nature of streams. Such changes may include, but are not limited to, increased sediment and nutrient loading, abnormal temperature and flow regimes, and decreased habitat diversity. In turn, these alterations may be reflected in biotic changes such as, decreased diversity, taxonomic richness, and evenness through elimination of intolerant species. In this context, my first objective was to document temporal heterogeneity in a lotic system, as influenced by gate management of the Lake Decatur dam, as well as daily discharges from the Sanitary District of Decatur. I hypothesized that sites upstream of the SDD will experience extreme flow variations, resulting in a stressful environment, while the downstream sites will have a more predictable flow, leading to a more benign environment. My second objective was to document the response of diatom community structure to their physical and chemical environment and to evaluate the utility of these benthic algae as biocriteria for assessment of stream habitat quality.

MATERIALS AND METHODS

Study site

I utilized 10 sampling locations relative to prominent features associated with operation of the SDD or prominent landmarks within the city of Decatur, Illinois, USA. GPS coordinates were determined for all sites (Table 1). All sites were located in the main stem of the Sangamon River extending from just downstream of the dam which impounds Lake Decatur to the Wyckles Road Bridge on the west edge of Decatur. Throughout this paper, I will refer to general locations as either upstream (UPS) or downstream (DNS) of the SDD main treatment plant discharge. Seven sites were within the UPS reach extending from the dam to the discharge of the SDD main treatment plant, and three sites were included in the DNS reach which extends from the main treatment plant discharge to the Wyckles Road Bridge.

Field data collection and water chemistry determination

Water quality data were collected from each site every one to three weeks from June to December 2002 on 10 separate occasions (Table 2). Sampling was initiated at the Lake Decatur dam and proceeded downstream to Wyckles Road Bridge. While in the field, abiotic variables, such as dissolved oxygen, pH, conductivity, and temperature were determined using YSI meters. Surface water samples also were collected 0.3 m below the surface, returned to the laboratory on ice, and analyzed within generally accepted time limits. All sampling and analyses were conducted according to Standard Methods for Examination of Water and Wastewater (APHA 1995).

In the laboratory, suspended and total solids determinations were made by drying residue collected on standard glass fiber filters as well as unfiltered samples at 103-105 ^{0}C. Volatile and suspended solids fractions were determined by weight loss upon ignition

Table 1. Locations and GPS coordinates of sites relative to visible landmarks associated with the Sanitary District of Decatur for determination of water quality and analysis of diatom community structure.

Site #1 - Lincoln Park - above outfall	N 39^0 49.813’ W 088^0 57.819’
Site #2 - Lincoln Park - below outfall	N 39^0 49.892’ W 088^0 57.882’
Site #3 - Oakland (Lincoln Park Drive) - above outfall	N 39^0 49.890’ W 088^0 58.355’
Site #4 - Oakland (Lincoln Park Drive) - below outfall	N 39^0 49.924’ W 088^0 58.448’
Site #5 - 7th Ward - above outfall	N 39^0 49.924’ W 088^0 59.598’
Site #6 - 7th Ward - below outfall	N 39^0 50.028’ W 088^0 59.638’
Site #7 - SDD Main Treatment Plant - above main outfall	N 39^0 49.933’ W 089^0 00.033’
Site #8 - SDD Main Treatment Plant - below main outfall	N 39^0 49.916’ W 089^0 00.190’
Site #9 - Sangamon River - below Stevens Creek	N 39^0 49.955’ W 089^0 00.522’
Site #10 - Sangamon River at Wyckles Road	N 39^0 49.458’ W 089^0 01.712’

Table 2. Sample collection dates for water quality determinations and substrate exposure periods for assessment of diatom community structure at 10 main stem sites in the Sangamon River during 2002.

Water Quality Sample Date	Mean Discharge on Sample Date (cfs)	End of Diatom Exposure Period*	Mean Daily Discharge** (cfs)
6/19/2002	1,739		
6/27/2002	477		
7/18/2002	0.76	ONE	160.87
8/8/2002	0.1	TWO	0.70
8/27/2002	1,610		
9/3/2002	17	THREE	276.77
9/24/2002	0.1	FOUR	1.89
10/15/2002	1.9	FIVE	0.85
11/5/2002	9.6	SIX	5.54
12/10/2002	15		

* All substrates were exposed for 21 days, except during Exposure Period Three which extended to 27 days due to extreme hydrologic conditions on the intended collection date (8/27/2002).

**Mean daily discharge for entire exposure period.

at 550 °C. Turbidity was determined using a LaMotte portable turbidimeter and suspended chlorophyll *a* was measured *in vivo* using a Turner Designs laboratory fluorometer. Total phosphorus (following persulfate digestion) and soluble reactive phosphorus (utilizing filtered, undigested, sample aliquots) were determined using the ascorbic acid method. The phenate method was used for determination of ammonia nitrogen, and total oxidized nitrogen (NO_2-N + NO_3-N) was determined via the cadmium reduction method. Colorimetry of all nutrient analyses was determined using a Beckman DU® 530 Life Science UV/Vis Spectrophotometer. Hardness and alkalinity were measured using the EDTA-titrimetric and the titration to colorimetric endpoint methods, respectively. For all chemical analyses, due consideration was given to quality control and quality assurance procedures, including but not limited to parallel analyses of laboratory standards.

I used Principal Components Analysis (PCA) to combine physiochemical variables into overall measures of similarity. Factor loadings of individual measured variables were evaluated using Pearson correlations with Bonferroni corrected significance criteria. Analysis of variance was performed on extracted PCA factor scores to determine whether differences existed between UPS and DNS reaches. Differences in mean PCA factor scores for the UPS and DNS reaches were evaluated relative to discharge in the upstream reach (Table 2). Flow data were obtained via the United States Geological Survey website (www.usgs.gov) for gauging station number 05573540 which is located in the Sangamon River at Route 48 in Decatur, Illinois.

Diatom collection and identification

Diatom communities colonized artificial substrates (glass microscope slides measuring 25 x 80 mm) that were deployed at each site for a time period ranging from 21-26 days (Table 2). Variability in the length of exposure periods was due to instances of high flow in the river. After substrates were collected from the stream, diatom communities were dried, removed from the slides, weighed to the nearest 0.1 mg, and placed into glass vials. Material from four randomly selected substrates was combined in order to accurately characterize diatom community assemblage at each particular site. The combined material was digested in Pyrex centrifuge tubes with approximately 10 mL of concentrated sulfuric acid and a few potassium dichromate crystals (Patrick and Reimer 1966). After digesting for 24 hours, centrifuge tubes were filled to 10 mL with deionized water, agitated to suspend the digested material, and centrifuged at 1750 revolutions min^{-1} for 10 minutes. Samples were rinsed with deionized water at least two more times to assure that all acid was removed from the sample. These samples were then stored in 10 mL of deionized water. Samples were agitated to resuspend the material in the centrifuge tube and 200 μL were evenly distributed onto circular glass coverslips with a diameter of 1.2 cm. Coverslips were air dried overnight, then inverted and mounted onto glass microscope slides using Cargille MeltMount™ Quick Stick™ with a refractive index of 1.704. Approximately 5 replicate slides were made from each sample.

Coverslips were observed at 1000x using a Nikon Alpha-phot phase contrast microscope equipped with an ocular micrometer to identify species present at each site and to estimate relative abundance. A minimum of 300 frustules were identified and enumerated per sampling period. Three replicate counts on separate slides from a single sampling period revealed no significant difference in relative abundances of diatom taxa. As a result, one prepared slide from each sampling period was randomly chosen for detailed analysis of diatom community structure. Genera and species were identified according to Dodd (1987), Patrick and Reimer (1966, 1975), Tiffany and Britton (1952), and Wolle (1894). Data on relative abundance of diatom taxa were used to calculate the Shannon-Wiener Diversity Index (H') (Shannon and Weaver 1949) and evenness (Pielou 1977). In addition, Nonmetric Multidimensional Scaling (NMDS) based on the Bray-Curtis Index of Dissimilarity (Bray and Curtis 1957) was used to combine information on relative abundance into an overall assessment of similarity of the UPS and DNS reaches (Shepard 1962a, Shepard 1962b, Kruskal 1964a, Kruskal 1964b).

RESULTS

Water chemistry analyses

Levels of 15 separate water quality variables were determined for all ten main stem sites (Appendix A) and (Table 3). Greater variability in dissolved nutrient concentrations, such as total oxidized nitrogen, total phosphorus, and soluble reactive phosphorus existed in the DNS reach. The UPS reach was more variable with respect to temperature, pH, and hardness as well as concentrations of solids, dissolved oxygen, ammonia nitrogen, and chlorophyll *a*. Based on my observation, site 7 seems to be a transition zone between the UPS and DNS reaches. Site 7 occurs immediately upstream of the discharge from the main treatment plant of the SDD and at certain times when sampling, I noticed discharge backing up into this site. If site 7 were removed from the data, some chemical factors in the UPS reach would be less variable.

Principal Components Analysis of the measured variables extracted 4 factors which explained a total of 75 % of the variation in water quality observed within the Sangamon River (Appendix B). Analysis of variance for PCA factor 1 (df = 1.95; F_{calc} = 88.03; p = .0001) and PCA factor 2 (df = 1.95; F_{calc} = 8.38; p = .005) revealed significant differences between the UPS and DNS reaches. Significant correlations between PCA factors 1 and 2 on individual water quality variables were observed (Table 4). All variables were significantly correlated with PCA factor 1 except dissolved oxygen, temperature, hardness, and ammonia nitrogen, while 7 of 15 variables were correlated with PCA factor 2 (Table 4).

During periods of low discharge from the reservoir, UPS and DNS sites occupy discrete regions in the ordination space created by PCA factors 1 and 2 (Figure 1). By itself, PCA factor 1 explained 37.5% of the variability among sample sites. To examine

Table 3. Water quality summary statistics (mean (minimum - maximum)) for UPS and DNS sites in the Sangamon River during 2002.

	UPSTREAM	**DOWNSTREAM**
Dissolved Oxygen (DO) mg L^{-1}	5.93 (1.69 - 10.64)	5.62 (1.90 - 8.03)
Temperature (TEMP) ^{o}C	20.4 (2.5 - 26.9)	23.3 (11.3 - 29.7)
pH (pH)	8.3 (7.7 - 9.1)	8.2 (7.8 - 8.8)
Specific Conductance (COND) µS m^{-1}	587.8 (448.0 - 4009.0)	2404.23 (483.0 - 4060.0)
Hardness (HRD) mg $CaCO_3$ L^{-1}	258.5 (197.8 - 390.8)	255.3 (232.8 - 297.6)
Total Alkalinity (TALK) mg $CaCO_3$ L^{-1}	205.9 (103.1 - 369.7)	270.3 (123.8 - 388.8)
Total Oxidized Nitrogen (TON) mg (NO_2-N + NO_3-N) L^{-1}	0.65 (0.01 - 9.29)	4.35 (0.07 - 17.43)
Ammonia Nitrogen (AMM) mg (NH_3-N) L^{-1}	0.65 (0.00 - 5.82)	0.15 (0.00 - 1.80)
Total Phosphorus (TP) mg (PO_4-P) L^{-1}	0.18 (0.03 - 2.05)	1.80 (0.33 - 3.98)
Soluble Reactive Phosphorus (SRP) mg (PO_4-P) L^{-1}	0.06 (0.00 - 2.15)	1.84 (0.21 - 3.24)
Chlorophyll *a* (CHL) µg chl *a* L^{-1}	3.26 (0.52 - 7.06)	2.40 (1.10 - 4.61)
Fixed Suspended Solids (FSS) mg L^{-1}	16.9 (1.0 - 67.1)	17.2 (2.0 - 45.9)
Volatile Suspended Solids (VSS) mg L^{-1}	8.1 (2.1 - 16.7)	7.2 (3.7 - 14.2)
Fixed Dissolved Solids (FDS) mg L^{-1}	251.8 (172.5 - 2250.8)	1384.4 (241.5 - 2171.3)
Volatile Dissolved Solids (VDS) mg L^{-1}	106.7 (62.2 - 146.7)	123.9 (90.7 - 146.8)

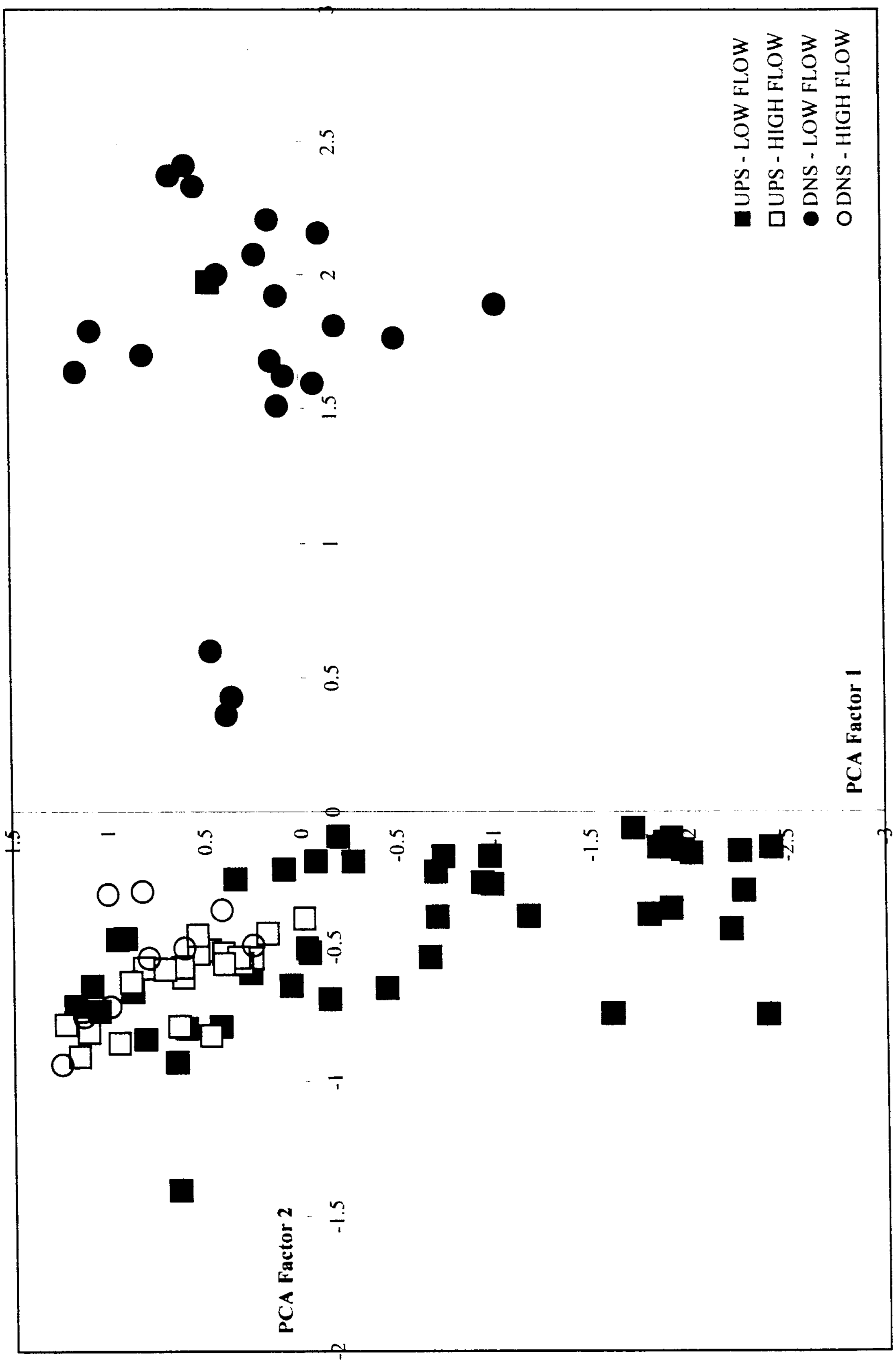
Table 4. Correlation matrix of derived PCA factor scores and individual water quality variables for 10 main stem Sangamon River sample sites during 2002.

	PCA Factor Score 1	**PCA Factor Score 2**
Dissolved Oxygen (DO) mg L^{-1}	--	--
Temperature (TEMP) ^{o}C	--	.892*
pH (pH)	-.388*	-.435*
Specific Conductance (COND) μS m^{-1}	.945*	--
Hardness (HRD) mg $CaCO_3$ L^{-1}	--	--
Total Alkalinity (TALK) mg $CaCO_3$ L^{-1}	.652*	--
Total Oxidized Nitrogen (TON) mg (NO_2-N + NO_3-N) L^{-1}	.754*	--
Ammonia Nitrogen (AMM) mg (NH_3-N) L^{-1}	--	-.594*
Total Phosphorus (TP) mg (PO_4-P) L^{-1}	.910*	--
Soluble Reactive Phosphorus (SRP) mg (PO_4-P) L^{-1}	.940*	--
Chlorophyll *a* (CHL) mg chl *a* L^{-1}	-.539*	.675*
Fixed Suspended Solids (FSS) mg L^{-1}	-.497*	.543*
Volatile Suspended Solids (VSS) mg L^{-1}	-.500*	.651*
Fixed Dissolved Solids (FDS) mg L^{-1}	.972*	--
Volatile Dissolved Solids (VDS) mg L^{-1}	.350*	.477*

-- Not Significant

* $P<0.01$ (2-tailed)

Figure 1. Scatterplot of UPS and DNS factor scores (PCA 1, PCA 2) derived from measured water quality variables in the Sangamon River during 2002.


■ UPS - LOW FLOW
□ UPS - HIGH FLOW
● DNS - LOW FLOW
○ DNS - HIGH FLOW
PCA Factor 1
PCA Factor 2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3

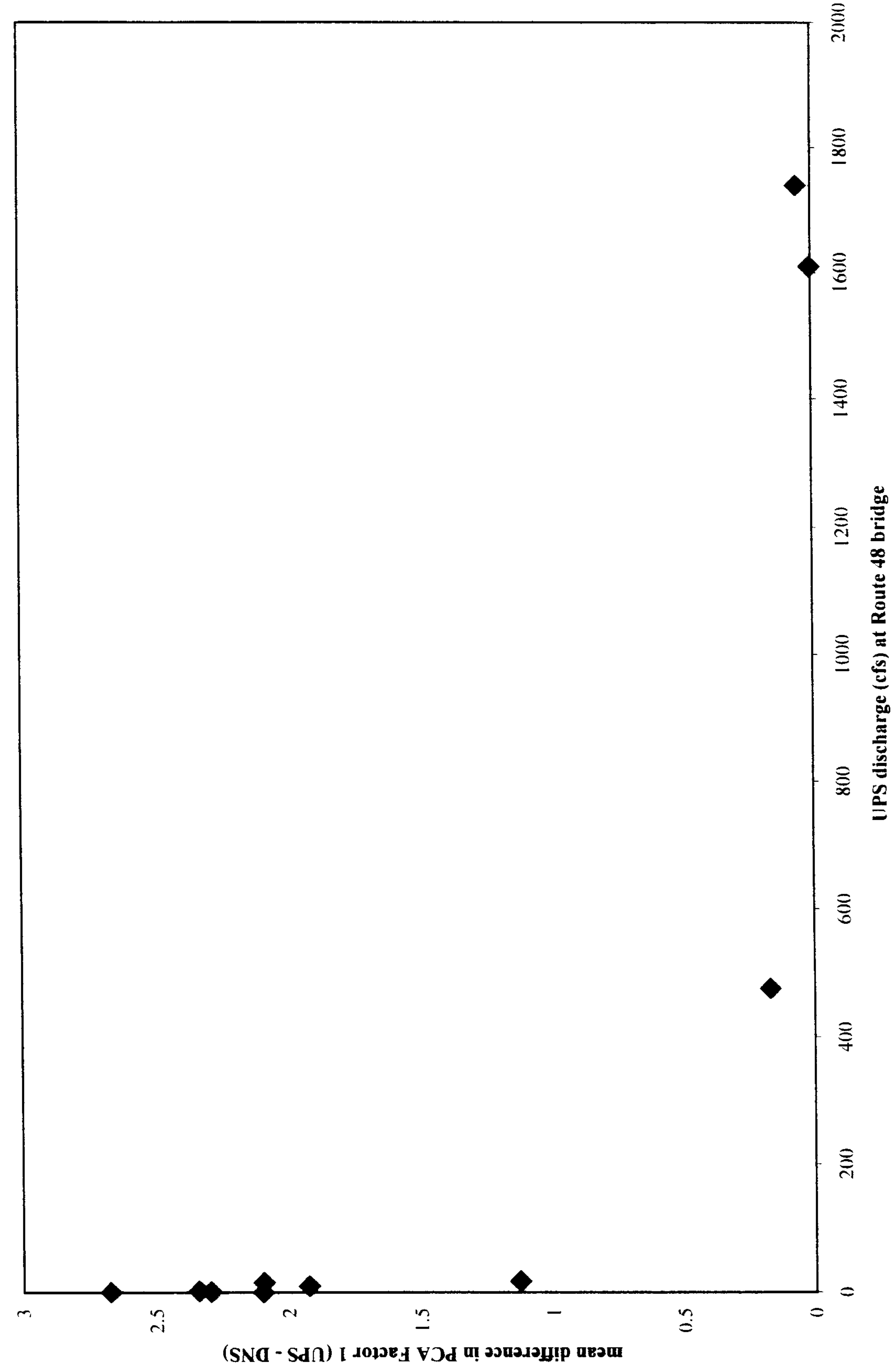
the effect of reservoir discharge on spatial heterogeneity in the Sangamon River. I calculated an average PCA factor 1 score for the UPS and DNS reaches for each date on which water chemistry determinations were made. The average difference between UPS and DNS sites became asymptotic at zero when discharge measured at the Route 48 Bridge exceeded 400 cubic feet per second (cfs) (Figure 2).

Description of diatom assemblages

Forty-one different diatom varieties including 38 species and 15 genera were identified from substrates recovered during 2002 (Appendix C). Cosmopolitan species which exhibit high relative abundance throughout the entire stream reach included *Cyclotella meneghiniana* and *Nitzschia palea*. Shifts in other dominant taxa mark the distinct nature of the two stream reaches. UPS communities include high numbers of *Amphora ovalis*, *Achnanthes linearis*, and *Gomphonema parvulum* while common, dominant species in the DNS reach include *Navicula protracta*, *Achnanthes exigua*, *Navicula menisculus*, and *Nitzschia valdestriata*. Finally, both reaches are characterized by somewhat unique subordinate taxa. Most notably, *Cocconeis placentula*, *Cyclotella stelligera*, *Cymbella tumida*, and *Gomphonema brasiliense* are present in UPS communities but typically absent downstream of the SDD discharge. In contrast, species absent from the UPS reach, but present at DNS sites include *Aulacoseira italica*, *Caloneis hultenii*, *Nitzschia dissipata* and *Pleurosira laevis*.

Community based indices of diatom community structure (Appendices D, E, F) pooled for UPS and DNS reaches reveal significant differences. Taxonomic richness (df = 1,52; $F_{calc} = 7.58$; $p = .008$), diversity (df = 1,52; $F_{calc} = 6.18$; $p = .016$), and evenness (df = 1,52; $F_{calc} = 4.46$; $p = .039$) all are higher downstream of the SDD discharge

Figure 2. Influence of measured discharge at the Route 48 bridge on the average overall difference in PCA factor 1 scores of the UPS and DNS reaches in the Sangamon River during 2002. Note the two reaches become indistinguishable at an apparent threshold of approximately 400 cfs.


mean difference in PCA Factor 1 (UPS - DNS)
0
0.5
1
1.5
2
2.5
3
UPS discharge (cfs) at Route 48 bridge
0
200
400
600
800
1000
1200
1400
1600
1800
2000

(Figures 3, 4, 5). Furthermore, NMDS of overall diatom community structure (Figure 6) based on the Bray Curtis Index of Dissimilarity (Appendix G) reflects the multivariate portrayal of stream heterogeneity revealed by PCA. Of six exposure periods, two were distinguished by higher than average discharge in the UPS reach (Figure 7). Diatom assemblages in the UPS and DNS reaches converged during these periods of relatively higher discharge, but were distinct during periods of low flow.

Figure 3. Mean taxonomic richness of diatom communities collected on artificial substrates at 10 main stem sites in the Sangamon River during 2002.

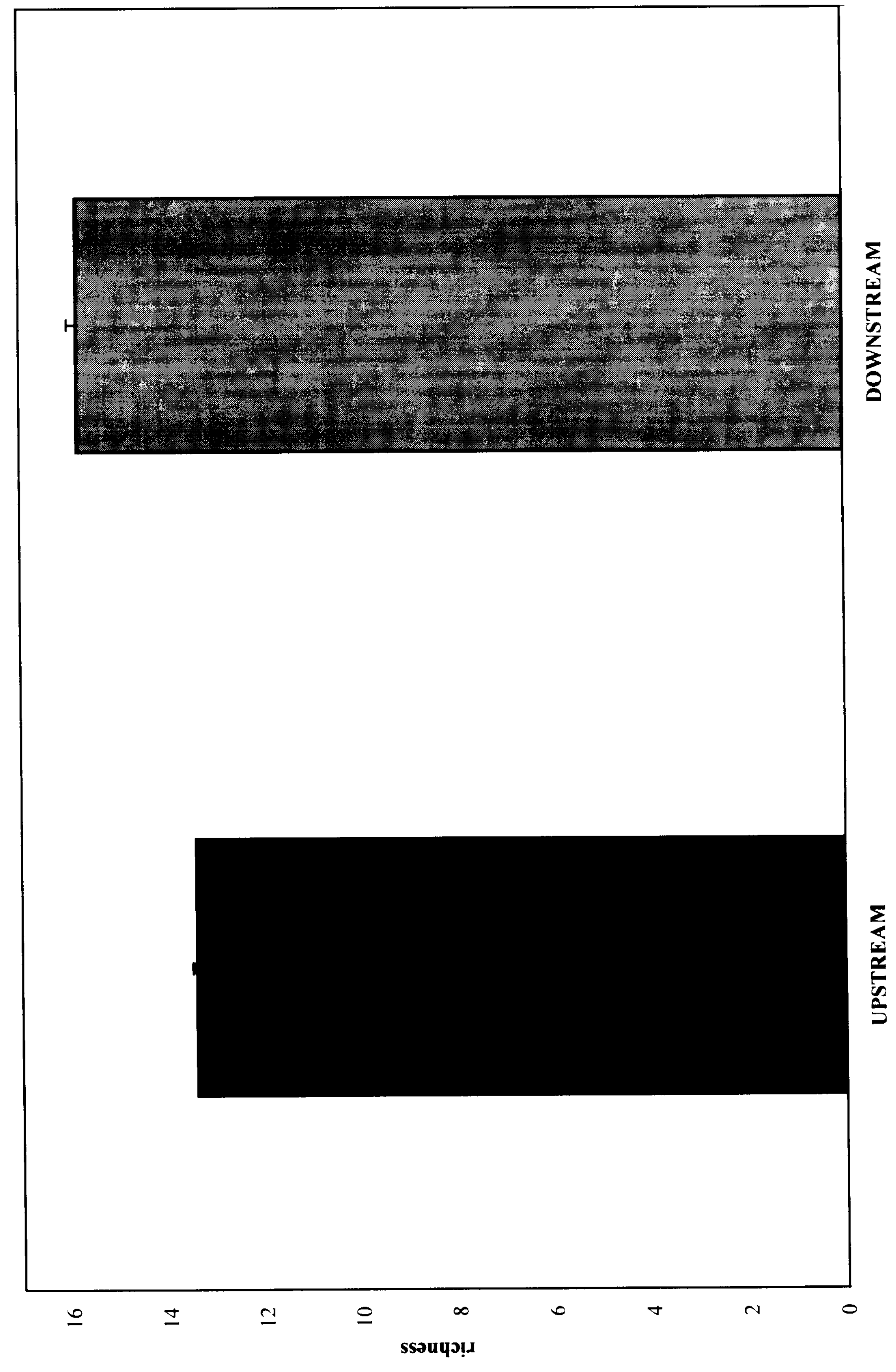

richness
0
2
4
6
8
10
12
14
16
UPSTREAM
DOWNSTREAM

Figure 4. Mean diversity (Shannon-Wiener Index) of diatom communities collected on artificial substrates at 10 main stem sites in the Sangamon River during 2002.

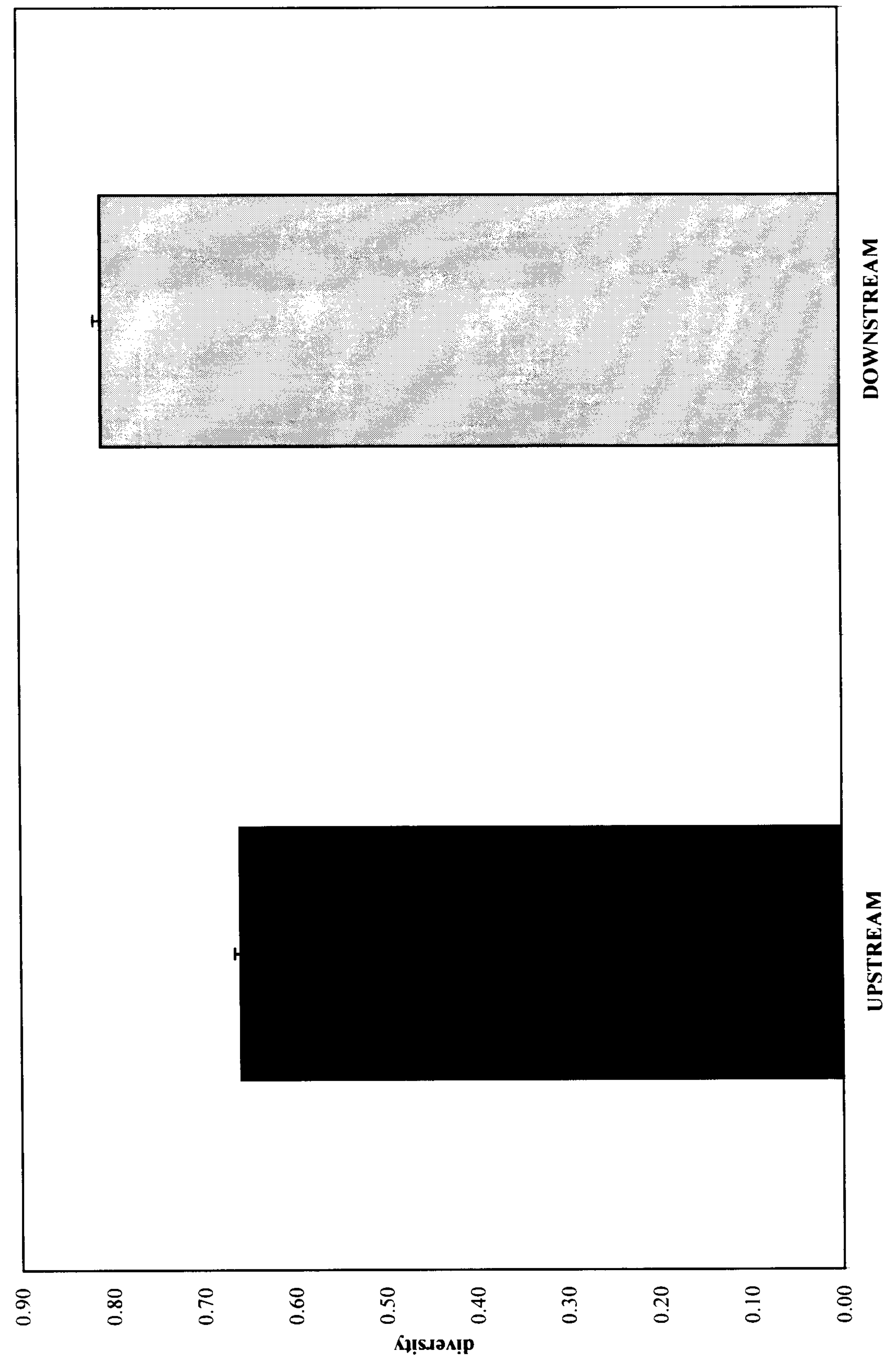

diversity
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
UPSTREAM
DOWNSTREAM

Figure 5. Mean evenness of diatom communities collected on artificial substrates at 10 main stem sites in the Sangamon River during 2002.

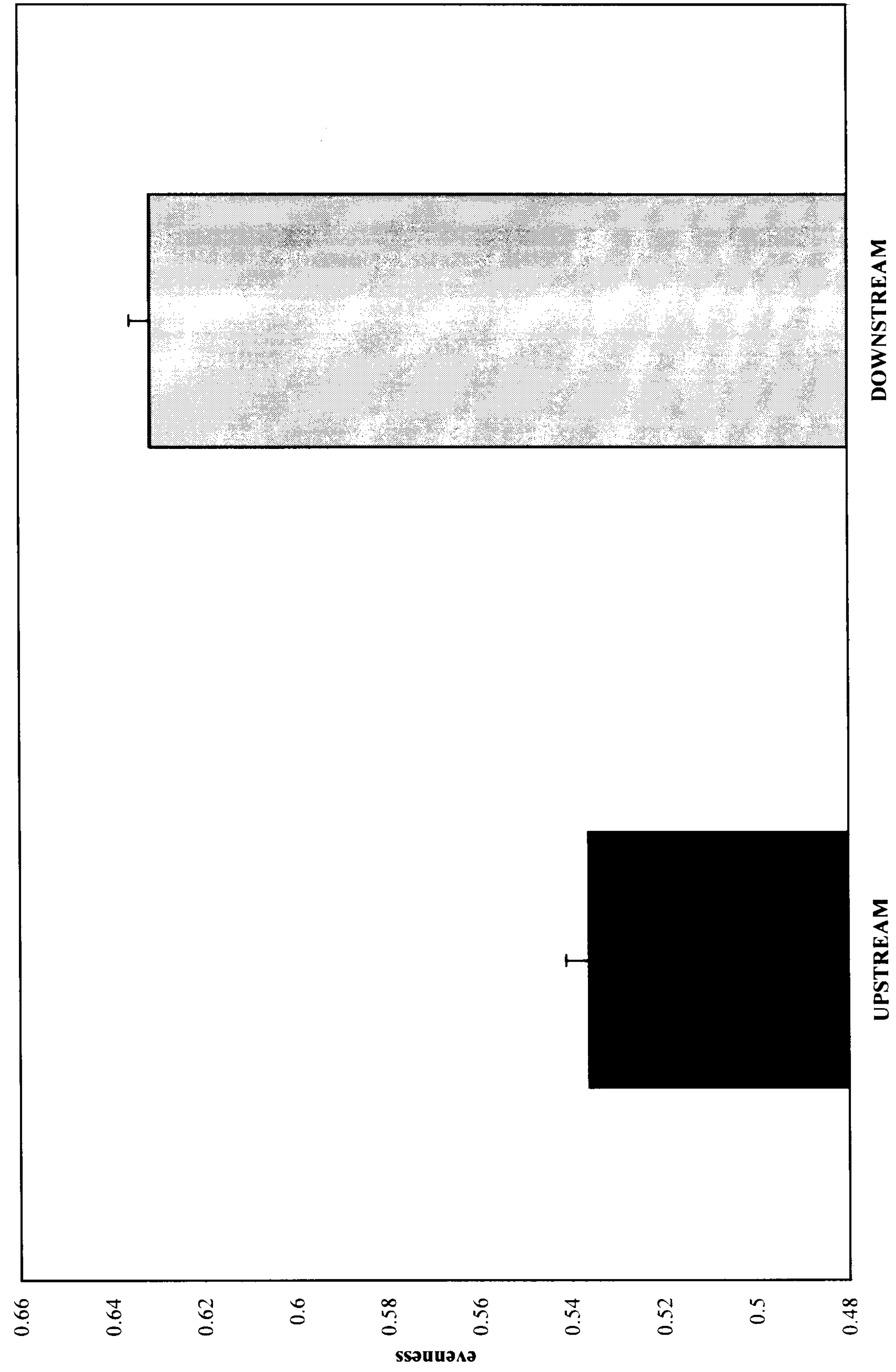

evenness
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
UPSTREAM
DOWNSTREAM

Figure 6. Ordination of diatom communities from 10 main stem sites in the Sangamon River during 2002. Ordination space is based on two axes created by nonmetric multidimensional scaling.

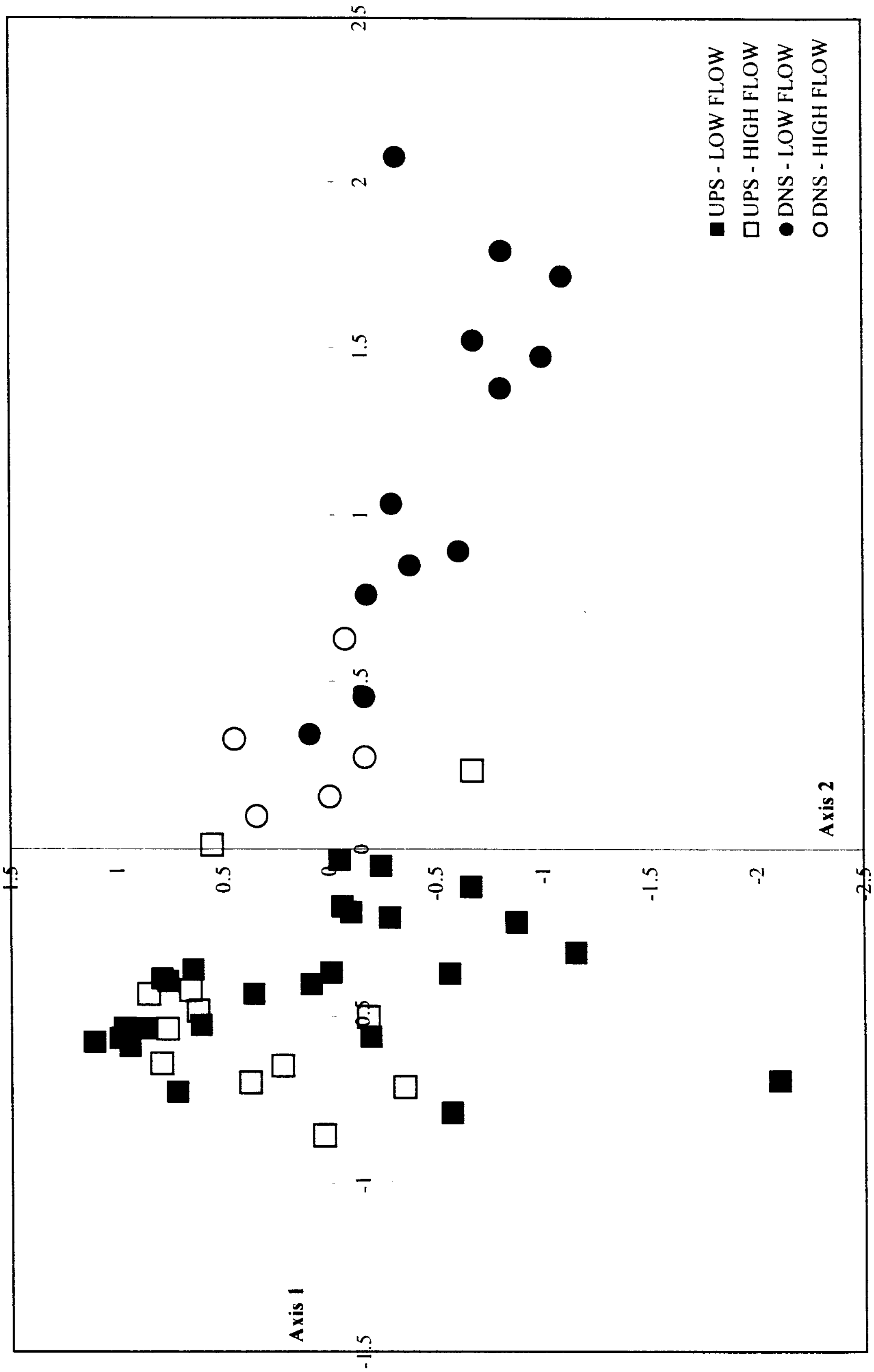
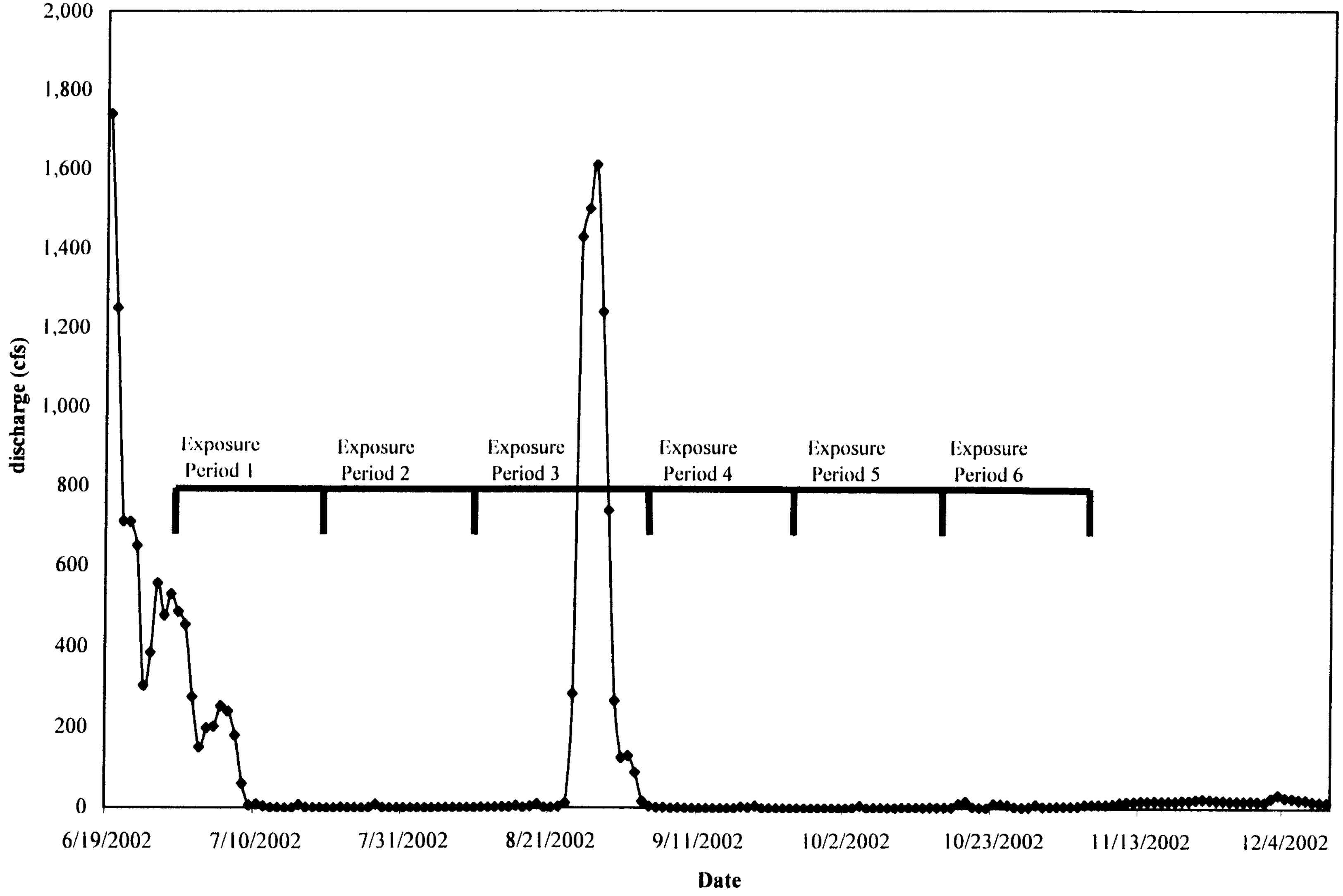

■ UPS - LOW FLOW
□ UPS - HIGH FLOW
● DNS - LOW FLOW
○ DNS - HIGH FLOW
Axis 1
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Axis 2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5

Figure 7. Hydrograph of measured discharge in the Sangamon River at the Route 48 bridge during diatom substrate exposure periods in 2002.



2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
discharge (cfs)
Exposure Period 1
Exposure Period 2
Exposure Period 3
Exposure Period 4
Exposure Period 5
Exposure Period 6
6/19/2002
7/10/2002
7/31/2002
8/21/2002
9/11/2002
10/2/2002
10/23/2002
11/13/2002
12/4/2002
Date

DISCUSSION

Physical and chemical heterogeneity

Overall, the Sangamon River extending from the dam which impounds Lake Decatur to the Wyckles Road Bridge has been considered a fair quality aquatic system with minimal habitat variety (Fischer and Pederson 2003). In contrast, my comprehensive analysis of physical and chemical variables establishes the distinct nature of the UPS and DNS portions. Additionally, UPS flow varies greatly due to unpredictable reservoir discharges (Figure 7), whereas the DNS reach receives continuous flow from the SDD. The Sangamon River experienced marked hydrologic variability during 2002 due to discharge from the dam that impounds Lake Decatur. Extreme flow events were punctuated by periods of low discharge which often approached zero cubic feet per second. The impact of drastically reduced discharge from Lake Decatur eliminates flow in the UPS reach for almost three months during an average year (IDNR 1999b). Such alterations have lead to simplification of stream habitat with concomitant reduction in species diversity and biotic integrity and an overall decline in quality of the aquatic resources. Poff and Ward (1989) suggest that species richness and trophic complexity are highest in streams which have predictable instream flow, and lowest in those wherein discharge is intermittent. Delucchi (1988) concluded that one mechanism might be elimination of poorly colonizing species from communities that develop in unpredictable stream environments.

Interpretation of PCA factor analysis provides insight into functioning of the UPS and DNS reaches. Sites DNS of SDD are characterized by lower pH, perhaps resulting from addition of CO_2 due to respiratory breakdown of organic matter in the wastewater treatment process. These sites may also have greater potential for instream primary productivity as a result of nutrient loading as indexed by higher levels of dissolved solids, conductivity, total alkalinity, oxidized nitrogen, and phosphorus. Elevated concentrations of suspended solids and chlorophyll *a* at UPS sites indicate that suspended organic material including phytoplankton algae derived from the reservoir may be supporting heterotrophs in the UPS reach. In contrast, DNS sites are maintained by autochthonous primary productivity that is supported by relatively higher concentrations of plant nutrients derived from the sanitary discharge. Therefore, the SDD discharge may be facilitating a shift from a stream system that relies on allochthonous input of algae to one that relies on autochthonous instream primary productivity (Lewis 1986).

Biocriteria for stream habitat quality

Qualitative evaluation of the two stream reaches requires assessment of stream biota to determine whether or not differences in the two stream reaches are reflected at higher trophic levels. Such an evaluation of overall stream habitat quality can be made via biotic indices involving macroinvertebrates and fish, taxa which have become widely used for biotic assessments. Fischer and Pederson (2003) found that DNS sites were characterized by significantly lower MBI scores, indicative of improved habitat quality capable of supporting diverse biota and a variety of different trophic levels. In contrast, their data on general diversity indices (species richness, evenness) and IBI scores indicate that fish may be insensitive to the environmental gradient that I studied.

Although both groups are sensitive to stream perturbation, benthic macroinvertebrates may be better biomonitors than fish because they are associated with substrates and therefore are less likely to move from an area of poor quality to one of better quality. Benthic algae may be even better indicators of stream habitat quality.

There are several advantages of using benthic algae as biomonitors (Patrick 1973, Stoneburner *et al.* 1976, Marcus 1980, Barbour *et al.* 1999, Growns 1999). First of all, they are ubiquitous in aquatic systems with species occurring in both the northern and southern hemispheres. Diatoms are easily sampled, and since they are compact, they are easy to store. The number of species that occur at a specific site greatly exceeds the number of species of fish and macroinvertebrates in the entire urban reach, thereby providing potentially greater information content in a given sample. As with macroinvertebrates and fish, algal species vary in their sensitivity to perturbations, and their response occurs even though the disturbance is not always detected via routine physical and chemical assessment. Benthic diatoms are attached to substrates and as such, they remain in a fixed location, integrating all environmental factors which impact them. Additionally, they respond quickly to any environmental change because of their short life cycles and reflect changes in aquatic systems through changes in diversity. Finally, benthic algal communities have global relevance due to long term use for water quality monitoring in other countries.

Response of diatoms to physiochemical heterogeneity in the Sangamon River

Because the reach scale is important to stream monitoring, identifying which characteristics of diatom communities differ over this scale can improve use of these biota in monitoring stream conditions (Kutka and Richards 1996). The existence of a physical and chemical discontinuity has been established when comparing UPS and DNS reaches and most likely, the range of tolerance of species determines diatom community structure in these discreet reaches. Overall environmental heterogeneity is reflected by separation of the UPS and DNS reaches in the ordination space created by NMDS of diatom communities. During periods of low discharge, diatom communities were quite distinct, whereas periods of high flow precipitated convergent diatom community structure. The remarkable concurrence of multivariate portrayals of diatom communities and the physiochemical nature of two reaches of the Sangamon River confirms the utility of benthic algae as indicators of biotic integrity in this urban reach of the Sangamon River. Nonetheless, evaluation of species autecologies coupled with additional refinement of diatom community data is necessary before quantitative relationships to stream water quality become apparent.

Species diversity has been recognized as an indicator of good water quality and a healthy ecosystem (Theinemann 1939). Generally, diversity is expected to decrease following any alteration of an ecosystem, and therefore, serves as a good biological indicator for most perturbations (Cole 1973, Odum 1985, Rapport *et al.* 1985). Patrick and Strawbridge (1963) suggested a positive relationship between environmental quality, species diversity, and evenness. Species diversity, as calculated by the Shannon-Wiener formula, is considered one of the best indicators of altered environments (Wilhm and Dorris 1968, Hooper 1969). Conditions resulting from discharge by the Sanitary District of Decatur appear to create a more favorable habitat for diatoms as indicated by higher scores for taxonomic richness, diversity, and evenness in the DNS reach when compared to the UPS reach. However, factors affecting benthic algal diversity are complex. Various explanations may be offered for increased diversity of DNS diatom assemblages. Foremost, qualitative shifts in dominance and appearance of rare species may indicate tolerance or sensitivity to ambient conditions in the two stream reaches.

The autecologies of resident diatom species in both stream reaches are probably determined by their ranges of tolerance for certain abiotic variables in the stream. Cosmopolitan species such as, *Cyclotella meneghiniana* and *Nitzschia palea* are uninformative because they are very tolerant and able to withstand the wide variety of environmental conditions in both the UPS and DNS reaches. Based on Palmer's (1969) genus and species pollution indices, *Cyclotella meneghiniana* and *Nitzschia palea* both are common in waters with high organic content.

Overall, UPS assemblages are characterized by dominant species that are halophobic and alkaliphilous, including *Amphora ovalis* v. *pediculus*, *Achnanthes linearis*, and *Gomphonema parvulum*. Common occurrence of these species directly reflects the higher pH and lower dissolved solids concentrations in the UPS reach. *Amphora ovalis* v. *pediculus* most often is epiphytic on filamentous algae or larger diatoms in oxygen rich, standing or slowly flowing water of low conductivity (Patrick and Reimer 1966, 1975). *Achnanthes linearis* appears to prefer streams with relatively lower dissolved solids concentrations (i.e., low conductivity) and is indifferent to pH (Patrick and Reimer 1966, 1975). Johansen and Rushforth (1981) commonly encountered *A. linearis* in Evacuation Creek, Utah which alternated between a series of stagnant pools and a flowing stream on a seasonal basis, conditions similar to those which I observed in the UPS reach. *Gomphonema parvulum* prefers waters with higher content of organic materials (Patrick and Reimer 1966, 1975), which may derive from nutrient rich sediments in the UPS reach. *Cymbella tumida*, a rarely observed species restricted to the UPS reach, is reported as intolerant of high conductivity waters (Lowe 1974), which can account for its disappearance from DNS assemblages. Other rare taxa, including *Gomphonema brasiliense*, *Cyclotella stelligera*, and *Cocconeis placentula*, have similar autecologies (Patrick and Reimer 1966, 1975), which may explain their occurrence in the UPS, but absence from the DNS reach.

Discharge from SDD appears to produce a halocline within the Sangamon River, such that the DNS reach often can be defined as a brackish water system - i.e., one with total dissolved solids ranging from 500 - 3500 mg L^{-1} (Wetzel 2001). Dominance of DNS assemblages by species such as *Navicula protracta*, *Achnanthes exigua*, *Nitzschia valdestriata*, and *Navicula menisculus* can be elucidated by the slightly brackish water characteristic of the reach. Although I found little information on most of these species, Patrick and Reimer (1966, 1975) noted that *Navicula protracta* prefers slightly brackish water with high mineral content. Subordinate taxa typical of DNS assemblages were *Aulacoseira italica*, *Pleurosira laevis*, *Nitzschia dissipata*, and *Caloneis hultenii*. Of these, I found information only on *P. laevis*, which is common in naturally and anthropogenically salinized waters in North America (Czarnecki and Blinn 1978, Kociolek *et al.* 1983).

Effects of flow resulting from reservoir discharge

Flow fluctuations and extreme conditions such as low or zero flow and floods are main sources of environmental disturbance (Stanford and Ward 1983). Disturbance frequency, in the form of currents in rivers and streams, possibly has the strongest impact on benthic algal community structure. Benthic algal standing crop and structure of algal assemblages respond to changes in current velocity as documented in laboratory streams (McIntire 1966, 1968) and in field experiments (Jones 1951, Gumtow 1955, Whitford 1956, Blum 1960, Reisen and Spencer 1970, Keithan and Lowe 1985). Development of epilithic diatom communities in lotic systems is influenced by the severity of the ambient current (Peterson 1986). Significant changes in discharge affect patterns of diatom accumulation and change the composition of epilithic diatom communities in diverse current environments (Peterson 1986). This is due to the fact that water motions strongly affect the balance between biomass accumulation and loss, along with controlling nutrient supply (Graham and Wilcox 2000).

The effects of river regulation on biota vary between weirs and dams according to the structural features of the impoundment, how it is operated, and the purpose of the dam (Armitage 1984, Finlayson *et al.* 1994). Constant discharge associated with various types of river regulation, favors growth of benthic algae (Lowe 1979). Streams with constant seasonal flow have uniform currents, which may improve riparian and aquatic vegetation through bed stability. However, some impoundments and reservoirs, operated for irrigation or power generation, can cause vast fluctuations in flow that could have disastrous effects on phytobenthos (Growns and Growns 2001). Ward and Stanford (1979) suggested that rivers with reduced flow would have decreased local current velocities, increased siltation of the stream bed, and decreased overall stream habitat. Increased flow in some regulated rivers may lead to higher current velocities, which can scour the bed, resulting in a change to a coarse substratum. Diatoms likely respond to changes in water flow since they are sensitive to variations in water velocity (Stevenson 1984, Reiter and Carlson 1986).

Diatom assemblages may be influenced by the differences between UPS and DNS reaches with respect to instream flow volume in the Sangamon River. The primary input to the UPS reach is controlled by the dam that impounds Lake Decatur. From 19 June through 10 December 2002, mean daily discharge in the UPS reach was less than 20 cfs on 131 of 175 days, often approaching zero. In contrast, discharge from SDD (ca. 45 cfs) provides a continuous and stable flow that results in a more predictable environment that is able to sustain biotic function in the DNS reach as confirmed by work conducted in other riverine systems (Sanders 1969, Fisher 1983, Peckarsky 1983, Ward and Stanford 1983, Reice 1985, Ross *et al.* 1985, Walde 1986, Resh *et al.* 1988). During periods of high flow such as were observed during exposure periods 1 and 3, successful attachment of diatom immigrants in both the UPS and DNS reaches may have been hindered by stress (McIntire 1966, Stevenson 1983, Silvester and Sleigh 1985), thereby precipitating an overall similarity in community structure.

Summary

The physical and chemical environment as well as biotic processes in the UPS reach likely are driven by extreme variability in flow. Overlap between the UPS and DNS reaches occur during times of high discharge from the reservoir as seen in the PCA and NMDS ordination space. At these times, the river becomes one homogeneous unit in which the two spatially discrete reaches are no longer distinguishable. Drastic reduction of instream flow resulting from elimination of reservoir discharge also is detrimental to habitat quality in the UPS reach. My results suggest that a threshold of 400 cfs exists relative to flow. When flow is below 400 cfs, the UPS and DNS reaches are distinct while they are indistinguishable when discharge surpasses the 400 cfs threshold. This suggests that water quality is compromised in the reach extending from the Lake Decatur dam to the main treatment plant of the SDD as a result of management to maintain reservoir levels by eliminating outflow.

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APPENDICES

Appendix A. Measured water quality variables at 10 main stem sites in the Sangamon River during 2002.

Date	Site	$D\text{-}O_2$ (ppm)	Temp. °C	pH	Conductivity µS m^{-1}	Hardness mg $CaCO_3$ L^{-1}	T alk mg $CaCO_3$ L^{-1}	NO_2/NO_3 (ppm)	NH_3 (ppm)	TP (ppm)	SRP (ppm)	Chl *a* (ppb)	FSS (ppm)	VSS (ppm)	FDS (ppm)	VDS (ppm)
6/19/2002	1	8.7	23.1	8.2	506	263.7	199.4	0.36	0.13	0.21	0.10	2.98	18.25	6.00	204.42	112.67
6/27/2002	1	7.8	26.5	8.4	491	243.1	192.5	0.37	0.00	0.09	0.00	3.57	13.43	9.14	197.24	134.86
7/18/2002	1	6.4	26.4	8.2	484	232.1	192.5	0.21	0.34	0.14	0.00	5.71	15.13	13.03	179.54	93.64
8/8/2002	1	7.1	25.0	8.3	526	259.9	233.8	0.01	0.10	0.18	0.00	3.92	17.00	16.67	181.67	86.00
8/27/2002	1	5.8	26.6	8.4	483	247.2	178.8	0.06	0.00	0.20	0.07	4.25	22.40	11.60	197.60	87.07
9/3/2002	1	4.8	25.9	8.3	463	220.4	165.0	0.02	0.00	0.20	0.08	2.82	16.37	8.63	183.63	63.37
9/24/2002	1	5.6	17.2	8.3	498	249.3	199.4	5.02	0.31	0.12	0.02	2.11	15.50	5.25	172.50	101.42
10/15/2002	1	3.9	12.5	9.1	462	221.8	146.6	0.42	5.73	0.07	0.00	1.14	1.67	8.67	182.33	100.67
11/5/2002	1	5.4	7.9	9.0	530	264.1	210.3	1.54	5.82	0.12	0.00	0.94	2.00	10.22	220.67	145.78
12/10/2002	1															
6/19/2002	2	8.0	23.1	8.2	506	265.7	220.0	0.49	0.05	0.20	0.09	2.86	24.86	8.00	207.14	110.67
6/27/2002	2	7.3	26.6	8.4	491	241.0	192.5	0.46	0.00	0.10	0.00	4.09	13.14	8.86	201.52	135.14
7/18/2002	2	5.5	26.6	8.1	505	263.9	247.5	0.26	0.00	0.14	0.00	6.23	24.80	12.00	184.53	102.67
8/8/2002	2	3.1	23.6	7.7	597	269.8	199.4	0.06	0.57	0.21	0.00	4.07	25.59	15.29	233.08	96.71
8/27/2002	2	5.8	26.6	8.4	481	241.0	151.3	0.06	0.08	0.22	0.06	4.13	27.33	10.00	188.67	111.33
9/3/2002	2	4.3	25.9	8.3	482	226.6	144.4	0.04	0.00	0.21	0.08	3.08	15.45	8.43	193.88	88.91
9/24/2002	2	4.4	17.2	8.2	575	259.6	192.5	1.42	0.02	0.12	0.02	2.10	9.00	4.20	244.33	85.13
10/15/2002	2	1.7	12.3	8.9	511	241.9	178.5	0.53	4.59	0.16	0.00	2.10	18.00	10.00	210.00	111.33
11/5/2002	2	5.0	10.3	8.6	651	304.4	255.0	2.23	1.63	0.16	0.01	0.52	10.67	4.89	334.67	101.78
12/10/2002	2															

Appendix A. continued

		D-O$_2$	Temp.	pH	Conductivity	Hardness	T alk	NO$_2$/NO$_3$	NH$_3$	TP	SRP	Chl *a*	FSS	VSS	FDS	VDS
Date	Site	(ppm)	°C		µS m^{-1}	mg CaCO$_3$ L^{-1}	mg CaCO$_3$ L^{-1}	(ppm)	(ppm)	(ppm)	(ppm)	(ppb)	(ppm)	(ppm)	(ppm)	(ppm)
6/19/2002	3	9.0	23.1	8.2	511	263.7	206.3	0.48	0.05	0.21	0.09	2.93	29.14	8.29	214.86	105.05
6/27/2002	3	7.6	26.3	8.3	513	253.4	206.3	0.48	0.00	0.10	0.00	3.94	13.43	8.86	199.90	136.48
7/18/2002	3	5.6	26.9	8.1	536	287.7	302.5	0.22	0.00	0.14	0.00	6.39	17.05	10.61	221.62	122.73
8/8/2002	3	5.6	24.8	7.7	650	265.9	220.0	0.04	0.22	0.15	0.01	3.12	8.05	7.07	233.28	100.93
8/27/2002	3	4.7	26.6	8.4	482	236.9	247.5	0.07	0.00	0.21	0.07	4.13	30.77	9.23	187.90	112.10
9/3/2002	3	4.2	25.9	8.4	470	218.4	199.4	0.03	0.00	0.20	0.08	2.95	19.00	6.25	177.00	99.08
9/24/2002	3	3.4	17.3	8.1	507	239.0	206.3	0.66	0.19	0.13	0.04	2.19	7.33	3.78	218.00	106.89
10/15/2002	3	4.3	12.3	8.6	588	268.1	184.8	0.44	3.59	0.11	0.01	2.08	7.45	4.18	236.55	118.48
11/5/2002	3	6.0	7.8	8.7	679	290.3	197.6	0.94	2.68	0.15	0.02	0.80	8.22	3.78	294.44	98.89
12/10/2002	3	9.1	3.2	8.6	650	308.4	248.6	0.84	0.40	0.04	0.00	0.72	1.00	2.50	319.00	78.83
6/19/2002	4	9.1	23.1	8.2	511	267.8	199.4	0.47	0.04	0.22	0.10	2.94	26.86	9.43	210.48	118.57
6/27/2002	4	8.1	26.7	8.4	503	247.2	199.4	0.46	0.00	0.10	0.00	4.23	13.14	10.29	201.52	131.05
7/18/2002	4	4.9	26.7	8.0	540	341.2	302.5	0.23	0.00	0.15	0.00	6.30	19.64	11.43	217.69	120.57
8/8/2002	4	5.4	25.4	7.9	604	271.8	206.3	0.03	0.34	0.14	0.03	2.52	7.50	6.14	235.17	115.20
8/27/2002	4	5.8	26.6	8.4	483	247.2	144.4	0.07	0.00	0.23	0.07	4.14	32.40	12.00	184.93	122.67
9/3/2002	4	4.7	26.0	8.4	472	224.5	199.4	0.02	0.00	0.20	0.08	2.90	16.86	7.14	184.48	95.52
9/24/2002	4	3.4	17.4	8.1	514	239.0	206.3	0.67	0.35	0.14	0.04	1.70	11.45	4.18	219.21	77.15
10/15/2002	4	4.6	11.7	8.5	592	272.2	191.2	0.42	3.74	0.10	0.01	1.72	7.67	4.33	231.00	110.33
11/5/2002	4	5.3	7.4	8.5	553	282.2	235.8	0.68	2.42	0.12	0.01	0.80	5.82	2.55	274.18	100.12
12/10/2002	4															

Appendix A. continued

		D-O_2	Temp.	pH	Conductivity	Hardness	T alk	NO_2/NO_3	NH_3	TP	SRP	Chl *a*	FSS	VSS	FDS	VDS
Date	Site	(ppm)	°C		µS m^{-1}	mg $CaCO_3$ L^{-1}	mg $CaCO_3$ L^{-1}	(ppm)	(ppm)	(ppm)	(ppm)	(ppb)	(ppm)	(ppm)	(ppm)	(ppm)
6/19/2002	5	9.4	23.2	8.2	507	261.6	199.4	0.46	0.01	0.21	0.10	2.84	28.86	8.86	212.48	105.81
6/27/2002	5	8.2	26.7	8.3	496	247.2	192.5	0.49	0.00	0.10	0.00	4.61	16.86	9.71	189.81	138.29
7/18/2002	5	6.6	26.5	8.1	544	257.9	220.0	0.23	0.00	0.12	0.00	6.96	18.80	11.20	237.20	116.80
8/8/2002	5	4.3	25.7	7.9	652	289.7	137.5	0.03	0.46	0.16	0.00	3.30	13.66	11.49	273.00	92.51
8/27/2002	5	4.6	26.5	8.4	483	241.0	103.1	0.06	0.02	0.21	0.06	4.12	35.38	12.31	191.28	139.69
9/3/2002	5	7.0	26.5	8.5	453	212.2	178.8	0.03	0.00	0.16	0.00	4.22	15.14	10.86	180.86	95.81
9/24/2002	5	2.4	17.0	8.1	487	197.8	185.6	1.10	1.04	0.23	0.11	2.61	40.00	5.76	204.00	62.24
10/15/2002	5	6.3	11.9	8.4	575	264.1	197.6	0.46	2.39	0.25	0.00	6.18	67.14	16.07	256.86	82.60
11/5/2002	5	4.2	7.3	8.4	555	258.0	229.5	0.94	0.01	0.11	0.03	0.82	6.00	2.91	272.67	82.42
12/10/2002	5	9.2	2.8	8.4	651	304.4	280.4	0.91	0.00	0.04	0.00	1.89	2.20	4.00	312.47	77.33
6/19/2002	6	8.4	23.3	8.2	508	255.4	206.3	0.46	0.00	0.20	0.10	3.00	28.57	8.57	216.76	107.43
6/27/2002	6	6.6	26.7	8.4	498	241.0	199.4	0.49	0.00	0.10	0.00	4.51	16.86	9.71	193.81	135.62
7/18/2002	6	6.5	26.5	8.1	546	265.9	206.3	0.26	0.00	0.11	0.00	7.06	14.78	9.62	225.22	127.71
8/8/2002	6	2.0	24.2	7.7	669	293.6	199.4	0.03	1.18	0.15	0.00	2.33	7.84	6.47	253.49	125.53
8/27/2002	6	5.1	26.6	8.4	483	243.1	199.4	0.05	0.01	0.23	0.06	4.40	35.38	13.08	175.28	125.59
9/3/2002	6	6.8	26.7	8.5	448	212.2	165.0	0.04	0.00	0.14	0.00	4.78	16.29	12.86	174.38	93.81
9/24/2002	6	4.1	17.0	8.1	502	210.1	171.9	1.00	0.88	0.20	0.11	2.18	13.64	5.82	223.70	84.85
10/15/2002	6	6.9	11.4	8.2	588	264.1	165.7	0.46	1.12	0.09	0.00	5.45	6.23	4.91	247.11	105.76
11/5/2002	6	4.8	7.3	8.2	568	270.1	229.5	1.03	0.00	0.11	0.02	0.94	4.83	2.83	260.50	87.83
12/10/2002	6	9.7	2.8	8.3	653	300.4	274.1	0.99	0.00	0.04	0.00	1.92	2.80	3.60	315.87	80.40

Appendix A. continued

Date	Site	D-O_2 (ppm)	Temp. °C	pH	Conductivity µS m^{-1}	Hardness mg $CaCO_3$ L^{-1}	T alk mg $CaCO_3$ L^{-1}	NO_2/NO_3 (ppm)	NH_3 (ppm)	TP (ppm)	SRP (ppm)	Chl *a* (ppb)	FSS (ppm)	VSS (ppm)	FDS (ppm)	VDS (ppm)
6/19/2002	7	8.8	23.4	8.2	505	263.7	192.5	0.49	0.02	0.20	0.10	2.95	30.00	8.86	206.00	113.81
6/27/2002	7	8.4	26.7	8.4	496	243.1	192.5	0.50	0.00	0.10	0.00	4.68	21.14	9.71	190.86	142.29
7/18/2002	7	5.8	26.9	8.1	551	390.8	316.3	0.24	0.00	0.12	0.00	4.75	14.56	9.39	228.10	127.95
8/8/2002	7	6.7	25.8	7.8	670	299.6	247.5	0.01	1.50	0.16	0.03	2.75	9.35	6.96	266.65	101.04
8/27/2002	7	5.0	26.5	8.4	481	243.1	165.0	0.06	0.01	0.24	0.06	4.26	37.69	11.92	179.64	146.74
9/3/2002	7	5.4	26.5	8.4	467	228.7	185.6	0.02	0.00	0.17	0.04	3.54	19.72	7.50	177.61	119.17
9/24/2002	7	2.9	18.3	8.0	516	222.5	178.8	0.85	0.76	0.20	0.10	1.75	8.75	2.14	220.58	89.86
10/15/2002	7	4.0	11.2	8.1	604	274.2	153.0	0.44	0.90	0.12	0.02	3.06	6.00	4.55	258.00	88.79
11/5/2002	7	5.9	21.7	8.1	4009	237.9	369.7	9.29	0.00	2.05	2.15	1.85	17.20	7.00	2250.80	129.00
12/10/2002	7	10.6	2.5	8.4	618	288.3	248.6	1.14	0.00	0.03	0.00	1.64	1.60	2.80	298.40	79.87
6/27/2002	8	7.9	26.9	8.3	527	249.3	206.3	0.42	0.00	0.15	0.00	4.61	16.86	9.71	215.14	135.62
7/18/2002	8	5.8	29.4	7.9	3386	250.0	151.3	0.23	0.00	3.88	3.27	3.35	6.61	5.95	1841.39	132.72
8/8/2002	8	5.9	29.8	7.9	3775	261.9	378.1	0.15	0.00	2.56	2.70	1.21	5.00	4.50	2023.00	124.83
8/27/2002	8	5.0	26.6	8.4	483	239.0	158.1	0.05	0.00	0.23	0.07	4.40	37.69	10.00	188.97	146.00
9/3/2002	8	5.2	27.7	8.3	1577	232.8	240.6	0.21	0.00	1.65	1.79	3.05	14.63	7.07	856.03	98.26
9/24/2002	8	4.6	26.6	7.8	3853	247.2	192.5	17.99	0.00	2.70	3.24	1.43	3.83	7.17	2104.17	123.50
10/15/2002	8	5.5	24.5	7.9	3936	233.9	172.1	5.08	0.91	2.19	2.12	1.16	1.54	5.54	2159.79	126.46
11/5/2002	8	6.5	22.4	8.1	4060	235.9	376.1	10.24	0.00	2.19	2.22	1.68	3.69	5.38	2268.31	126.62
12/10/2002	8	6.6	17.8	7.8	3809	260.1	369.7	10.22	0.00	1.98	2.15	1.72	3.75	8.50	2166.92	123.50

Appendix A. continued

Date	Site	D-O_2 (ppm)	Temp. °C	pH	Conductivity µS m^{-1}	Hardness mg $CaCO_3$ L^{-1}	T alk mg $CaCO_3$ L^{-1}	NO_2/NO_3 (ppm)	NH_3 (ppm)	TP (ppm)	SRP (ppm)	Chl *a* (ppb)	FSS (ppm)	VSS (ppm)	FDS (ppm)	VDS (ppm)
6/19/2002	9	8.0	23.4	8.1	580	263.7	254.4	0.44	0.05	0.33	0.21	2.85	28.57	9.43	266.10	110.57
6/27/2002	9	6.9	27.3	8.3	860	253.4	233.8	0.44	0.00	0.69	0.52	4.61	18.86	10.29	395.81	121.71
7/18/2002	9	6.3	29.7	7.9	3378	259.9	220.0	0.24	0.00	3.98	3.14	2.84	9.30	5.44	1832.04	135.89
8/8/2002	9	6.0	27.1	8.1	1753	269.8	364.4	0.20	0.11	2.36	2.70	1.10	3.97	4.44	1929.37	130.22
8/27/2002	9	4.9	26.7	8.4	577	234.8	123.8	0.07	0.00	0.46	0.26	4.39	38.46	14.23	241.54	116.44
9/3/2002	9	4.8	28.5	8.2	1938	236.9	247.5	0.29	0.00	1.72	1.92	2.81	13.72	7.67	991.61	100.33
9/24/2002	9	5.0	25.9	8.0	3749	251.3	220.0	17.43	0.00	2.63	3.24	1.43	5.85	5.23	2015.49	146.77
10/15/2002	9	6.8	23.8	8.1	3904	235.9	261.3	6.06	1.80	2.19	2.12	1.17	2.00	4.77	2124.67	129.90
11/5/2002	9	7.2	21.0	8.2	3908	243.9	388.8	10.58	0.00	2.15	2.22	1.69	6.00	4.00	2171.33	118.67
12/10/2002	9	6.8	16.2	8.1	3466	260.1	369.7	11.03	0.00	1.88	2.12	1.71	6.04	9.34	2095.29	130.66
6/19/2002	10	7.9	23.5	8.1	603	265.7	213.1	0.48	0.06	0.34	0.23	2.86	41.43	8.86	267.90	112.48
6/27/2002	10	7.3	26.8	8.2	830	261.6	226.9	0.46	0.00	0.61	0.44	4.25	25.14	10.57	382.86	134.76
7/18/2002	10	5.7	27.4	7.9	3072	297.6	302.5	0.23	0.00	3.27	3.00	2.81	15.50	5.00	1677.83	135.00
8/8/2002	10	5.4	21.3	7.9	706	265.9	364.4	0.14	0.31	2.60	2.97	1.22	14.86	4.80	1957.14	128.53
8/27/2002	10	1.9	22.6	8.3	623	239.0	185.6	0.07	0.26	0.44	0.26	3.30	45.93	13.70	250.07	126.30
9/3/2002	10	4.0	26.9	8.3	1736	232.8	240.6	0.19	0.00	1.58	1.79	2.73	22.86	8.00	887.81	90.67
9/24/2002	10	3.6	20.7	7.8	3448	255.4	233.8	17.35	0.00	2.67	3.21	1.72	14.17	5.50	1992.50	137.17
10/15/2002	10	4.9	19.1	8.2	3800	248.0	216.7	5.59	0.41	2.15	2.15	1.40	12.77	4.92	2089.90	125.74
11/5/2002	10	3.5	16.1	8.5	3510	252.0	376.1	7.05	0.00	1.88	2.02	1.54	12.67	3.83	1967.33	125.50
12/10/2002	10	5.5	11.3	8.8	3772	278.2	363.3	8.74	0.00	2.02	2.25	1.61	5.50	3.67	2151.83	120.33

Appendix B. PCA factor scores for 10 main stem sites in the Sangamon River during 2002.

Date	Site	PCA 1	PCA 2	PCA 3	PCA 4
6/19/2002	1	-0.395	-0.011	0.937	-0.034
6/27/2002	1	-0.511	0.481	0.202	0.779
7/18/2002	1	-0.842	0.817	-0.155	-0.397
8/8/2002	1	-0.802	0.607	0.421	0.078
8/27/2002	1	-0.828	0.478	-0.269	-0.488
9/3/2002	1	-0.692	-0.142	-0.821	-2.009
9/24/2002	1	-0.222	-0.700	-0.134	-0.604
10/15/2002	1	-0.749	-2.399	-2.939	2.084
11/5/2002	1	-0.434	-2.215	-1.719	3.984
6/19/2002	2	-0.450	0.181	0.804	0.032
6/27/2002	2	-0.524	0.541	0.092	0.716
7/18/2002	2	-0.737	1.057	0.507	-0.190
8/8/2002	2	-0.663	0.882	-0.180	-1.114
8/27/2002	2	-0.793	0.642	-0.552	-0.030
9/3/2002	2	-0.642	0.063	-0.934	-1.397
9/24/2002	2	-0.262	-0.939	0.061	-1.578
10/15/2002	2	-0.746	-1.604	-2.700	1.825
11/5/2002	2	-0.097	-1.909	0.394	0.723
6/19/2002	3	-0.540	0.262	0.903	0.021
6/27/2002	3	-0.457	0.544	0.480	0.737
7/18/2002	3	-0.472	0.961	1.229	0.530
8/8/2002	3	-0.213	0.096	0.790	-1.538
8/27/2002	3	-0.611	0.621	-0.446	-0.042
9/3/2002	3	-0.505	-0.023	-0.921	-1.060
9/24/2002	3	-0.165	-0.738	-0.394	-1.443
10/15/2002	3	-0.379	-1.791	-0.975	1.239
11/5/2002	3	-0.292	-2.278	-0.060	0.987
12/10/2002	3	-0.132	-2.419	1.934	0.113
6/19/2002	4	-0.523	0.411	0.931	0.479
6/27/2002	4	-0.574	0.624	0.376	0.894
7/18/2002	4	-0.468	0.916	1.974	0.688
8/8/2002	4	-0.184	-0.074	0.580	-0.897
8/27/2002	4	-0.857	0.953	-0.579	0.453
9/3/2002	4	-0.521	-0.037	-0.714	-0.988
9/24/2002	4	-0.268	-0.988	-0.461	-2.160
10/15/2002	4	-0.357	-1.905	-0.785	0.975
11/5/2002	4	-0.145	-2.259	0.093	0.394

Appendix B. continued

Date	Site	PCA 1	PCA 2	PCA 3	PCA 4
6/19/2002	5	-0.561	0.315	0.917	0.083
6/27/2002	5	-0.577	0.821	0.435	0.906
7/18/2002	5	-0.718	1.179	0.627	0.189
8/8/2002	5	-0.595	0.271	0.183	-1.138
8/27/2002	5	-0.906	1.160	-1.188	0.647
9/3/2002	5	-0.795	0.426	-0.567	-0.287
9/24/2002	5	-0.651	-0.440	-1.839	-2.495
10/15/2002	5	-1.401	0.646	-0.662	1.276
11/5/2002	5	-0.132	-1.843	0.085	-1.355
12/10/2002	5	-0.141	-1.965	2.286	-0.160
6/19/2002	6	-0.538	0.332	0.642	-0.058
6/27/2002	6	-0.582	0.715	-0.067	0.759
7/18/2002	6	-0.644	1.094	0.744	0.364
8/8/2002	6	-0.091	-0.190	0.060	-0.977
8/27/2002	6	-0.816	1.112	-0.613	0.641
9/3/2002	6	-0.927	0.657	-0.699	-0.209
9/24/2002	6	-0.390	-0.705	-1.112	-1.814
10/15/2002	6	-0.538	-0.664	0.548	-0.059
11/5/2002	6	-0.060	-1.713	0.573	-1.398
12/10/2002	6	-0.113	-1.875	2.377	-0.257
6/19/2002	7	-0.562	0.408	0.769	0.230
6/27/2002	7	-0.629	0.890	0.301	1.212
7/18/2002	7	-0.250	0.347	2.970	1.320
8/8/2002	7	-0.185	-0.268	1.283	-0.501
8/27/2002	7	-0.787	1.230	-0.813	1.030
9/3/2002	7	-0.561	0.345	-0.582	-0.188
9/24/2002	7	-0.164	-0.978	-0.944	-2.291
10/15/2002	7	-0.386	-1.175	0.036	-1.279
11/5/2002	7	1.973	0.463	-0.195	0.509
12/10/2002	7	-0.154	-2.009	2.219	-0.204
6/19/2002	8	-0.494	0.258	0.833	0.090
6/27/2002	8	-0.542	0.798	0.458	0.843
7/18/2002	8	1.636	1.154	-0.626	-0.489
8/8/2002	8	2.000	0.420	0.609	-0.328
8/27/2002	8	-0.758	1.136	-0.847	0.826
9/3/2002	8	0.428	0.357	-0.552	-0.769
9/24/2002	8	2.372	0.664	-1.118	-0.643
10/15/2002	8	1.677	0.146	-1.051	-0.495
11/5/2002	8	2.207	0.156	0.042	0.340
12/10/2002	8	2.076	0.224	0.649	0.173

Appendix B. continued

Date	Site	PCA 1	PCA 2	PCA 3	PCA 4
6/19/2002	9	-0.364	0.419	0.890	0.042
6/27/2002	9	-0.295	0.828	0.296	0.517
7/18/2002	9	1.790	1.078	-0.105	-0.170
8/8/2002	9	1.620	0.078	0.681	0.158
8/27/2002	9	-0.937	1.253	-1.199	0.248
9/3/2002	9	0.600	0.466	-0.550	-0.852
9/24/2002	9	2.411	0.583	-0.957	0.327
10/15/2002	9	1.809	-0.191	-0.706	0.598
11/5/2002	9	2.156	-0.109	0.363	0.408
12/10/2002	9	1.922	0.114	0.451	1.006
6/19/2002	10	-0.505	0.615	0.619	0.033
6/27/2002	10	-0.307	1.007	0.476	0.820
7/18/2002	10	1.699	0.808	0.799	0.193
8/8/2002	10	1.508	0.111	0.551	-0.183
8/27/2002	10	-0.720	0.999	-1.624	0.155
9/3/2002	10	0.363	0.386	-0.920	-1.023
9/24/2002	10	2.332	0.538	-0.986	-0.290
10/15/2002	10	1.594	-0.076	-0.882	0.065
11/5/2002	10	1.763	-0.499	-0.484	0.616
12/10/2002	10	1.889	-1.022	0.144	1.524

Appendix C. Number of frustules observed for each of 41 different varieties of diatoms observed at 10 main stem sites in the Sangamon River during 2002.

Exposure period = 6/27/2002 - 7/18/2002	**Sample Site**								
Species	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**
Achnanthes exigua				1	1		9	8	11
Achnanthes lanceolata	2	1	1	15	1	9	1	5	7
Achnanthes linearis	7	8	1	32		16	1		
Amphora acutiuscula								9	1
Amphora ovalis v. pediculus	14	23		11	1				
Aulacosira distans v. alpigena	3		1	1	8	3	2	1	
Aulacosira granulata									
Aulacosira varians									
Caloneis hultenii									
Cocconeis placentula									3
Cocconeis placentula v. euglypta				2			1		1
Cyclotella meneghiniana	169	153	116	93	223	96	82	79	101
Cyclotella stelligera v. stelligera	15	4	6		15	11	3	7	4
Cyclotella stelligera v. tenuis	3	0	1	1		7	2	5	9
Cymatopleura solea v. solea									
Cymbella triangulum v. triangulum									
Cymbella tumida									
Diploneis puella									
Gomphonema affine									
Gomphonema brasiliense									
Gomphonema parvulum	55	51	109	83	3	49	8	7	9
Navicula annexa							1		
Navicula capitata			1		1				
Navicula confervacea									
Navicula indifferens						1	6	11	11
Navicula menisculus	3	5	3	2	1	6	1	13	31
Navicula mutica									
Navicula protracta							7	38	8
Navicula pupula v. elliptica									
Navicula pupula v. rectangularis									
Navicula vaucheriae	3	17	1	22	1	10	13	11	27
Navicula viridula v. rostellata		1						3	2
Nitzschia amphibia									
Nitzschia dissipata									
Nitzschia hungarica									
Nitzschia palea	25	32	58	28	45	78	31	58	33
Nitzschia plana									
Nitzschia valdestriata	1	5	1	10		14	132	45	41
Pleurosira laevis								1	1
Surirella ovata			1						1
Synedra acus						1			

Appendix C. continued

Exposure period = 7/18/2002 - 8/08/2002	**Sample Site**								
Species	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**9**	**10**
Achnanthes exigua	3	8	13	6	2		75	25	30
Achnanthes lanceolata	32	2	12	19	9	101	6		8
Achnanthes linearis	73	11	3	3		103			4
Amphora acutiuscula							1	10	15
Amphora ovalis v. pediculus	3	3				4			
Aulacosira distans v. alpigena		4	3	2	2				1
Aulacosira granulata									
Aulacosira varians		1							
Caloneis hultenii			1						
Cocconeis placentula					1				1
Cocconeis placentula v. euglypta						1			1
Cyclotella meneghiniana	34	107	84	52	60	7	7	9	30
Cyclotella stelligera v. stelligera		3			32				7
Cyclotella stelligera v. tenuis		31	8	9	27	1	2		4
Cymatopleura solea v. solea									
Cymbella triangulum v. triangulum			1						
Cymbella tumida	1	1	1						
Diploneis puella									
Gomphonema affine									
Gomphonema brasiliense				7		1	1		
Gomphonema parvulum	32	8	21	56	19	42	9	14	10
Navicula annexa									
Navicula capitata									
Navicula confervacea							2		
Navicula indifferens									
Navicula menisculus	4	4	22	9	32	5	5	21	31
Navicula mutica									
Navicula protracta		2	6	1			29	5	3
Navicula pupula v. elliptica		1							
Navicula pupula v. rectangularis				1	1	1			
Navicula vaucheriae	20	10	35	27	18		13	6	8
Navicula viridula v. rostellata									
Nitzschia amphibia	18	10	2	12	7	11	7	3	8
Nitzschia dissipata									
Nitzschia hungarica									
Nitzschia ignorata									
Nitzschia palea	52	81	76	61	80	9	10	34	35
Nitzschia plana									1
Nitzschia valdestriata	28	12	13	36	13	14	133	173	101
Pleurosira laevis									
Surirella ovata		3							
Synedra acus		1							2

Appendix C. continued

Exposure period = 8/08/2002 - 9/03/2002	**Sample Site**							
Species	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**10**
Achnanthes exigua	12	10	6	3		11	32	16
Achnanthes lanceolata	3			2	4	39		6
Achnanthes linearis	4					8	1	
Amphora acutiuscula								7
Amphora ovalis v. pediculus	1	1				3		
Aulacosira distans v. alpigena	4	2	12	13			3	3
Aulacosira granulata							1	
Aulacosira varians	6	1		1	12	5	15	5
Caloneis hultenii								
Cocconeis placentula	1							
Cocconeis placentula v. euglypta								1
Cyclotella meneghiniana	125	191	209	236	216	64	112	123
Cyclotella stelligera v. stelligera		1					1	
Cyclotella stelligera v. tenuis	82	18	10	5	20	20	62	46
Cymatopleura solea v. solea								
Cymbella triangulum v. triangulum								
Cymbella tumida			1			1		
Diploneis puella								
Gomphonema affine								
Gomphonema brasiliense								2
Gomphonema parvulum	4		5	2	2	22	1	1
Navicula annexa								
Navicula capitata								
Navicula confervacea								
Navicula indifferens		2		1	2		1	13
Navicula menisculus	6	1	10	3	2	37		11
Navicula mutica								
Navicula protracta							8	3
Navicula pupula v. elliptica								
Navicula pupula v. rectangularis								
Navicula vaucheriae	2	2	1			12		2
Navicula viridula v. rostellata								
Nitzschia amphibia	8	1		4		19		1
Nitzschia dissipata		2						
Nitzschia hungarica								
Nitzschia palea	32	66	41	27	38	19	27	36
Nitzschia plana								
Nitzschia valdestriata	8	2	5	5	4	42	37	24
Pleurosira laevis								1
Surirella ovata	1							
Synedra acus	1							

Appendix C. continued

Exposure period = 9/03/2002 - 9/24/2002	**Sample Site**								
Species	**1**	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**
Achnanthes exigua	11	13	9	8	3	9	29	13	46
Achnanthes lanceolata	12	10	9	5	18	12	10	6	5
Achnanthes linearis	1	2	6	1	18	40	2		1
Amphora acutiuscula						1	1	30	7
Amphora ovalis v. pediculus	7	8	3	1	3				
Aulacosira distans v. alpigena	3	3	4	7	12	7	4	1	
Aulacosira granulata									
Aulacosira varians									1
Caloneis hultenii									
Cocconeis placentula			6	3	3				2
Cocconeis placentula v. euglypta			5	2	3		1		
Cyclotella meneghiniana	118	108	88	231	128	107	107	70	22
Cyclotella stelligera v. stelligera			2	3	3	4	1	7	1
Cyclotella stelligera v. tenuis			2						
Cymatopleura solea v. solea									
Cymbella triangulum v. triangulum									
Cymbella tumida									
Diploneis puella									
Gomphonema affine									
Gomphonema brasiliense							1	1	
Gomphonema parvulum	40	23	47		23	28	8	4	8
Navicula annexa									
Navicula capitata									
Navicula confervacea									
Navicula indifferens							4		
Navicula menisculus	21	14	26	5	12	23	3	8	8
Navicula mutica	1								
Navicula protracta	1		1		1	4	36	36	1
Navicula pupula v. elliptica									
Navicula pupula v. rectangularis									
Navicula vaucheriae	15	40	8	4	3	15	7	1	2
Navicula viridula v. rostellata									1
Nitzschia amphibia	4	1	3			1	1	2	1
Nitzschia dissipata									
Nitzschia hungarica									
Nitzschia palea	30	57	44	26	57	31	28	28	12
Nitzschia plana									
Nitzschia valdestriata	36	21	36	5	13	18	56	92	181
Pleurosira laevis							1	1	
Surirella ovata			1			1			1
Synedra acus									

Appendix C. continued

Exposure period = 9/24/2002 - 10/15/2002	**Sample Site**								
Species	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Achnanthes exigua	3	1	5		4	2	123	14	12
Achnanthes lanceolata	8	3	5	1	2	7	18	3	24
Achnanthes linearis	1			1					2
Amphora acutiuscula	1	1	1				11	15	14
Amphora ovalis v. pediculus			19		1	3	2		9
Aulacosira distans v. alpigena	1	4	2	8	6	5		3	7
Aulacosira granulata									
Aulacosira varians		21	19					1	1
Caloneis hultenii									
Cocconeis placentula	1				2	5			4
Cocconeis placentula v. euglypta					4	9			2
Cyclotella meneghiniana	97	63	43	257	228	204	7	58	87
Cyclotella stelligera v. stelligera	1			1	4	5			
Cyclotella stelligera v. tenuis			2	1			1	2	2
Cymatopleura solea v. solea									
Cymbella triangulum v. triangulum									
Cymbella tumida		2	1						
Diploneis puella									5
Gomphonema affine			2						
Gomphonema brasiliense		1							
Gomphonema parvulum	31	82	53	7	8	4	4	3	7
Navicula annexa									
Navicula capitata									
Navicula confervacea									
Navicula indifferens							2	1	
Navicula menisculus	8	19	11	2	8	4	5	21	18
Navicula mutica		1							
Navicula protracta		1	26		1	2	2	50	4
Navicula pupula v. elliptica									
Navicula pupula v. rectangularis									
Navicula vaucheriae	5	1	3		2	3	2	5	3
Navicula viridula v. rostellata									
Nitzschia amphibia		3	27	1		6	9	4	6
Nitzschia dissipata			1						1
Nitzschia hungarica									
Nitzschia palea	132	94	57	21	24	31	5	12	24
Nitzschia plana									
Nitzschia valdestriata	12	4	21		6	10	110	105	68
Pleurosira laevis								3	
Surirella ovata									1
Synedra acus		1	2			1			

Appendix C. continued

Exposure period = 10/15/2002 - 11/05/2002	Sample Site									
Species	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**
Achnanthes exigua								27	26	19
Achnanthes lanceolata				3		1		1	6	12
Achnanthes linearis		3			1				2	1
Amphora acutiuscula								121	28	21
Amphora ovalis v. pediculus				2		1				
Aulacosira distans v. alpigena	4	20	13	12	6	3		1		3
Aulacosira granulata										
Aulacosira varians			1	11						1
Caloneis hultenii										
Cocconeis placentula										
Cocconeis placentula v. euglypta										1
Cyclotella meneghiniana	208	228	231	152	252	203	270	5	9	53
Cyclotella stelligera v. stelligera	2				1	3				
Cyclotella stelligera v. tenuis		10	11	4	5	5	1			3
Cymatopleura solea v. solea		2								
Cymbella triangulum v. triangulum										
Cymbella tumida					1					
Diploneis puella										
Gomphonema affine										
Gomphonema brasiliense	1									1
Gomphonema parvulum				10	2	19	5	6	7	4
Navicula annexa										
Navicula capitata	1	2				1				1
Navicula confervacea										
Navicula indifferens										1
Navicula menisculus		1	5	7	3	7	2	13	14	51
Navicula mutica										
Navicula protracta			1	8	1			1	2	4
Navicula pupula v. elliptica										
Navicula pupula v. rectangularis										
Navicula vaucheriae		1		3		1			3	4
Navicula viridula v. rostellata	2	1		1	1	4				
Nitzschia amphibia								49	12	6
Nitzschia dissipata										2
Nitzschia hungarica			1	6		10				
Nitzschia palea	80	29	33	70	22	33	18	5	2	23
Nitzschia plana										
Nitzschia valdestriata	2	1	4	10	3	5		71	189	88
Pleurosira laevis										
Surirella ovata				2	1	4	3			
Synedra acus		2			1		1			1

Appendix D. Richness values for diatom community structure for 10 main stem sites in the Sangamon River during 2002.

Sites

Exposure Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	12	12	13	13	11	13		16	16	18
2	12	20	16	15	14		13	14	10	19
3	17	14	10	12	9		14	13		18
4	14	12	18		13	15	15	18	15	17
5	13		17	19	10	14	16	14	16	21
6	8	12	9	15	14	15	7	11	12	21

Appendix E. Shannon-Wiener diversity index values for diatom community structure for 10 main stem sites in the Sangamon River during 2002.

Sites

Exposure Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.63	0.68	0.58	0.81	0.40	0.82		0.72	0.95	0.95
2	0.92	0.87	0.91	0.96	0.93		0.72	0.74	0.66	0.97
3	0.77	0.51	0.49	0.41	0.44		1.01	0.78		0.86
4	0.85	0.83	0.95		0.44	0.83	0.91	0.86	0.86	0.63
5	0.65		0.77	1.02	0.27	0.47	0.60	0.68	0.86	0.99
6	0.35	0.41	0.38	0.72	0.32	0.57	0.20	0.71	0.61	0.94

Appendix F. Evenness values for diatom community structure for 10 main stem sites in the Sangamon River during 2002.

Sites

Exposure Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.59	0.63	0.52	0.73	0.38	0.74		0.60	0.79	0.75
2	0.85	0.67	0.75	0.81	0.81		0.65	0.65	0.66	0.76
3	0.62	0.44	0.49	0.38	0.47		0.88	0.70		0.69
4	0.74	0.77	0.76		0.40	0.70	0.78	0.69	0.73	0.52
5	0.58		0.63	0.80	0.27	0.41	0.50	0.59	0.71	0.75
6	0.39	0.38	0.40	0.61	0.28	0.48	0.23	0.68	0.57	0.71

Appendix G. Matrix of dissimilarity (Bray Curtis Index of Dissimilarity) for diatom community structure for 10 main stem sites in the Sangamon River during 2002.

	s101	**s102**	**s103**	**s104**	**s105**	**s106**	**s108**	**s109**	**s110**	**s201**	**s202**
s101	0.000										
s102	0.127	0.000									
s103	0.297	0.300	0.000								
s104	0.331	0.281	0.295	0.000							
s105	0.270	0.347	0.417	0.567	0.000						
s106	0.324	0.301	0.275	0.272	0.464	0.000					
s107	0.570	0.517	0.563	0.507	0.583	0.481	0.000				
s109	0.564	0.517	0.474	0.518	0.537	0.359	0.328	0.000			
s110	0.498	0.418	0.484	0.422	0.517	0.379	0.318	0.239	0.000		
s201	0.633	0.547	0.583	0.411	0.710	0.431	0.600	0.521	0.541	0.000	
s202	0.443	0.400	0.383	0.437	0.446	0.222	0.459	0.368	0.361	0.502	0.000
s203	0.507	0.441	0.428	0.385	0.537	0.229	0.438	0.316	0.269	0.451	0.262
s204	0.504	0.448	0.418	0.365	0.647	0.292	0.488	0.365	0.372	0.311	0.404
s205	0.559	0.526	0.499	0.507	0.572	0.288	0.549	0.397	0.381	0.476	0.284
s207	0.747	0.730	0.783	0.591	0.927	0.657	0.857	0.840	0.824	0.383	0.778
s208	0.877	0.833	0.890	0.804	0.920	0.790	0.367	0.567	0.624	0.710	0.761
s209	0.817	0.763	0.793	0.767	0.837	0.724	0.330	0.547	0.547	0.663	0.715
s210	0.703	0.670	0.700	0.654	0.733	0.574	0.333	0.418	0.388	0.540	0.569
s301	0.423	0.403	0.460	0.507	0.437	0.448	0.523	0.507	0.408	0.657	0.277
s302	0.317	0.360	0.400	0.567	0.190	0.408	0.553	0.471	0.464	0.680	0.303
s303	0.300	0.330	0.437	0.544	0.120	0.454	0.550	0.491	0.434	0.687	0.390
s304	0.309	0.365	0.495	0.556	0.126	0.522	0.581	0.575	0.506	0.734	0.461
s305	0.320	0.353	0.463	0.554	0.140	0.488	0.583	0.547	0.478	0.720	0.416
s307	0.578	0.538	0.625	0.479	0.698	0.473	0.472	0.423	0.327	0.389	0.438
s308	0.511	0.511	0.517	0.551	0.517	0.498	0.434	0.442	0.349	0.687	0.358
s310	0.458	0.438	0.464	0.515	0.444	0.429	0.451	0.355	0.286	0.631	0.305
s401	0.323	0.260	0.353	0.301	0.470	0.304	0.387	0.364	0.231	0.447	0.360
s402	0.407	0.330	0.347	0.334	0.453	0.268	0.437	0.328	0.258	0.423	0.280
s403	0.383	0.343	0.363	0.314	0.513	0.238	0.383	0.314	0.248	0.420	0.350
s405	0.298	0.338	0.491	0.532	0.121	0.508	0.554	0.548	0.465	0.724	0.454
s406	0.330	0.297	0.310	0.338	0.360	0.238	0.500	0.388	0.371	0.430	0.277
s407	0.391	0.321	0.404	0.262	0.481	0.279	0.424	0.395	0.259	0.381	0.325
s408	0.483	0.460	0.493	0.458	0.510	0.428	0.307	0.248	0.261	0.587	0.386
s409	0.620	0.607	0.617	0.591	0.623	0.544	0.277	0.258	0.391	0.633	0.546
s410	0.827	0.807	0.830	0.790	0.860	0.764	0.367	0.604	0.614	0.713	0.748
s501	0.451	0.408	0.351	0.402	0.498	0.206	0.514	0.402	0.412	0.501	0.288
s503	0.485	0.472	0.296	0.386	0.598	0.303	0.618	0.486	0.546	0.555	0.418
s504	0.505	0.468	0.462	0.472	0.672	0.392	0.585	0.392	0.529	0.411	0.481
s505	0.313	0.380	0.497	0.577	0.140	0.557	0.610	0.624	0.554	0.777	0.516
s506	0.277	0.323	0.470	0.527	0.117	0.498	0.550	0.541	0.458	0.720	0.449
s507	0.275	0.308	0.458	0.488	0.158	0.455	0.527	0.515	0.429	0.654	0.397
s508	0.910	0.897	0.923	0.837	0.933	0.841	0.521	0.684	0.708	0.727	0.808
s509	0.710	0.703	0.730	0.681	0.733	0.644	0.313	0.338	0.444	0.680	0.615
s510	0.524	0.524	0.574	0.455	0.581	0.478	0.318	0.336	0.302	0.541	0.444
s601	0.333	0.367	0.403	0.587	0.133	0.398	0.603	0.521	0.534	0.707	0.353
s602	0.313	0.370	0.493	0.571	0.123	0.527	0.603	0.607	0.524	0.770	0.479
s603	0.293	0.340	0.467	0.574	0.080	0.494	0.587	0.567	0.507	0.750	0.479
s604	0.321	0.298	0.358	0.492	0.295	0.319	0.511	0.399	0.402	0.607	0.275
s605	0.317	0.380	0.503	0.584	0.150	0.544	0.610	0.607	0.534	0.780	0.496
s606	0.237	0.263	0.397	0.494	0.167	0.428	0.547	0.517	0.441	0.673	0.423
s607	0.350	0.407	0.523	0.604	0.183	0.591	0.643	0.651	0.574	0.803	0.546
s608	0.927	0.910	0.927	0.897	0.943	0.874	0.667	0.687	0.720	0.767	0.824
s609	0.903	0.887	0.917	0.860	0.940	0.837	0.443	0.657	0.681	0.747	0.798
s610	0.680	0.680	0.700	0.624	0.710	0.594	0.353	0.424	0.388	0.603	0.579

Appendix G. continued

	s203	**s204**	**s205**	**s207**	**s208**	**s209**	**s210**	**s301**	**s302**	**s303**	**s304**
s203	0.000										
s204	0.279	0.000									
s205	0.235	0.331	0.000								
s207	0.757	0.624	0.765	0.000							
s208	0.714	0.657	0.755	0.803	0.000						
s209	0.611	0.607	0.662	0.827	0.320	0.000					
s210	0.494	0.471	0.479	0.777	0.370	0.260	0.000				
s301	0.444	0.551	0.489	0.833	0.800	0.747	0.613	0.000			
s302	0.414	0.547	0.486	0.927	0.883	0.803	0.710	0.350	0.000		
s303	0.454	0.567	0.549	0.893	0.863	0.767	0.677	0.357	0.153	0.000	
s304	0.549	0.652	0.630	0.890	0.874	0.827	0.731	0.399	0.223	0.116	0.000
s305	0.527	0.631	0.569	0.903	0.897	0.830	0.730	0.353	0.157	0.117	0.136
s307	0.376	0.340	0.362	0.605	0.631	0.585	0.419	0.485	0.605	0.598	0.642
s308	0.482	0.551	0.560	0.890	0.677	0.654	0.551	0.228	0.421	0.454	0.476
s310	0.399	0.498	0.467	0.847	0.737	0.641	0.527	0.195	0.341	0.351	0.420
s401	0.288	0.308	0.420	0.680	0.660	0.563	0.463	0.363	0.443	0.407	0.445
s402	0.158	0.301	0.353	0.750	0.717	0.627	0.523	0.393	0.387	0.403	0.488
s403	0.265	0.261	0.367	0.667	0.680	0.557	0.410	0.440	0.490	0.460	0.538
s405	0.532	0.648	0.626	0.887	0.854	0.810	0.700	0.398	0.221	0.138	0.081
s406	0.295	0.388	0.400	0.677	0.810	0.703	0.583	0.357	0.343	0.317	0.395
s407	0.276	0.409	0.407	0.614	0.724	0.621	0.498	0.401	0.481	0.428	0.479
s408	0.408	0.478	0.556	0.813	0.473	0.527	0.403	0.420	0.480	0.470	0.485
s409	0.494	0.514	0.562	0.840	0.430	0.427	0.300	0.550	0.617	0.590	0.618
s410	0.714	0.661	0.751	0.833	0.270	0.180	0.333	0.753	0.827	0.803	0.831
s501	0.272	0.395	0.348	0.757	0.807	0.714	0.614	0.474	0.424	0.464	0.536
s503	0.357	0.357	0.359	0.754	0.847	0.711	0.628	0.575	0.538	0.571	0.636
s504	0.429	0.289	0.454	0.672	0.662	0.645	0.542	0.589	0.605	0.615	0.687
s505	0.597	0.707	0.682	0.903	0.903	0.867	0.780	0.467	0.273	0.180	0.096
s506	0.527	0.637	0.605	0.870	0.850	0.793	0.693	0.403	0.240	0.127	0.093
s507	0.495	0.595	0.553	0.830	0.820	0.774	0.641	0.361	0.221	0.148	0.158
s508	0.781	0.688	0.818	0.784	0.251	0.424	0.388	0.814	0.894	0.887	0.891
s509	0.531	0.551	0.585	0.847	0.373	0.377	0.287	0.620	0.693	0.667	0.681
s510	0.382	0.439	0.513	0.734	0.564	0.474	0.334	0.454	0.554	0.511	0.536
s601	0.451	0.607	0.516	0.937	0.933	0.850	0.767	0.457	0.127	0.150	0.199
s602	0.567	0.674	0.655	0.927	0.927	0.863	0.760	0.417	0.217	0.123	0.086
s603	0.567	0.677	0.619	0.917	0.910	0.827	0.730	0.430	0.230	0.123	0.073
s604	0.336	0.492	0.440	0.844	0.810	0.740	0.647	0.348	0.231	0.245	0.310
s605	0.584	0.697	0.675	0.913	0.907	0.867	0.770	0.443	0.253	0.163	0.080
s606	0.474	0.584	0.549	0.840	0.867	0.770	0.683	0.387	0.210	0.127	0.173
s607	0.634	0.740	0.715	0.920	0.917	0.887	0.810	0.493	0.297	0.217	0.140
s608	0.800	0.727	0.824	0.843	0.570	0.537	0.490	0.833	0.917	0.877	0.904
s609	0.757	0.691	0.791	0.820	0.337	0.173	0.350	0.813	0.910	0.873	0.900
s610	0.478	0.468	0.499	0.797	0.477	0.383	0.207	0.580	0.663	0.640	0.658

Appendix G. continued

	s305	**s307**	**s308**	**s310**	**s401**	**s402**	**s403**	**s405**	**s406**	**s407**	**s408**
s305	0.000										
s307	0.601	0.000									
s308	0.411	0.476	0.000								
s310	0.344	0.456	0.209	0.000							
s401	0.467	0.319	0.361	0.308	0.000						
s402	0.473	0.405	0.421	0.328	0.187	0.000					
s403	0.533	0.312	0.438	0.384	0.160	0.250	0.000				
s405	0.161	0.629	0.482	0.409	0.414	0.448	0.488	0.000			
s406	0.407	0.452	0.461	0.334	0.260	0.210	0.277	0.361	0.000		
s407	0.501	0.376	0.432	0.359	0.181	0.225	0.238	0.432	0.225	0.000	
s408	0.503	0.445	0.285	0.328	0.280	0.323	0.340	0.451	0.387	0.324	0.000
s409	0.633	0.478	0.474	0.451	0.440	0.490	0.440	0.587	0.540	0.484	0.257
s410	0.843	0.625	0.641	0.667	0.643	0.690	0.637	0.790	0.740	0.700	0.527
s501	0.511	0.529	0.525	0.445	0.348	0.285	0.324	0.505	0.285	0.349	0.441
s503	0.588	0.536	0.615	0.562	0.439	0.435	0.362	0.638	0.432	0.473	0.601
s504	0.642	0.470	0.586	0.539	0.425	0.401	0.365	0.683	0.452	0.492	0.512
s505	0.190	0.681	0.534	0.491	0.487	0.520	0.577	0.121	0.437	0.507	0.517
s506	0.167	0.621	0.494	0.418	0.410	0.447	0.480	0.055	0.343	0.428	0.457
s507	0.178	0.595	0.475	0.382	0.371	0.414	0.428	0.126	0.311	0.402	0.424
s508	0.910	0.648	0.714	0.738	0.704	0.767	0.720	0.874	0.800	0.781	0.594
s509	0.717	0.462	0.544	0.521	0.477	0.557	0.480	0.674	0.630	0.541	0.343
s510	0.581	0.330	0.429	0.385	0.288	0.361	0.285	0.498	0.384	0.355	0.285
s601	0.173	0.718	0.517	0.451	0.490	0.433	0.533	0.195	0.357	0.514	0.523
s602	0.143	0.671	0.488	0.441	0.487	0.517	0.570	0.118	0.417	0.504	0.520
s603	0.147	0.691	0.504	0.434	0.463	0.490	0.543	0.082	0.380	0.471	0.507
s604	0.281	0.579	0.415	0.346	0.378	0.324	0.418	0.329	0.225	0.392	0.421
s605	0.167	0.674	0.504	0.464	0.490	0.527	0.573	0.111	0.443	0.511	0.520
s606	0.167	0.595	0.488	0.404	0.383	0.407	0.457	0.175	0.330	0.408	0.477
s607	0.203	0.701	0.561	0.517	0.523	0.557	0.617	0.165	0.490	0.557	0.560
s608	0.937	0.661	0.744	0.757	0.723	0.780	0.733	0.900	0.843	0.797	0.643
s609	0.923	0.641	0.740	0.730	0.687	0.740	0.693	0.874	0.807	0.754	0.607
s610	0.690	0.359	0.514	0.478	0.423	0.510	0.417	0.641	0.570	0.481	0.383

Appendix G. continued

	s409	**s410**	**s501**	**s503**	**s504**	**s505**	**s506**	**s507**	**s508**	**s509**	**s510**
s409	0.000										
s410	0.443	0.000									
s501	0.551	0.747	0.000								
s503	0.601	0.787	0.310	0.000							
s504	0.515	0.709	0.452	0.333	0.000						
s505	0.663	0.843	0.564	0.668	0.739	0.000					
s506	0.583	0.773	0.491	0.608	0.662	0.113	0.000				
s507	0.551	0.780	0.465	0.595	0.613	0.205	0.118	0.000			
s508	0.507	0.358	0.844	0.884	0.770	0.930	0.877	0.831	0.000		
s509	0.183	0.403	0.647	0.635	0.542	0.730	0.670	0.654	0.458	0.000	
s510	0.288	0.501	0.482	0.566	0.516	0.574	0.494	0.458	0.525	0.318	0.000
s601	0.653	0.873	0.398	0.495	0.652	0.220	0.200	0.191	0.953	0.750	0.611
s602	0.660	0.870	0.564	0.668	0.729	0.133	0.130	0.195	0.947	0.740	0.584
s603	0.613	0.847	0.531	0.625	0.702	0.123	0.093	0.155	0.927	0.720	0.571
s604	0.561	0.774	0.332	0.423	0.472	0.361	0.304	0.282	0.864	0.634	0.475
s605	0.657	0.843	0.567	0.668	0.732	0.047	0.113	0.195	0.927	0.720	0.574
s606	0.600	0.803	0.451	0.558	0.619	0.203	0.147	0.148	0.900	0.693	0.537
s607	0.687	0.860	0.594	0.704	0.766	0.057	0.157	0.238	0.937	0.747	0.621
s608	0.530	0.560	0.860	0.864	0.719	0.930	0.877	0.870	0.537	0.557	0.561
s609	0.443	0.167	0.827	0.847	0.739	0.923	0.863	0.840	0.388	0.420	0.517
s610	0.250	0.430	0.607	0.605	0.555	0.710	0.643	0.604	0.458	0.240	0.248

	s601	**s602**	**s603**	**s604**	**s605**	**s606**	**s607**	**s608**	**s609**	**s610**
s601	0.000									
s602	0.187	0.000								
s603	0.170	0.093	0.000							
s604	0.238	0.331	0.304	0.000						
s605	0.207	0.113	0.110	0.351	0.000					
s606	0.180	0.183	0.160	0.248	0.187	0.000				
s607	0.247	0.170	0.163	0.401	0.077	0.227	0.000			
s608	0.957	0.957	0.930	0.880	0.933	0.900	0.943	0.000		
s609	0.957	0.947	0.930	0.857	0.930	0.893	0.940	0.450	0.000	
s610	0.723	0.707	0.700	0.621	0.693	0.663	0.737	0.510	0.417	0.000