# Patterns of Fish Diversity and Community Structure Along the Longitudinal Gradient of the Kiamichi River in Southeastern Oklahoma

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**Abstract:** In riverine systems, patterns of fish community structure and diversity show changes along the longitudinal profile, i.e., from upstream to downstream. Previous research has shown longitudinal patterns may include changes in various measure of species diversity, such as species richness and species abundance, and patterns of species accumulation that often include species addition and/or species zonation. We used seines and electrofishing gear to sample the small-bodied fish community along the longitudinal gradient of the Kiamichi River in southeastern Oklahoma. Our objectives were to look for longitudinal patterns of (1) species diversity and (2) community structure. We sampled at 11 sites during 2012-2013. We standardized sampling based on 30 minutes of electrofishing and 200 meters of seine hauls at each site. We also used experimental gill nets to contribute to the baseline information of large-bodied fishes in the Kiamichi River. A total of 9,620 fish were collected representing 54 species and 15 families. The Kiamichi River showed increasing species diversity along the longitudinal gradient, as well as patterns of species addition. Further, we found four distinct groups of fish along the longitudinal gradient, including ubiquitous species, widespread but scattered species, species restricted to downstream sites, and rare species. 

## Introduction

One of the key constructs in stream ecology is that of the River Continuum Concept (Vannote et al. 1980), which provided a framework for understanding changes in stream ecology along the longitudinal gradient, that is, how various aspects of stream ecology change from upstream to downstream. While the River Continuum Concept addressed numerous aspects of general stream ecology, including characteristics of organic matter, energy flow, and invertebrate community composition, many subsequent research questions addressed changes more specific to stream fish community structure along the longitudinal gradient.

Over the past few decades, numerous studies have elucidated how stream fish communities change along the longitudinal gradient, including studies in the United States (e.g., Sheldon 1968; Evans and Noble 1978; Guillory 1982; Rahel and Hubert 1991) and abroad (Ibarra and Stewart 1989; Chadderton and Allibone 2000; Bistoni and Hued 2002). While specific goals and objectives of these studies have varied, most have sought to identify community patterns along the upstream to downstream gradient, and to relate these patterns to environmental variables. Environmental variables may include abiotic factors such water temperature, depth, substrate, and disturbance, or biotic variables such as predation and competition.

One of the patterns that has emerged from past studies is that species diversity tends to increase along the longitudinal gradient. (Lotrich 1973; Gorman and Karr 1978; Vannotte et al. 1980; Matthews 1985; Rahel and Hubert 1991; Pires et al. 1999). Increases in species diversity are generally attributed to a concomitant increase in habitat diversity along the upstream to downstream gradient, and greater habitat stability in downstream reaches (Gorman and Karr 1978; Schlosser 1987). It is also noteworthy that measuring species diversity may take numerous forms, but most protocols generally rely on measures of the number of species present (species richness), and the relative abundances of individuals within each species (species abundance), or indices that consider richness and abundance simultaneously (Hamilton 2005; McGinley 2014).

In addition to changes in fish species diversity along the longitudinal gradient of streams, another area of research emphasis has been that of describing patterns of species accumulation along that gradient. Rahel and Hubert (1991) note that most studies have attributed longitudinal changes in fish community structure to one of two processes: biotic zonation or continual addition of species in the upstream to downstream direction. The concept of biotic zonation in general suggests that specific groups of organisms are associated with specific areas, or zones, with appreciable replacement of species along some spatial gradient. The concept of zonation has been applied to a variety of taxa including crustaceans on beaches (e.g., Dahl 1953), marine coral (e.g., Alevizon et al. 1985), stream invertebrates (e.g., Statzner and Higler 1986), amphibians and reptiles (e.g., Ravkin et al. 2010), woodland birds (e.g., Colquhoun and Morley 1943), small mammals (e.g., Heaney et al. 1989), and many others. With respect to stream fishes, zonation associated with water temperatures that create distinct temperature-dependent fish zones have been described in several studies (Rahel and Hubert 1991; Bistoni and Hued 2002; Moyle 2002; Quist et al. 2006; Torgersen et al. 2006; Lasne et al. 2007), but beyond those associated with temperature, causal mechanisms driving zonal associations appear to vary widely among studies. Rahel and Hubert (1991) concisely summarized that, in addition to temperature influences, zonation results from discontinuities in stream geomorphology.

In contrast to biotic zonation, biotic addition implies a continual downstream increase in species richness (Rahel and Hubert 1991), that is, new species are added along the upstream to downstream gradient, with limited species (or community) replacement along spatial gradients. Numerous previous studies have identified patterns of species addition along the longitudinal gradient (e.g., Evans and Noble 1979; Foltz 1982; Petry and Schultz 2006). Interestingly, some researchers report finding indications of both species zonation and species addition within their study sites (Rahel and Hubert 1991; Paller 1994; Williams et al. 1996; Bistoni and Hued 2002). For example Rahel and Hubert (1991) report an upstream cold-water zone and a downstream warm-water zone, with species added within the warm-water zone through the process of species addition.

The Kiamichi River in southeastern Oklahoma is an appropriate study site for investigating patterns of species diversity and community composition along the longitudinal gradient for at least two reasons. First, it is relatively speciose and approximately 100 species of fish have been collected in previous studies (Pigg and Hill 1974; Pyron et al. 1998); however, it should be noted that most previous surveys have included many tributary streams and the main stem of the river does not likely have all of those species. Second, the Kiamichi River has only a single impoundment on the main stem (Hugo Reservoir), and few, if any, water withdrawal structures or major barriers. Additionally, the Kiamichi River is of high conservation interest because it has such a rich diversity of fish (Pigg and Hill 1974; Matthews 1985; Pyron et al. 1998) and freshwater mussels (Vaughan et al. 1996; Gailbraith et al. 2008), and the region of southeastern Oklahoma that encompasses the Kiamichi River was selected by The Nature Conservancy as a critical area for protecting freshwater diversity (Master et al. 1998).

Our overall goal for this study was to look for patterns of fish diversity and community structure along the longitudinal gradient of the Kiamichi River, thereby leading to a greater understanding of a river system that truly warrants meaningful conservation efforts. The first objective was to describe diversity of the fish community along the longitudinal gradient based on three metrics: species abundance, species richness, and Shannon diversity. The second objective was to see if fish exhibited patterns of biotic zonation or biotic addition along the longitudinal gradient, or other recognizable patterns of community structure.

## Methods

*Study sites*- The Kiamichi River is located in southeastern Oklahoma and flows generally west, then southeasterly, eventually reaching its confluence with the Red River on the Oklahoma-Texas border (Figure1). The Kiamichi River is 172km long and has an average gradient of 1.46m/Km (Pigg and Hill, 1974). The head waters of the Kiamichi River begins in the Ouachita Mountain range near Big Cedar Oklahoma, with an initial elevation of 367m AMSL and reaching a final elevation of 109m AMSL at its confluence with the Red River. The drainage has been described as crescent shaped (Pigg and Hill 1974), and drains approximately 4739km$^2$ within seven counties; LeFlore, Latimer, Pittsburg, Atoka, Pushmataha, Choctaw, and McCurtain Counties. The Kiamichi River drainage encompasses a large portion of southeastern Oklahoma, while covering many topographic and ecological features of this area of the state (Figure 1).

There are eight major tributaries to the Kiamichi River, including Jackfork, Buck, Walnut, Buffalo, Cedar, Gates, Anderson, and Pine Creeks. Along with the tributaries, there are two large reservoir impoundments within the watershed (Figure 1). The furthest upstream reservoir is Sardis Lake, which is an impoundment on Jackfork Creek and was constructed in 1983. Sardis Lake is not on the mainstem of the Kiamichi River but is on a major tributary and contributes considerably to the flow of the Kiamichi River. Further downstream, Hugo Lake was constructed on the mainstem of the Kiamichi River near Hugo Oklahoma in 1974. These reservoirs were constructed primarily for water storage for municipalities throughout southeastern Oklahoma. These tributaries and reservoirs are a vital source of flow regimes for the Kiamichi River and help sustain water levels and base flows. With alteration to natural environments and flow regimes, it follows that the ichthyofauna of the river may be impacted due to these anthropogenic effects. We sampled eleven sites along the longitudinal profile of the Kiamichi River starting at Highway 259 bridge at Big Cedar and extending downstream to Hugo Lake (Figure 1).

Fish Sampling. We used three sampling methods for fish collections: seining, electrofishing, and gill netting. Analyses of patterns of fish diversity and community structure were restricted to data collection from seines and electrofishing efforts, therefore, just small-bodied fishes. However, we also wanted to provide some baseline information on the large-bodied fish community of the Kiamichi River, as it has not been previously described in the literature. Therefore, we used experimental gill nets to capture large-bodied fishes.

*Seining*- We sampled eleven sites on the mainstem of the Kiamichi River using 6m x 1.21m seines with a 5mm mesh. We standardized the seining protocol to include twenty seine hauls per sample site, and each seine haul was ten meters in length, for a total of 200 meters/site. A four person crew was used each time that sampling was conducted. Patton et al. (2000) found that that seining four 50 meter seine hauls captured 90% of the species present in prairie streams in Wyoming. However, because substrates in streams of southeastern Oklahoma are likely more complex than those of prairie streams in Wyoming, we also used electrofishing to further sample the small-bodied fish community. Onorato et al.

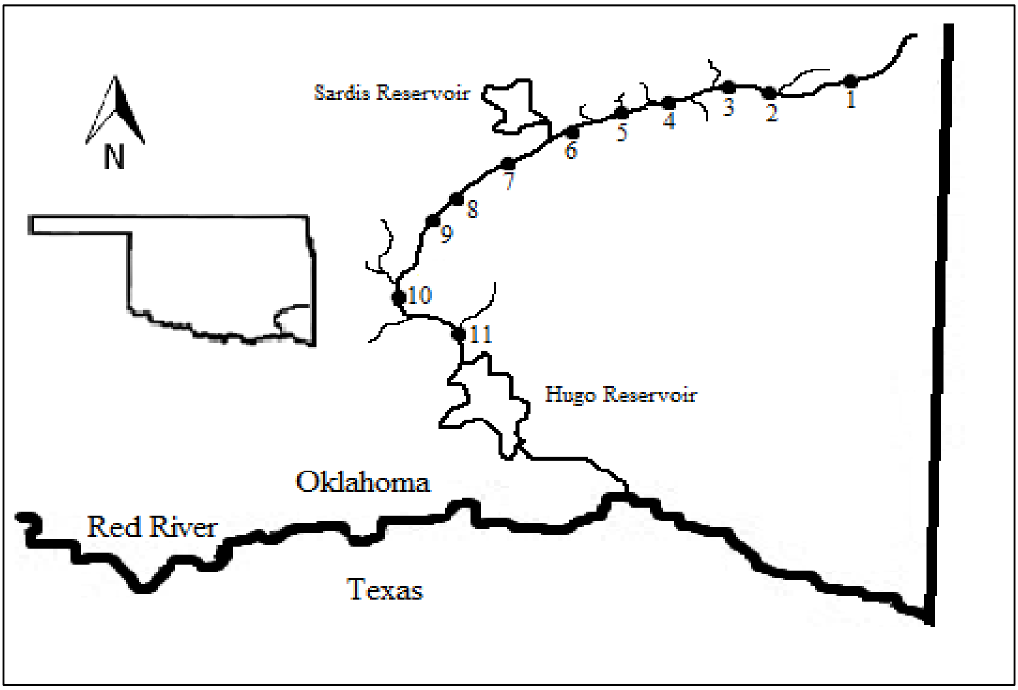


**Figure 1. Sample sites along the Kiamichi River in southeastern Oklahoma, October 2012 – January 2013. Numbered sample sites correspond to coordinates in appendix A.**

(1998) and Patton et al. (2000) showed that seining was an effectivegear, and when paired with electroshocking it can produce more complete samples in terms of species richness and abundance than either gear would have on its own. When arriving at each site, habitat was qualitatively classified for the presence of pools, riffles, runs, backwaters, side channels, or other unique habitat types, and seine hauls were conducted in each habitat type present at each sample location. Kick seining was conducted where riffles were present, wherein the seine was placed at the downstream end of the riffle and a one pass kick method was used to dislodge substrate, thereby washing fish into the seine. Once fish were collected from a site, they were pooled and preserved in a 10% formalin solution, then identified in the laboratory at the Oklahoma Department of Wildlife Conservation (ODWC) at Holdenville Oklahoma. All seine hauls were conducted from October 2012 through January 2013 to avoid high-flow conditions that often occur during the spring.

*Electrofishing*- Electrofishing was conducted using a Halltech HT2000 backpack based electrofishing unit. As with seining, all available habitats were qualitatively classified before electrofishing sampling began. We standardized electrofishing effort by sampling a total of 30 minutes at each location, sampling all available habitats present. While conducting electrofishing, a one pass method was used to collect fish. While many past studies have utilized multiple pass electrofishing methods, an important sampling consideration is the feasibility of time and cost constraints when sampling multiple sites (Meador, et al. 2003). Further, many past studies have shown that a single-pass method is effective, especially if sampling for species richness is a goal. Pusey et al. (1998) found that a single pass method was adequate in collecting a significant proportion of the total species present when using a single pass method vs. multiple pass methods. Meador et al. (2003) showed that with a single pass method, between 80.7-100% of total species present were collected the first pass using backpack electrofishing units. Bertrand et al. (2006) showed that a single pass electrofishing method was sufficient in sampling streams by collecting all species at 14 of 19 sites on the first pass.

*Gill Netting*- We used 24.4x1.8m experimental gill nets for sampling large-bodied fishes (Hubert 1996). Nets were composed of 8 panels, each 3.1m in length, and ranging in mesh size from 19-63mm. The various mesh panels on each net occurred randomly along the length of the net to allow for more randomization of sampling. We chose these nets because they are used by ODWC as per their standardized sampling protocol for gill netting, and have been shown to be effective for capturing a variety of species and sizes (ODWC 2009). We gill netted at four of the 11 sample sites, plus one site downstream from Hugo Lake, and site selection was based on the presence of large pools to allow for net placement and boat accessibility. At each of the five sample sites, fifteen nets were placed perpendicular to the bank and fished for a 24 hour, equating to 15 net-nights/site and a total of 75 net-nights. All fishes captured were identified to species in the field; live fish were released and dead fish were discarded onto the adjacent stream banks within areas of thick vegetation.

*Data Analysis*- We used linear regression (Zar 1973) to look at patterns of species diversity along the longitudinal gradient. We regressed distance downstream (as the independent variable) against each of three measures of diversity (as the dependent variables): species abundance, species richness, and Shannon diversity (Shannon 1948). All linear regressions were calculated in SAS version 13.2 (SAS 2014). To look for patterns of community composition along the longitudinal gradient, we constructed an arranged data table following Rahel and Hubert (1991). We tried numerous iterations of arrangement to look for patterns, and determined that the most parsimonious interpretation came by sorting data rows by frequency of occurrence, followed by placement of some of the species into like groups.

## Results

*Fish Sampling*- A combined effort of 220 seine hauls were completed, encompassing 2200m of seining at 11 sites (Table 1). Seining resulted in the capture of 3,490 individual fish, representing 30 species (Table 1). Electrofishing for 30 minutes at each of the 11 sites totaled 330 minutes (5.5 hours) of electrofishing effort. Electrofishing resulted in the capture of 5383 individual fish, representing 39 species (Table 1). Combined, seining and electrofishing resulted in the capture of 8,873individual small-bodied fish, representing 39 species (Table 1). Experimental gill nets were used for a total of 75 net-nights and resulted in the capture of 747 individual large-bodied fish, including 25 species. With all the gears combined we captured a total of 9,620 individual fish representing 54 species.

*Patterns of Diversity*- To assess species diversity along the longitudinal gradient of the Kiamichi River, three components were measured; species abundance, species richness, and Shannon Diversity. With respect to species abundance, we captured an average of 873 individual fish among the 11 sites, with a range of 148 (site 5) to 1,674 (site 8) fish/site (Table 2). Regression analysis indicated that abundance generally increased along the longitudinal gradient ($R^2$ = 0.352) but not significantly (P = 0.424; Figure 2a). With respect to species richness, we captured an average of 22.6 species among the 11 sites, with a range of 13 (site 5) to 32 (site 8) species/site (Table 2). Raw values of species richness varied among the sites, but richness was generally lowest at the more upstream sites, highest at sites 7 and 8, and decreased somewhat among the more downstream sites (Table 2). However, regression analyses indicated that species richness increased significantly along the longitudinal gradient ($R^2$ = 0.374, p = 0.001; Figure 2b). With respect to Shannon diversity, values did not vary widely along the longitudinal gradient (mean = 2.255, range = 1.82 – 2.58), but regression analysis revealed it was a significant increase $R^2$ = 0.368, p = 0.001; Figure 2c).

*Patterns of Community Structure*- We assessed community structure using an arranged data table, which is qualitative approach for

**Table 1. Numbers of fish collected using three sampling gears in the Kiamichi River, southeastern Oklahoma, October 2012 – January 2013.**

| Common Name | Scientific Name | Numbered captured by seine | Number captured by electrofishing | Number captured by gill net | Total |
|---|---|---|---|---|---|
| Alligator Gar | *Atractosteus spatula* | 0 | 0 | 4 | 4 |
| Bigeye Shiner | *Notropis boops* | 236 | 165 | 0 | 401 |
| Bigmouth Buffalo | *Ictiobus cyprinellus* | 0 | 0 | 11 | 11 |
| Black Bullhead | *Ameiurus melas* | 0 | 1 | 0 | 1 |
| Black Crappie | *Pomoxis nigromaculatus* | 0 | 0 | 11 | 11 |
| Blackside Darter | *Percina maculata* | 3 | 7 | 0 | 10 |
| Blackspotted topminnow | *Fundulus olivaceus* | 89 | 48 | 0 | 137 |
| Blackstripe Topminnow | *Fundulus notatus* | 16 | 11 | 0 | 27 |
| Blue Catfish | *Ictalurus furcatus* | 0 | 0 | 119 | 119 |
| Bluegill | *Lepomis macrochirus* | 110 | 681 | 4 | 795 |
| Bluntnose Darter | *Etheostoma chlorosoma* | 9 | 8 | 0 | 17 |
| Bluntnose Minnow | *Pimephales notatus* | 165 | 647 | 0 | 812 |
| Bowfin | *Amia calva* | 0 | 0 | 1 | 1 |
| Brook Silverside | *Labidesthes sicculus* | 1604 | 316 | 0 | 1920 |
| Channel Catfish | *Ictalurus punctatus* | 0 | 1 | 71 | 72 |
| Channel Darter | *Percina copelandi* | 19 | 29 | 0 | 48 |
| Chestnut Lamprey | *Ichthyomyzon castaneus* | 0 | 1 | 0 | 1 |
| Common Carp | *Cyprinus carpio* | 0 | 0 | 8 | 8 |
| Cypress Darter | *Etheostoma proeliare* | 1 | 4 | 0 | 5 |
| Drum | *Aplodinotus grunniens* | 0 | 1 | 9 | 10 |
| Dusky Darter | *Percina sciera* | 15 | 21 | 0 | 36 |
| Emerald Shiner | *Notropis atherinoides* | 222 | 94 | 0 | 316 |
| Flathead Catfish | *Pylodictis olivaris* | 0 | 0 | 13 | 13 |
| Freckled Madtom | *Noturus nocturnus* | 2 | 20 | 0 | 22 |
| Gizzard Shad | *Dorosoma cepedianum* | 0 | 3 | 75 | 78 |
| Golden Redhorse | *Moxostoma erythrurum* | 0 | 3 | 10 | 13 |
| Green Sunfish | *Lepomis cyanellus* | 25 | 463 | 0 | 488 |
| Hybrid Striped Bass | *Morone chrysops x saxatilis* | 0 | 0 | 1 | 1 |
| Johnny Darter | *Etheostoma nigrum* | 26 | 60 | 0 | 86 |
| Kiamichi Shiner | *Notropis ortenburgeri* | 47 | 79 | 0 | 126 |
| Largemouth Bass | *Micropterus salmoides* | 8 | 14 | 1 | 23 |
| Log Perch | *Percina caprodes* | 7 | 516 | 0 | 523 |
| Longear Sunfish | *Lepomis megalotis* | 32 | 667 | 0 | 699 |
| Longnose Gar | *Lepisosteus osseus* | 0 | 0 | 64 | 64 |
| Mimic Shiner | *Notropis volucellus* | 9 | 22 | 0 | 31 |
| Mosquito Fish | *Gambusia affinis* | 89 | 177 | 0 | 266 |
| Orangebelly Darter | *Etheostoma radiosum* | 135 | 511 | 0 | 646 |
| Orangespotted Sunfish | *Lepomis humilis* | 10 | 84 | 0 | 94 |

**Table 1. Continued**

| Common Name | Scientific Name | Numbered captured by seine | Number captured by electrofishing | Number captured by gill net | Total |
|---|---|---|---|---|---|
| Orangethroat Darter | *Etheostoma spectabile* | 11 | 32 | 0 | 43 |
| Paddlefish | *Polyodon spathula* | 0 | 0 | 1 | 1 |
| Redear Sunfish | *Lepomis microlophus* | 0 | 20 | 0 | 20 |
| Redfin Shiner | *Lythrurus umbratilis* | 110 | 65 | 0 | 175 |
| River Carpsucker | *Carpiodes carpio* | 0 | 0 | 14 | 14 |
| River Redhorse | *Moxostoma carinatum* | 0 | 1 | 21 | 22 |
| Slenderhead Darter | *Percina phoxocephala* | 13 | 16 | 0 | 29 |
| Smallmouth Buffalo | *Ictiobus bubalus* | 0 | 0 | 70 | 70 |
| Spotted Bass | *Micropterus punctulatus* | 4 | 62 | 20 | 86 |
| Spotted Gar | *Lepisosteus oculatus* | 1 | 2 | 12 | 15 |
| Spotted Sucker | *Minytrema melanops* | 0 | 14 | 1 | 15 |
| Steelcolor Shiner | *Cyprinella whipplei* | 390 | 330 | 0 | 720 |
| Stoneroller | *Campostoma anomalum* | 82 | 180 | 0 | 262 |
| Tadpole Madtom | *Noturus gyrinus* | 0 | 3 | 0 | 3 |
| Warmouth Sunfish | *Lepomis gulosus* | 0 | 4 | 0 | 4 |
| White Bass | *Morone chrysops* | 0 | 0 | 10 | 10 |
| White Crappie | *Pomoxis annularis* | 0 | 0 | 147 | 147 |
| Yellow Bass | *Morone mississippiensis* | 0 | 0 | 49 | 49 |
| **Total** | | 3490 | 5383 | 747 | 9620 |

looking for patterns along the longitudinal gradient (Rahel and Hubert 1991). After trying several iterations of arranging the data to look for an interpretable pattern, the most parsimonious interpretation came from sorting the data by frequency of occurrence of species, and then rearranging the tabular position of a few species to fit into appropriate categories. In so doing, and as supported by the regression of species richness (Figure 2b), the Kiamichi River showed a pattern of species addition along the longitudinal gradient (Table 2). Further, by arranging the data as described, we was able to identify several somewhat distinct groups of fishes along the longitudinal gradient, in addition to the broad general pattern of species addition. Specifically, these groups could be described as: (1) a group of 13 species that were ubiquitous, found throughout the longitudinal gradient, and occurred at 90-100% of the sites, (2) a group of nine species that were widespread but scattered along longitudinal gradient, including upstream and downstream sites, and occurred at 36-73% of the sites, (3) a group of seven species that showed a pattern of zonation in that they only occurred at downstream sites, and (4) a group of 10 species that were rare, indeed too rare to assign to as particular location along the longitudinal gradient in the catch (Table 2). Species identified as rare were present in only one or two of the 11 sites sampled, and were represented by only 1-20 total individuals ($\leq$ 4 individuals, or 0.05% of the total number of fish captured, were collected among nine out of ten species classified as rare).

## Discussion

*Patterns of Species Richness-* The Kiamichi River showed a statistically significant increase in species diversity along the upstream to downstream gradient, as indicated by species richness and Shannon diversity. These findings are consistent with many previous works (Sheldon 1968; Evans and Noble 1979; Rahel

**Table 2. Numbers of fish captured from 11 sites along the Kiamichi River in Southeastern Oklahoma via seining and electrofishing, October 2012 – January 2013.**

| | Site Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Total | Frequency |
| Ubiquitous species, occurred throughout longitudinal gradient | | | | | | | | | | | | | |
| Brook Silverside | 148 | 391 | 356 | 53 | 4 | 182 | 90 | 141 | 423 | 55 | 81 | 1924 | 100 |
| Bluntnose Minnow | 9 | 35 | 42 | 28 | 7 | 51 | 80 | 103 | 271 | 62 | 124 | 812 | 100 |
| Bluegill Sunfish | 22 | 137 | 79 | 55 | 2 | 30 | 54 | 152 | 122 | 10 | 128 | 791 | 100 |
| Longear Sunfish | 36 | 52 | 71 | 23 | 10 | 7 | 131 | 340 | 3 | 7 | 19 | 699 | 100 |
| Green Sunfish | 48 | 77 | 59 | 16 | 14 | 21 | 37 | 55 | 66 | 27 | 68 | 488 | 100 |
| Stoneroller | 17 | 12 | 26 | 9 | 21 | 21 | 72 | 53 | 7 | 23 | 1 | 262 | 100 |
| Steelcolor Shiner | 1 | 1 | 11 | 15 | | 17 | 102 | 257 | 67 | 77 | 172 | 720 | 91 |
| Orangebelly Darter | 2 | 2 | 17 | | 7 | 50 | 127 | 303 | 6 | 106 | 26 | 646 | 91 |
| Bigeye Shiner | 55 | 34 | 25 | 13 | 6 | 9 | | 59 | 76 | 17 | 107 | 401 | 91 |
| Blackspotted Topminnow | 22 | 45 | 23 | 2 | 3 | 1 | 18 | 1 | 20 | | 2 | 137 | 91 |
| Johnny Darter | 2 | 8 | 7 | 5 | | 40 | 1 | 7 | 1 | 12 | 3 | 86 | 91 |
| Spotted Bass | 1 | 4 | 11 | 3 | 2 | 1 | 2 | 16 | 11 | | 15 | 66 | 91 |
| Mosquitofish | | 22 | 9 | 11 | 64 | 42 | 6 | 16 | 46 | 7 | 43 | 266 | 91 |
| Ubiquitous species, but scattered along the longitudinal gradient | | | | | | | | | | | | | |
| Orangespotted Sunfish | | 3 | | 23 | | 9 | 6 | 14 | 26 | 2 | 11 | 94 | 73 |
| Channel Darter | | 1 | | 2 | | 1 | 2 | 28 | 1 | 1 | 12 | 48 | 73 |
| Spotted Sucker | | 2 | 1 | 3 | | 2 | 1 | 1 | 4 | | | 14 | 64 |
| Dusky Darter | | | 6 | 2 | | 1 | | 19 | 1 | 2 | 5 | 36 | 64 |
| Blackstripe Topminnow | 2 | | 8 | 2 | | | 2 | 8 | | | 5 | 27 | 55 |
| Log Perch | | 3 | | 1 | | 2 | 6 | 20 | | | 491 | 523 | 55 |
| Orangethroat Darter | | 4 | | 7 | | | 14 | 6 | | | 12 | 43 | 45 |
| Largemouth Bass | | 2 | 4 | 14 | | | | 2 | | | 1 | 23 | 45 |
| Blackside Darter | | | 3 | | | | 3 | 2 | | | 2 | 10 | 36 |
| Species generally restricted to downstream sites | | | | | | | | | | | | | |
| Redfin Shiner | | | | 22 | | 20 | 1 | 24 | 9 | 8 | 91 | 175 | 64 |
| Kiamichi Shiner | | | | | 1 | 8 | 12 | 1 | 71 | 19 | 14 | 126 | 64 |
| Slenderhead Darter | | | | | 7 | 7 | 3 | | 2 | 2 | 8 | 29 | 55 |
| Emerald Shiner | | | | | | 38 | 12 | | 131 | 78 | 57 | 316 | 45 |
| Mimic Shiner | | | | | | 2 | 3 | 1 | 16 | | 9 | 31 | 45 |
| Freckled Madtom | | | | | | 1 | 3 | 15 | | 1 | 2 | 22 | 45 |
| Bluntnose Darter | | | | | | 2 | 4 | 8 | 1 | 2 | | 17 | 45 |
| Rare species, occurred in few sites, and very few individuals | | | | | | | | | | | | | |
| Redear Sunfish | | | | | | | 5 | 15 | | | | 20 | 18 |
| Warmouth Sunfish | 2 | | | | | | 2 | | | | | 4 | 18 |
| Golden Redhorse | | | | | | | 3 | | 1 | | | 4 | 18 |
| Spotted Gar | | 1 | | | | | | 2 | | | | 3 | 18 |
| Channel Catfish | | | | | | | | 1 | | | | 1 | 9 |
| Gizzard Shad | | | 3 | | | | | | | | | 3 | 9 |
| Tadpole Madtom | | | | | | | | 3 | | | | 3 | 9 |
| Chestnut Lamprey | | | 1 | | | | | | | | | 1 | 9 |
| Freshwater Drum | | | | | | | | 1 | | | | 1 | 9 |
| Black Bullhead | | | | | | | | | 1 | | | 1 | 9 |
| Total | 367 | 836 | 762 | 309 | 148 | 565 | 802 | 1674 | 1383 | 518 | 1509 | 8873 | |
| Number of species | 14 | 20 | 20 | 21 | 13 | 25 | 29 | 32 | 25 | 20 | 27 | 39 | |

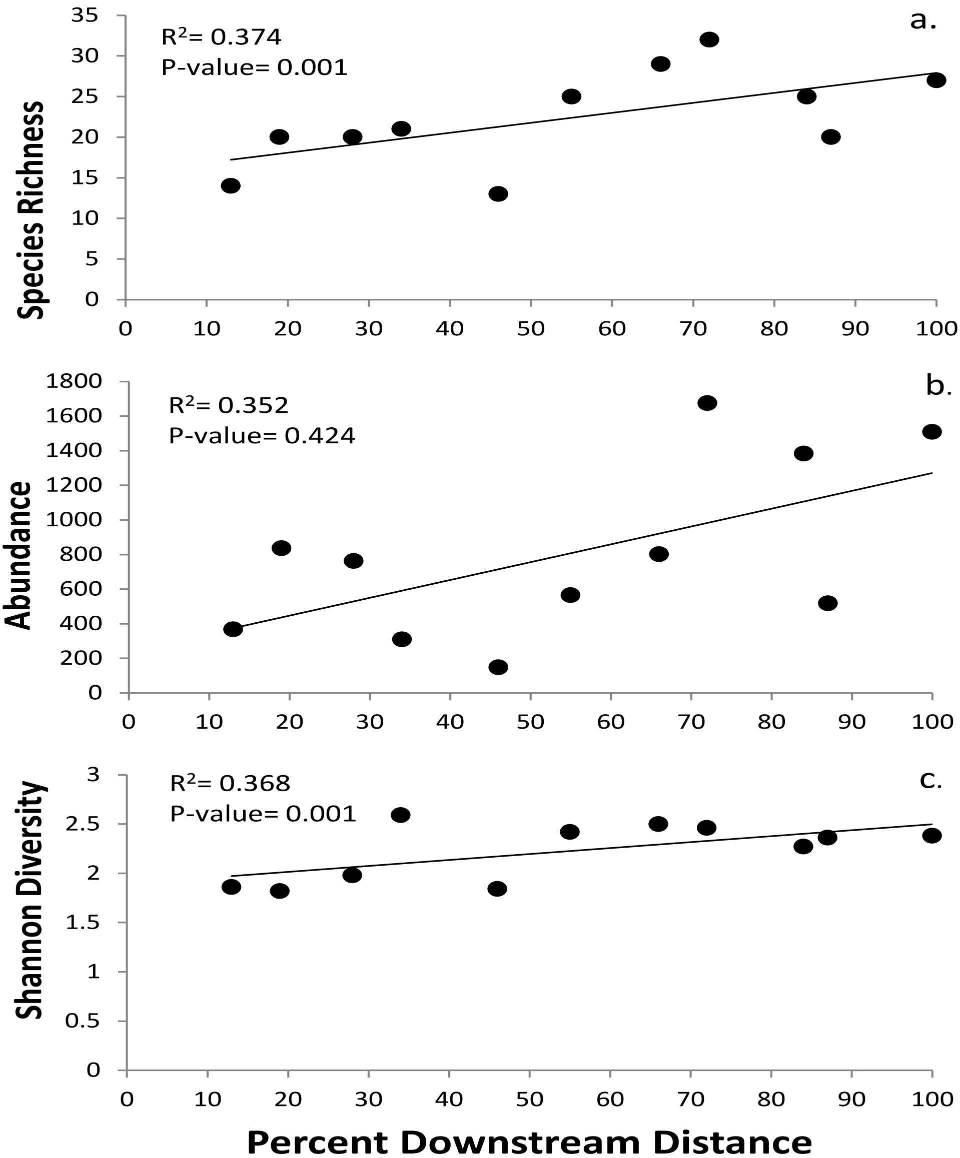


**Figure 2: Regression analysis of species richness (a), abundance (b), and Shannon diversity along the longitudinal gradient of the Kiamichi River, southeastern Oklahoma, October 2012 – January 2013.**

and Hubert 1991; Williams et al. 1996; Bistoni and Hued 2002). And while our results also suggested an increase in overall abundance along the longitudinal gradient ($R^2$=0.352), that increase was not significant (P=0.424). It is noteworthy that species richness peaked before reaching the downstream-most sites, and decreased somewhat among the last few sites. This finding is somewhat inconsistent with other work. However, peak species richness was achieved when several species that were classified as rare (group 4, Table 2) were added at reaches 7-8; within the last few reaches, these same rare species were not present, thereby contributing to the decrease in species richness among the last few sample sites. It is unlikely that all individuals in a system will be detected during a study (MacKenzie et al. 2005), but inclusion of rare species has been shown to be important for overall assessment of diversity and detection of ecological changes over time (Cao et al. 1998; Cucherousset et al. 2008). Further, in many cases, rare species may provide unique and vulnerable ecological function (Mouillot et al. 2013). While it is beyond the scope of this study to consider each species' ecological function, in this study, consideration of rare species affected the interpretation of total species richness as well as longitudinal patterns of species richness, and may certainly be useful for monitoring change over time.

*Patterns of community structure*- Previous research has shown that, when sampling over some distance with the goal of demonstrating species richness, species accumulation is rapid within the first few sites, and may or may not become asymptotic (Kanno et al. 2009). While the general pattern of community structure indicated species addition along the longitudinal gradient of the Kiamichi River, 36% of all species captured were captured at the first site, 56% of all species had been captured by the time we included the second site, and 67% of all species were captured by the time we included the third site. In that regard, species accumulation was very rapid. Our first sample was ~17km from the uppermost headwaters. Inclusion of samples further upstream may have resulted in the capture of fewer species; however, given the broad range of habitat and stream sizes utilized by the ubiquitous species that we captured at the first few sites, it may require sampling in the smallest headwaters to find areas in which these species do not occur. Further, much of the headwaters of the Kiamichi River is subject to intermittent water and long reaches of desiccation during dry periods (T. Patton, unpublished data).

Though species addition was evident along the longitudinal gradient of the Kiamichi River, four groups of species were detected: (1) a group of 13 species that were ubiquitous and found throughout the longitudinal gradient, (2) a group of nine species that were widespread but scattered along longitudinal gradient, (3) a group of seven species that showed a weak pattern of zonation in that they only occurred at downstream sites, and (4) a group of 10 species that were rare in our catch. Though it is beyond the scope of this paper to review the specific habitat preferences of each species captures, we addressed the general habitat requirements of species as they relate to the four groups defined above, and referred to Robison and Buchanan (1988) and by Miller and Robison (2004) for general habitat descriptions that may provide insight on species' distributions in the Kiamichi River.

Among the ubiquitous species, a variety of minor habitat preferences are indicated by Robison and Buchanan (1988) and by Miller and Robison (2004); however, these sources suggest that all 10 of the species we classified as ubiquitous are basically habitat generalists, occurring in a variety of habitats, and all 10 are relatively common among streams and rivers in southeastern Oklahoma.

Among the widespread but scattered species, all nine of the species included in this group can be regarded largely as habitat generalists as well (Robison and Buchanan 1988; Miller and Robison 2004), and where specific habitat preference is indicated, those habitats appear to be relatively common in the Kiamichi River. This group also included several species of darters (*Etheostoma* and *Percina*) that are generally common in rivers of southeastern Oklahoma, and that show preference for large substrate size; this may explain why they were captured throughout the longitudinal profile, but not at every location; i.e., they were found where appropriate substrates and other microhabitat features were available. The total number of each species captured within this group also suggests that the widespread but scattered species were not nearly as abundant as the ubiquitous species; reduced overall abundance may also have led to their absence in our catch at some sites.

We captured seven species that were only present in downstream sites. A review of general stream size preference indicates that six of these seven species are most commonly found in medium to larger streams and rivers, and most of which prefer sluggish pools (Robison and Buchanan 1988; Miller and Robison 2004). This may explain their absence from the upstream sites. Only one species in this group did not fit that general habitat description; freckled madtom (*Noturus nocturnus*) is described as a resident of small-medium sized streams and rivers, where it is usually found over gravel and cobble substrates (Robison and Buchanan 1988; Miller and Robison 2004). Though this species was not abundant in our samples, it was not collected at the more upstream sites, and was found at five out of six of the most downstream sites, suggesting it may be more tolerant of larger rivers than the literature suggests.

We captured 10 species that were classified as rare based on low overall abundance (1 – 20 individuals; usually 1-4 individuals) and their presence at only one or two sites. Among these, four are generally considered large-bodied fishes, which makes them more difficult to capture with sampling gears designed for use while wading; these include golden redhorse (*Moxostoma erythrurum*), spotted gar (*Lepisosteus oculatus*), channel catfish (*Ictalurus punctatus*), and freshwater drum (*Aplodinotus grunniens*). However, we captured each of these species in gill nets at 60-100% of the sites in which we used gill nets, suggesting these species were relatively common, but are more likely to be captured with gill nets than with seining or hand-held electrofishing gear. Gizzard shad (*Dorosoma cepedianum*) were also rare in the seine and electrofishing catch, but common (present in 100%) in our gill net samples. When these five species are excluded due to gear selectivity, only five species were rare in our catch: redear sunfish (*Lepomis microlophus*), warmouth (*Lepomis gulosus*), tadpole madtom (*Noturus gyrinus*), chestnut lamprey (*Ichthyomyzon castaneus*), and black bullhead (*Ameiurus melas*).

*Individual species of interest-* while it was not a specific objective to address questions related to the presence of species of concern or non-native fishes, it is noteworthy to describe what we found within the constraints of our sampling protocol. We captured two state-sensitive species, Kiamichi shiner (*Notropis ortenburgeri*) and blackside darter (*Percina maculata*), which are classified as Tier I and Tier III, respectively, indicating species of greatest conservation need (CWCS 2005). We captured only 10 blackside darters, and 126 Kiamichi shiners. Among the seine and electrofishing samples we captured no non-native species; however, in the gill net samples we captured two non-native species: bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix* ). These species were first captured in the Red River Drainage in Oklahoma in 2012 (Patton and Tackett 2012). In this study and in the study by Patton and Tackett (2012), these non-native species were captured downstream from Hugo Reservoir, and were the only two non-native species captured during this study.

In summary, the Kiamichi River showed a pattern of increasing species diversity along the longitudinal gradient, as well as species addition from upstream to downstream. Further, unique fish communities were detected within the overall pattern of species addition. Inclusion of rare species in our analyses facilitated analysis of overall species richness, and affected our interpretation of community patterns.

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