Patterns of fish communities and limnological conditions relative to floodplain landscapes

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PATTERNS OF FISH COMMUNITIES AND LIMNOLOGICAL CONDITIONS RELATIVE TO FLOODPLAIN LANDSCAPES

By

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RELATIVE TO FLOODPLAIN LANDSCAPES

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The Yazoo River Basin of Mississippi includes several rivers and hundreds of floodplain lakes within an area greatly impacted by agriculture. I studied 17 of these lakes distributed over the lower half of the Yazoo River Basin to document fish assemblages and limnological patterns and to identify environmental variables that might influence these assemblages. Potential connectivity of the lake to parent river and wetland-lake area ratio in the watershed were related to the limnological conditions and fish communities. Lakes with greater potential connectivity tended to be deeper and had greater specific conductance and greater fish species richness including more riverine species. Conversely, as the potential connectivity decreased, lakes were shallower, had greater chlorophyll-a fluorescence, wetland-lake area ratio, and a less speciose lacustrine fish community. Species richness and assemblage composition of riverine species were related directly to potential connectivity. Lacustrine species assemblages were linked to wetland-lake area ratio and turbidity.

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CHAPTER I

INTRODUCTION

The Yazoo River Basin of Mississippi includes several rivers that drain an area greatly impacted by agriculture (Nett et al. 2004). The basin was dominated by bottomland hardwood forests in the nineteenth century, but these forests were cleared for timber and conversion to agriculture (Smith 1954; Forsythe 1985). The region includes hundreds of floodplain lakes created by the meandering of the rivers, possibly one of the largest concentrations of floodplain lakes in North America. Many of these lakes have high recreational value (e.g., fishing, hunting), and some are used for irrigation of agricultural lands (Snipes et al. 2004). Water quality and the aquatic biota in these lakes have been affected by nutrients and sediments introduced from runoff originating in surrounding agricultural lands and retained within the lakes (McHenry et al. 1982; Cooper 1987).

Effects of Suspended Sediments on Aquatic Ecosystems

High turbidity caused by soil in runoff and resuspension of materials already in the lake can have various effects on aquatic ecosystems in floodplain lakes. Suspended sediments increase the attenuation rate of light (Kirk 1985) and decrease photosynthesis of primary producers (Wood and Armitage 1997). Suspended sediments also affect food consumption, growth, and survival rate of zooplankton (Arruda et al. 1983). Because each zooplankton taxon has different sensitivity to turbidity arising from feeding behavior and food size niche (Kirk and Gilbert 1990; Pollard et al. 1998), zooplankton community structure also can be affected by turbidity (Mccabe and O'Brien 1983; Hart 1987; Hart 1988). Habitat suitability of benthic fauna that are important food resources for fish species (e.g., redear sunfish *Lepomis microlophus*) also is decreased by sedimentation through degradation of bottom habitats (Rosenberg and Wiens 1978; Cooper 1987; Wood and Armitage 1997).

Effects of high turbidity on fishes also have been reported on various scales (e.g., individual level to community level). Reactive distance and feeding ability of predatory fishes decrease as turbidity level increases (Barrett et al. 1992). Some predatory fishes change their feeding strategies according to prey visibility (Crowl 1989), and the prey also may shift their habitats (e.g., near shore to open water) according to level of turbidity (Miner and Stein 1996). Food consumption rate and selectivity of adult and larval fishes are changed by turbid water and turbidity also affects food resource competition among fish taxa (Breitburg 1988; Bonner et al. 2002). Under very turbid conditions, some fishes decrease their spawning frequency and egg number and timing of spawning is delayed because of the loss of visual stimuli needed for successful reproduction (Morgan II et al. 1983; Burkhead and Jelks 2001). High turbidity condition may have positive effects on some fish taxa. Moderate turbidity decreases predation pressure on prey fishes (Bruton 1985; Gregory 1993; Johnson and Hines 1999). Nocturnal fishes such as channel catfish *Ictalurus punctatus* and omnivorous fishes such as gizzard shad *Dorosoma cepedianum* dominate in turbid lakes (Rodriguez and Lewis, Jr. 1997; Tejerina-Garro et al. 1998; Miranda and Lucas 2004; Vanni et al. 2005). In oxbow lakes, differences in tolerance to turbidity can cause fish community changes, a decrease in visual feeders and domination by small tolerant species (Miranda and Lucas 2004).

Factors Controlling Fish Communities

Turbidity is not the only factor that controls aquatic ecosystems in floodplain lakes. Various other biotic processes and abiotic factors can have major effects on aquatic biota, including predation, competition, physicochemical, and spatial factors (Jackson et al. 2001). Predation by piscivores can cause local extinction of small-bodied fishes (Jackson et al. 1992), shift in habitat use results from resource competition (Werner 1984), and physical factors such as lake area and chemical factors such as dissolved oxygen concentrations affect habitat and species diversity and community composition (Tonn and Magnuson 1982; Eadie and Keast 1984; Tonn 1985; Rahel 1986). Spatial isolation of lakes by dams and waterfalls, or levees in the Mississippi Delta, prevent fish movements among water bodies (Jackson et al. 2001).

In floodplain lakes, river connectivity influences spatial patterns of biota because temporal connections between rivers and lakes affect fish community composition via fish dispersal and migration (Schiemer 2000; Olden et al. 2001). Fish dispersal and migration also depends on swimming ability, body size, life history, direction of river flow, habitat conditions, and food availability (Olden et al. 2001). Degree of connectivity can be influenced by distance to the river, the river hydrograph, elevation change between lake and river, and fragmentation by levees. Large fishes with high swimming abilities can seasonally and stochastically migrate between lakes and rivers to look for spawning habitats and food resources or avoid harsh environmental conditions (e.g., hypoxia and water shortage). Small fishes tend to drift with the current of the river and disperse to backwater and downstream habitats (Sheaffer and Nickum 1986).

Lakes connected to main rivers tend to be influenced by fish communities of these rivers. Miranda (2005) reported that oxbow lakes well connected to the Mississippi River had more riverine fishes than isolated oxbow lakes that are separated from the river by levees. Lakes that are geographically isolated or have no connection periods, tend to have more lentic conditions and the aquatic biota seem to be more influenced by local conditions (e.g., predation and habitat condition) (Winemiller et al. 2000; Pouilly and Rodriguez 2004). The aquatic biota in the disconnected lakes can be influenced by periodic desiccation, resource limitation, hypoxia, and predation pressure (Rodriguez and Lewis Jr 1994; Winemiller et al. 2000) causing local extinctions. In the Yazoo River Basin, most floodplain lakes appear to have connectivity to rivers through small streams, forested wetlands, or manmade drainage structures, visible from aerial photographs of the region. If lakes are connected to main rivers by seasonal flood events, flood pulses can influence the habitat diversity and the fish community in these lakes (Feyper et al. 2006). The timing, frequency, and size of flood events may strongly affect fish community dynamics via fish dispersal and colonization. In addition, many of the lakes are partially surrounded by forested wetlands. These wetlands can become inundated during flooding and provide additional temporal habitats and food resources to fishes. Gutreuter et al. (1999) reported that fish species (e.g., largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus*) using littoral habitats increased somatic growth during rising-water seasons in the Upper Mississippi River system. Bayley (1988) also reported that omnivore growth was related positively to flooding rate in high water seasons because of increased resource availability. Flood events also promote migration of predatory fishes such as spotted gar *Lepisosteus oculatus* from rivers to floodplain lakes and increase predation pressure on prey species (Zeug et al. 2005).

Floodplain Lake Limnology

The creation of floodplain lakes is characterized by fluvial dynamics and processes of lake ontogeny (Ward et al. 2002). Fluvial lakes have a wide variety of connection types that vary according to lake age, human alterations and fluvial processes including channel migration, erosion, transport, and deposition (Ward et al. 2002; Welcomme et al. 2005). Some lakes are part of a stream system and backwaters that have a functional connection all or most of the year (Welcomme et al. 2005). Channel meandering creates abandoned loops that become oxbow lakes that can be seasonally connected to main rivers (Ward et al. 2002; Welcomme et al. 2005). Parts of abandoned loops become floodplain wetlands by accumulations of sediments and organic matters (Welcomme et al. 2005).

Limnological conditions of lakes connected to main rivers tend to be affected by water-mediated transfers of suspended sediments, nutrients, and organic matter from the rivers (Knowlton and Jones 1997). Rivers bring suspended sediments into the lakes (Amoros and Bornette 2002) and turbid condition caused by the suspended sediments negatively affects some aquatic vegetation and animals (Van den Brink et al. 1993). Flood events promote the importance of the land-water interaction and increase allochtonous inputs represented by dead leaves, woody debris, and insects to floodplain lakes (Vegas-Vilarrubia and Herrera 1993). Forested wetlands around these lakes can be sources of organic matter and macro- and micronutrients to the lakes in flood seasons (Vegas-Vilarrubia and Herrera 1993). Flood-pulses resulting in organic matter inputs are influenced by local topography, sediment porosity, and anthropogenic effects such as channelization and levee construction (Amoros and Bornette 2002). Flood events also can cause periodic water level and chemical fluctuations in these lakes. Water inputs from main rivers affect the specific conductance in the floodplain lakes. Vegas-Vilarrubia and Herrera (1993) reported that water inputs of Orinoco River changed conductivity, calcium, magnesium, and alkalinity of the floodplain lakes in the flood seasons.

Isolated lakes have limited water inputs and tend to experience water shortage (Vegas-Vilarrubia and Herrera 1993). Water chemistries of these lakes tend to be influenced primarily by land use and watershed characteristics around the lakes (Bornette et al. 1998) and sediment inputs from agricultural lands decrease lake depth. Water clarity of shallow lakes can be decreased by phytoplankton development (Tockner et al. 1999), and the resuspension of sediments by wind mixing, and forage activities of benthic fishes (Scheffer 2004). Forested wetlands around the disconnected lakes can be sources for bottom organic matters through leaf fall. The accumulated dead organic matter is decomposed through microbial activity, which can lower DO concentrations and has the potential to lower pH in systems that are weakly buffered (Brooks et al. 2003).

Aim of Research and Project Objectives

Limited information exists about fish assemblages and limnological conditions in the Yazoo River Basin. Some investigations on lakes of the basin have focused on a small number of the lakes and studied impacts of sediment loads on bottom habitat conditions

(McHenry et al. 1982; Cooper 1987). Miranda and Lucas (2004) studied relationships between fish assemblages and limited environmental variables (e.g., lake shape, size, and transparency) in more than 20 oxbow lakes in the Mississippi River and Yazoo River basins. Miranda (2005) reported fish assemblage patterns relative to connectivity (presence/absence of levee), lake area, and depth in 11 oxbow lakes in the Mississippi River basin. However, information about the relationships among fish assemblage characteristics, water quality, lake morphology, and landscape factors are still extremely limited in the Yazoo River Basin. Considering this limitation in existing knowledge, I studied 17 floodplain lakes widely distributed over the Southern Yazoo River Basin. Specific objectives of this study are to (1) describe spatial and temporal limnological and fish community patterns, (2) examine relationships of limnological conditions to landscape factors, and (3) determine patterns of fish species richness and assemblage composition relative to multiple environmental factors (physicochemical and landscape factors).

CHAPTER II

METHODS

Study Sites

This research was conducted in the Yazoo River Basin, which is situated in the lower half of the Mississippi Alluvial Valley (Figure 1). The study lakes were distributed widely over southern half of the basin from Yazoo County in the south to Tallahatchie County in the north and are associated with the Yazoo and Tallahatchie rivers (Table 1). Seven of the lakes were located on Bear Creek and its floodplain in Leflore and Humphreys counties. Three lakes were on Tippo Bayou and its floodplain in Tallahatchie and Leflore counties. Other lakes were located on floodplains of the Yazoo River from Yazoo County to Leflore County. The 17 floodplain lakes were chosen from 7 sub-watersheds of the Yazoo River Basin, considering accessibility and the need to include a broad range of lake characteristics (e.g., area, surrounding landscape, and connectivity to adjacent streams).

Limnological Sampling

Water quality in summer (June-August) and fall (September-November), 2006 was measured near the deepest point of each lake. The sampling position was recorded with a geographic positioning system (GPS) and returned to during the subsequent sampling trip. Water transparency and various physicochemical variables were measured at each lake between 1200-1300 hours. Sediment and water samples were collected only during the summer sampling trip. Water transparency was measured with a Secchi disc (20 cm diameter). Dissolved oxygen (DO), pH, specific conductance, turbidity (nephelometric turbidity units), and temperature were measured with a Eureka Manta® multiprobe (Eureka Environmental Engineering) at 0.5-meter intervals throughout the water column. After the water quality sampling, the multiprobe was recalibrated in the laboratory. Water samples (500 ml each) were collected from the surface and at 0.5 m above the bottom with a 4-l Van Dorn water sampler for chemical analysis and to measure fluorescence of chlorophyll-a and phycocyanin by in-vivo fluorescence (Wetzel and Likens 1991). Fluorescence of chlorophyll-a and phycocyanin were directly related to relative phytoplankton and cyanobacteria biomass, respectively. Sediment samples were collected with a Petersen grab and homogenized. The water and sediment samples were preserved on ice for transport to the laboratory and refrigerated or frozen until analyses.

In the laboratory, sediments were oven-dried at 100 Cº for 24 hour, ground, and sieved (0.25 mm mesh) for nitrogen, phosphorus, and carbon analyses. Concentrations of cations (potassium, magnesium, and calcium) in the water samples were measured by ion chromatography (Clesceri et al. 1998) and the alkalinity was determined by Gran titration (Wetzel and Likens 1991). In the sediment nutrient analyses, concentrations of total nitrogen were measured by dry combustion, total carbon by Dumas method (Carter 1993), and total phosphorus by Vanadomolybdophoric acid colorimetric method (Clesceri et al. 1998).

Landscape Factors

Lake area and length were measured from aerial photography collected in 2006 by the National Agriculture Imagery Program (NAIP). Lake maximum length was measured by digitizing middle points between longitudinally opposite shores. Shoreline development index was measured by dividing the lake perimeter length by the circumference of a circle with the same area as the lake (Wetzel and Likens 1991). Mean width was measured by dividing lake surface area by lake maximum length (Wetzel and Likens 1991). Five concentric zones (25, 50, 100, 150, and 200 m) were drawn around each lake and percentages of agricultural lands, forested wetlands, and others (e.g., catfish ponds, lake, streams, and rivers) within each boundary were measured. In addition, area of all forested wetlands and water bodies (e.g., lakes and floodplain ponds) connected to the study lakes were quantified.

Various measures have been used to describe level of hydrological connectivity. These include straight line and water course distances between river and lake (Tonn et al. 1990; Magnan et al. 1994), presence/absence of inlet and outlet (Rahel 1986; Robinson and Tonn 1989), connection days (Zeug et al. 2005), water area near the lake (Magnuson et al. 1998), and a combination of water course distance and lake elevation (Olden et al. 2001). Some of these methods were applicable to the lakes in this study, but some could not be used because of data limitations and the difficulties of identifying where connections occur in a region where topographic relief is minimal (Baker et al. 1991). I created a potential connectivity index. The index combined three hydrological variables; horizontal distance between lakes and rivers, area of neighboring water bodies, and number of inlets/outlets. The horizontal distance was the straight line distance between the main river and the nearest inlet of the lake. As the horizontal distances increase, flood frequency is expected to decrease. Horizontal distances of lakes directly connected to creeks/streams were zero because their inlets and outlets were part of the water bodies. There were several lakes with zero horizontal distance. Some of them (e.g., Wasp and Sixmile lakes) had both inlet and outlet, but others (e.g., Sidon and Long Brake lakes) had an inlet only. Lakes with an inlet and outlet can have shorter water retention time because of potential water flow through the lakes. Number of inlet/outlets was computed as the total number of streams flowing into and out of the lakes. Area of neighboring water bodies was calculated by summing stream, river, and backwater areas within 500 m of the lakes. These water bodies can be water sources that aid in preventing desiccation and provide refugia for riverine fishes in floodplain lakes. Depending on their distribution, each of the three of hydrological parameters was assigned a score (0, 1, or 2) and then, the scores were summed. The horizontal distance, number of inlet/outlet, and water body area were determined from the aerial photography of NAIP. The spatial analyst and X-tool of ArcMap were used to digitize and quantify the aerial photography.

Lake Ontogenetic Groups

Lake ontogenetic processes can influence potential connectivity and the area of forested wetland covers. As lakes age and the river migrates farther away, lake depth and potential connectivity can be decreased by accumulations of sediments and organic matters, simultaneously forested wetlands develop in shallow areas of the lakes through hydrarch succession (Mitsch and Gosselink 2000). The study lakes were grouped into three categories (parapotamon, plesiopotamon, and paleopotamon) according to location of lakes and connection type (Welcomme et al. 2005). Parapotamon lakes were those that are part of a stream or river system and have a functional connection all or most of the year. Plesiopotamon lakes included lakes adjacent to main rivers (horizontal distance between main rivers and inlets of lakes < 600 m) and can connect to the rivers by way of streams, ditches, and over-bank flow. Paleopotamon lakes included headwaters of creeks (e.g., Townsend and Blue lakes) and lakes with greater horizontal distance (> 600 m). The inlets/outlets of these lakes were covered with forested wetlands and can be connected to main rivers by way of these wetlands. These three categories were used to examine limnological and fish community patterns relative to the lake ontogenetic processes in subsequent statistical analyses.

Fish Collection

Fish samples from the 17 floodplain lakes were collected by boat electrofishing in summer and fall, 2006. Two netters collected stunned fish from the bow of an electrofishing boat with 2.7-m dip nets (0.4 cm mesh). Three to nine samples were taken per lake along shorelines between 0600 and 1200 hours. Each sample lasted 0.25 h of continuous electrofishing and covered 200-500 m of shoreline. Pulsed DC (60 Hz) generated by a GPP 7.5 Smith-Root electrofisher was adjusted to maintain 6-8 amperes output in water with conductivity ranging 36-353 (μS/cm). The fish collected were identified to species level, enumerated, measured for total length, and returned to the water. Fishes that could not be identified in the field were preserved in 10% formalin for laboratory analysis with taxonomic keys (Ross 2001).

Statistical Analyses

Pearson product moment correlations were used to examine associations among the chemical, morphological, and spatial data. To meet model requirements (skewness and kurtosis < 1), environmental variables were log-transformed as $\log_e(X+1)$ except for temperature, pH, DO, and number of inlet/outlets.

Principal components analysis (PCA) was used to examine distribution of 16 study lakes (Ole Lake was excluded because a fall sample was unavailable) in relation to summer and fall water quality (DO, pH, specific conductance, turbidity, chlorophyll-a fluorescence, phycocyanin fluorescence, and ratio of chlorophyll-a to phycocyanin fluorescence) from the 1 m sample. PCA reduces correlated variables into a few axes that express strong covariations among the variables (McCune and Grace 2002). The seven water quality variables and 32 sampling units (Ole Lake was excluded because fall samples were not available) were included in a matrix for the PCA (i.e., row: 32 sampling units, column: 7 water quality variables). PCA also was used to summarize eight environmental variables (sediment nitrogen, chlorophyll-a fluorescence, wetland-lake area ratio, ratio of chlorophyll-a to phycocyanin fluorescence, site depth, dissolved oxygen, specific conductance, and connectivity potential) of the 17 lakes.

Fish percentage compositional data rather than catch rate were used in multivariate analyses because each lake has different water conductivity levels that affect electrofishing catch rates (Reynolds 1996). Small fishes less than 5 cm were removed because of difficulty of species identification and low representation in electrofishing catch rates (Reynolds 1996). Because electrofishing was conducted near shoreline, pelagic species (e.g., clupeids) also were removed (Reynolds 1996). Species that occurred in a single study lake (e.g., silver carp) were removed because these fishes had lesser catch rate (< 2.5 fish per hour) and little importance on future fish monitoring. As a result, 26 fish species were included in the analyses. The percentage compositional data were transformed with an arcsine of the square root transformation.

Assemblage patterns of functional groups were examined because each group was expected to have a unique life history and environmental tolerance. The 26 fish taxa were classified into two groups (riverine and lacustrine species; Table 11) based on life history strategies as proposed by Winemiller (1992). Riverine species included fishes with periodic life-history strategies that include seasonal hydrological variability (e.g., flood events and river discharges) and produce abundant offspring to get through harsh environmental conditions (Winemiller 1992). Lacustrine species included fish taxa with equilibrium life-history strategies that invest in protecting limited numbers of offspring in more lentic habitat conditions (Winemiller 1992). Because some sunfishes and ictalurid catfishes had intermediate life history (Hoeinghaus et al. 2007), these species were classified into riverine or lacustrine type, with modifications suggested by Ross (2001).

Multiresponse permutation procedures (MRPP) with the relative Sorensen distance measure were performed to examine fish assemblage dissimilarity between summer and fall. MRPP is a nonparametric statistics that examine group differences (McCune and Grace 2002). If a significant temporal assemblage difference existed, summer and fall data would need to be examined separately. If fish composition showed no seasonal differences, summer and fall data were combined and converted into percentage compositional data. Then, species richness of summer and fall combined data for 26 fishes, riverine species, and lacustrine species were recorded for each lake. Species richness was measured as the total number of species collected in each lake. MRPP was also applied to examine fish assemblage dissimilarity among the lake ontogenetic groups (i.e., parapotamon, plesiopotamon, and paleopotamon).

Species-sites associations of 26 fishes and riverine and lacustrine species were examined with nonmetric multidimensional scaling (NMS) with the relative Sorensen distance measure. NMS finds similarities in species and environmental space by using rank distance measure and is not affected severely by zero-truncation problems (McCune and Grace 2002). This ordination technique allows use of various distance measures and does not make assumptions of linearity (McCune and Grace 2002).

Pearson product moment correlations were used to examine relationships between species richness (number of species in total catch of each lake) and community compositions of 26 fishes with 17 environmental variables. SAS version 9.1 was used for this analysis.

Canonical correspondence analysis (CCA; ter Braak 1986) was used to identify aspects of fish assemblages correlated strongly with environmental variables. The CCA is a useful direct gradient analysis for ecological studies (Palmer 1993) and has been used for fish community studies in floodplain lakes (Rodriguez and Lewis, Jr. 1997; Tejerina-Garro et al. 1998; Penczak et al. 2004; Zeug et al. 2005). In the CCA, matrixes of the 26 fish species and riverine and lacustrine species were examined in relation to a matrix of environmental variables. In the ordination plots, fish species and environmental variables were represented by points and arrows, respectively. Perpendicular lines traced between species points and environmental arrows indicated associations between fish species and environmental variables. The arrow length indicated the strength of correlation between species scores and environmental variables.

To select environmental parameters for the CCA, Monte Carlo permutation tests with 999 random permutations were used to examine the P-values (cutoff value: P=0.1) of each variable relative to the axes in the CCA. A forward selection procedure was used to decrease redundancy of the environmental variables (ter Braak and Smilauer 2002). Relationships between species and the selected environmental variables were examined with the CCA ordination plots based on species and site scores.

In the PCA, NMS, and CCA, ordination plots of axis 1 and 2 were examined because these two axes explained most of the variability. Rare species were down-weighted in the CCA. The PC-ORD version 5 was used to perform the PCA, NMS, MRPP analyses (McCune and Mefford 1999); the CANOCO version 4.5 was performed for the CCA.

CHAPTER III

RESULTS

Lake Morphology and Landscape

The study lakes had a wide range of areas (mean: 100 ha; range: 7-549 ha), shapes (length-width ratio mean: 50; range: 7-145), and depths (summer average: 2.6 m, range: 0.5-7.1m; fall average: 2.7 m, range: 0.5-8.6 m) (Table 5).

There were no significant differences (Pearson product moment correlations; P>0.05) in percentage compositions of agricultural lands and forested wetlands among the 50, 100, 150, and 200 m boundaries (Table 6; Figure 2). Average percentages of agriculture and forested wetlands in the 200 m buffer zone were 51% (range: 27-80) and 42% (range: 17-67), respectively. Within the 25 meter buffer zone, mean percentages of agricultural lands and forested wetlands were 10% (range: 0-29) and 80 (range: 58-95) %, suggesting that most lakes had a majority of forest cover around the shore.

Two of the three lake ontogenetic groups had a wide variety of connectivity potential scores. Range of connectivity potential scores of plesiopotamon and paleopotamon lakes was 1 to 4. All parapotamon lakes had high connectivity potential scores (>5; Table 6). Horseshoe, Macon, and Ole lakes had lesser connectivity potential scores than other plesiopotamon lakes. Townsend and Blue lakes had the greatest connectivity potential scores in the paleopotamon lake group.

Summer and Fall Water Quality

In summer, mean Secchi depth and turbidity values were 0.46 m (range: 0.15-0.75 m) and 23 NTU (range: 7.5 to 76 NTU), respectively (Table 3). In fall, mean Secchi depth and turbidity values were 0.39 m and 30.5 NTU and ranged from 0.15 to 0.72 m and 11.1 to 109 NTU, respectively (Table 4). One particularly variable lake was Sixmile Lake. The turbidity increased from 12.1 to 109 and Secchi depth decreased from 0.75 to 0.15 m between summer and fall.

Summer average temperature was 30.3 ˚C and ranged from 28.1 to 32.3 ˚C. Lakes were isothermal except for McIntyre (vertical temperature range = 9.8). In fall, temperature in the study lakes averaged 20.3 ˚C and ranged from 13.4 to 26.3 ˚C and all lakes were well mixed.

Specific conductance averaged 125.3 µS cm^{-1} (range: 47-353 µS cm^{-1}) in summer. In fall, average specific conductance was 114.5 µS cm^{-1} and the range was from 35 to 328 µS cm^{-1}. Dump Lake had the greatest specific conductance, alkalinity, magnesium, and calcium concentrations.

Summer dissolved oxygen concentrations in the study lakes averaged 7.5 mg l^{-1}, ranging from 2.1 to 11.9 mg l^{-1}. In fall, DO averaged 7.8 mg l^{-1} and ranged from 4.6 to 12.3 mg l^{-1}. Two lakes that had large seasonal shifts were Sixmile Lake which decreased to 4.6 mg l^{-1} and Long Brake Lake increased to 12.3 mg l^{-1}.

In summer, pH averaged 7.6 and ranged from 5.9 to 8.4. Average of fall pH was 7.5, ranging from 6.9 to 8.2. The pH of Townsend Lake increased from 5.9 to 7.

In summer, relative fluorescence of chlorophyll-a and phycocyanin, and chlorophyll-a-phycocyanin fluorescence ratio was 336 (range: 66-809), 2.49 (range: 0.8-6.5), and 154 (range: 38-308), respectively. The fall relative fluorescence of chlorophyll-a and phycocyanin averaged 227 and 2.3 (range: 81 to 418 and 1 to 4.2), respectively. The average chlorophyll-a to phycocyanin ratio was 98.1, ranging from 39 to 163 in fall. Most of the lakes (n=14) showed decreases in chlorophyll-a fluorescence and nine lakes showed increases in phycocyanin fluorescence between summer and fall.

Average sediment carbon, nitrogen, and phosphorus were 28.7 (range: 17-51), 3.3 (range: 2.1-5.6), and 1.0 (range: 0.6-1.4) g kg^{-1} dry weight, respectively, in summer. Carbon-nitrogen and nitrogen-phosphorus ratios averaged 8.6 (range: 7 to 9.7) and 3.2 (range: 2.1 to 5.9), respectively.

Temporal Water Quality Variability

Summer and fall samples differed in water quality patterns in the PCA ordination. The first two PCA-axes accounted for 57% of variation in summer and fall water quality (Table 8). The PCA ordination plot showed that fall water quality samples concentrated in the center of the plot and summer samples were more scattered, suggesting that summer water quality samples had more variability than fall samples (Figure 3). As such, summer water quality has more discerning power between lakes and was used for subsequent statistical analyses.

Correlation Analysis

Many of the environmental variables were inter-correlated (Table 7). The wetland-lake area ratio was related directly to sediment phosphorus (r=0.6; P=0.04) and nitrogen (r=0.49; P=0.05) and inversely related to dissolved oxygen concentrations (r=-0.46; P=0.06), suggesting that lakes surrounded by forested wetlands tended to have greater sediment nutrient concentrations and lower DO. Wetland-lake area ratio had positive associations with chrolophyll-a-phycocyanin fluorescence ratio (r=0.62; P<0.01). As horizontal distance between lakes and rivers increased, site depth decreased (r=-0.49; P=0.05). Lakes with limited water body area tended to have chlorophyll-a fluorescence (r=-0.44; P=0.08). Lakes with more inlets/outlets had greater specific conductance (r=0.66; P<0.01). Potential connectivity had weak positive correlations with specific conductance (r=0.49; P=0.03) and site depth (r=0.43; P=0.08). Site depth was related inversely to turbidity (r=-0.73; p<0.01) and fluorescence of chlorophyll-a (r=-0.68; P<0.01).

Landscape and Limnological Patterns

Each lake ontogenetic group had unique limnological and landscape patterns as suggested by the PCA ordination with eight environmental variables. The PCA ordination showed that the first two axes accounted for 57% of total variation (Table 9). The ordination plot of the PCA showed that the axis 1 and 2 represented gradients of connectivity potential and wetland-lake area ratio, respectively (Figure 4). In the plot, most parapotamon lakes had greater specific conductance, connectivity potential, and site depth; plesiopotamon lakes were positioned in the upper graph and had less wetland cover and greater DO; paleopotamon lakes were positioned in the lower right and had greater wetland-lake area ratio, sediment nitrogen, and ratio of chlorophyll-a to phycocyanin. Two of the parapotamon lakes, Long Brake and Wasp, were shallower and had greater turbidity.

Fishes

I collected 46,235 (summer: 28,288 and fall: 17,947) fish representing 53 species (summer: 48 and fall: 45) and 17 families (summer: 17 and fall: 14) from the 17 lakes in summer and fall 2006. Numerically, Clupeidae accounted for 59.7 % of total catch, Centrarchidae for 25.2 %, Catostomidae for 5.8 %, Atherinidae for 3.4 %, Cyprinidae for 2.1 %, and Lepisosteidae for 1.8 % (Table 13). Spotted gar, gizzard shad, warmouth, orangespotted sunfish, bluegill, largemouth bass, and white crappie were caught in all lakes. Thirteen fish species occurred in one lake only. Numerically, the collections were dominated by threadfin shad (45%), bluegill (14%), and gizzard shad (13%). Lakes with limited connectivity such as Ole, Horseshoe, and Macon tended to have more bluegill. A large number of threadfin shad and brook silverside were caught in Bee and Little Eagle lakes. Gizzard shad were very abundant in Blue Lake, whereas buffalos were most numerous in Townsend Lake. Conversely, no buffalos were collected in Horseshoe Lake, a lake with minimum potential connectivity. Most golden shiners were collected in Ole and Horseshoe lakes. Typical riverine fishes such as American eel, spotted bass, and white bass were caught in well connected lakes of Bear Creek.

Fish Assemblage Patterns

There were no marked differences in fish percentage compositional data between seasons (MRPP; P=0.41). Therefore, summer and fall fish assemblage data were combined and used in subsequent analyses. The axes 2 and 3 of NMS accounted for 92%

of the total variability (axis 2: 61%; axis 3: 32%; Kruskal stress value: 5.8). As axis-2 progressed from left to right, the community patterns changed from riverine to lacustrine species assemblages (Figure 5). Points representing lacustrine species were more widely scattered along axis 3 than points representing riverine species. Parapotamon and plesiopotamon lakes clustered in the upper left and lower right parts of the plot, respectively. Paleopotamon lakes were in the upper parts of the plot and had more variability in the ordination position, suggesting this lake group had a wide variety of fish assemblages. The three lake groups clearly separated the fish assemblages (MRPP; $P<0.05$).

Potential connectivity separated the riverine species assemblages. The first two NMS axes accounted for 97% of the total variability (axis 1: 20%; axis 2: 77%; Kruskal stress value: 7.0). Axis 2 was related inversely to potential connectivity. Freshwater drum, common carp, and spotted gar positioned at the upper part of the NMS plot, suggesting that these species could inhabit lakes with low potential connectivity (Figure 6). Conversely, rare riverine species such as longnose gar, spotted bass, and flathead catfish clustered at the lower part of the plot, suggesting that these species were collected mainly in connected lakes. Paleopotamon and plesiopotamon lakes had similar assemblage patterns (MRPP; $P=0.29$). Parapotamon lakes clustered in the lower part of the plot and had distinct assemblage structures (MRPP: $P<0.01$). Horseshoe Lake was positioned at the upper end of the plot and differed from other lakes by having no riverine specialists.

Wetland-lake area ratio separated paleopotamon lakes from other lake groups (MRPP; $P<0.01$). The first two NMS axes accounted for 86% of the total variability in lacustrine fish assemblages (axis 1: 38%; axis 2: 48%; Kruskal stress value: 12). Bowfin, black crappie, and bullheads clustered at the right part of the NMS plot, suggesting that these species were collected in paleopotamon lakes (Figure 7). Assemblage patterns of Wasp and Mossy lakes differed from other lakes because these lakes had greater white crappie numbers. Most longear sunfish inhabited lakes with greater potential connectivity and less forested wetland covers.

Correlation Analysis for Species Richness

Potential connectivity was correlated strongly with species richness of the 26 fish taxa and riverine species subset (26 fishes: $r=0.73$; $P<0.01$; riverine species: $r=0.87$; $P<0.01$) (Table 15; Figure 8). Species richness of the 26 fishes and riverine species had inverse relationships with fluorescence of chlorophyll-a (26 fishes: $r=-0.54$; $P=0.02$; riverine species: $r=-0.55$; $P=0.02$).

Canonical Correspondence Analysis

In the CCA analysis with the 26 fish taxa, 11 environmental variables were related significantly to the fish assemblages (Table 17). The first two CCA axes of the fish assemblages explained 47% of the total variation (axis 1: 30%; axis 2: 17%). Potential connectivity and wetland-lake area ratio (27.5% and 15.7%, respectively) explained the greatest percentages of total variation in the CCA model and were retained by the forward selection procedure. Of the individual subcomponents of the potential connectivity, horizontal distance (23.3%) had greater contribution to the CCA model than water body area (19%) and number of inlet/outlet (18%). Fish species points in the CCA ordination plot corresponded to gradients of potential connectivity and wetland-lake area ratio (Figure 9). The CCA plot showed that riverine specialists represented by longnose gar and flathead catfish inhabited lakes with greater potential connectivity. Buffalos and spotted gar were abundant in lakes with high potential connectivity and wetland-lake area ratio. Bowfin, black crappie, and black bullhead were collected in lakes with high wetland-lake area ratio. Most sunfishes except for longear sunfish had their greatest abundances in lakes with low potential connectivity. The CCA ordination plot based on site scores showed that potential connectivity and wetland-lake area ratio best separated lakes (Figure 9). Parapotamon lakes were grouped in the left side of the CCA plot. Lakes having reduced potential connectivity and wetland-lake area ratio were positioned in the extreme right of the CCA plot.

Connectivity potential was correlated with assemblages of riverine species. The first two CCA axes of the fish assemblages explained 35% of the total variation (axis 1: 19%; axis 2: 16%). The potential connectivity and lake area were retained by the forward selection procedure. Of the individual subcomponents of the potential connectivity, water body area (13%) was correlated with the assemblages more than horizontal distance (8%) and number of inlet/outlet (8%). The CCA plot showed that flathead catfish, blue catfish, and American eel were collected in large lakes with higher potential connectivity (Figure 10). Tolerant riverine species such as spotted gar were collected in lakes with lesser potential connectivity. The CCA ordination plot based on site scores showed that parapotamon lakes scattered at the left side of the plot and most paleopotamon lakes grouped in the lower portion of the plot. Lakes having lesser potential connectivity were positioned in the extreme right of the CCA plot.

Patterns of lacustrine species were better associated with wetland-lake area ratio and turbidity than riverine species. The first two CCA axes of the fish assemblages explained 43% of the total variation (axis 1: 30%; axis 2: 13%). The wetland-lake area ratio, turbidity, and site depth were retained by the forward selection procedure. Fish taxa preferring vegetation covers (e.g., black crappie and bowfin) were collected in paleopotamon lakes with greater wetland-lake area ratio (Figure 11). Longear sunfish and green sunfish inhabited in plesiopotamon lakes. Wasp and Long Brake lakes were positioned in the upper right part of the plot by having high turbidity condition and tolerant species such as white crappie.

Correlation Analysis for Fish Compositions

Potential connectivity, wetland-area ratio, and related variables were correlated significantly with the fish community compositions (Table 16). The connectivity potential was related directly to eight riverine species. Shortnose gar (r=0.73; P<0.01) and buffalos (smallmouth buffalo: r=0.87; P<0.01; bigmouth buffalo: r=0.78; P<0.01) were very correlated with the potential connectivity. Lacustrine species were correlated inversely with the potential connectivity including bluegill (r=-0.86; P<0.01), warmouth (r=-0.54; P=0.02), and black crappie (r=0.56; P=0.01). White crappie composition had positive relationships with turbidity (r=0.61; P<0.01). Phycocyanin fluorescence was related directly to warmouth (r=0.62; P<0.01) and orangespotted sunfish (r=0.7; P<0.01) representation. The wetland-lake area ratio had positive associations with spotted gar (r=0.65; P<0.01) and bowfin (r=0.80; P<0.01), and inverse relationships with longear sunfish (r=-0.65; P<0.01) and channel catfish (r=-0.54; P=0.02) composition. Bowfin composition ($r=-0.62$; $P<0.01$) were correlated inversely with dissolved oxygen concentrations.

CHAPTER IV

DISCUSSION

Factors Controlling Landscape Variables

Lake ontogenetic processes and human activities were associated with potential connectivity and wetland-lake area ratio. The natural progression is for parapotamon lakes to evolve into paleopotamon lakes via plesiopotamon lakes, decreasing potential connectivity and increasing forested wetland covers. However, my study lakes did not precisely track this ontogenetic pattern. Plesiopotamon and paleopotamon lakes had a wide range of potential connectivity. Deviations from the expected pattern were often due to anthropogenic alteration to the landscape. Water exchanges between plesiopotamon lakes and rivers were prevented by levees. Conversely, some paleopotamon lakes had high potential connectivity. These lakes were connected directly to rivers, but had the least stream/backwater area, suggesting that in this highly manipulated system, parapotamon lakes can shift paleopotamon lakes rapidly. Parapotamon lakes had intermediate levels of forested wetland cover. Forested wetlands of parapotamon lakes were situated at convex sides (i.e., point bar), suggesting that sediments brought in by river floods have accumulated at the point bars and vegetation has grown thickly at the bars (Mitsch and Gosselink 2000). These areas often remain as wetlands or flood often, discouraging agriculture development. Plesiopotamon lakes had the least forested wetland cover and were surrounded by agricultural lands, suggesting that the wetlands around the lakes had been cleared for agriculture. Conversely, paleopotamon lakes were entirely surrounded by forested wetland lands. Generally, mesic wetlands have successional directions from aquatic to terrestrial stages through decreases in water level (Howard-Williams 1985). Water level reductions in the wetlands are caused by evapotranspiration and litter and sediment depositions from through-flowing waters (Howard-Williams 1985). Seemingly, after my study lakes separate from their parent river, they have functioned as sinks for sediments and organic matters introduced by rivers/streams and the watershed (Tockner et al. 1999), resulting in loss of depth. As the lakes become progressively shallower, their area is reduced, and surrounding forested wetlands increased via plant colonization in the littoral zones (Barko and Herzog 2003).

Limnological Conditions Relative to Landscape Variables

Physicochemical factors of the study lakes were associated with potential connectivity variables and wetland-lake area ratio. Number of inlets/outlets had significant positive relationships with specific conductance. Inputs of major ions from main rivers could enhance the specific conductance in lakes with many inlets/outlets (Vegas-Vilarrubia and Herrera 1993), but specific conductance also can be affected by factors such as weathering of carbonates, forest stream dilution, nutrient uptake by phytoplankton, nutrient release in decomposition process, nitrogen fixation, denitrification, and evaporation and rainfall (Brewer and Goldman 1976; Goldman and Brewer 1980; Forsberg et al. 1988). Lakes with less stream/backwater area also had greater chlorophyll-a fluorescence and likely high phytoplankton biomass. As lakes become isolated from rivers/streams, the limnological conditions can change from more lotic to more lentic by having greater water retention time that allow the accumulation of algal biomass (Scheffer 2004). Lake depth decreased as horizontal distance between lakes and rivers increased possibly because oxbow lakes adjacent to rivers tend to be younger and accumulated fewer sediments or they are scoured frequently (Winemiller et al. 2000). Long Brake Lake was directly connected to the main river, but its depth was the shallowest of all study lakes. This lake was a backwater of Tippo Bayou and periodic flood events and through-flowing waters from the main river may cause high siltation in the lake (Vegas-Villarrubia and Herrera 1993; Tockner et al. 1999). Limnological conditions in lakes with greater potential connectivity can be associated with river dynamics (Tockner et al. 1999). From summer to fall, some connected lakes showed remarkable temporal changes in limnological conditions. Sixmile Lake, in the middle reach of Bear Creek, showed the greatest turbidity increase and dissolved oxygen decrease between summer and fall. Because the chlorophyll-a fluorescence measured in fall was the least value, the high turbidity conditions could likely be attributed to suspended sediments (Scheffer 2004). Conversely, Townsend Lake increased dissolved oxygen concentrations from summer to fall. Rates of dissolved oxygen change are associated with water column mixing, water inflow, and oxygen consumption (Wetzel 2001). Townsend (2006) studied a channel lake in the Mary River of northern Australia and reported that the dissolved oxygen concentration (0.5-2 mg l^{-1}) in the through-flow periods were less than in the hydraulic isolation period (4-7 mg l^{-1}). A storm that occurred the day before the summer water quality sampling in Townsend Lake, could have increased water in flows, mixed density layered water, contributed organic matters, and reduced the DO concentration in the water column of this lake. Lakes surrounded by forested wetlands had greater sediment nutrients and lesser dissolved oxygen concentrations. Because dead leaves were mingled commonly in the sediment samples of lakes with higher wetland-lake area ratio, woody debris and leaf materials from forested wetlands could have accumulated in lake bottoms and become sediment nutrient sources for the lakes (Mitsch and Gosselink 2000). Decomposition of sediment organic matter through microbial activity will decrease dissolved oxygen concentrations in the lakes (Brooks et al. 2003). Wetland-lake area ratio also was correlated directly with ratio of chlorophyll-a to phycocyanin fluorescence. Plesiopotamon lakes surrounded by agricultural lands also had greater ratios of phycocyanin fluorescence. Cyanobacteria, the source of phycocyanin fluorescence, tend to have greater turbidity tolerance than other algae (Scheffer 2004). Suspended sediments and nutrients introduced from runoff originating in surrounding agricultural lands may indirectly decrease the ratio of chlorophyll-a to phycocyanin fluorescence.

Variations of Summer and Fall Water Quality

Summer water quality was more variable among lakes than fall water quality. During summer and fall, most study lakes had mixed water column. The mixed water column would homogenize surface and bottom waters, decreasing variation of water quality parameters such as pH and DO among lakes as exposure to atmospheric oxygen was increased. The change in the chlorophyll-a-phycocyanin fluorescence ratio could be attributed to the change in summer to fall water quality. In fall, chlorophyll-a fluorescence decreased and phycocyanin fluorescence increased in several study lakes. The likely decrease of phytoplankton, the source of chlorophyll-a fluorescence, could be attributed to change in light and nutrient limitation, declining water temperatures and the resulting reduction in water column stability, and grazing by zooplankton during summer and fall (Wetzel 2001). Wetzel (2001) also described that cyanobacterial abundance can continue until the autumn in eutrophic lakes. This difference of seasonal abundance patterns of phytoplankton and cyanobacteria would further decrease the ratio of chlorophyll-a-phycocyanin fluorescence in fall.

Potential Connectivity Index

The potential connectivity index was strongly correlated with assemblages of 26 fish species. The potential connectivity index included three hydrological variables (horizontal distance, number of inlets/outlets, and area of streams/backwaters) and had higher contributions to the CCA model than its individual components. Seemingly, the potential connectivity index improved predictability of the fish assemblage patterns by combining the three hydrological variables. Addition of other hydrological variables such as connection days, local topography, and discharge volume through the lake may improve the potential connectivity index.

Fish Assemblages Relative to Environmental Variables

The major environmental factor determining the species richness and assemblages of 26 fish species was potential connectivity variables. Lakes with direct connection to rivers tended to have greater fish species richness and included more riverine species such as flathead catfish, smallmouth buffalo, and shortnose gar. Conversely, lakes that were isolated by levee construction and lake ontogenetic processes, had less speciose lacustrine fish communities dominated by centrarchid species. Similar assemblage patterns have been reported in other floodplain lake studies (Winemiller et al. 2000; Miranda 2005; Zeug et al. 2005). The CCA ordination showed that horizontal distance between lakes and rivers explained a greater portion of the variation of the fish assemblages. As horizontal distance increased, the lakes had characteristics indicative of being older and the community structure shifted from riverine to lacustrine species. The horizontal distance has helped determining distribution of riverine and lacustrine species groups in the floodplains.

Analyses showed that the species richness and assemblage compositions of the riverine fishes were correlated more strongly with potential connectivity than lacustrine species. Most riverine specialists such as spotted bass, flathead catfish, and American eel were collected in parapotamon lakes. Few tolerant riverine species such as spotted gar were sampled in lakes with low potential connectivity. In the CCA ordination, the horizontal distance was not correlated significantly with species assemblages within the riverine group. Some plesiopotamon lakes (e.g., Horseshoe) had disproportionately short horizontal distances and included fewer riverine species because inlets of these lakes were often leveed preventing water exchanges and fish migration with main rivers. On the other hand, areas of streams/backwaters around lakes were significantly correlated with riverine fish assemblages. Schiemer (2000) described the needs of riverine species including wider spatial scale and extended time for migration and spawning than lacustrine species. Kwak (1988) reported that adult fishes of the Kankakee River, Illinois, seasonally migrated between the river and floodplain and used the backwaters as spawning and nursery habitats. Loss of dispersal path between rivers and lakes can decrease reproductive and colonization opportunities of riverine species and eventually cause local extinctions in lakes. Streams/backwaters around lakes may be important refugia for riverine fishes in my study lakes.

The lacustrine fish assemblages showed a distinct pattern relative to wetland-lake area ratio. This ratio explained the greatest variation in assemblage patterns of lacustrine species in CCA ordinations. Bowfin, black crappie, and black bullhead inhabited paleopotamon lakes surrounded by forested wetlands. Bowfin and black crappie spawn in sites with inundated terrestrial vegetation (Echelle and Riggs 1972; Ross 2001) and young black bullhead inhabit areas near littoral plants (Forney 1955). Forested wetlands adjacent to my study lakes could provide these fishes with spawning and nursery habitats, suggesting that removal of inundated terrestrial vegetation around lakes can have significant impacts on these lacustrine species.

Water clarity was not a strong predictor for the assemblages of 26 fish species in my study lakes. Although this variable has often been cited as fish assemblage predictors in floodplain lake studies, the CCA ordination did not show significant associations between the fish assemblages and water quality variables. Miranda and Lucas (2004) reported that water clarity was one of environmental variables useful in contrasting patterns of fish assemblages in floodplain lakes in the Mississippi Alluvial Valley. Their results showed that visually oriented predators such as largemouth bass were related directly to water clarity, suggesting that turbid conditions limited forage activities of the piscivores (Rodriguez and Lewis 1997; Tejerina-Garro et al. 1998; Miranda and Lucas 2004). In my study, representation of visual lacustrine predators such as largemouth bass was positioned at the center of the CCA plot and was not correlated significantly with any of the environmental variables because these fishes were collected in lakes with intermediate turbidity, depth, and potential connectivity. Connected lakes should have greater seasonal hydrological variability (e.g., flood events and river discharges), whereas shallow disconnected lakes can have water shortages and hypoxia (Rodriguez and Lewis Jr 1994; Winemiller et al. 2000). The lakes with intermediate potential connectivity could have fewer environmental disturbances and stock more visual lacustrine predators. Potential connectivity could influence overall fish distributions and mask relationships between fish assemblages and local habitat conditions (e.g., water quality).

Conversely, CCA ordination with lacustrine species showed that water quality variables were correlated significantly with the group's species assemblage. This ordination more closely examined relationships of 13 lacustrine species assemblages to water quality variables by removing 13 riverine species from the 26 fish species. Tolerant species such as white crappie and orangespotted sunfish were correlated directly with turbidity. Numerous white crappies were collected in Wasp and Mossy lakes. These lakes had greater turbidity, but potential connectivity of Wasp Lake was much greater than Mossy Lake. White crappie can adapt to lentic and lotic water bodies due to their swimming ability and turbidity tolerance (Ross 2001). Orangespotted sunfish inhabited shallow riverine and lacustrine habitats with high turbidity (e.g., Long Brake and Ole). These shallow lakes included the greatest chlorophyll-a and phycocyanin fluorescence values and could have high diurnal DO variability through photosynthesis and respiration of the microbial community (Kalff 2001; Wetzel 2001). High diel DO fluctuations negatively affect intolerant species such as largemouth bass (Miranda et al. 2001). Orangespotted sunfish could colonize the shallow lakes because of high tolerance to turbidity and fluctuating DO (Gould and Irwin 1962; Becker 1983) and opportunistic life-history strategy (early maturity, low fecundity, and low survivorship; Winemiller 1992).

Temporal Fish Community Changes

There was no significant temporal variation in fish community compositions between summer and fall. Community compositions in lakes connected to rivers were expected to have greater temporal changes than lakes with limited connectivity because riverine fishes migrate seasonally between lakes and rivers to seek spawning and nursery habitats (Kwak 1988). However, other floodplain lake studies also have reported limited or no temporal fish community changes (Rodriguez and Lewis Jr 1994; Zeug et al. 2005). This failure to find differences may be because sampling interval was too short or wrong time for fishes to migrate between the lakes and rivers; water course distances were too long to travel to other water bodies; fish migration/dispersal occurs in large flood events only; or my gear and sampling effort were unable to detect minor shifts in fish communities. Fish community structure in oxbow lakes may be deterministically shaped over evolutionally timescales and seasonal local fish migration between lakes and rivers may not greatly influence fish assemblage patterns.

Summary and Conclusions

- Although floodplain lakes and associated aquatic ecosystems in the Yazoo River Basin have been and continue to be heavily influenced by agriculture, limited information exists about fish assemblages and limnological conditions in these systems.
- I studied 17 floodplain lakes widely distributed over the Southern Yazoo River Basin to expand the available information about fish assemblages and limnological conditions and further examine relationships between fish communities, limnological conditions, and landscape factors.
- The natural progression is for parapotamon lakes to evolve into paleopotamon lakes via plesiopotamon lakes, decreasing the likelihood connectivity and increasing forested wetland covers. I found that some Yazoo River Basin plesiopotamon lakes had low connectivity potential and least forested wetland covers. These plesiopotamon lakes were surrounded by levees and agriculture development.
- Potential connectivity variables were correlated with some physicochemical variables in the lakes. Inputs of major ions from main rivers could enhance the specific conductance in lakes with more inlets/outlets though changes in specific conductance were small. Lake depth decreased as horizontal distance between lakes and rivers increased. Lakes with smaller water body areas had greater chlorophyll-a fluorescence.

- Lakes surrounded by forested wetlands tended to have greater sediment nutrient concentrations, lesser dissolved oxygen concentrations, and greater chlorophyll-a to phycocyanin fluorescence ratios.
- Fish communities in the study lakes were correlated strongly with potential connectivity. As potential connectivity decreased, community compositions shifted from riverine to lacustrine species assemblages.
- Species richness and assemblage composition of riverine species were related directly to potential connectivity variables. Lacustrine species assemblages were linked to wetland-lake area ratio.
- Overall, water clarity was not a strong predictor for the assemblage patterns of the 26 fish species. Visual predators such as largemouth bass were not associated with water clarity, inhabiting lakes with intermediate turbidity and potential connectivity.
- Abundance of some tolerant species, white crappie and orangespotted sunfish, were correlated with turbid riverine and lacustrine habitats.
- There were no significant temporal variation in fish community compositions between summer and fall. This failure to find differences suggest sampling may be conducted anytime during this period.

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TABLES

Table 1. Descriptions of study lakes in the Yazoo River Basin, Mississippi, 2006.

Lake	ID	Description
Bee	BEE	This lake has the largest area and is connected to Tchula Lake. A forested wetland is situated on the north end of the lake.
Blue	BLU	This lake is positioned in the headwaters of Bear Creek and connected to Roebuck Lake. A forested wetland is situated on the north end of the lake.
Dump	DUM	This lake is located in the southern end of the study lakes and connected to the Yazoo River.
Horseshoe	HOR	Both ends of the lake are leveed to water exchanges with Tchula Lake. A drainage can connect the two lakes during major flood events.
Little Eagle	LIT	This lake is connected to Tchula Lake by way of two streams. Wetlands occur on both ends of this lake.
Long Brake	LON	This lake is next to Tippo Bayou. Two levees divide this lake into parts.
McIntyre	MCI	The lower end of this lake is connected to the Yalobusha and Yazoo rivers and the upper end of the lake is connected to Tippo Bayou. Forested wetlands are situated on the north end of the lake.
Macon	MAC	This lake is situated next to next to Bear Creek. One stream flows into this lake.
Robinson	ROB	The east end of this lake is connected to the Yalobusha River. Wetlands are situated adjacent to the north side of this lake.
Mossy	MOS	This lake is connected to Bear Creek. Wetlands surround part of this lake.
Ole	OLE	This lake has no direct connection to Bear Creek and has a large forest buffer in the west side.
Pleasant	PLE	The north side of this lake is surrounded by a forested wetland.
Sidon	SID	This lake is situated adjacent to the Yazoo River. Discharge gates have been constructed on the south side.
Sixmile	SIX	Bear Creek flows through this lake.
Townsend	TOW	This lake is connected to Tchula Lake. Forested wetlands are situated on the north and south end of the lake.
Walker	WAL	This lake is connected to Bear Creek. One stream flows into this lake.
Wasp	WAS	This lake is situated on the lower end of the Bear Creek. A gate is situated on the outlet.

Table 2. Definition of environmental variables of the study lakes in the Yazoo River Basin, Mississippi, 2006.

Variable	Definition
Latitude	Latitude of sampling site
Longitude	Longitude of sampling site
Area (ha)	Lake surface area
Perimeter (km)	Length of lake shoreline
Maximum length (km)	Maximum distance between two points on curved lake shoreline
Mean width (km)	Lake surface area divided by lake maximum length
Max length/average width	Ratio of lake maximum length to lake mean width
Shoreline development	Lake perimeter divided by length of the circumference of a circle with the same area as the lake
Forested wetlands	Area of forested wetland surrounding lake
Forested wetlands / lake area	Ratio of forested watershed area to lake area
Agriculture area	Agricultural area within boundary of lake
Percentage agriculture	Percentage of agricultural area within each boundary of lake
Percentage forested wetland	Percentage of forested wetlands within each boundary of lake
Lake ontogenetic group	Lake categories determined by lake location and forested wetland covers
Inlet/outlet	Sum of inlets and outlets
Horizontal distance	Straight line distance between river and inlet of lake
Water body within buffer	Area of stream and floodplain backwater in 500 m boundary around lake
Potential connectivity	Index based on inlet/outlet, horizontal distance, and water body area
Depth (m)	Maximum depth on sampling site of each lake

Table 2. Continued.

Variable	Definition
Secchi (cm)	Average of the depth of Secchi disc disappearance on lowering and reappearing on rising
Temperature (°C)	Temperature at 1 m below surface
Temp range (°C)	Temperature range of water column
Specific conductance (µS cm^{-1})	Specific conductance at 1 m below surface
Dissolved oxygen (mg l^{-1})	Dissolved oxygen concentration at 1 m below surface
DO range (mg l^{-1})	Dissolved oxygen concentration range of water column
DO sat (%)	Dissolved oxygen saturation at 1m below surface
DO sat range (%)	Dissolved oxygen saturation range of water column
pH	pH at 1 m below surface
pH range	pH range of water column
Turbidity (NTU)	Turbidity at 1 m below surface
Turbidity range (NTU)	Turbidity range of water column
Alkalinity (µeq l^{-1})	Alkalinity of surface water samples
K (µg l^{-1})	Potassium ion of surface water samples
Mg (µg l^{-1})	Magnesium ion of surface water samples
Ca (µg l^{-1})	Calcium ion of surface water samples
Phycocyanin	Relative fluorescence of phycocyanin in surface water samples
Chlorophyll-a	Relative fluorescence of chlorophyll-a in surface water samples
Sediment phosphorus (µg l^{-1})	Concentration of total phosphorus of summer sediment samples
Sediment nitrogen (µg l^{-1})	Concentration of total nitrogen of summer sediment samples
Sediment carbon (µg l^{-1})	Concentration of total carbon of summer sediment samples

Table 3. Water quality variables collected from 17 lakes in the Yazoo River Basin, Mississippi during summer 2006. Depth represents water depth at the site the samples were collected.

Variable	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Ole	Pleasant	Robinson	Sidon	Sixmile	Townsend	Walker	Wasp
Depth (m)	3	4.1	1.9	3	2	0.8	3.1	7.1	2	0.7	0.5	0.8	4.1	2.2	3.9	3.4	1.7
Secchi (cm)	35	60	40	40	67	17	67	60	45	25	15	35	55	75	62	75	15
Temperature (Cº)	30.74	29.4	30.5	30.5	28.9	28.12	31.6	30.5	32.2	29.8	30.9	29.2	30.1	32.3	28.9	30.3	31.7
Temperature range (Cº)	1.87	2.9	0.6	2.3	0.02	2.1	1.3	9.8	1.7	0	0.1	1	3.4	2.4	4.8	2	1.1
Specific conductance (µS/cm)	87	125	353	74	107	89	49	135	130	75	124	56	181	225	120	47	154
DO (mg l^{-1})	7.55	9.2	10.8	8	4.7	5.58	11.6	5.8	6.46	7.6	5.36	6	6.1	10.8	2.1	11.9	8.5
DO range (mg l^{-1})	5.88	9.8	3.5	9.7	0.51	6.4	11.75	5.4	5.17	0.4	0.1	1.8	8.1	13.5	1.8	11.8	5.8
pH	8.41	6.9	8.31	8.25	6.95	6.83	6.7	7	7.14	6.8	6.7	6.4	7.4	7.3	5.9	7.2	7.4
pH range	2.16	0.96	0.36	2.4	0.02	0.9	1.1	1	0.48	0.6	0.2	0.4	1.5	1.29	2	1.7	0.5
Turbidity (NTU)	17	8.3	20.1	13.5	8.2	61.3	11.8	12.3	24.1	34.4	39.2	23.6	9	12.1	7.5	11.8	76
Turbidity range (NTU)	9.6	37.9	33.7	3	0.9	2.4	8.8	120.8	10.3	2.1	0.1	3.7	8.8	9.9	101	32.5	72
Alkalinity (µeq l^{-1})	1146	926	3050	505	632	754	378	1423	1097	569	666	378	1355	1641	1140	337	1139
K (µg l^{-1})	4.88	4.71	4.1	5.41	4.61	3.15	6	3.64	3.66	4.67	6.16	2.65	2.91	4.69	4.16	2.94	5.44
Mg (µg l^{-1})	1.56	1.9	11.42	1.17	2.02	1.99	0.84	3.56	2.82	1.38	2.5	1.14	4.41	4.55	2.51	0.98	2.85
Ca (µg l^{-1})	8.02	8.97	36.27	7.2	8.89	8.17	4.62	14.2	12.72	7.27	10.52	3.72	17.66	18.93	11.16	4.08	12.14
Phycocyanin	3.88	1.17	1.68	5.92	1.94	6.51	3.12	1.37	1.53	3.03	3.44	1.25	0.8	1.07	1.93	1.31	2.44
Chlorophyll-a	370.2	360.8	196.2	226.3	378.8	809.4	340.7	177.7	291.5	619.9	600.3	376.9	66.6	177.7	239.4	195.1	292.9
Chlorophyll-a/phycocyanin	95.4	308.3	116.8	38.2	195.2	124.3	109.2	129.7	190.5	204.6	174.5	301.5	83.3	166.0	124.0	148.9	120.0

Table 4. Water quality variables collected from 16 lakes in the Yazoo River Basin, Mississippi, during fall 2006. Ole Lake was excluded because a fall sample was unavailable. Depth represents water depth at the site the samples were collected.

Variable	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Pleasant	Robinson	Sidon	Sixmile	Townsend	Walker	Wasp
Depth (m)	2.2	4.4	1.8	0.9	1.8	0.8	3.1	8.6	2	0.5	1.3	4.3	3	3.8	3.1	2.3
Secchi (cm)	41	50	38	31	48	22	40	65	26	21	43	48	15	72	43	35
Temperature (Cº)	21.4	16.8	25.8	24.4	23.1	15.5	19.5	16.1	18.6	26.3	13.4	23.4	18.2	24.3	20.7	17.7
Temp range (Cº)	0.09	0.6	0.92	0.43	0.82	0.07	0.14	1.8	0.69	0.07	0.1	1.09	1.5	2.99	1.65	0.75
Specific conductance (μS/cm)	90	129	328	81	96	59	43	100	150	118	36	126	181	103	35	157
Dissolved oxygen (mg l^{-1})	7.17	7.85	6	7.2	7.03	12.3	7.44	6.86	6.86	7.37	8.71	7.12	4.6	6.58	9.85	12.13
DO range (mg l^{-1})	0.3	0.92	2.55	0.7	2.88	0	0.86	1.86	0.44	0.05	0.8	6.48	1.7	7.31	1.16	3.41
pH	7.46	7.26	8.21	7.22	7.17	7.71	7.06	6.93	7.47	7.27	6.96	7.19	7.2	7.01	7.42	8.14
pH range	0.07	0.17	0.35	0.11	0.81	0.19	0.61	0.39	0.06	0.07	0.45	0.78	0.8	0.96	0.6	0.3
Turbidity (NTU)	18.2	12.2	29.4	28.4	12.2	53.5	13.9	15.5	44.1	37.4	22.7	26	109	11.1	15.1	38.7
Turbidity range (NTU)	2.7	8.6	43.4	1.2	1.7	8	10.7	30.6	3.4	2	6.7	104	36	61.3	42.1	27.8
Phycocyanin	3.64	1.87	1.65	2.77	2.15	4.24	3.62	1.6	1.87	3.12	1.78	1.52	2.2	1	1.89	2.38
Chlorophyll-a	367.8	304.7	81.74	267.5	250.3	416.4	272.5	102	153.9	418.5	258.4	198.1	87.76	116.5	134.4	205.7
Chlorophyll-a/phycocyanin	101	163	49	97	117	98	75	64	82	134	145	131	40	117	71	86

Table 5. Lake morphology and sediment nutrients of 17 lakes in the Yazoo River Basin, Mississippi, 2006. Lake ontogenetic groups include parapotamon (par), plesiopotamon (ple), and paleopotamon (pal).

Variable	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Ole	Pleasant	Robinson	Sidon	Sixmile	Townsend	Walker	Wasp
Latitude	33.0666	33.4710	32.6413	33.2378	33.1404	33.7611	33.3560	33.6702	33.3536	33.2399	33.4444	33.6600	33.4156	33.3345	33.1492	33.3071	33.2467
Longitude	-90.3282	-90.3625	-90.6148	-90.3014	-90.3609	-90.1453	-90.4901	-90.2017	-90.3965	-90.4518	-90.1529	-90.1710	-90.2167	-90.4328	-90.4117	-90.4346	-90.4784
Lake ontogeny	ple	pal	ple	ple	pal	par	ple	par	pal	ple	pal	pal	par	par	pal	ple	par
Area	549.95	29.46	160.87	313.39	86.93	8.08	16.97	50.69	91.87	15.82	19.63	64.92	66.64	47.76	7.17	16.50	225.80
Perimeter (km)	44.80	8.41	12.57	46.62	6.75	3.43	4.03	10.47	9.49	2.56	3.27	7.51	14.70	10.77	3.92	4.31	38.16
Maximum Length (km)	21.58	4.08	5.56	20.47	3.25	1.63	1.92	5.18	4.56	1.06	1.44	3.67	7.24	5.30	1.87	2.08	18.10
Average Width (km)	0.22	0.07	0.29	0.15	0.27	0.05	0.09	0.10	0.20	0.15	0.14	0.18	0.09	0.09	0.04	0.08	0.12
Max length/ average width	96.08	56.62	19.21	133.66	12.15	33.07	21.62	53.03	22.61	7.06	10.52	20.73	78.65	58.72	48.91	26.22	145.03
Shoreline development	5.74	4.37	2.80	7.43	2.04	3.41	2.76	4.15	2.79	1.82	2.08	2.63	5.08	4.40	4.13	3.00	7.17
Sediment Phosphorus ($\mu g\ l^{-1}$)	0.75	1.1	1.1	0.88	1.4	0.86	0.86	1.3	0.86	1.1	1.4	0.96	0.98	1.3	1.3	0.61	0.89
Sediment Nitrogen ($\mu g\ l^{-1}$)	2.11	3.45	2.49	2.65	5.67	2.26	4.41	3.53	3.32	3.78	3.15	3.89	2.44	2.82	4.04	3.6	2.57
Sediment carbon ($\mu g\ l^{-1}$)	17.68	30.29	18.09	25.74	51.88	22.15	39.59	26.98	28.18	34.03	26.66	36.73	19.73	21.96	38.87	31.97	18.02

Table 6. Landscape characteristics within selected boundaries and connectivity metrics of 17 lakes in the Yazoo River Basin, Mississippi, 2006.

Variable	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Ole	Pleasant	Robinson	Sidon	Sixmile	Town	Walker	Wasp
%Agriculture 25m	5	25	18	30	1	25	0	14	0	3	4	3	4	2	4	20	10
%Wetlands 25m	95	74	77	70	99	70	100	83	98	97	96	97	91	98	96	63	90
%Agriculture 50m	71	67	73	82	56	41	57	61	39	44	29	39	63	46	40	50	52
%Wetlands 50m	29	30	25	17	43	49	43	38	56	56	71	61	31	54	60	50	45
%Agriculture 100m	71	69	73	82	56	39	53	61	40	50	29	39	62	44	39	48	52
%Wetlands 100m	29	29	25	17	43	52	45	38	56	49	71	61	32	52	61	49	45
%Agriculture 150m	70	69	73	82	56	38	54	61	41	50	29	39	62	45	39	48	52
%Wetlands 150m	29	29	25	17	43	49	44	38	55	49	71	61	32	51	61	49	45
%Agriculture 200m	70	66	72	81	55	34	51	59	40	46	27	38	61	44	34	45	52
%Wetlands 200m	29	27	25	17	42	44	41	38	54	46	67	60	31	50	54	46	45
Wetlands (ha)	430	862	128	232	544	17	67	720	854	57	582	769	212	264	162	54	755
Wetland/ lake area	0.9	31.3	0.8	0.7	6.3	2.1	3.9	14.2	9.3	3.6	30.4	11.8	3.3	5.5	22.6	2.0	3.3
Potential connectivity	3	4	3	1	2	5	1	6	2	1	1	2	5	5	4	3	6
Inlet/outlet	2	3	3	0	3	1	0	3	1	0	2	2	2	4	3	1	5
Horizontal distance (m)	252	0	513	295	890	37	466	0	1213	579	2070	1534	166	0	0	438	0
Water bodies 500m buffer (ha)	1.52	0	2.2	0	1.24	5.54	0	6.08	2.6	0	0	1.39	12.6	2.12	0.54	2.36	16.7

Table 7. Correlation matrix for 17 environmental variables including specific conductance (sp.cond), sediment phosphorus (phosphorus), sediment nitrogen (nitrogen), shoreline development (SD), chlorophyll-a fluorescence (chla), phycocyanin fluorescence (PC), wetland-lake area ratio (wetlands), potential connectivity index (connectivity), horizontal distance (H-distance), water body area (WB area), and number of inlet/outlet (inlet/outlet) of 17 lakes in the Yazoo River Basin, Mississippi, 2006. Specific conductance was strongly correlated with major ions (Ca and Mg; r>0.8; P<0.01) and sediment nitrogen and carbon were highly correlated (r>0.9; P<0.01) with each other; therefore, these correlations were not included in this table.

Variable	Temperature	DO	pH	Depth	Sp.cond	Turbidity	Chla	PC	Chla/PC	Nitrogen	Area	Phosphorus	SD	Wetlands
DO	0.52													
pH	0.36	0.45												
Depth	0.11	0.10	0.16											
Sp.cond	0.24	-0.04	0.31	0.10										
Turbidity	0.10	-0.03	0.04	-0.73	0.01									
Chla	-0.30	-0.18	-0.30	-0.68	-0.40	0.56								
PC	-0.16	-0.12	0.20	-0.39	-0.35	0.48	0.63							
Chla/PC	-0.24	-0.06	-0.50	-0.30	-0.12	0.00	0.37	-0.43						
Nitrogen	-0.21	-0.17	-0.64	0.05	-0.38	-0.41	0.16	-0.27	0.46					
Area	0.39	0.16	0.80	0.13	0.27	0.04	-0.29	0.03	-0.27	-0.40				
Phosphorus	-0.13	-0.45	-0.37	-0.05	0.48	-0.21	0.04	-0.22	0.24	0.38	-0.22			
SD	0.23	0.07	0.51	0.41	0.15	0.01	-0.38	0.19	-0.51	-0.57	0.57	-0.30		
Wetlands	-0.12	-0.46	-0.75	0.03	0.05	-0.17	0.16	-0.38	0.62	0.49	-0.47	0.60	-0.33	
Connectivity	-0.08	-0.07	0.03	0.43	0.49	-0.03	-0.41	-0.39	-0.08	-0.38	0.02	0.03	0.39	0.04
H-distance	-0.02	0.05	0.17	-0.49	-0.36	0.13	0.23	0.23	0.02	0.14	0.12	-0.26	-0.48	-0.30
WB area	0.11	-0.06	0.19	0.17	0.38	0.29	-0.44	-0.27	-0.28	-0.43	0.25	-0.20	0.34	-0.25
Inlet/outlet	0.11	-0.10	0.00	0.17	0.66	0.00	-0.26	-0.47	0.15	-0.10	0.24	0.45	0.28	0.28

Table 8. Loadings of the first three axes of seven environmental variables on principal components analysis (PCA) of 16 lakes in the Yazoo River Basin, Mississippi, 2006. The summer and fall surface water samples were used for this PCA. The first three axes accounted for 75% of total variation (axis 1: 31%, axis 2: 26%, and axis 3: 18%).

Variable	Axis1	Axis2	Axis3
Specific conductance	0.350	-0.241	-0.418
Turbidity	0.180	0.408	-0.394
Phycocyanin	-0.144	0.674	-0.147
Chlorophyll-a	-0.530	0.372	-0.037
Chlorophyll-a/phycocyanin	-0.495	-0.282	0.122
DO	0.154	0.194	0.762
pH	0.524	0.258	0.229

Table 9. Loadings of axes 1, 2, and 3 on eight environmental variables on principal components analysis of 17 lakes in the Yazoo River Basin, Mississippi, 2006. Axes 1, 2, and 3 accounted for 73% of total variation (axis 1: 35%, axis 2: 23%, and axis 3: 16%).

Variable	Axis 1	Axis 2	Axis 3
DO	-0.172	0.356	0.287
Depth	-0.341	-0.311	0.549
Sp.cond	-0.332	-0.304	-0.468
Chlorophyll-a	0.455	0.234	-0.329
Nitrogen	0.377	-0.256	0.477
Wetland/lake area	0.315	-0.566	-0.018
Connectivity	-0.365	-0.393	-0.237
Chla/PC	0.404	-0.298	-0.074

Table 10. List of common names, scientific names, family names, and species identification acronym (ID) for the species collected in the 17 lakes in the Yazoo River Basin, Mississippi, 2006.

Common name	Scientific name	Family	ID
Spotted gar	*Lepisosteus oculatus*	Lepisosteidae	SPGAR
Longnose gar	*Lepisosteus osseus*	Lepisosteidae	SNGAR
Shortnose gar	*Lepisosteus platostomus*	Lepisosteidae	LNGAR
Bowfin	*Amia calva*	Amiidae	BOW
American eel	*Anguilla rostrata*	Angillidae	EEL
Gizzard shad	*Dorosoma cepedianum*	Clupeidae	GSHAD
Threadfin shad	*Dorosoma petenense*	Clupeidae	TSHAD
Grass carp	*Ctenopharyngodon idella*	Cyprinidae	GCARP
Blacktail shiner	*Cyprinella venusta*	Cyprinidae	BLACK
Common carp	*Cyprinus carpio*	Cyprinidae	CCARP
Silver carp	*Hypophthalmichthys molitrix*	Cyprinidae	SCARP
Golden shiner	*Notemigonus crysoleucas*	Cyprinidae	GOLD
Taillight shiner	*Notropis maculatus*	Cyprinidae	TAIL
Pugnose minnow	*Opsopoeodus emiliae*	Cyprinidae	PUG
Bullhead minnow	*Pimephales vigilax*	Cyprinidae	BLHM
Creekchub sucker	*Erimyzon oblongus*	Catostomidae	CRKCS
Smallmouth buffalo	*Ictiobus bubalus*	Catostomidae	SMBUF
Bigmouth buffalo	*Ictiobus cyprinellus*	Catostomidae	BMBUF
Black buffalo	*Ictiobus niger*	Catostomidae	BLBUF
Spotted sucker	*Minytrema melanops*	Catostomidae	SPSUCK
Blacktail redhorse	*Moxostoma poecilurum*	Catostomidae	BTRH
Black bullhead	*Ameiurus melas*	Ictaluridae	BBUL
Yellow bullhead	*Ameiurus natalis*	Ictaluridae	YBUL
Blue catfish	*Ictalurus furcatus*	Ictaluridae	BCF
Channel catfish	*Ictalurus punctatus*	Ictaluridae	CCF
Tadpole madtom	*Noturus gyrinus*	Ictaluidae	TMAD
Flathead catfish	*Pylodictis olivaris*	Ictaluridae	FHCF
Chain pickerel	*Esox niger*	Esocidae	CHPIC
Pirate perch	*Aphredoderus sayanus*	Aphredoderidae	PIRP
Brook silverside	*Labidesthes sicculus*	Atherinidae	BSILV
Golden topminnow	*Fundulus chrysotus*	Fundulidae	GTM
Northen starhead topminnow	*Fundulus dispar dispar*	Fundulidae	NSTM
Blackspotted topminnow	*Fundulus olivaceus*	Fundulidae	BSTM
Western mosquitofish	*Gambusia affinis*	Poeciliids	GAM

Table 10. Continue.

Common name	Scientific name	Family	ID
White bass	*Morone chrysops*	Percichthyidae	WB
Yellow bass	*Morone mississippiensis*	Percichthyidae	YB
Green sunfish	*Lepomis cyanellus*	Centrarchidae	GSF
Warmouth	*Lepomis gulosus*	Centrarchidae	WAR
Orangespotted sunfish	*Lepomis humilis*	Centrarchidae	OSS
Bluegill	*Lepomis macrochirus*	Centrarchidae	BG
Longear sunfish	*Lepomis megalotis*	Centrarchidae	LE
Redear sunfish	*Lepomis microlophus*	Centrarchidae	RED
Hybrid sunfish		Centrarchidae	HYBSUN
Largemouth bass	*Micropterus salmoides*	Centrarchidae	LMB
Spotted bass	*Micropterus punctulatus*	Centrarchidae	SBASS
White crappie	*Pomoxis annularis*	Centrarchidae	WC
Black crappie	*Pomoxis nigromaculatus*	Centrarchidae	BC
Bluntnose darter	*Etheostoma chlorosoma*	Percidae	BLNTD
Swamp darter	*Etheostoma fusiforme*	Percidae	SWMPD
Cypress darter	*Etheostoma proeliare*	Percidae	CYPD
Speckled darter	*Etheostoma stigmaeum*	Percidae	SPCKD
Freshwater drum	*Aplodinotus grunniens*	Sciaenidae	FWD
Pygmy sunfish	*Elassoma zonatum*	Elassomatidae	PYGMY

Table 11. List of riverine and lacustrine species for 26 fish taxa of 17 lakes in the Yazoo River Basin, Mississippi, 2006. These groups were classified by life history strategies according to Winemiller (1992) with modification by Ross (2001).

Riverine species	Lacustrine species
Spotted gar	Channel catfish
Longnose gar	Largemouth bass
Shortnose gar	White crappie
Freshwater drum	Bowfin
American eel	Black crappie
Smallmouth buffalo	Black bullhead
Black buffalo	Yellow bullhead
Bigmouth buffalo	Green sunfish
Common carp	Warmouth
Spotted sucker	Bluegill
Blue catfish	Longear sunfish
Flathead catfish	Redear sunfish
Spotted bass	Orangespotted sunfish

Table 12. Presence/absence of fish taxa of 17 lakes in the Yazoo River Basin, Mississippi, 2006. X = present in summer and fall, S = present in summer, and F = present in fall. Blanks in the table indicate absence of fish in summer and fall.

Species code	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Ole	Pleasant	Robinson	Sidon	Sixmile	Town	Walker	Wasp
SPGAR	X	X	X	X	X	X	X	X	X	S	X	X	X	X	X	X	X
LNGAR						X		X						S		F	
SNGAR		S	S			F		X		S			F	F	X		X
BOW	F	X		F	X	S		S	F	S	X	X		S	X		F
EEL														S			S
GSHAD	X	X	X	X	X	S	X	X	X	S	X	X	X	X	X	X	X
TSHAD	X	X	X		X	X	X	X	X	S	X	X	X	X	X	X	X
GCARP					F												
BLACK													F				
CCARP	X	X	S	X	X	F		S	F		F	X	X	X	X	F	X
SCARP													F				
GOLD	X	S		X	X					S	S			S	S		S
TAIL	X				X	X	S	S	F	S	S	X				X	
PUG	X		F		X	X	X	S	F		S	X	X	S	F	X	S
BLHM	F												X				
CRKCS												F					
SMBUF	X	X	X		X	X	X	X	X	S	X	X	X	X	X	X	X
BLBUF		S					S	S			F	S	F	S			S
SPSUCK								S				F	F				
BTRH													F				
BBUL		F	F	F							F	S			F		
YBUL	X		F		S				F		S				X		
BCF	F				S			F					F	S	S		S
CCF	X		X	X			X	S	X	S	S	S	X	X	X	X	X
TMAD					S												

Table 12. Continued.

Species code	Bee	Blue	Dump	Horse shoe	Little Eagle	Long Brake	Macon	McIntyre	Mossy	Ole	Pleasant	Robinson	Sidon	Sixmile	Town	Walker	Wasp
FHCF			S					S					X	S			F
CHPIC												X					
PIRP		X					S					S					
BSILV	X	X	X		X	X	X	S	X	S	X	X	S	X	X	X	X
GTM		X															
NSTM												S					
BSTM	X					S	X					X	S		F	F	
GAM	X	F		X		F		S		S	X	S	S	F	S	F	X
WB																	X
GSF	F	S	X	F			X	S			S		F	F		X	
WAR	X	X	X	X	X	X	X	X	X	S	X	X	X	X	X	X	X
OSS	X	X	X	X	X	X	X	X	X	S	X	X	X	X	S	X	X
BG	X	X	X	X	X	X	X	X	X	S	X	X	X	X	X	X	X
LE	X	X	X	X	X	X	X	X				S	X	X	S	X	X
RED	S			S	X	S	X	S			X	X	X				
HYBSUN		S		X							F					F	
LMB	X	X	X	X	X	X	X	X	X	S	X	X	X	X	X	X	X
SBASS		S						S					F				
WC	X	X	X	X	S	X	X	X	X	S	X	X	X	X	X	F	X
BC	F	X	F	X	X	X	F		X	S	X	X	F	F			F
BLNTD	S					S		S			S						
SWMPD							S										
CYPD											S						
SPCKD					S							S					
FWD	X	S	X	X	F	X	X	X	X			X	X	X	X	X	X
PYGMY											S						

Table 13. Percentage composition by fish family in collections made in 17 lakes of the Yazoo River Basin, Mississippi, 2006.

Family	Summer (%)	Fall (%)	Summer and Fall (%)
Amiidae	0.14	0.5	0.28
Angillidae	0.01	0	0
Aphredoderidae	0.02	0.01	0.02
Atherinidae	3.43	3.43	3.43
Catostomidae	3.75	9.1	5.83
Centrarchidae	23.42	28.04	25.21
Clupeidae	64.45	52.42	59.78
Cyprinidae	2.28	2.04	2.19
Esocidae	0.01	0.03	0.02
Fundulidae	0.04	0.07	0.05
Ictaluridae	0.39	0.65	0.49
Lepisosteidae	1.22	2.86	1.85
Percichthyidae	0.01	0.06	0.03
Percidae	0.04	0	0.02
Poeciliidae	0.23	0.11	0.18
Sciaenidae	0.51	0.66	0.57

Table 14. Species richness computed based on 26 fish species, riverine species, and lacustrine species of 17 lakes in the Yazoo River Basin, Mississippi, 2006.

Lake	26 fishes	Riverine species	Lacustrine species
Bee	18	6	12
Blue	18	8	10
Dump	18	7	11
Horseshoe	15	3	12
Little Eagle	16	6	10
Long Brake	16	7	9
Macon	15	5	10
McIntyre	22	12	10
Mossy	14	5	9
Ole	12	4	8
Pleasant	17	5	12
Robinson	18	7	11
Sidon	21	11	10
Sixmile	21	11	10
Town	18	7	11
Walker	14	6	8
Wasp	19	10	9
Mean	17	7	10
Max	22	12	12
Min	12	3	8
Range	10	9	4

Table 15. Pearson correlation coefficients between 17 environmental variables and species richness of percentage composition of 26 fish species and riverine and lacustrine species of 17 lakes in the Yazoo River Basin, Mississippi, 2006.

Variable	26 fishes	Riverine species	Lacustrine species
Temperature	0.11	0.11	0
Dissolved oxygen	-0.14	-0.02	-0.25
pH	0.08	-0.05	0.27
Depth	0.43	0.42	0.06
Specific conductance	0.59	0.54	0.16
Turbidity	-0.21	-0.12	-0.21
Chlorophyll-a	-0.54	-0.55	-0.05
Phycocyanin	-0.45	-0.59	0.23
Nitrogen	-0.3	-0.22	-0.2
Area	0.23	0.04	0.4
Phosphorus	0.37	0.26	0.27
Shoreline development	0.39	0.28	0.27
Wetland/lake area	0.22	0.19	0.08
Potential connectivity	0.73	0.87	-0.22
Inlet/outlet	0.72	0.73	0.09
Horizontal distance	-0.69	-0.6	0.11
Water body area	0.71	0.52	-0.33

Table 16. Pearson correlation coefficients between 17 environmental variables and percentage composition of 26 fish species including chlorophyll-a fluorescence (chla), specific conductance (sp.cond), sediment nitrogen (nitrogen), sediment phosphorus (phosphorus), shoreline development (SD), wetland-lake area ratio (wetlands), potential connectivity (connectivity), number of inlet/outlet (inlet/outlet), water body area (WB area), and horizontal distance (H-distance) of the 17 lakes in the Yazoo River Basin, Mississippi, 2006.

Variable	SPGAR	LNGAR	SNGAR	EEL	CCARP	SMBUF	BMBUF	BLBUF	SPSUCK	BCF	FHCF	SBASS	FWD
Area	-0.45	-0.32	-0.17	0.17	0.06	-0.14	-0.32	-0.04	0.07	0.42	0.21	-0.03	0.44
Chla	0.27	0.1	-0.28	-0.18	-0.17	-0.37	-0.23	-0.36	-0.53	-0.51	-0.66	-0.47	-0.47
Sp. cond	0.17	0.01	0.56	0.4	0.47	0.54	0.36	0.25	0.07	0.35	0.62	0.25	0.46
Depth	0.04	0.17	0.39	0.06	0.32	0.38	0.52	0.3	0.38	0.41	0.54	0.66	0.36
Nitrogen	0.13	-0.19	-0.2	-0.23	-0.1	-0.16	0.15	-0.06	-0.03	-0.28	-0.28	-0.05	-0.42
PC	-0.23	0.16	-0.23	-0.2	-0.3	-0.45	-0.45	-0.49	-0.47	-0.26	-0.47	-0.47	-0.25
Turbidity	0.07	0.19	0.03	0.18	-0.13	0.06	-0.21	-0.09	-0.2	-0.18	-0.11	-0.39	0.08
Wetlands	0.65	-0.02	0.18	-0.05	0.35	0.25	0.52	0.45	0.16	-0.04	-0.04	0.33	-0.32
Temperature	-0.39	-0.23	-0.16	0.53	-0.23	0.11	-0.21	0.27	-0.14	0.15	0.28	-0.12	0.45
DO	-0.24	-0.1	-0.23	0.32	-0.3	-0.12	-0.33	0.07	-0.27	-0.2	0.08	-0.11	0.17
pH	-0.54	-0.12	-0.16	0.1	-0.08	-0.23	-0.44	-0.2	-0.12	0.27	0.22	-0.04	0.41
Phosphorus	0.34	0.04	0.33	0.16	0.32	0.18	0.43	0.32	0.08	0.08	0.28	0.2	-0.28
SD	-0.03	-0.03	0.27	0.35	0.32	0.23	0.11	0.13	0.06	0.49	0.26	0.18	0.35
Connectivity	0.46	0.5	0.73	0.41	0.71	0.87	0.78	0.33	0.32	0.55	0.62	0.48	0.54
Inout/outlet	0.5	0.03	0.57	0.6	0.69	0.72	0.64	0.41	0.09	0.51	0.49	0.21	0.36
WB area	0	0.39	0.46	0.33	0.43	0.7	0.42	0.27	0.46	0.59	0.64	0.29	0.63
H-distance	-0.66	-0.37	-0.78	-0.53	-0.62	-0.75	-0.83	-0.36	-0.04	-0.32	-0.46	-0.43	-0.26

Table 16. continued.

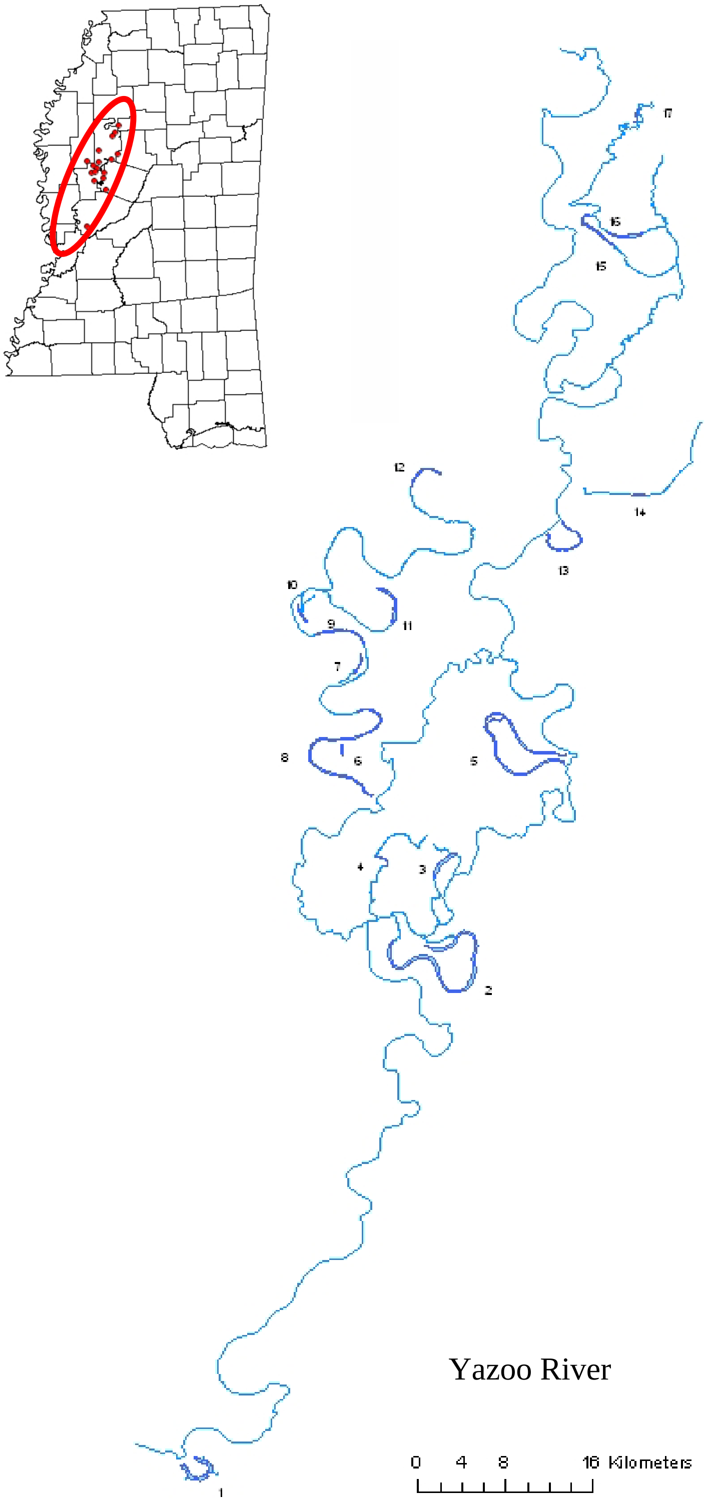
Variable	BOW	BBUL	YBUL	CCF	GSF	WAR	OSS	BG	LE	RED	LMB	WC	BC
Area	-0.4	-0.1	0.12	0.59	-0.03	0.06	-0.03	-0.08	0.35	0.08	0.25	0.26	-0.01
Chla	0.32	0.12	0.09	-0.24	-0.27	0.45	0.4	0.21	-0.43	0.18	-0.09	0.22	0.45
Sp.cond	0.03	0.15	0.23	0.03	0.01	-0.27	-0.08	-0.62	0.23	-0.28	-0.05	0.21	-0.17
Depth	-0.08	-0.14	0.02	0.16	0.47	-0.27	-0.35	-0.27	0.35	-0.32	-0.18	-0.39	-0.56
Nitrogen	0.45	0.01	0.13	-0.43	-0.05	-0.13	-0.52	0.44	-0.57	0.39	0.26	-0.43	0.26
Phosphorus	0.63	0.37	0.25	-0.45	-0.1	-0.14	-0.21	-0.13	-0.34	0.25	-0.02	-0.23	0.35
Phycocyanin	-0.12	0.1	0.04	0.26	-0.15	0.62	0.7	0.19	0.04	0.02	-0.28	0.27	0.15
Turbidity	-0.21	-0.09	-0.2	-0.01	-0.4	0.14	0.43	-0.2	-0.18	-0.05	-0.3	0.61	0.15
Wetlands	0.80	0.41	0.14	-0.54	0.01	-0.32	-0.51	-0.13	-0.65	0.18	-0.17	0.02	0.45
Temperature	-0.41	-0.23	-0.08	0.6	0.22	-0.25	-0.11	-0.06	0.14	-0.37	-0.15	0.43	-0.2
DO	-0.62	-0.25	-0.48	0.35	0.6	0.12	0.18	0.17	0.38	-0.4	0.24	-0.03	-0.29
pH	-0.65	-0.14	0	0.68	0.25	0.33	0.41	-0.03	0.64	-0.23	0.23	0.19	-0.25
SD	-0.21	-0.01	-0.16	0.44	0.02	-0.06	0	-0.43	0.3	-0.29	-0.42	0.2	-0.27
Connectivity	-0.03	-0.28	-0.1	-0.25	-0.08	-0.54	-0.25	-0.86	0.33	-0.32	-0.45	-0.01	-0.57
Inlet/outlet	0.27	0.06	0.17	-0.20	-0.12	-0.65	-0.53	-0.67	0.03	-0.06	-0.24	-0.05	-0.11
WB area	-0.44	-0.52	-0.19	-0.10	-0.28	-0.51	-0.17	-0.64	0.35	-0.10	-0.32	0.23	-0.51
H-distance	-0.31	0.02	0.14	0.21	-0.03	0.40	0.26	0.78	0.00	0.49	0.65	0.06	0.42

Table 17. Percentage contribution to variance by 17 environmental variables on the canonical correspondence ordination (CCA) of 26 fish taxa, riverine and lacustrine species of 17 lakes in the Yazoo River Basin, Mississippi, 2006.

	26 fishes	Riverine species	Lacustrine species
Variable	Variation (%)	Variation (%)	Variation (%)
Area	7.4	12.9	6.4
Chlorophyll-a	10.4	14.4	10.6
Specific conductance	11	9.4	6.9
Potential connectivity index	27.5	15.6	10.9
Horizontal distance	23.3	7.6	8.5
Number of Inlets/outlets	18.0	7.6	5.9
Water body area	19.5	13.2	13.6
Depth	11	7.9	10.9
DO	8.9	3.8	14.1
Sediment nitrogen	11.4	6.8	18.4
Phycocyanin	7.8	8.2	3.5
Chlorophyll-a/Phycocyanin	10.4	8.8	14.9
pH	13.3	11.8	15.2
Sediment phosphorus	8.9	5.9	10.6
Shoreline development	7.2	6.5	7.7
Temperature	7.4	9.4	10.1
Turbidity	5.9	3.5	11.4
Wetland-lake area ratio	15.7	10.0	19.1

FIGURES

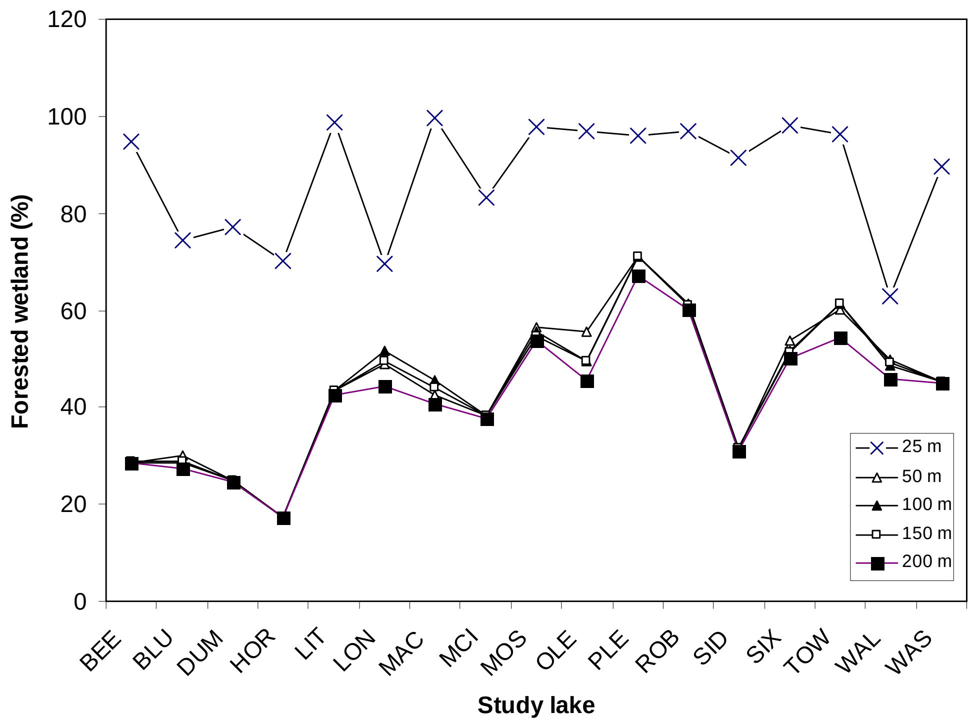
Figure 1. Study sites in the Yazoo River Basin, Mississippi, 2006.



ID	Lake name
1	Dump
2	Bee
3	Little Eagle
4	Townsend
5	Horseshoe
6	Ole
7	Walker
8	Wasp
9	Sixmile
10	Macon
11	Mossy
12	Blue
13	Sidon
14	Pleasant
15	McIntyre
16	Robinson
17	Long Brake

Figure 1 continued.

Figure 2. Percentages of forested wetlands (upper) and agricultural lands (lower) within 25, 50, 100, 150, and 200 m buffer zones of 17 lakes in the Yazoo River Basin, Mississippi, 2006.



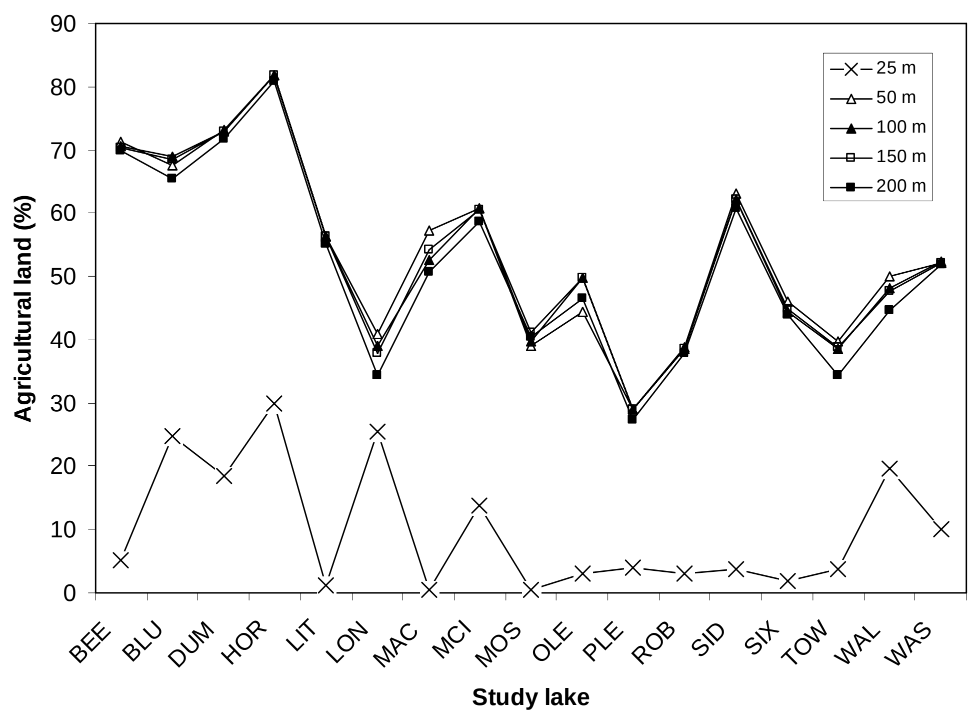


Figure 2 continued.

Figure 3. Axes 1 and 2 from a principal components analysis of seven water quality variables in the summer (solid circle) and fall (empty circle) data (n=32) of 16 lakes in the Yazoo River Basin, Mississippi, 2006.

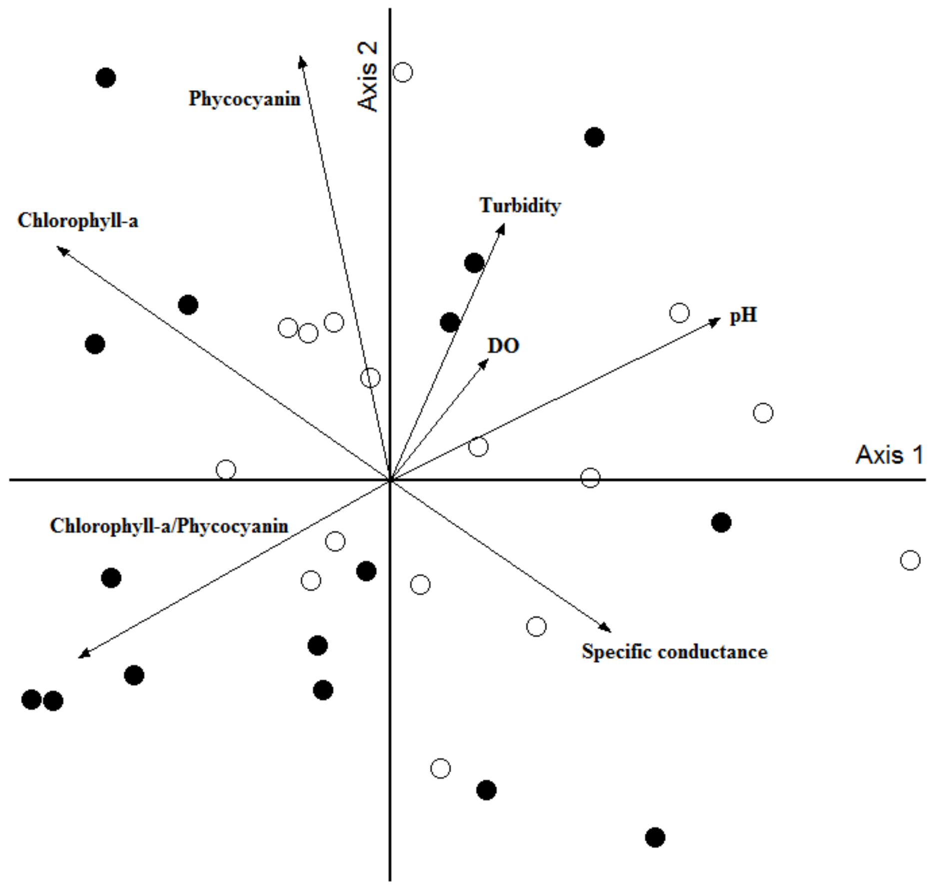


Figure 3 continued.

Figure 4. Axes 1 and 2 from a principal components analysis of eight environmental variables in the summer samples of 17 lakes in the Yazoo River Basin, Mississippi, 2006. Symbols represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon).

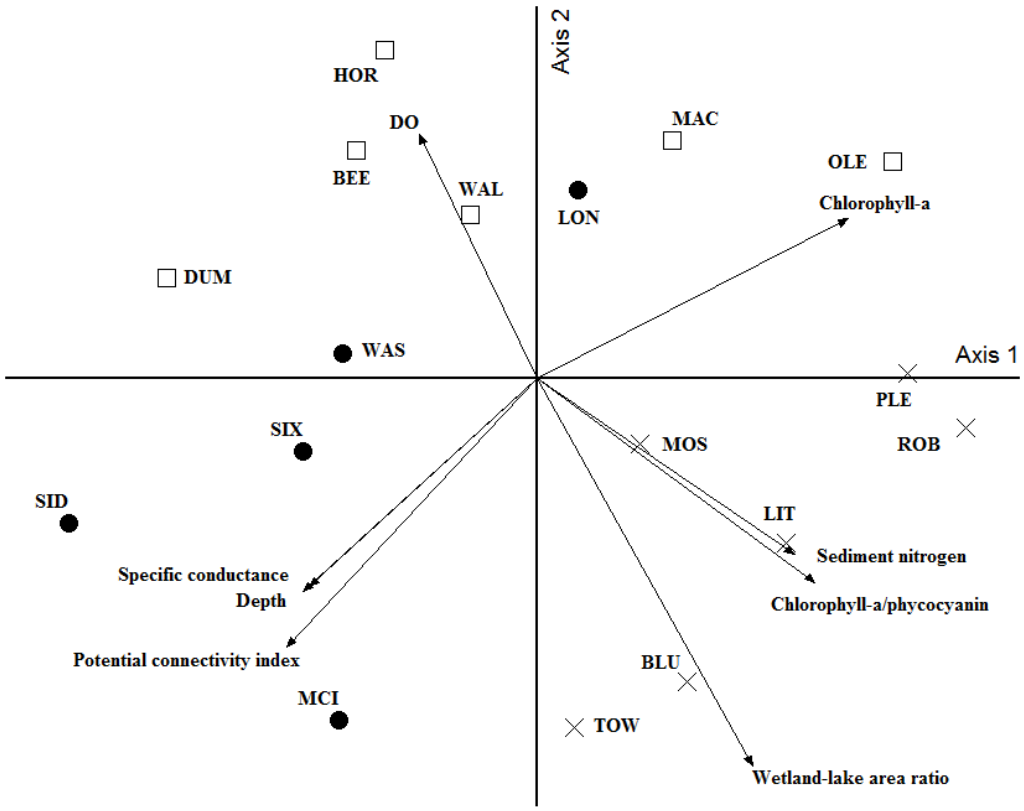
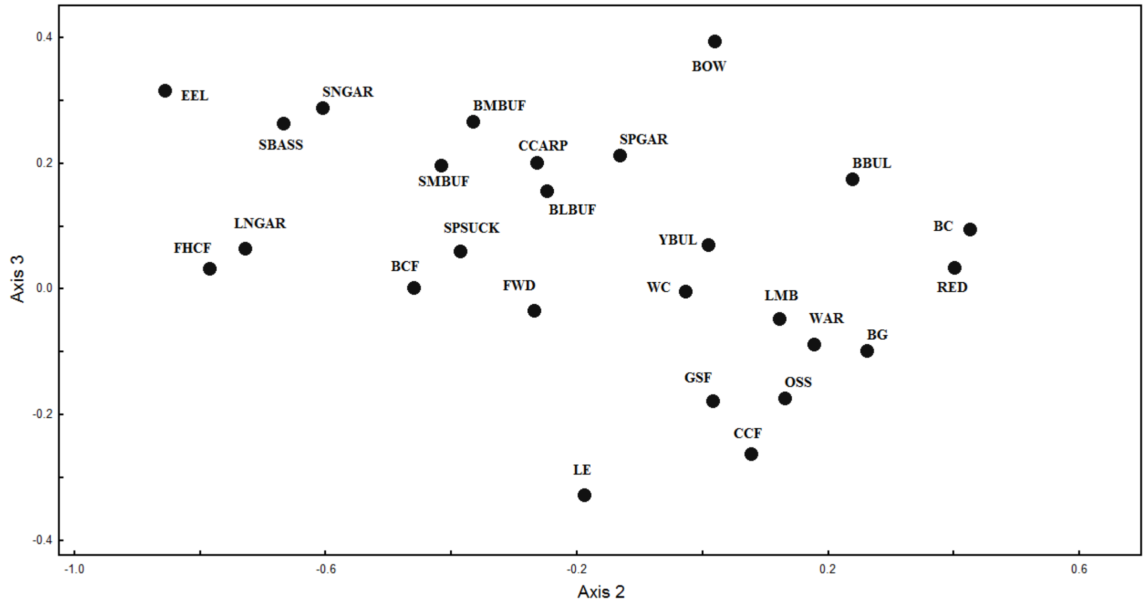


Figure 4 continued.

Figure 5. Ordination plot based on species (upper) and site (lower) scores of nonmetric multidimensional scaling axes 1 and 3 for 26 fish taxa. Symbols in lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon) of 17 lakes in the Yazoo River Basin, Mississippi, 2006.



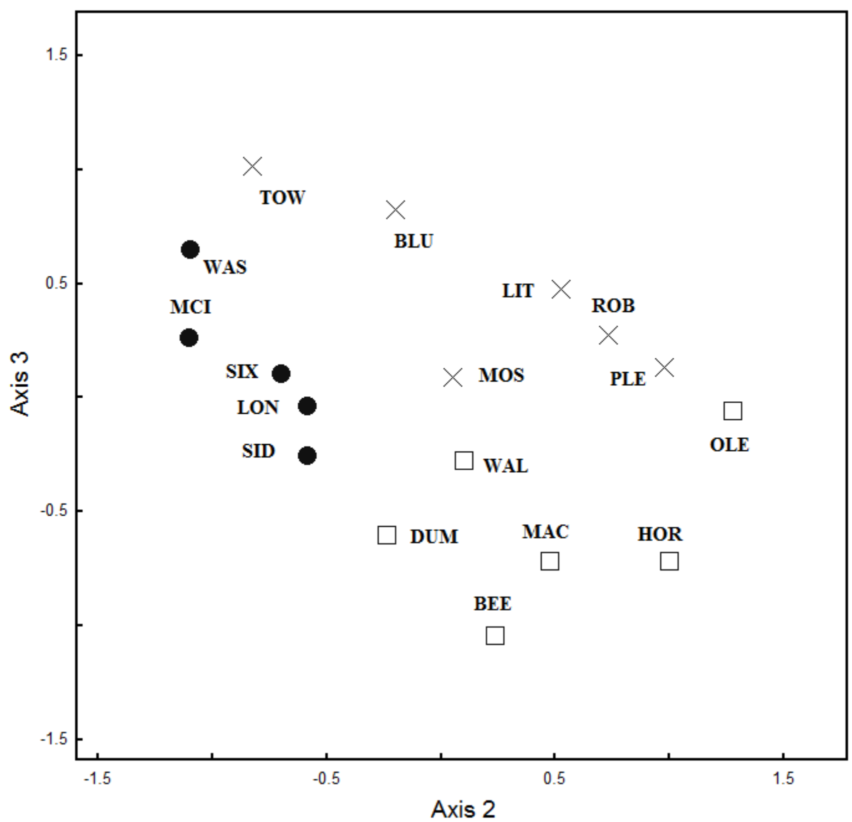
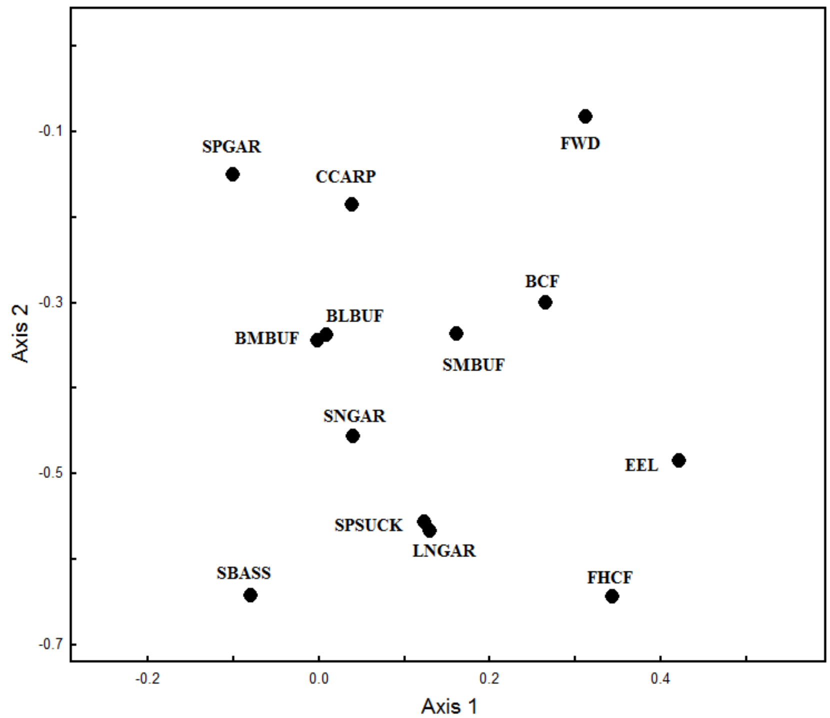


Figure 5 continued.

Figure 6. Ordination plot based on species (upper) and site (lower) scores of nonmetric multidimensional scaling axes 1 and 2 for riverine species. Symbols in the lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon) of 17 lakes in the Yazoo River Basin, Mississippi, 2006.



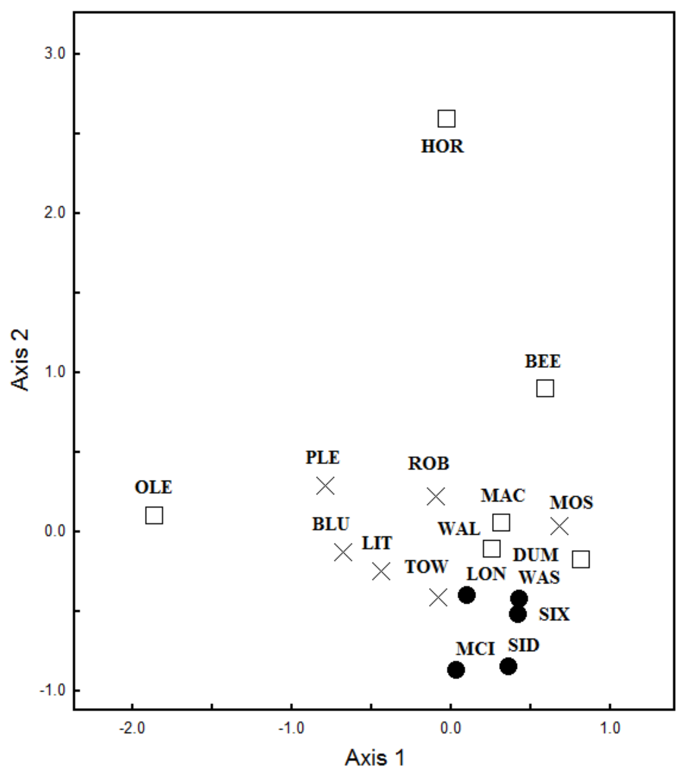


Figure 6 continued.

Figure 7. Ordination plot based on species (upper) and site (lower) scores of nonmetric multidimensional scaling axes 1 and 2 for lacustrine species. Symbols in lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon) of 17 lakes in the Yazoo River Basin, Mississippi, 2006.

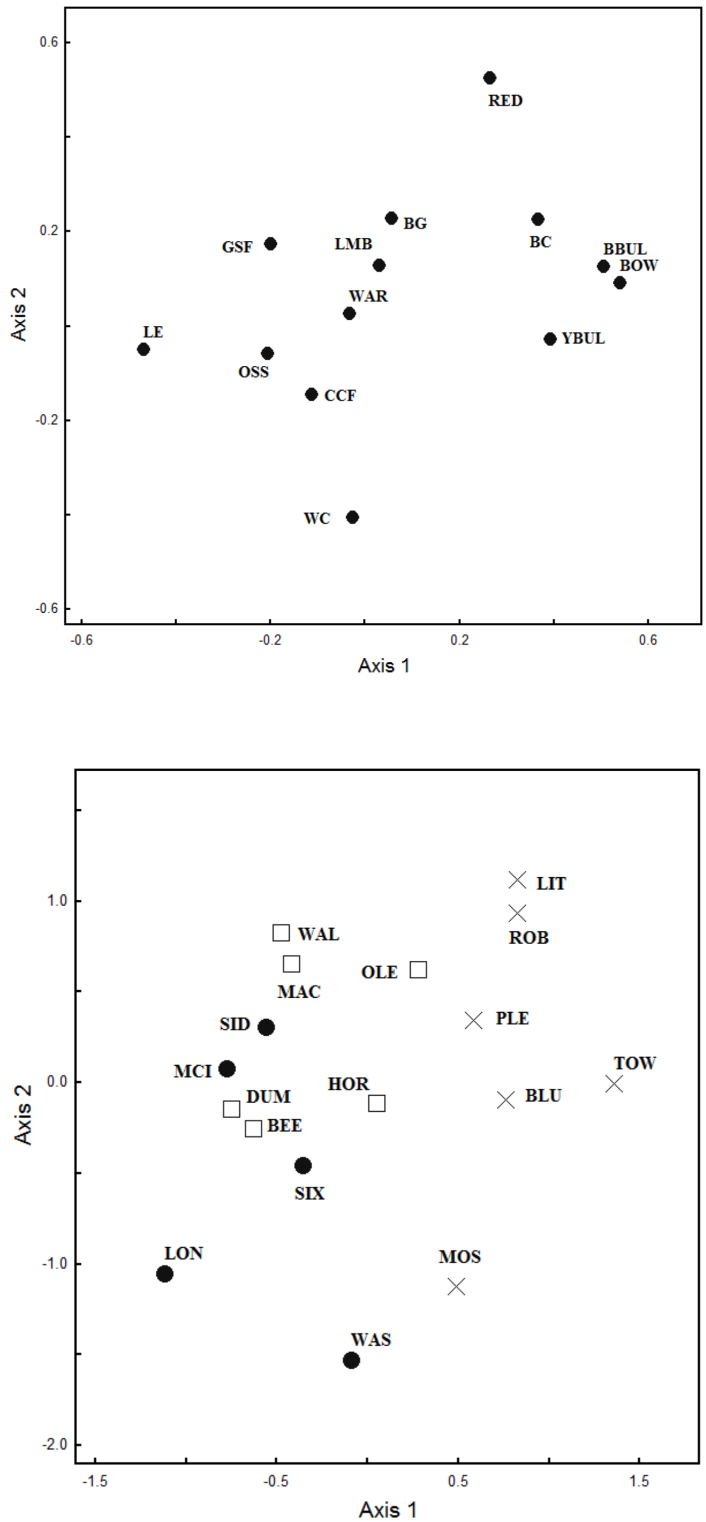
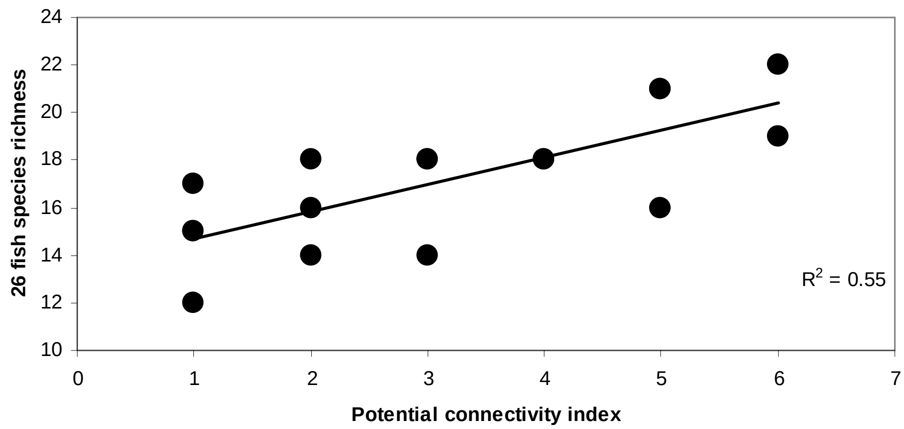
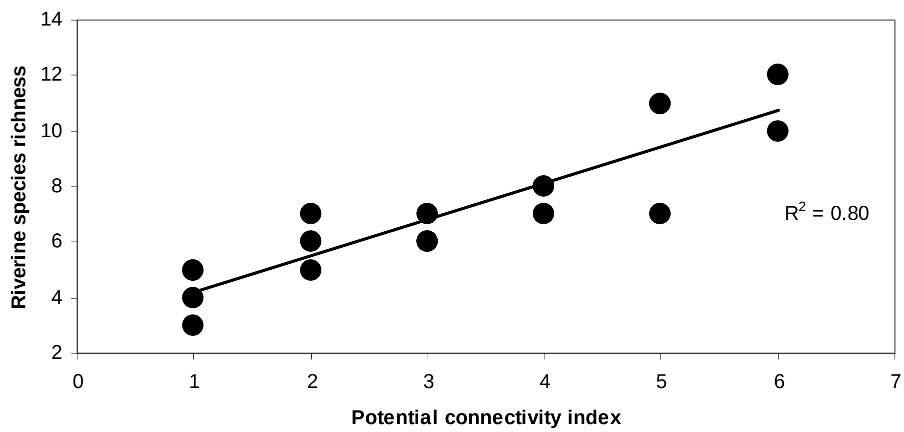


Figure 7 continued.

Figure 8. Species richness of 26 fish species (upper), riverine species (middle), and lacustrine species (lower) relative to potential connectivity of 17 lakes in the Yazoo River Basin, Mississippi, 2006.





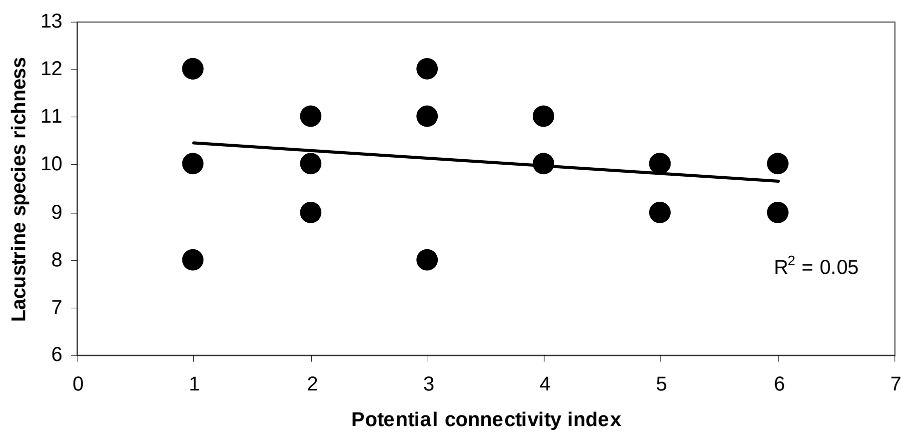
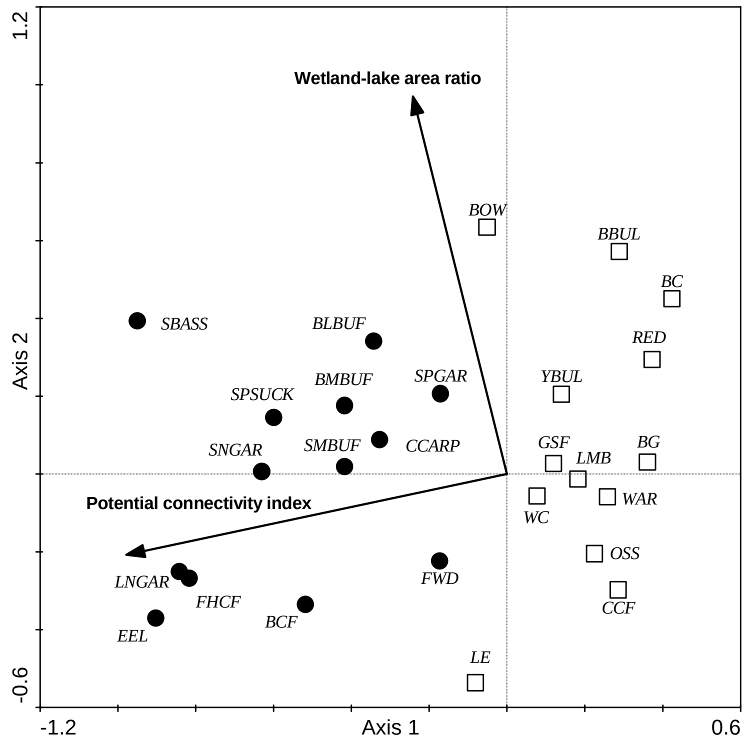


Figure 8 continued.

Figure 9. Ordination of species (upper) and site (lower) scores computed by canonical correspondence analysis for percent composition of 26 fish taxa of 17 lakes in the Yazoo River Basin, Mississippi, 2006. The length of the arrows identify the strength of the connection between the species/site scores and environmental variables. Symbols in the upper plot represent fish assemblage types (solid circle: riverine species; empty square: lacustrine species). Symbols in the lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon).



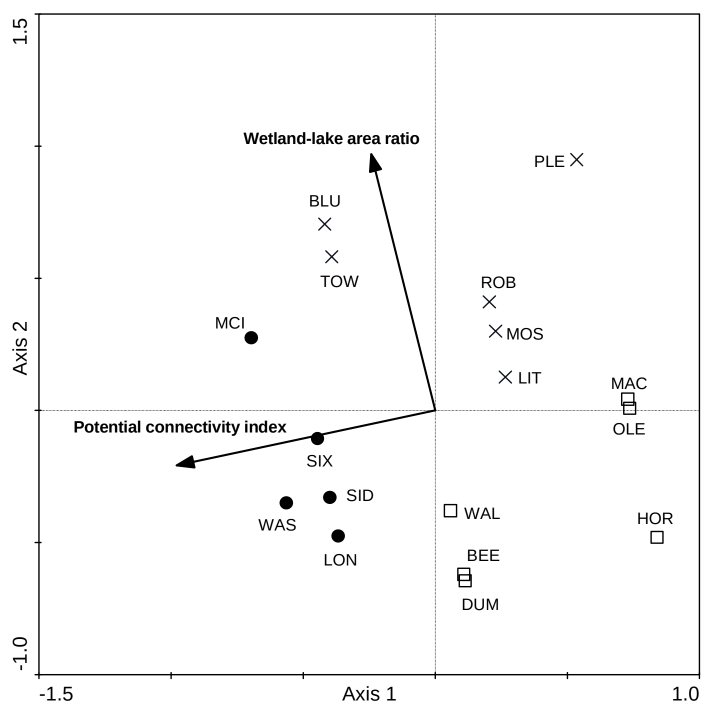


Figure 9 continued.

Figure 10. Ordination of species (upper) and site (lower) scores computed by canonical correspondence analysis for percent composition of riverine species of 17 lakes in the Yazoo River Basin, Mississippi, 2006. The arrow length identifies the strength of the connection between the species scores and environmental variables. Symbols in the lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon).

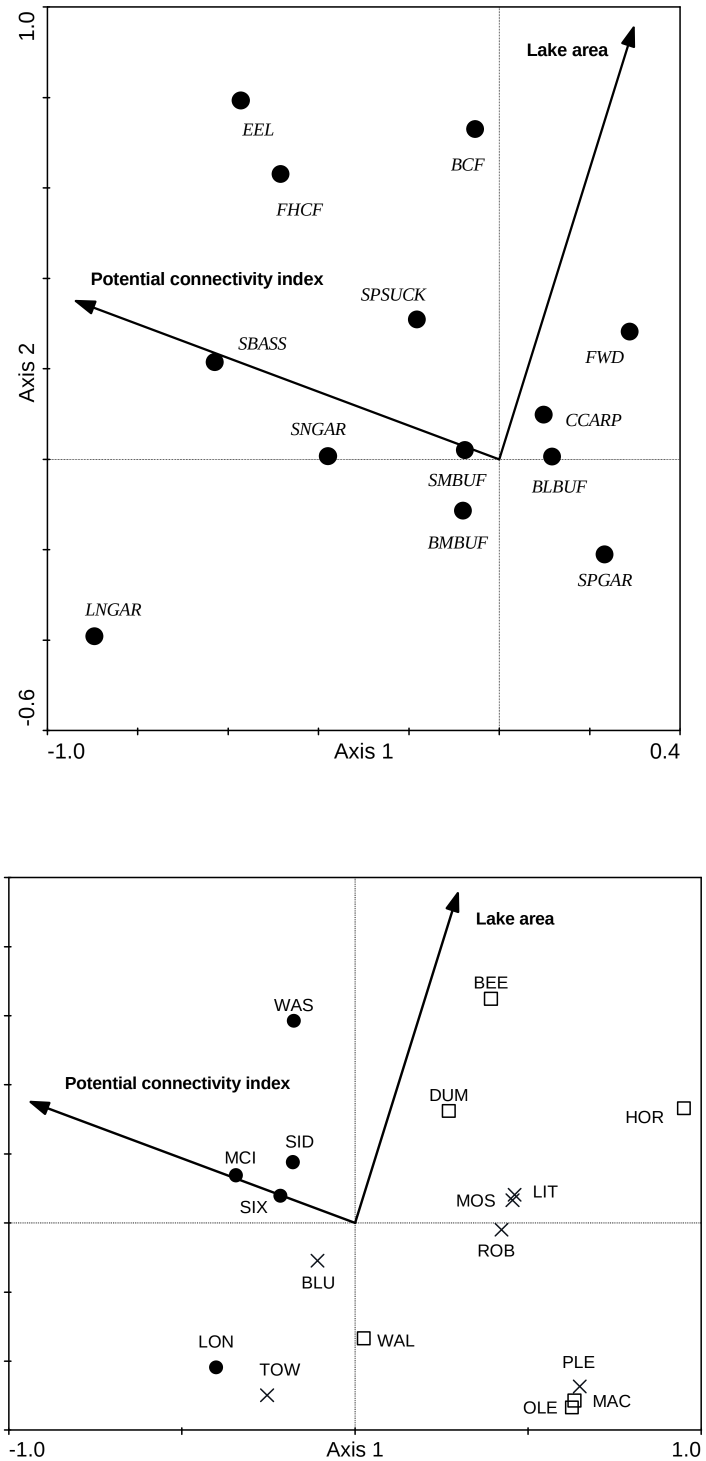
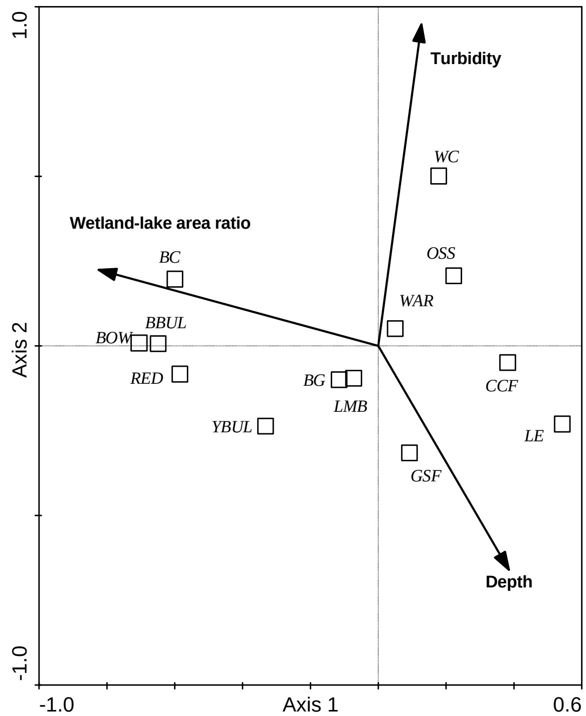


Figure 10 continued.

Figure 11. Ordination of species (upper) and site (lower) scores computed by canonical correspondence analysis for percent composition of lacustrine species of 17 lakes in the Yazoo River Basin, Mississippi, 2006. The arrow length identifies the strength of the connection between the species scores and environmental variables. Symbols in the lower plot represent lake ontogenetic types (solid circle: parapotamon, empty square: plesiopotamon, and cross: paleopotamon).



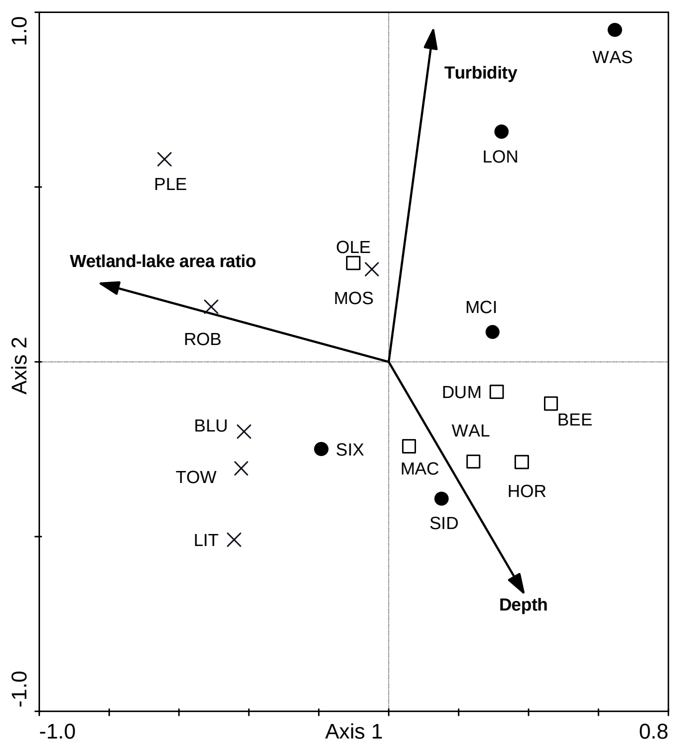


Figure 11 continued.