1-2014

Habitat Associations of Fish Assemblages in the Cache River, Illinois

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Recommended Citation

Bouska, Kristen L. and Whitledge, Gregory. "Habitat Associations of Fish Assemblages in the Cache River, Illinois." *Environmental Biology of Fishes* 97, No. 1 (Jan 2014): 27-42. doi:10.1007/s10641-013-0120-z.

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Key words: fish assemblages, habitat associations, conservation, restoration

Abstract:

Fish and habitat were sampled by state agencies at 48 stations throughout the Cache River watershed, Illinois between 1992 and 2009. Two distinct fish assemblages were identified, one primarily found in the lower mainstem Cache River and a second found throughout tributaries and the upper mainstem Cache River. Using a canonical correspondence analysis, the distribution of fish species was largely explained by substrate, land use, drainage area and local habitat features. Creek chub, central stoneroller, fringed darter and fantail darter are species found to be positively associated with gravel substrate and forest. In contrast, black buffalo, gizzard shad, smallmouth buffalo, freshwater drum and bigmouth buffalo were positively associated with drainage area, silt, channel width and row crops. Cobble appears to be rare habitat associated with fringed darter, freckled madtom and fantail darter. Results suggest that substrate, land use and local habitat features influence fish assemblage within the Cache River watershed. This information contributes to both understanding aquatic community structure in a highly altered yet diverse watershed as well as management activities within the Cache River watershed.

Introduction

As streams flow downstream, they encompass a number of environmental gradients. Understanding the role of environmental gradients on community assemblage has been a major focus of stream ecology (Vannote et al. 1980) and can provide insight into the ecological processes that regulate assemblages (Wiens 2002; Cooper et al. 1998). Furthermore, in order to successfully manage, conserve and restore native stream and riverine fishes, thorough knowledge of the relationships between species' life history characteristics and habitat is essential (Schlosser 1991).

In temperate lotic systems, there is evidence of abiotic and biotic factors in association with fish communities (Power et al. 1988). However, due to the hierarchical nature of riverine systems, species-habitat relationships are often complicated by issues of scale (Frissell et al. 1986). As a result of processes occurring at various and interacting scales, it has long been suggested to incorporate multiple spatial and temporal scales when analyzing community assembly (Poff 1997; Ricklefs 1987; Fausch et al. 2002). Given the widespread influence of human activities at the landscape scale, different land uses and covers are commonly found to be associated with fish assemblages (Lammert and Allan 1999; Roth et al. 1996; Stewart et al. 2001; Allan et al. 1997; Pease et al. 2011). Agricultural land use, specifically, can have long-term effects on fish assemblages (Harding et al. 1998). Local stream habitat, including stream size, width, depth, woody debris and substrate also perform well in explaining fish community structure (Fischer and Paukert 2008; Talmage et al. 2002). Stream water quality, including pesticide and phosphorus concentrations, has been linked to fish assemblage structure in the Willamette River basin (Waite and Carpenter 2000). Climate is also well known to be a dominant control over the natural distribution of species, with water temperature commonly found in association with fish assemblages (Hoeinghaus et al. 2007; Marsh-Matthews and Matthews 2000; Quist et al. 2004).

Due to the strong influence that environmental factors have on fish communities, fish assemblages are often used as indicators of ecological integrity (Karr 1981). As primary and secondary consumers, fishes can integrate and link underlying ecological functions and processes throughout the watershed (Schlosser 1991). For similar reasons, fish populations and habitats are also commonly used as targets in stream restoration (Bernhardt et al. 2007; Bond and Lake 2003). Understanding the current state of assemblage-habitat relationships is increasingly important for guiding conservation activities, especially where reference conditions are unknown. As management agencies and communities pursue stream restoration, knowledge of the influence of habitats on assemblage structure is essential in identifying project goals and objectives (Palmer et al. 2005; Palmer et al. 1997; Lake et al. 2007).

Similar to many streams in the agricultural midwestern USA, the Cache River in southern Illinois has a history of alteration and channelization (Karr et al. 1985; Mattingly et al. 1993; Demissie et al. 1990). Once a region of dense bottomland forests and wetlands, centuries of timber harvest and agricultural activities have altered the landscape and hydrology of the watershed (Bhowmik et al. 1997). Seasonal flooding from the Ohio River led to the ditching of large sections of the river and its tributaries and drainage of thousands of acres of wetlands. Numerous alterations have impacted the hydrology of the river, including the construction of the Post-Creek Cutoff, a large ditch which drains the upper portion of the Cache River and its eastern tributaries into the Ohio River at a point further upstream than the natural outlet (Cache River Watershed Resource Planning Committee 1995). This alteration has essentially split the river and watershed into two distinct sections for nearly a century. Gradually over the past 40 years, cultural interest in the watershed's historically high biodiversity, bald cypress and water tupelo swamps and over 100 state threatened and endangered species has set management on a trajectory towards restoration.

The Cache River Watershed includes portions of three Level III Ecoregions: Interior Plateau, Interior River Valleys and Hills, and Mississippi Alluvial Plain (Omernik 1987). Eighty-five native fish species have been found within the watershed, representing 42% of all native fish found in Illinois and 21% of all native fish in the Mississippi River basin (Burr 1992; Bennett et al. 2001). Included are five state-listed species; the cypress minnow (*Hybognathus hayi*), pallid shiner (*Hybopsis amnis*), bigeye shiner (*Notropis boops*), redspotted sunfish (*Lepomis miniatus*), and bantam sunfish (*Lepomis symmetricus*) (Bennett et al. 2001). Although the watershed has extensive fish species records dating back to the late 1800's, there is a lack of understanding of how fish communities are structured along environmental gradients within the watershed (Phillippi et al. 1986; Bennett et al. 2001; Muir et al. 1995; Shasteen et al. 2002). Moreover, relatively little is known about the role of bottomland habitats in structuring fish communities (Hoover and Killgore 1997). Therefore, our objective was to describe the current fish assemblages and to identify important environmental variables influencing fish assemblage structure throughout the Cache River watershed. Specifically, because the watershed contains forested uplands, agricultural lowlands and bottomland forest remnants, we were interested in how habitat variables differed among locations within the watershed and how those habitat variables related to fish assemblage structure. Our results contribute to the understanding of general fish-habitat associations in temperate water courses and expand the knowledge base on this topic by investigating this highly altered yet diverse watershed. These results also contribute to management and restoration activities within the Cache River watershed.

Methods

Fish and Habitat Sampling

A total of 86 fish assemblage samples were collected at 48 stations by Illinois Department of Natural Resources (IDNR) during the years 1992, 1999, 2004, and 2009 (Fig. 1). IDNR conducts intensive basin surveys on a five-year rotating cycle, however sampling locations vary each year. For example, some sampling stations are sampled every five years and others have only been sampled once throughout the timeframe of the analysis. Sampling occurred between May and August of each year. Habitat variability throughout the watershed required the use of multiple fish sampling gears, including boat electrofishing, seines and electric seines. To minimize any influence of sampling bias, abundance data was transformed into rank abundance and abundance classes (Table 1). Prior to transformation of the dataset, all species found in <5% of sites were removed because multivariate statistical techniques are often sensitive to rare species (Guy and Brown 2007).

For all samples collected during an intensive basin survey, habitat data were collected at each fish sampling site on the same day of sampling by Illinois Environmental Protection Agency (IEPA) staff. The IEPA's 11-transect and qualitative Stream Habitat Assessment Procedure was used and supplemented by measurement of stream discharge (Shasteen et al. 2002; Illinois Environmental Protection Agency 1994). Habitat variables collected and used for this analysis include substrate (i.e., percent silt, percent sand, percent gravel, etc.), discharge, mean velocity, mean wetted width, mean depth, and percent of channel shaded (Table 2). Latitude and longitude were acquired from IDNR's list of sample site locations.

Additionally, elevation, slope, geology and land use variabes were extracted from geographic information system (GIS) layers and used in analysis. Elevation of station sites was obtained from the U.S. Geological Survey's ASTER Global Digital Elevation Model (ASTGTM). The spatial analyst slope tool in ArcMap 9.3 was used to calculate the slope of each pixel in the ASTGTM raster (Environmental Systems Research Institute 2011). Drainage area was derived from the National Hydrography Dataset. Geology of each site was quantified as presence or absence of rock types, as recorded by USGS Mineral Resources' Illinois Geologic GIS layer. Land use percentages originated from the NASS/USDA Cropland Data Layer and were calculated for each sampling occurrence's respective watershed and year. Temperature data were obtained through the National Climate Data Center.

Data Analysis

A variety of multivariate statistical techniques were used to assess patterns in fish assemblage structure and relationships between fish assemblages and environmental characteristics in the watershed. Similarities of fish assemblages among stations were evaluated using Euclidean distance. The matrix of similarity coefficients was then clustered using the unweighted pair-group with arithmetic averaging method (Kwak and Peterson 2007) to produce a dendrogram depicting clusters of stations with similar fish assemblages. A bootstrap approach to dendrogram evaluation was used to assess the reliability of the results through the approximately unbiased (AU) test (Shimodaira 2002). Ranging between 0 and 1, a high AU value indicates a high level of consistency between the resampled data sets and the original data set. AU values were based on 10,000 bootstrapped data sets (Jackson et al. 2010). Assemblage types were mapped using ArcMap 9.3 to view spatial patterns in assemblage structure (Environmental Systems Research

Institute 2011). Calculation of similarity indices, cluster analyses and AU indices were conducted using the R library *pvclust* (Suzuki and Shimodaira 2011) and mapped with ArcMap 9.3.

Relationships between fish assemblage structure and environmental variables were examined using canonical correspondence analysis (CCA) conducted in CANOCO software, Version 4.5 and graphed using CanoDraw, Version 4.14 (TerBraak and Smilauer 2002). All environmental variables were screened for high inflation factors (>20) to remove highly correlated variables. All remaining variables were analyzed using the manual forward-selection procedure, which is a stepwise process of building a model for species data using Monte Carlo permutation tests (TerBraak and Smilauer 2002). Variables with $p<0.05$ were selected for the final model. The CCA plots species and samples in an ordination figure with environmental variables represented as vectors. Samples are plotted based on fish assemblages, where closely plotted samples are more similar. The direction and length of vectors represents the influence of environmental variables on the fish assemblage (Jongman et al. 1995). Nominal environmental variables are represented by shaded triangles.

Results

A total of 85 fish species were recorded in the watershed by IDNR between 1992 and 2009, of which 58 species were used in analysis. The most ubiquitous species were longear sunfish (*Lepomis megalotis*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*) and bluntnose minnow (*Pimephales notatus*), which were found in 93, 88, 79 and 78 percent of all samples, respectively. The least common species of those analyzed, found in less than 10% of sites, included fringed darter (*Etheostoma crossopterum*), silvery minnow (*Hybognathus nuchalis*), spottail darter (*Etheostoma squamiceps*), black bullhead (*Ameiurus melas*), dusky darter (*Percina sciera*), quillback (*Carpiodes cyprinus*), and flathead catfish (*Pylodictis olivaris*). Species richness ranged from 1 to 34 across samples.

Fish Assemblage Structure

Both data transformations produced two robust groupings of sites at the AU alpha level of 0.95. One cluster represented a fish assemblage strongly associated with lower mainstem sites while the other represented a fish assemblage characterizing upper mainstem and tributary sites (Fig. 2). However, grouped with the lower mainstem sites were a few sites in tributaries close to the confluence with the lower mainstem and one site on the upper mainstem (Fig. 3). Similarity among sites with each cluster varied with type of data transformation, but was generally consistent for groupings with high AU test values (≥0.95).

Species most common to the lower mainstem cluster included gizzard shad (*Dorosoma cepedianum*), bluegill, longear sunfish , smallmouth buffalo (*Ictiobus bubalus*), freshwater drum (*Aplodinotus grunniens*), bigmouth buffalo (*Ictiobus cyprinellus*), shortnose gar (*Lepisosteus platostomus*), warmouth (*Lepomis gulosus*), bowfin (*Amia calva*), channel catfish (*Ictalurus punctatus*), and river carpsucker (*Carpiodes carpio*). Most common to the upper mainstem and tributary cluster included longear sunfish, bluntnose minnow, bluegill, blackspotted topminnow (*Fundulus olivaceus*), green sunfish, redfin shiner (*Lythrurus umbratilis*), central stoneroller (*Campostoma anomalum)*, red shiner (*Cyprinella lutrensis*), creek chub (*Semotilus *atromaculatus),* pirate perch (*Aphredoderus sayanus*), and creek chubsucker (*Erimyzon oblongus*).

Fish Assemblage and Habitat Associations

No habitat variables or GIS-extracted environmental characteristics were found to be strongly correlated (e.g., inflation factor >20) with one another, and therefore none were initially removed from the CCA. The stepwise procedure identified 16 variables to include in the rank abundance final model and 13 variables for the class abundance final model (Table 3). Significant variables common to both analyses included drainage area, stream width, longitude, percent of channel shaded, substrates of silt, cobble and clay, percent row crops, wetlands, and pasture, and presence of chert and siltstone geology.

Canonical correspondence analysis results from both datasets showed similar trends. The first canonical axis of both datasets was positively correlated with drainage area, width, silt, and row crops (Table 4, Fig. 4). Negatively correlated with axis one were gravel, shade, and forest. These correlations suggest this axis represents a longitudinal gradient. The second canonical axis in both data sets was most strongly correlated with cobble, followed by drainage area, and most negatively correlated with silt. The strength of cobble driving the second axis is of interest because only thirteen of 86 sampling events had >10% cobble substrate, and from aerial photographs, it appears as though 4 of those sites have natural cobble and the other sites have cobble due to road crossings or weir construction. Overall, the first two axes explained 51.8% of the variance between fish assemblages and environmental variables in the class abundance data set and 54.0% in the rank abundance data set.

Species with high scores on axis one were strongly associated with environmental variables positively correlated with that axis and similarly, species with low scores on axis one were strongly associated with environmental variables negatively correlated with axis one. Species were coded based on scientific names (listed in Table 5) to simplify graphics and are included parenthetically in the text. The rank abundance data set had high species scores on axis one for gizzard shad (Doce), smallmouth buffalo (Icbu), freshwater drum (Apgr), and black buffalo (*Ictiobus niger,* Icni), suggesting these species are associated with drainage area, row crops and silt (Figure IV). Species with low axis one scores included creek chub (Seat), central stoneroller (Caan), creek chubsucker (Erob), redfin shiner (Lyum) and white sucker (*Catostomus commersoni*, Caco), suggesting these species are associated with shade and forest. Species with an axis score close to zero are suggested to not be driven by environmental variables correlated with the axis. Species with scores on axis one close to zero included bluegill (Lema), silvery minnow (Hynu), spotted sucker (*Minytrema melanops,* Mime) and suckermouth minnow (*Phenacobius mirabilis,* Phmi). Regarding the second axis, highest species scores included channel catfish (Icpu), central stoneroller (Caan), and freckled madtom (*Noturus nocturnus,* Nono), suggesting these species are positively associated with cobble habitats and drainage area. Low species scores on axis two included golden shiner (*Notemigonus crysoleucas*, Nocr) and warmouth (*Lepomis gulosus*, Legu), suggesting these species are associated with silt. Species with scores close to zero included redfin shiner (Lyum), bullhead minnow (*Pimephales vigilax,* Pivi), tadpole madtom (*Noturus gyrinus*, Nogy) and smallmouth buffalo (Icbu).

Analysis of the class abundance data set had high axis one scores for white bass (*Morone chrysops,* Moch), river carpsucker (Caca), spotted gar (*Lepisosteus oculatus*, Leoc), quillback, (Cacy), black buffalo (Icni), and bigmouth buffalo (Iccy) suggesting these species are positively associated with drainage area, channel width, row crops and silt. Species with low axis one scores included fantail darter (*Etheostoma flabellare*, Etfl), fringed darter (Etcr), spottail darter (Etsq), creek chub (Seat), and central stoneroller (Caan), suggesting these species are positively associated with gravel, forest and shade (Fig. 4). For the first axis, species with scores near zero included bluegill (Lema), mosquitofish (*Gambusia affinis*, Gaaf), tadpole madtom (Nogy), bluntnose darter (*Etheostoma chlorosomum*, Etch) and golden shiner (Nocr). Regarding the second axis, highest species scores included freckled madtom (Nono), fantail darter (Etfl), fringed darter (Etcr), channel catfish (Icpu), silvery minnow (Hynu) and flathead catfish (Pyol), suggesting a positive association with cobble and drainage area. Low species scores on axis two included bluntnose darter (Etch) and flier (Cema) and suggested these species to be positively associated with silt substrate. Species with scores close to zero included longear sunfish (Leme), common carp (*Cyprinus carpio*, Cyca) and tadpole madtom (Nogy).

Goodness of fit, represented by percent variance explained by the first four axes, is a useful diagnostic to determine how well each species was described by the environmental variables. Species with high goodness of fit (>62%) for both data sets included channel catfish, gizzard shad, freshwater drum, creek chub, central stoneroller, shortnose gar and black buffalo (Table 5). Species with the lowest variance explained (<24%) included dusky darter, redear sunfish (*Lepomis microlophus*), black bullhead and tadpole madtom. However, while some species had similar percent variance explained between the two data transformations, other species differed by as much as 27%.

Discussion

Although we found two distinct fish assemblages in the Cache River watershed, previous work in this watershed described five distinct fish assemblage guilds, including an upland guild, a lower reach guild, a midreach guild, a bottomland guild and an ubiquitous guild (Bennett et al. 2001). When comparing these previously described guilds with our results, we found species representative of the upland guild (e.g., creek chub), midreach (e.g., redfin shiner), and ubiquitous guilds (e.g., longear sunfish) in our tributary assemblage and overlap of the lower (e.g., freshwater drum) and ubiquitous guilds in the lower mainstem of the Cache River. Spatial coexistence of the upland, midreach and ubiquitous guilds is to be expected in a natural continuum such as a river network. However, this overlap can be escalated through degradation of habitats and may result in biotic homogenization, where, as habitats are degraded, the distribution and abundance of specialist species commonly decline while generalist species benefit through range expansion (McKinney and Lockwood 1999; Rahel 2002). A number of sensitive species have been documented to be negatively affected by sedimentation, channelization and loss of wetlands in the watershed, including fringed darter, pallid shiner, cypress minnow and bantam sunfish (Poly and Wilson 1998; Pflieger 1997; Bennett et al. 2001; Burr et al. 1996; Smith 2002; Illinois Endangered Species Protection Board 2011).

Notably, there was an absence of a bottomland guild among the sites analyzed. Although bottomland habitats are limited and not extensively sampled, lack of representatives from the bottomland guild is likely to be at least partially due to habitat loss, heavy sedimentation and hydrologic alteration (Burr et al. 1996; Smith 2002; Warren and Burr 1989; Bennett et al. 2001; Pflieger 1997). Sedimentation rates from a 6-mile stretch of the lower Cache River were found to range from 0.2 cm/year in forested floodplain to >2 cm/year in the main river channel since 1963 (Allgire and Cahill 2001). Sedimentation has been found to have varying effects on lotic fish communities, although fish species most sensitive to sedimentation tend to be herbivores, benthic insectivores or simple lithophilous spawners (Rabeni and Smale 1995; Berkman and Rabeni 1987). Along large rivers, sedimentation has degraded and reduced backwater habitats available for use by fishes (Brown and Coon 1994). Although sedimentation rates in the Cache River have likely declined due to efforts to reduce erosion through the conversion to a more natural land cover (Kruse and Groninger 2003) and construction of upland water retention structures (Guetersloh 2002; Union County Soil and Water Conservation District 2006), the lack of flow resulting from the fragmentation of the mainstem Cache River may continue to trap legacy sediment in bottomland habitats. The restoration of surface hydrology has been found to be necessary to restore bottomland wetland functions important for nutrient and sediment removal (Hunter et al. 2008). Focused research in bottomland habitat is needed to more thoroughly understand the status of bottomland fish species and their habitat requirements.

Changes in fish community composition along a longitudinal gradient are typically recognized as a result of biotic zonation, continual addition of species downstream, or both of these processes occurring together at different scales (Rahel and Hubert 1991). Biotic zonation refers to a discontinuity in geomorphology or temperature resulting in distinct biological communities whereas the continual addition of species process is a consequence of communities becoming more complex downstream due to more heterogeneous and stable habitat (Evans and Noble 1979). At the watershed scale, it appears as though longitudinal changes in fish assemblage structure in the Cache River are largely due to the addition of species downstream, similar to that described in other studies where headwater sites commonly have small, invertivorous fishes while downstream sites often have larger-bodied, piscivorous species (Schlosser 1982). However, if we recognize the confluence of large rivers (e.g., Mississippi River) and their tributaries (e.g., Cache River) as discontinuities in channel morphology and hydrology (Benda et al. 2004), then the Cache River fish assemblages could support the idea of both biotic zonation and the downstream addition of species occurring simultaneously at different scales.

Species richness has been found to be higher in tributaries that converge into large rivers (Osborne and Wiley 1992; Fausch et al. 1984; Thornbrugh and Gido 2010). Numerous riverine species have been found to overwinter in backwaters where temperatures are less extreme (Raibley et al. 1997; Dettmers et al. 2001). Additionally, low gradient streams flowing into larger rivers have also been found to serve as backwater habitat for early life history stages of numerous riverine species, especially where natural backwater habitats have been lost (Brown and Coon 1994). The Cache River may serve as important nursery habitat for large river species as well as a refuge during extreme temperatures. It is probable that the presence of large river species in the lower mainstem of the Cache River is largely due to the proximity to the Mississippi River.

The fish-habitat associations in the Cache River suggest both local and regional factors are important in structuring the community (Ricklefs 1987). Regional and local environmental factors are often linked, for example, high gradient systems commonly have more natural land cover (e.g., forest) due to the difficulty in farming steep hillsides and coarser substrates than low gradient systems which often have increased agricultural activities and increased sediment runoff via erosion (Allan 2004). The relation between regional and local environmental factors makes it difficult to identify the impact of any single environmental gradient. However, understanding the link between the landscape and habitat variables provides a more holistic perspective.

The abundance of cobble across sites is relatively rare and thus represents a habitat that may be particularly valuable for the persistence of some species in the watershed, including fringed darter, freckled madtom and fantail darter. Fantail darters and freckled madtoms are commonly found near rock and gravel riffles in permanent-flowing streams with moderate gradients and strong flow (Pflieger 1997). Fringed darters require rocky substrates for reproduction; however, this species has been observed to build nests on artificial substrates (Poly and Wilson 1998). These species were found in less than 10% of total sites, respectively, suggesting limited habitat availability in the Cache River. Interestingly, the highest amounts of cobble in the watershed were found in the artificial Post Creek Cutoff. However, rock weirs, constructed between 2001 and 2004 in the upper mainstem to reduce channel incision and improve in-stream habitat, have been found to be 'hot spots' for biodiversity of aquatic insects and birds (Walther and Whiles 2008; Heinrich 2011) and could be providing additional habitat for cobble-associated fish species as well.

Our results provide insight into how environmental gradients, specifically land use, substrate, geology and local habitat variables, influence fish assemblages in the Cache River watershed. The consistency of our results across two different abundance transformations suggests robust relationships between fish assemblages and habitats. The results found in the Cache River watershed likely apply to other altered agricultural watersheds, especially those that flow directly into large rivers or contain bottomland hardwood forests. This information contributes to understanding aquatic community structure and can inform management activities within the Cache River watershed. For example, various land and in-stream restoration projects have been implemented in the watershed with additional projects currently in the planning stages (Guetersloh 2002; Demissie et al. 2010; Kruse and Groninger 2003). Our results can help guide and prioritize restoration projects by incorporating species- and community-specific habitat associations.

Acknowledgments

We thank all personnel involved from Illinois Department of Natural Resources, Illinois Natural History Survey and Illinois Environmental Protection Agency for sharing data for this study. We would especially like to thank Jana Hirst, Les Frankland, Jim Mick and technicians involved in data collection. Funding was provided by the National Science Foundation - Integrated Graduate Education, Research and Training program, "Watershed Science and Policy" at Southern Illinois University Carbondale.

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Table 1. Classification scheme used to transform relative abundance of fishes into ordinal abundance classes (Adler et al. 2010).

Relative Site Abundance	**Class**
0% (absent)	0
>0 to <1% (sporadic)	1
>1 to <5% (rare)	2
>5 to <10% (regular)	3
>10 to <30% (common)	4
>30 to <60% (frequent)	5
>60 to 100% (dominant)	6

Table 2. Description and source information of thirty-two environmental variables evaluated in this study using canonical correspondence analysis.

Variable	Description of variable
Substrate and Instream Cover	
Bedrock	Predominant substrate and cover is recorded at 9 points along each of 11 habitat transects at a sampling station and a percentage calculated. Collected through IEPA's Stream Habitat Assessment Procedure.
Boulder	
Clay	
Cobble	
Gravel	
Logs	
Sand	
Silt	
Land Use	
Fallow	Using the NASS/USDA Cropland Data Layer, land uses were calculated for each sampling occurrence's respective watershed and year.
Forest	
Pasture	
Row crops	
Small Grains	
Urban	
Wetlands	
Geology	
Chert	Recorded as the presence or absence of rock types, as sourced by USGS Mineral Resources' Illinois Geologic GIS layer.
Limestone	
Sandstone	
Shale	
Siltstone	
Local Habitat	
Depth	Depth, velocity and width are calculated as averages of all transect points and transects in the sampling reach. Discharge is calculated using a stream gauging method. Percent shade is an estimate of the percent of the stream surface shaded between 1000 and 1600 hours. Collected through IEPA's Stream Habitat Assessment Procedure.
Discharge	
Shade	
Velocity	
Width	
Other	
Drainage Area	Calculated using the National Hydrography Dataset.
Latitude	Acquired via IDNR list of sampling stations.
Longitude	
Max. Temp.	Obtained through the National Climate Data Center.
Min. Temp.	
Elevation	Derived from the U.S. Geological Survey's ASTER Global Digital Elevation Model.
Slope	

Table 3. Using manual forward-selection canonical correspondence analyses, thirteen environmental variables for rank abundance and sixteen environmental variables for class abundance groupings (shown in bold type) were found to be significantly related to fish assemblage structure in the Cache River watershed, Illinois.

Variable	Mean (standard deviation)	Range	Rank Abundance		Class Abundance	
			F-value	P-value	F-value	P-value
Bedrock	1.6 (9.4)	0-81	0.898	0.624	0.764	0.710
Boulder	2.7 (5.9)	0-32	0.755	0.830	0.975	0.478
Clay	15.9 (18.8)	0-70	2.987	**0.002**	2.056	**0.002**
Cobble	5.6 (10.2)	0-56	2.232	**0.002**	2.589	**0.002**
Gravel	18.9 (23.0)	0-97	0.928	0.592	3.438	**0.002**
Logs	4.53 (6.0)	0-33	1.453	0.054	1.367	0.088
Sand	8.8 (16.1)	0-73	1.963	**0.004**	1.535	0.056
Silt	28.9 (24.9)	0-84	7.924	**0.002**	7.708	**0.002**
Fallow	3.8 (5.2)	0-20	1.236	0.162	1.422	0.068
Forest	38.4 (20.2)	9-92	1.184	0.222	2.202	**0.004**
Pasture	30.2 (12.7)	2-54	2.436	**0.002**	1.970	**0.002**
Row crops	15.9 (11.1)	0-46	1.638	**0.012**	2.570	**0.002**
Small Grains	2.6 (3.0)	0-10	2.049	**0.002**	0.936	0.594
Urban	2.2 (2.7)	0-11	1.071	0.310	1.370	0.086
Wetlands	4.0 (4.6)	0-34	1.572	**0.046**	1.883	**0.020**
Chert	0.1 (0.3)	0-1	1.675	**0.014**	1.773	**0.004**
Limestone	0.7 (0.5)	0-1	1.014	0.442	1.241	0.148
Sandstone	0.5 (0.5)	0-1	1.146	0.256	1.053	0.378
Shale	0.4 (0.5)	0-1	3.812	**0.002**	1.296	0.122
Siltstone	0.2 (0.4)	0-1	2.238	**0.002**	3.062	**0.002**
Depth	1.7 (3.2)	0.3-22	1.161	0.238	1.142	0.310
Discharge	6.5 (11.8)	0-62	0.999	0.472	1.462	0.058
Shade	35.6 (28)	0-95	2.030	**0.002**	2.300	**0.002**
Velocity	0.8 (1.9)	0-9.9	2.016	**0.006**	1.345	0.082
Width	28.2 (21.2)	9-118	3.132	**0.002**	2.602	**0.004**
Drainage Area	188.2 (251.2)	7-969	12.911	**0.002**	10.310	**0.002**
Latitude	37.34 (0.1)	37.15-37.52	0.830	0.742	0.690	0.920
Longitude	-89.1 (0.1)	-89.34--89.79	3.140	**0.002**	2.490	**0.002**
Max. Temp.	30.1 (1.5)	26.9-32.9	1.058	0.350	0.881	0.692
Min. Temp.	17.7 (1.9)	11.7-21.4	0.869	0.686	1.037	0.416
Elevation	106.4 (12)	88-158	0.940	0.596	0.794	0.806
Slope	3.7 (3.3)	0-26	0.745	0.832	0.768	0.772

Table 4. Correlation coefficients of environmental variables and the first two canonical axes for each canonical correspondence analysis and total variance explained by each axis.

	Class abundance		**Rank Abundance**	
Environmental variables	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**
Clay	-0.1299	-0.1566	-0.1725	-0.2001
Cobble	-0.1296	0.5946	-0.0921	0.4876
Gravel	-0.582	0.3172		
Sand			0.1079	0.1539
Silt	0.6827	-0.3134	0.6153	-0.3639
Forest	-0.4579	0.094	-0.3618	0.1336
Pasture	0.0932	0.0752	0.0548	0.0295
Row crops	0.5812	-0.0922	0.5362	-0.1576
Wetlands	0.1789	-0.1717	0.1596	-0.1232
Small grains			-0.0422	0.062
Shale			-0.3655	-0.0244
Siltstone	0.0213	0.1222	0.0752	0.0847
Chert	-0.2068	-0.0831	-0.1864	-0.0138
Drainage area	0.693	0.4739	0.6877	0.4132
Shade	-0.4908	-0.2011	-0.4714	-0.119
Width	0.6271	0.0221	0.626	-0.1097
Velocity			0.0391	0.1356
Longitude	-0.0575	-0.1795	-0.0897	-0.2332
Variance Explained	**37.90%**	**13.90%**	**42.90%**	**11.10%**

Table 5. Proportion of variance explained for each species and data transformation in the Cache River watershed, Illinois, using canonical correspondence analysis. The difference between the two data transformation methods provides insight into robustness of results for each species.

Species Common Name	Scientific Name	Species Code	Percent Variance Explained		Difference between Class and Rank
			Class	Rank	
Banded sculpin	*Cottus carolinae*	Coca	38.77	48.34	9.57
Bigmouth buffalo	*Ictiobus cyprinellus*	Iccy	64.04	60.15	3.89
Black buffalo	*Ictiobus niger*	Icni	68.93	64.82	4.11
Black bullhead	*Ameiurus melas*	Amme	16.24	24.32	8.08
Black crappie	*Pomoxis nigromaculatus*	Poni	39.97	34.27	5.7
Blackside darter	*Percina maculata*	Pema	34.48	45.67	11.19
Blackspotted topminnow	*Fundulus olivaceus*	Puol	59.95	61.77	1.82
Blackstripe topminnow	*Fundulus notatus*	Funo	20.24	33	12.76
Bluegill	*Lepomis macrochirus*	Lema	29.41	38.16	8.75
Bluntnose darter	*Etheostoma chlorosoma*	Etch	39.99	33.57	6.42
Bluntnose minnow	*Pimephales notatus*	Pino	53.54	46.59	6.95
Bowfin	*Amia calva*	Amca	49.38	46.48	2.9
Brook silverside	*Labidesthes sicculus*	Lasi	54.52	54.43	0.09
Bullhead minnow	*Pimephales vigilax*	Pivi	30.59	27.42	3.17
Common Carp	*Cyprinus carpio*	Cyca	59.93	59.43	0.5
Central stoneroller	*Campostoma anomalum*	Caan	70.81	65.28	5.53
Channel catfish	*Ictalurus punctatus*	Icpu	82.13	75.49	6.64
Creek chub	*Semotilus atromaculatus*	Seat	65.95	71.52	5.57
Creek chubsucker	*Erimyzon oblongus*	Erob	38.85	48.77	9.92
Dusky darter	*Percina sciera*	Pesc	18	22.03	4.03
Fantail darter	*Etheostoma flabellare*	Etfl	46.87	60.26	13.39
Flathead catfish	*Pylodictis olivaris*	Pyol	29.42	22.2	7.22
Flier	*Centrarchus macropterus*	Cema	43.95	33.29	10.66
Freckled madtom	*Noturus nocturnus*	Nono	56.76	51.95	4.81
Freshwater drum	*Aplodinotus grunniens*	Apgr	72.98	66.59	6.39
Fringed darter	*Etheostoma crossopterum*	Etcr	20.56	48.14	27.58
Gizzard shad	*Dorosoma cepedianum*	Doce	73.39	67.6	5.79
Golden redhorse	*Moxostoma erythrurum*	Moer	53.18	47.61	5.57
Golden shiner	*Notemigonus crysoleucas*	Nocr	40.49	41.66	1.17
Grass carp	*Ctenopharyngodon idella*	Ctid	30.47	27.5	2.97
Grass pickerel	*Esox americanus*	Exam	26.92	35.7	8.78
Green sunfish	*Lepomis cyanellus*	Lecy	45.26	43.77	1.49

Largemouth bass	*Micropterus salmoides*	Misa	37.4	34.41	2.99
Longear sunfish	*Lepomis megalotis*	Leme	35.54	44.37	8.83
Mosquitofish	*Gambusia affinis*	Gaaf	24.58	37.19	12.61
Orangespotted sunfish	*Lepomis humilis*	Lehu	33	33.75	0.75
Pirate perch	*Aphredoderus sayanus*	Apsa	48.5	54.48	5.98
Quillback	*Carpiodes cyprinus*	Cacy	30.18	26.87	3.31
Red shiner	*Cyprinella lutrensis*	Cylu	47.91	49.09	1.18
Redear sunfish	*Lepomis microlophus*	Lemi	20.39	21.27	0.88
Redfin shiner	*Lythrurus umbratilis*	Lyum	44.24	58.41	14.17
Ribbon shiner	*Lythrurus fumeus*	Lyfu	34.37	38.33	3.96
River carpsucker	*Carpiodes carpio*	Caca	51.13	49.63	1.5
Shortnose gar	*Lepisosteus platostomus*	Lepl	62.28	68.05	5.77
Silvery minnow	*Hybognathus nuchalis*	Hynu	28.23	36.17	7.94
Slough darter	*Etheostoma gracile*	Etgr	31.95	34.21	2.26
Smallmouth buffalo	*Ictiobus bubalus*	Icbu	64.11	64.68	0.57
Spottail darter	*Etheostoma squamiceps*	Etsq	43.09	54.66	11.57
Spotted bass	*Micropterus punctulatus*	Mipu	44.19	36.05	8.14
Spotted gar	*Lepisosteus oculatus*	Leoc	33.33	28.26	5.07
Spotted sucker	*Minytrema melanops*	Mime	43.63	49.08	5.45
Suckermouth minnow	*Phenacobius mirabilis*	Phmi	29.79	32.08	2.29
Tadpole madtom	*Noturus gyrinus*	Nogy	24.01	24.14	0.13
Warmouth	*Lepomis gulosus*	Legu	45.11	40.55	4.56
White bass	*Morone chrysops*	Moch	38.63	35.4	3.23
White crappie	*Pomoxis annularis*	Poan	28.45	28.08	0.37
White sucker	*Catostomus commersoni*	Caco	41.69	56.43	14.74
Yellow bullhead	*Ameiurus natalis*	Amna	34.9	41.65	6.75

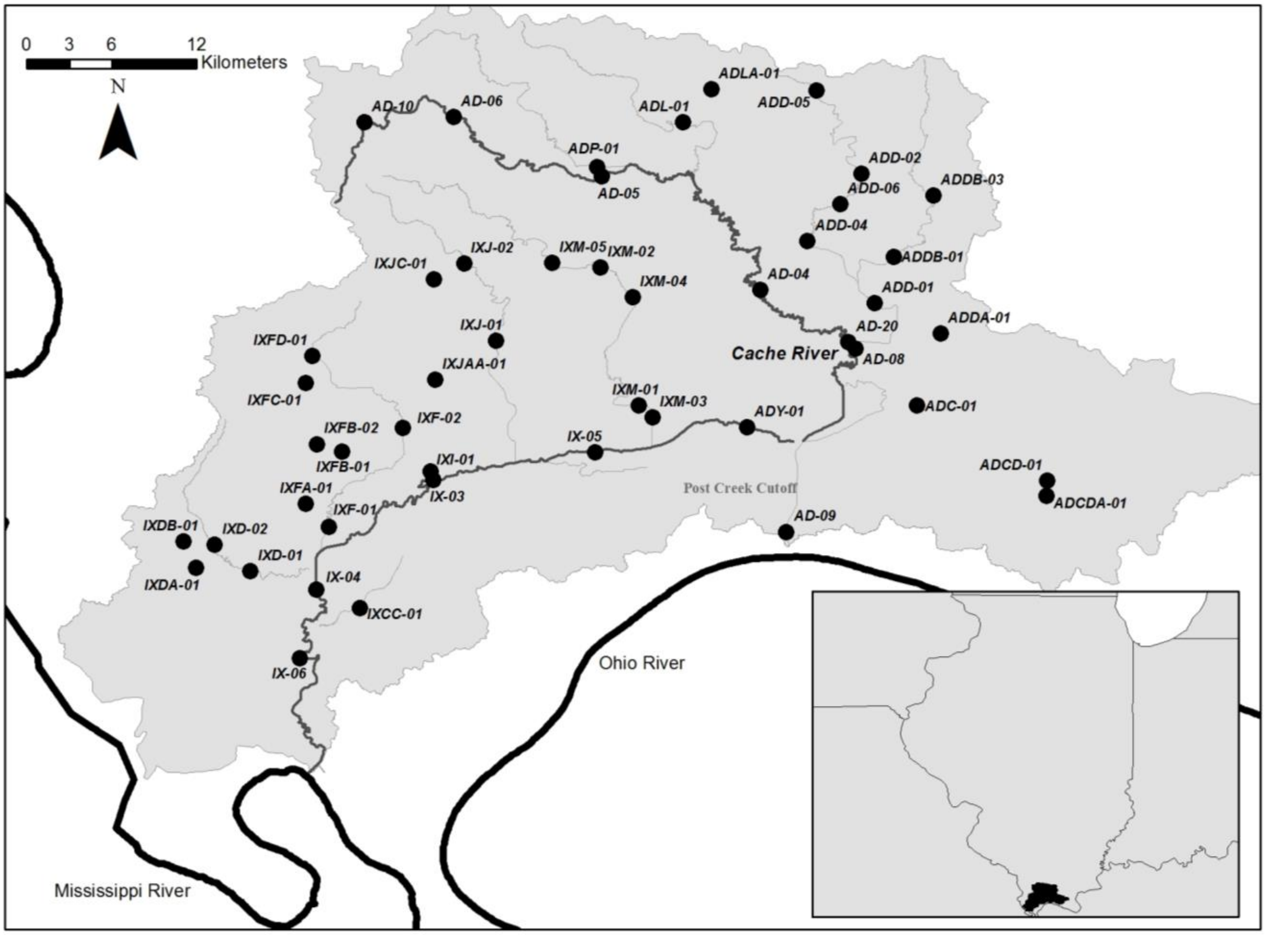
Figure Captions

Fig. 1. The Cache River Watershed is located in southern Illinois, near the confluence of the Ohio and Mississippi rivers. Sampling locations (black dots) included sites on tributaries and the mainstem Cache River.

Fig. 2. Rank abundance (A) and class abundance (B) dendrograms of Cache River watershed, Illinois sites clustered by fish assemblage similarity. Boxed clusters represent significant clusters, identified using the approximately unbiased (AU) test. Sites are identified by Illinois Department of Natural Resources site code (see Fig. 1) followed by the last two digits of the year.

Fig. 3. Sampling sites in the Cache River watershed, Illinois, symbolized by rank abundance fish assemblage cluster for each sampling year.

Fig. 4. Canonical correspondence analysis plot of species and environmental variables from the Cache River watershed, Illinois using rank abundance (A) and class abundance (B). Continuous environmental variables are represented by arrows with direction and length representing the influence of environmental variables on the fish assemblage. Nominal environmental variables are represented by shaded triangles.



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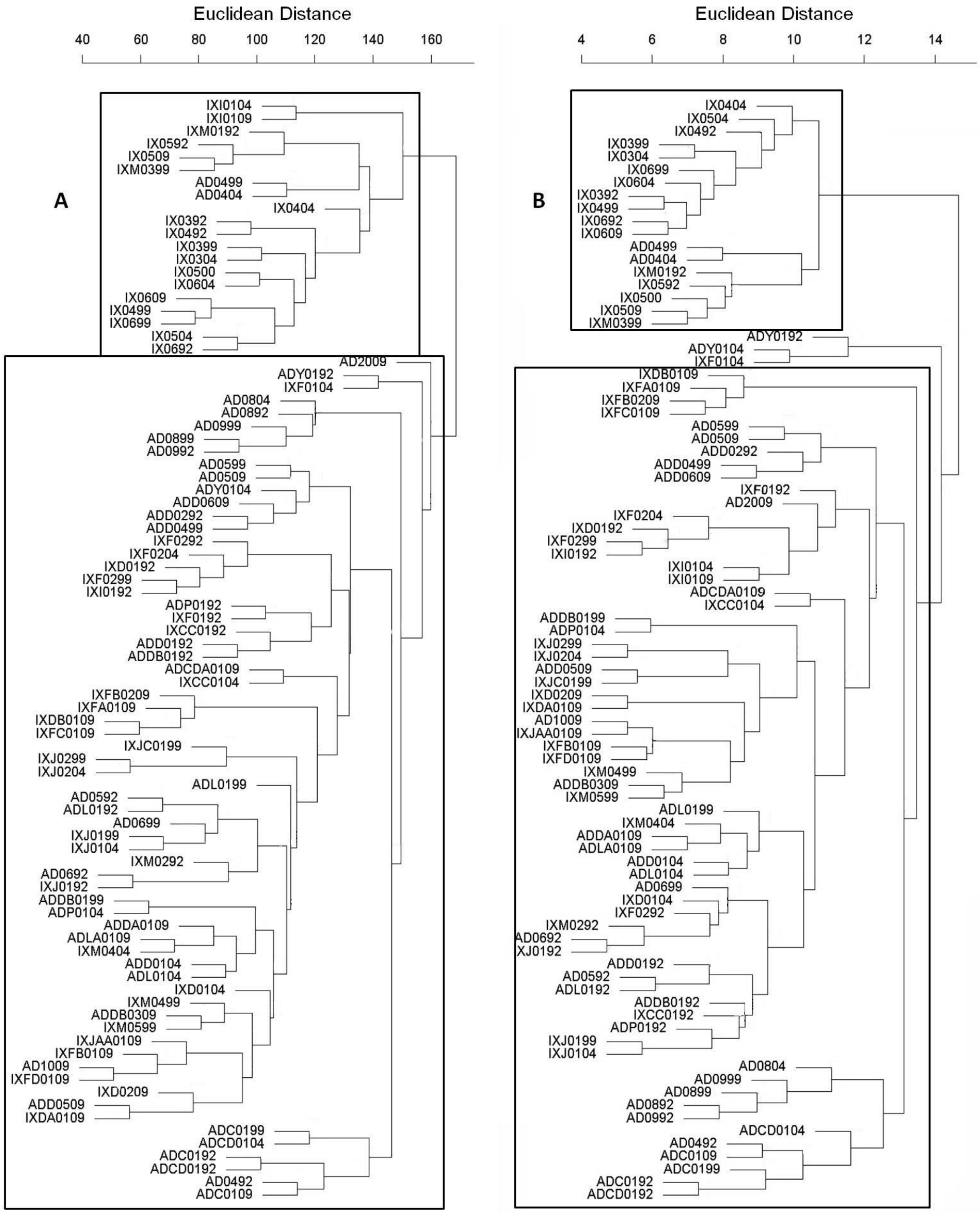
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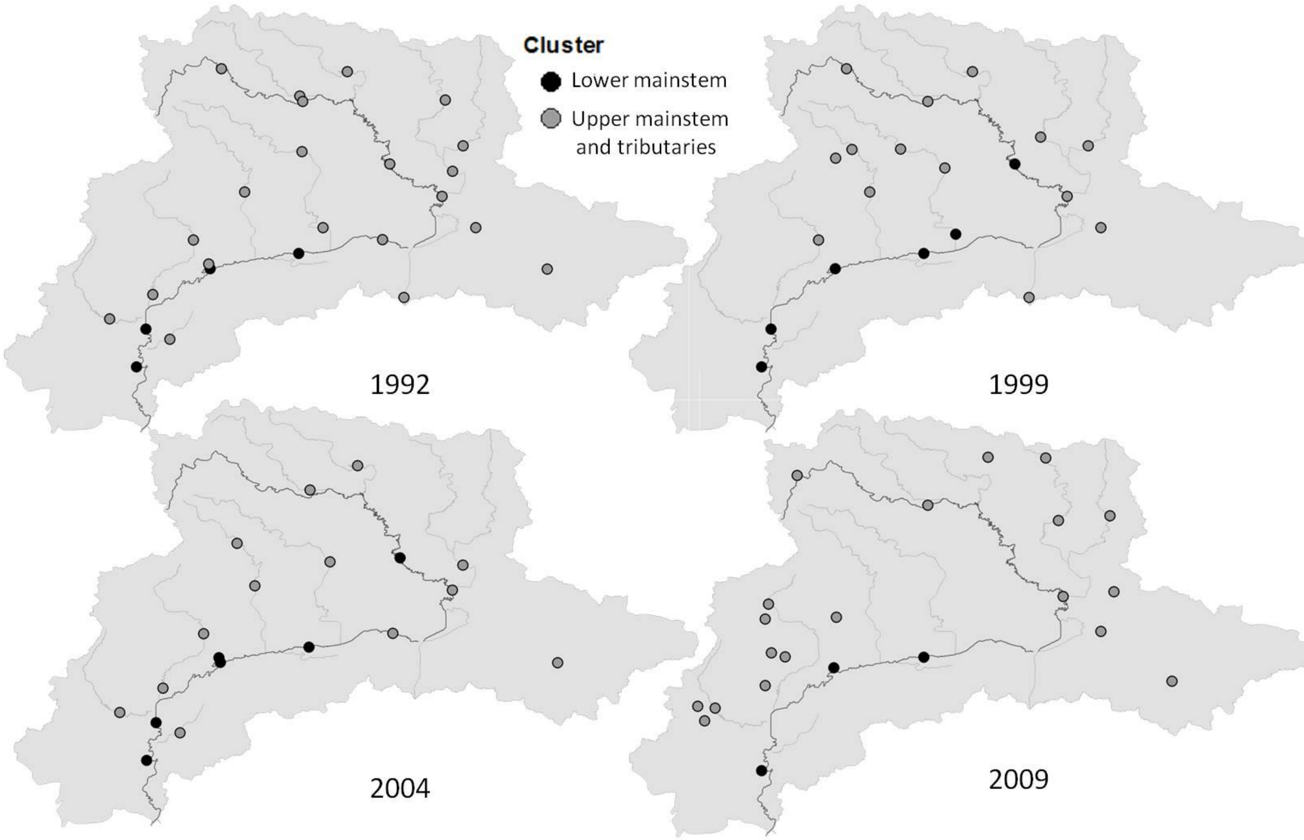
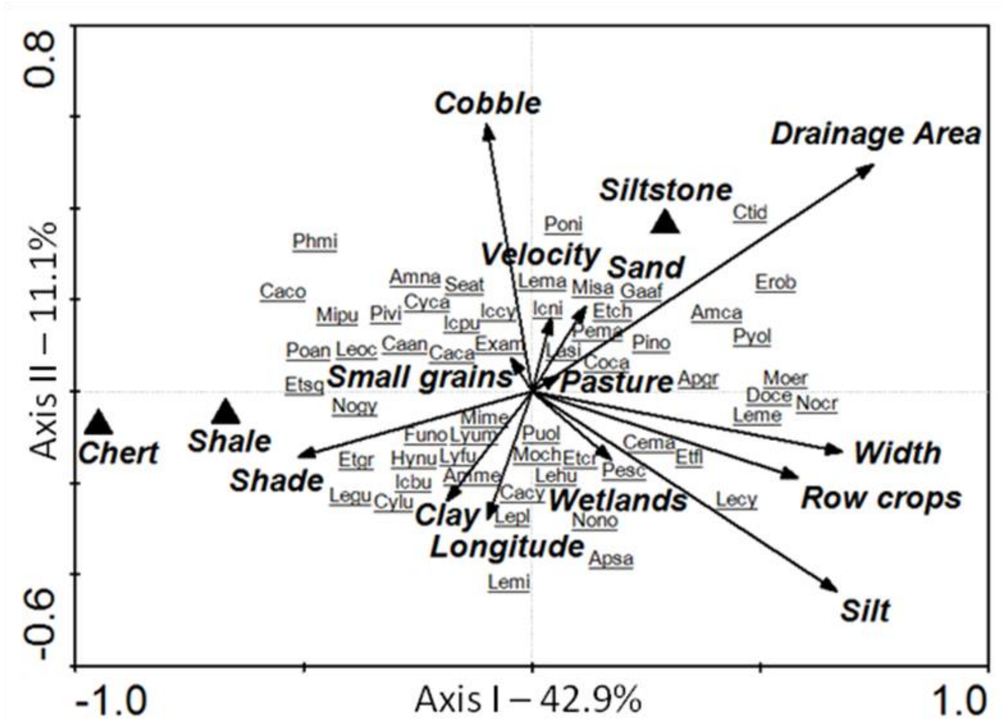
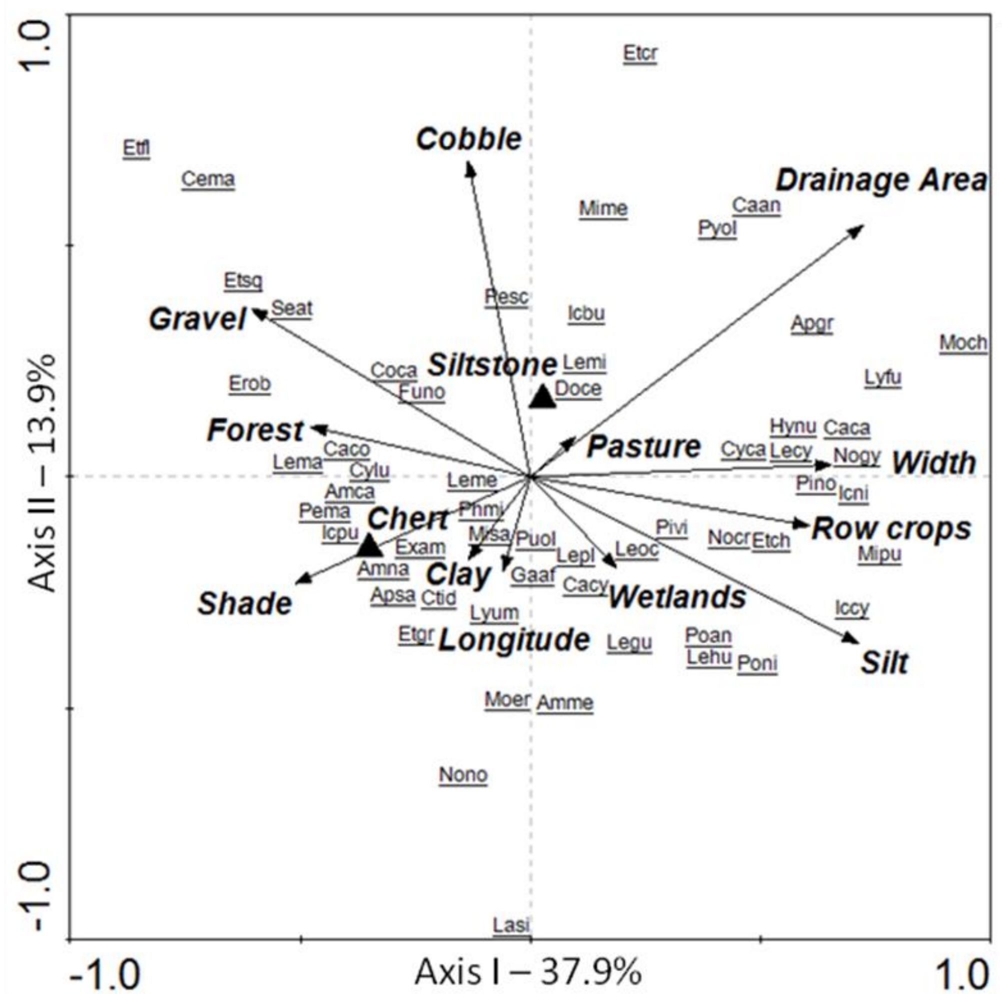
ADD0509
IXJC0199
IXD0209
IXDA0109
AD1009
IXJAA0109
IXFB0109
IXFD0109
IXM0499
ADDB0309
IXM0599
ADL0199
IXM0404
ADDA0109
ADLA0109
ADD0104
ADL0104
AD0699
IXD0104
IXF0292
IXM0292
AD0692
XJ0192
ADD0192
AD0592
ADL0192
ADDB0192
IXCC0192
ADP0192
IXJ0199
IXJ0104
AD0804
AD0999
AD0899
AD0892
AD0992
ADCD0104
AD0492
ADC0109
ADC0199
ADC0192
ADCD0192


Cluster
Lower mainstem
Upper mainstem and tributaries
1992
1999
2004
2009


0.8
-0.6
Axis II – 11.1%
-1.0
1.0
Axis I – 42.9%
Cobble
Drainage Area
Siltstone
Velocity
Sand
Small grains
Pasture
Chert
Shale
Shade
Clay
Longitude
Wetlands
Width
Row crops
Silt
Phmi
Caco
Mipu
Pivi
Amna
Cyca
Seat
Icpu
Iccy
Poan
Leoc
Caan
Caca
Exam
Etsq
Nogy
Poni
Lema
Misa
Gaaf
Icni
Etch
Pema
Lasi
Coca
Pino
Ctid
Erob
Amca
Pyol
Apgr
Moer
Doce
Nocr
Leme
Mime
Funo
Lyum
Puol
Etgr
Hynu
Lyfu
Moch
Etcr
Cema
Etfl
Pesc
Icbu
Amme
Lehu
Legu
Cylu
Cacy
Lecy
Lepl
Nono
Apsa
Lemi


1.0
-1.0
Axis II – 13.9%
-1.0
1.0
Axis I – 37.9%
Etcr
Etfl
Cema
Cobble
Drainage Area
Mime
Caan
Pyol
Etsq
Gravel
Seat
Pesc
Icbu
Apgr
Moch
Coca
Funo
Siltstone
Lemi
Doce
Lyfu
Erob
Forest
Pasture
Hynu
Caca
Cyca
Lecy
Nogy
Width
Lema
Caco
Cylu
Leme
Pino
Icni
Amca
Pema
Chert
Phmi
Icpu
Misa
Puol
Pivi
Nocr
Etch
Row crops
Mipu
Exam
Amna
Clay
Lepl
Leoc
Gaaf
Cacy
Shade
Apsa
Ctid
Wetlands
Iccy
Lyum
Etgr
Longitude
Legu
Poan
Lehu
Poni
Silt
Moer
Amme
Nono
Lasi