

INFLUENCE OF STREAM CONNECTANCE AND NETWORK SPATIAL POSITION ON
FISH ASSEMBLAGE STRUCTURE IN THE KANSAS RIVER BASIN, USA

by

DARREN JAY THORNBRUGH

B.S., University of Nebraska-Lincoln, 2000

B.A., University of Nebraska-Lincoln, 2001

A THESIS

Submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Division of Biology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Approved by:

Major Advisor
Keith B. Gido

Abstract

Stream networks provide complex habitats for fish assemblages that can vary gradually along a gradient of stream size or abruptly at transition zones between large rivers and their tributaries. We evaluated the relative importance of these gradual and abrupt habitat transitions in regulating stream fish assemblages by quantifying roles of stream size and spatial position within a drainage network as a determinant of fish assemblage structure within the Kansas River basin, KS. We predicted fish assemblage structure to generally be dependent on stream size and that smaller streams would be influenced by their connectance to larger mainstem rivers. Fishes in the Kansas River basin varied along a gradient of stream size and longitude, and after controlling for these effects, there was evidence that connectivity to a larger river influenced species richness and assemblage structure. In 1st order streams there was an increase in species richness with increasing distance from a mainstem confluence and species composition in larger tributaries (i.e., 4th order streams) varied with proximity to the mainstem river. We also found an increase in species richness at sites located on smaller tributaries connected to a larger downstream mainstem. Species composition in 1st and 4th order streams also varied with connectance to the mainstem river. Within three intensively sampled tributaries, there was an abrupt change in fish fauna between the Kansas River and sample sites above the confluence, but only gradual change in assemblage structure within each tributary with a high degree of seasonal variation. In the first 20 stream km of these three mainstem tributaries adult fishes were more structured along a gradient away from the mainstem river than juveniles, potentially suggesting more generalized habitat needs of juvenile fishes. At the spatial and temporal scale of our analysis, it appeared the effects of large rivers on tributary streams were generally localized. However, the documented influence of spatial position suggests movements between habitats could regulate community level dynamics as well as individual species over longer temporal scales.

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Acknowledgements

A number of people deserve my thanks for their advice and support throughout my master's program. My advisor, committee members, friends, and fellow graduate students helped me to see this project through to completion.

First and foremost I need to thank all of those people who helped me with field collections. I thank Nathan Franssen, Justin Bengtson, David Hoeinghaus, Katie Bertrand, Tyler Pilger, and Eric Kightley for help in field collections. Kansas Department of Wildlife and Parks for providing data used in this study. In particular, Kristen Hase, Chris Mamoliti, and Mark Shaw were instrumental in making these collections. This work was supported by grants from the U.S. Geological Survey National Gap Analysis Program and, the Kansas Department of Wildlife and Parks. The National Science Foundation Research Experiences for Undergraduates Program provided support for E. Kightley.

I would especially like to thank my major advisor, Dr. Keith Gido, for all the help, advice, and expertise he contributed to this project. Dr. Gido was an excellent mentor, whose door was always open to discuss questions, problems, research ideas, and he deepened my excitement for fish ecology. Without the instruction and mentoring that I received from Dr. Gido this thesis research would not have been possible and my graduate experience at Kansas State wouldn't have been as successful or as enjoyable. I would also like to thank my other advisory committee members: Dr. Walter Dodds, and Dr. Craig Paukert. Thanks to Dr. Walter Dodds for your excitement for algae, and training in limnology. You helped to instill in me an appreciation for the smaller things in the life aquatic. Again I thank Dr. Dodds and Dr. Paukert for your mentoring and advice and your open door policies to discuss my research. Lastly, thank the LAB aquatic journal club for the good times, good discussions, and all of the support that each of you provided during my research program.

Dedication

I dedicate this thesis research to my family without your endless love, support and encouragement this would not have been possible, especially to my mother and father whose constant support has always kept me focused on my goals. Thanks so much for always being there.

CHAPTER 1 - Influence of stream connectance and network spatial position on fish assemblage structure in the Kansas River basin, USA

Darren J. Thornbrugh and Keith B. Gido

Abstract

Stream networks provide complex habitats for fish assemblages that can vary gradually along a gradient of stream size or abruptly at transition zones between large rivers and their tributaries. We evaluated the relative importance of these gradual and abrupt habitat transitions in regulating stream fish assemblages by quantifying roles of stream size and spatial position within a drainage network as a determinant of fish assemblage structure within the Kansas River basin, KS. We predicted fish assemblage structure to generally be dependent on stream size and that smaller streams would be influenced by their connectance to larger mainstem rivers. Fishes in the Kansas River basin varied along a gradient of stream size and longitude, and after controlling for these effects, there was evidence that connectivity to a larger river influenced species richness and assemblage structure. In 1st order streams there was an increase in species richness with increasing distance from a mainstem confluence and species composition in larger tributaries (i.e., 4th order streams) varied with proximity to the mainstem river. We also found an increase in species richness at sites located on smaller tributaries connected to a larger downstream mainstem. Species composition in 1st and 4th order streams also varied with connectance to the mainstem river. Within three intensively sampled tributaries, there was an abrupt change in fish fauna between the Kansas River and sample sites above the confluence, but only gradual change in assemblage structure within each tributary with a high degree of seasonal variation. In the first 20 stream km of these three mainstem tributaries adult fishes were more structured along a gradient away from the mainstem river than juveniles, potentially suggesting more generalized habitat needs of juvenile fishes. At the spatial and temporal scale of our analysis, it appeared the effects of large rivers on tributary streams were generally localized. However, the documented

influence of spatial position suggests movements between habitats could regulate community level dynamics as well as individual species over longer temporal scales.

Introduction

Stream fish assemblages interact with aquatic habitats across a variety of spatial scales (Grossman et al. 1982, Schlosser 1982, Angermeier and Winston 1998; Grossman et al. 1998). Accordingly, measures of local fish assemblage structure are often predicted by the species composition of the surrounding drainage basin as well as the position of that locality within the drainage (Osborne and Wiley 1992; Matthews 1998; Matthews and Robinson 1998; Schaefer and Kerfoot 2004). Such spatial dependencies of fish populations and communities across scales have recently been conceptualized by several authors. Fausch et al. (2002) developed the riverscapes perspective, which posits that river environments cannot be viewed in the context of disjunct parts but rather must be considered in the context of the heterogeneous scenes of entire river landscapes. In addition, Benda et al. (2004) proposed the network dynamics hypothesis, stating that there are abrupt changes in water and sediment flux occurring at channel confluences and that these punctuated inputs of water and sediment at confluences cause breaks in the longitudinal processes that occur in rivers. Despite the increasing recognition that landscape and stream network properties influence fish assemblages, the relative importance of spatial position of a habitat within a drainage network and its connectivity to other habitats are not well documented.

Local stream condition and biotic structure are dependent on location along the stream gradient and geometry (i.e., drainage patterns) of the stream network (Horwitz 1978; Vannote et al. 1980; Osborne and Wiley 1992). Spatial positioning within this network can also affect the immigration and extinction risk in metapopulation dynamics (Fagan 2002). For example, Gotelli

and Taylor (1999) found that many fishes in a prairie river had greater colonization probabilities from surrounding habitats in downstream sites and higher extinctions risks in upstream or more isolated sites. Moreover, confluence zones are relatively productive habitat patches that may serve as source populations of emigrants which can disperse to less favorable or marginal habitat patches or sinks (Pulliam 1988; Dunning et al. 1992). Based on these studies, we predict fish to vary in assemblage structure and species richness at different positions within stream networks as a result of varying probabilities of biotic exchange and hierarchical structuring of habitats (Figure 1). More specifically, fish assemblage structure will vary with stream size and abrupt transition between streams of different orders (i.e., adventitious streams) will mediate biotic exchanges among these different community types.

Several studies have evaluated the influence of connectance (e.g., biotic exchange) in structuring stream fish assemblages. Hitt (2007) found the strongest influences to fish assemblage structure, total species richness and riverine species richness from stream network position in mid-sized tributary sites (i.e., basin areas 1000-5000 ha) followed by large tributary sites (i.e. basin areas > 5000 ha), with little variation in assemblage structure explained at sites on the smallest streams. He also noted, the effect on stream network positioning on species richness were relatively localized, with an upstream influence of approximately 20 stream km. Similarly, Falke and Gido (2006a) showed confluence sites between streams and reservoir had higher total nonnative and reservoir species richness than sites further away from those confluences, with the highest increases of reservoir species strongest in mid-order streams. Close proximity to a large river can also influence variability of stream fish assemblages, as sites closer to interface zones were found to be more temporally variable in an adventitious Illinois stream than sites more distant to those interfaces (Schaefer and Kerfoot 2004).

Our study focused on patterns of fish species richness and abundance in prairie streams in relation to proximity to a mainstem river. We used a suite of habitat variables collected at various spatial scales to describe upstream and downstream effects on fish assemblage structure by spatial position within a stream network. We predicted that local species richness and fish assemblage structure would be influenced by relative position along a stream gradient, but also that these influences would be greatest at sites of adventitious tributaries with close proximity to the mainstem (Figure 1). We also predicted that species richness and assemblage structure would be greatly influenced by riverine fauna and the distance this influence persists upstream would be limited by stream size.

Materials and methods

Study area

We evaluated the influence of connectivity to mainstem rivers on stream fish assemblages at two spatial scales; basin-wide surveys from existing records, and targeted sampling of three tributaries of the Kansas River. The Kansas River basin covers 156,286 km² and includes the Smokey Hill and Republican rivers as main tributaries in western Kansas and the Big Blue and Delaware rivers in the east. In addition, we included a few tributaries of the Missouri River in the Missouri-Nishnabotna and Lower Missouri subregions (e.g. level 2 HUC's) in our large-scale study area because they represented similar habitats to those in the nearby Kansas River basin (Figure 2; Seaber 1987). Hereafter, these Missouri tributaries and the Kansas River Basin proper are collectively referred to as the Kansas basin. This region contains seven EPA level III ecoregions (Omernik 1987) with land cover primarily comprised of grasses (49%) and agricultural (46%), with a small proportion of the basin forested (<3%) and the

remainder urban, water, wetlands or barren lands (USGS 1994; Table A.1). Streams at the collection sites ranged from 1st to 8th order (Strahler 1957) and catchment area of study reaches ranged from 0.3 to 116,978 km². Twenty major reservoirs with surface areas between 399 and 5911 ha occurred within the study area along with numerous smaller impoundments.

Three tributaries of the Kansas River were targeted to evaluate fine-scale variation in fish assemblage structure along a gradient of increasing distance from their confluence with the mainstem (Clarks Creek, McDowell Creek, and Wildcat Creek; Figure 2). Five 150 m reaches within the first 20 stream kilometers (skm) of the Kansas River, on each of the three study streams were sampled along with two reaches on the mainstem Kansas River (Figure 2). Land cover in the three study catchments were dominated by grasslands (68% - 81%) and agricultural (14%-24%), with the remainder of land cover comprised of shrub, forest, urban, water, and wetlands (USGS 1994). Stream nutrient concentrations are relatively low in this region when compared with regions dominated by row-crop agriculture (Dodds and Oakes 2004). McDowell Creek and Wildcat Creek were similar in catchment area, mean width, mean depth and substrates (Table A.2). Clarks Creek had a catchment area approximately twice that of McDowell Creek and Wildcat Creek, and as such, it also had a greater mean width and depth than the other two creeks.

Experimental design

Basin wide

Fish sampling – Collections at 413 localities made by the Kansas Department of Wildlife and Parks (KDWP) during their annual stream monitoring and assessment program between 1995 and 2006 were used in our analyses (Figure 2). These records did not include sites within 20 skm upstream of reservoirs because those sites may have been influenced by reservoir fish

assemblages (Falke and Gido 2006b). The KDWP sampling protocol followed that of the United States Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP; Lazorchak et al. 1998). Each sample reach was 40 times the average wetted width of the stream (reach length range: 150m-300m). Sites were sampled using a combination of straight and bag seines (4.7-mm mesh) and pulsed-DC backpack electrofishing. One upstream pass was made with the electrofishing gear, and one downstream pass was made seining all suitable habitats. Fishes were identified to species and each site was georeferenced with a geographical positioning system (GPS). Vouchers were deposited at the University of Kansas or Fort Hays State University Natural History Museums.

Habitat – Stream habitat was quantified at a variety of spatial scales. At the site and reach scales, width measurements were collected along multiple transects within each stream. Segment-scale habitat (range of segment lengths 0.1 to 33.4 skm) was quantified from a stream network derived from a modified version of the national hydrography data set (NHD; USGS 1997) using ArcGIS 9.2 software (ESRI 2006). These variables represented factors that have presently been linked to fish assemblage structure, including stream size and spatial position within a drainage network (Osborne and Wiley 1992; Fairchild et al. 1998; Zorn et al. 2002; Grenouillet et al. 2004; Smith and Kraft 2005; Gido et al. 2006). Maximum elevation of the stream reach, Strahler stream order (Strahler 1957), Shreve link or link magnitude (Shreve 1966), and catchment area, were used to quantify stream size and spatial position within a drainage network. Downstream order (DORDER), downstream link magnitude (DLINK), distance from the mainstem, and confluence link (CLINK) were used to quantify downstream stream size and downstream spatial position within a drainage network and connectivity to other habitats (Table 1). For the Kansas basin the mainstem river was defined as $\geq 5^{\text{th}}$ order stream and distances were

calculated as the distance (skm) between the collection site and the nearest 5th order stream segment. Decreasing altitude and increasing values of DLINK and stream order are associated with movement from headwaters to downstream reaches (Osborne and Wiley 1992). At the basin scale, Universal Transverse Mercator coordinates easting represented an east to west gradients of precipitation, land use, and geography (Metcalf 1966; Table A.1).

Local tributaries

Fish sampling – Fishes were collected at the 17 sites in three tributaries and the mainstem Kansas River over three seasons in 2006 and 2007; 6 – 12 July, 21 Aug – 9 Oct, 11 May – 21 June. Each site was sampled using a straight seine (4.7-mm mesh) and pulsed-DC backpack electrofishing along a 150 m reach. Similar to the EPA-EMAP protocol, one upstream pass was made with electrofishing gear followed by seining of all suitable habitats (Lazorchak et al.1998). Fishes ≥ 150 mm total length (TL) were identified in the field and released. Fishes < 150 mm TL were preserved in 10% formalin and returned to the laboratory for processing. Species with notable length classes were separated into small and large size classes. For most taxa (e.g., cyprinids and darters), the size classes represented juveniles (typically, < 30 mm TL) and adults (> 30 mm TL), whereas other taxa (e.g., catostomids and ictalurids) the large size class (> 60 mm TL) represented adults and subadults (hereafter referred to as adults).

Habitat –Habitat quantification at local tributary sites was similar to the EPA-EMAP physical habitat protocol described. Depth, width and substrate were quantified along ten transects in the sampling reach. Depth and dominate substrate were recorded every meter, except for Kansas River sites which were measured every 10 m. The relative proportion of the total area sampled for each macrohabitats (riffle, run, and pool) were measured for each sample

reach. Proximity to the Kansas River for each reach was measured from national hydrography dataset (NHD) as the number of skm downstream from each sampling reach to the Kansas River.

Data analyses

Basin wide

Longitudinal patterns – We tested for patterns of species richness and assemblage structure across a gradient of stream size. Changes in local fish species richness were evaluated across streams of different order using ANOVA and along a gradient of basin area using regression analysis. Post hoc least significant difference (LSD) tests were used to detect differences in fish species richness among sites with differing stream orders. For analyses of fish assemblages structure, rare fish species (i.e., occurred at < 5% of sample sites) were excluded because they can mask variation in the more biologically relevant (i.e., abundant) species in the assemblage. In addition, we reduced the influence of extreme high abundances with $\log(x+1)$ transformations. To characterize fish assemblage structure, we first developed a matrix of similarities among sites using a Bray-Curtis index. This was followed by non-metric multidimensional scaling (NMDS) to represent similarities in 3 dimensions. The Bray-Curtis dissimilarity matrices and NMDS ordinations were calculated using Primer 5 software (Primer-E Ltd, 2002). Similar to analysis of species richness, NMDS axes scores were regressed against basin area and ANOVA was used to test for differences among streams of different orders and along a gradient of basin area using regression analysis.

Proximity – We also tested the association between species richness and assemblage structure with proximity to the mainstem river. Because we observed strong longitudinal and geographical patterns in fish assemblage structure, it was necessary to correct these analyses for stream size and geographic location. Thus, we tested the association between proximity to the

mainstem river and residuals from multiple regression models that predicted local species richness (LSR) or NMDS axes scores. Habitat variables were selected as predictor variables in these models were developed using a stepwise forward selection procedure (SPSS 2001; Table 1). Prior to analyses, normality of habitat variables was tested and non-normal variables were $\log(x+1)$ transformed to reduce the effects of outliers and heterogeneity of variances. In addition, variables exhibiting a high degree of correlation (i.e., Pearson correlation, $r > 0.70$) were eliminated.

To evaluate the use of tributaries by fishes that occupy the mainstem river, we first classified species based on their affinity to large rivers according to Goldstein and Meador (2004), who classified species by medium to larger river preference. Species richness for this group of fishes was regressed against distance from the mainstem river.

Connectivity – To test the importance of connectivity of stream segments to mainstem segments, we tested for differences in species richness and assemblage structure among sites on stream segments with the same stream order, but differing downstream orders using both ANOVA and residuals analyses. If the ANOVA analysis showed a significant difference across sites with similar stream orders but different downstream orders then a post hoc LSD test was run on the comparison of mean fish species richness, to test for differences between species richness. Both sets of residuals from models predicting LSR and NMDS axes were used in a regression analysis quantifying variance explained by downstream order on local fish species richness and fish assemblage structure, while controlling for confounding effects of network variables.

Local tributaries

Spatial and temporal patterns – We characterized spatial and temporal variation in

assemblage structure among three tributaries or the mainstem Kansas River to evaluate the influence of mainstem rivers within the first 20 km of their confluence. We first tested for differences in fish species richness among the three sampling periods (summer, fall, and spring) and the three sampling streams (Clarks Creek, McDowell Creek and Wildcat Creek) with repeated measures ANOVA. As with the basin-wide analyses, a NMDS was performed to summarize variation in the fish assemblage structure within and among tributaries and among seasons based on a Bray-Curtis similarity matrix. In addition, using regression analysis we tested variation in abundance of two species trait categories along a gradient of distance from the mainstem Kansas River; medium to large river and small creeks to small rivers fish species as defined by Goldstein and Meador (2004).

Proximity - A regression analysis was used to quantify the association between fish assemblage structure (richness and abundance) and distance from the Kansas River. Species richness and NMDS axes scores were regressed against distance from the mainstem. In addition, we contrasted similarity of sample sites on each of the three tributaries (Clarks, McDowell, and Wildcat Creeks) to that of the Kansas River for all sampling periods. We predicted there would be an abrupt change in similarity between tributary and Kansas River sites, and that the fish assemblage within tributaries would continue to diverge from the Kansas River assemblage with increasing distance from the mainstem. Similarity of fish assemblage to that of the Kansas River was characterized by Euclidian distances between sites based on site scores from axis 1 and axis 2 of the NMDS ordination across all sampling periods. Means and standard deviations of Euclidian distance scores were calculated across sampling periods for each sample and regressed with distance from the mainstem Kansas River. Euclidian distance values were obtained using NTSYSpc software (version 2.1; Rohlf 2000).

To separate patterns of adult and juvenile fishes along a gradient of distance from the mainstem separate regression analyses for 18 species were conducted to test the dependence of juvenile and adult abundances on distance from the Kansas River. Coefficients of determinations from these analyses for adults and juvenile of each species were compared to characterize the deviation in longitudinal structuring between adult and juvenile fishes.

Results

Basin wide

Longitudinal patterns – Fourteen families, 39 genera, and 68 species of fish were collected from the 413 sites in the Kansas basin (Table A.3). Cyprinids were the dominant family comprising 84% of total fish individuals followed by centrarchids (8%) and percids (4%). The number of sites visited ranged from 4 in 8th order streams to 154 in 3rd order streams (Table A.3). Mean number of fish species significantly increased with increasing stream order from 8 in 1st order streams to 19 in 8th order streams. Because of the high degree of variation within stream orders, post hoc comparisons only indicated a significant difference in mean species richness between 1st order and higher order streams and between 7th and 8th orders and lower order streams (Figure A.1). The mean species richness was not significantly different among 2nd to 6th order streams or between 7th and 8th order stream. There also was an increase in the number of fish species with drainage area, and this pattern was significant for both eastern and western portions of the Kansas basin ($P = < 0.01$, $R^2 = 0.14$, $R^2 = 0.13$, respectively; Figure 3). A similar trend was observed for the Missouri tributary sites, but this was not significant ($P = 0.14$, $R^2 = 0.03$).

Local fish assemblage structure was characterized with a three-dimensional NMDS (Stress: 0.13). The first axis represented a gradient of stream size with sites in larger streams

having a negative association with this axis and small streams having a positive association (Figure 4). Fishes associated with larger streams were *Cyprinella lutrensis*, *Notropis stramineus*, and *Ictalurus punctatus* and fishes associated with small streams were *Campostoma anomalum*, *Etheostoma spectabile* and *Semotilus atromaculatus*. Axes 2 and 3 were not associated with stream size. The gradient on axis 2 indicated a negative association with *Pimephales promelas* and *Ameiurus natalis* on this axis and a positive association with *P. notatus*. High site scores on NMDS axis 3 were driven by high abundances of *Lepomis macrochirus*, *L. cyanellus* and *Micropterus salmoides*.

Proximity – Fish assemblage structure was only weakly associated with proximity to the mainstem and results varied by stream order. Species richness increased in 1st order streams with distance from the mainstem (Figure 5) and there was a significant trend ($P = < 0.01$, $r = 0.32$) in 4th order streams of increasing NMDS axis 1 scores with distance from the mainstem. Fish species richness of medium to larger rivers species showed a significant ($P = 0.02$, $r = 0.14$) decrease in 5th order sites as distance increased from the mainstem river; albeit the slope of this line was shallow (Figure 6). Abundance of medium to larger river fish species was greater in higher ordered tributary streams.

Multiple regression models that predicted fish species richness and assemblage structure in the Kansas basin indicated that stream width and longitude (i.e. universal transverse mercator easting coordinates) explained most of the variation in the richness model, whereas the fish assemblage structure model also included link magnitude as a predictor variable (Table 3). A residual analysis revealed a significant ($P = 0.05$, $R^2 = 0.12$) association between species richness in 1st order streams and distance, while controlling for other habitat factors (Figure 7). Fish assemblages (as represented by NMDS axis 1) in 4th order streams were significantly ($P = <$

0.01, $R^2 = 0.08$) associated with distance from the mainstem after controlling for habitat variables.

Connectivity – Streams that share their confluences with larger mainstem tributaries had higher mean species richness across 1st, 2nd, and 3rd order sites, than the streams that shared their confluence with smaller order tributaries (Figure 8). Moreover, residual analysis from the local fish species richness model that controlled for variation in stream size and easting revealed similar patterns with significantly ($P = < 0.01$, $P = 0.01$ and $P = < 0.04$, respectively) higher species richness in 1st, 2nd and 3rd order streams with higher downstream order (Figure 9). Residual analysis from the fish assemblage structure model showed a significant ($P = < 0.01$ and $P = 0.02$) positive association with increasing downstream order in 1st and 4th order streams (Figure 10).

Local tributaries

Spatial and temporal patterns – Nine families, 29 genera, and 39 species were collected during the intensive sampling of three tributaries (Table 3). Cyprinids were the dominant family collected, comprising 84% of total fish individuals followed by poeciliids (6%), centrarchids (5%), and percids (2%). All other families made up <3% of the total abundance (ictalurids, catostomids, clupeids, sciaenids, lepisosteids, and moronids).

Repeated measures ANOVA indicated species richness varied by season ($P = 0.03$) but there was no difference between tributaries or a combination of season plus tributaries (Figure 11). In addition, species richness was generally lower in spring than in summer and fall. A three-dimensional NMDS (Figure 12) characterized variation in the local fish assemblage structure across sites and seasons (Stress = 0.11). The 1st axis described a gradient of stream size, with wider and deeper streams that are closer in proximity to the Kansas River having a negative

association and narrower, shallow streams that are farther from the Kansas River having a positive association with this axis (Figure 12). Fishes associated with the Kansas River sites were typical riverine species: *N. straminius*, *N. atherinoides*, and *Aplodinotus grunniens*. Axis 2 also quantified a gradient of distance from the mainstem with sites further away having a positive association with axis 2 and sites closer to the Kansas River having a negative association with axis 2. Fishes having a positive association with axis 1 and axis 2 (i.e., further away from the mainstem) were typical headwater species: *C. anomalum*, *N. percobromis*, *Noturus exilis*, *E. spectabile*, and *E. nigrum*. Fish species that had a negative association with axis 2 occurred in higher abundance in transitional zones between medium to large tributaries and large rivers: *Dorosoma cepedianum*, *P. vigilax*, and *Gambusia affinis*. The 3rd axis described a gradient across sampling periods, with the summer sampling period having a negative association with this axis, the spring sampling period have a positive association and the fall sampling period falling intermediate to the summer and spring sampling periods. Fishes collected in higher abundance in the summer were *Lepisosteus osseus*, *Percina caprodes*, and *E. spectabile*. Fishes that occurred in higher abundance during spring were *N. straminius*, *P. promelas*, and *L. macrochirus*. A repeated measures ANOVA comparing difference in NMDS axes scores indicated no significant differences in assemblage structure among streams, but a significant difference among sample periods ($P < 0.01$).

Proximity –Fish assemblages changed abruptly between sites on the mainstem Kansas River and those on tributary streams. Regression analysis indicated a significant ($P < 0.01$) trend between axis 1 of the NMDS and increasing distance from the Kansas River (Figure 13), but this pattern appeared non-linear. Fishes driving these patterns were riverine species which were sampled in higher abundance near or in the Kansas River. In contrast, small stream fishes or

headwater species were collected farther away from the Kansas River and had a positive association on Axis 2. There were no significant relationships across the species trait category of stream size preference (i.e., classified by Goldstein and Meador 2004) in total, medium to larger river, or small creeks to small rivers fish species along a gradient from the mainstem Kansas River (Figure 14). Euclidean distance quantified the similarity of fish assemblages in tributary sample sites with those in the Kansas River. There was a general abrupt change in Euclidean distance between the first tributary sites and the Kansas River sites, but there only was a slight divergence from the mainstem fish assemblage with increasing distance (Figure 15).

Relationship between distance from the mainstem Kansas River and abundance for the 18 dominant fish species suggested adults were more structured along this gradient than juveniles (Figure 16). Coefficients of determinations (r^2) describing this relationship ranged from approximately 0.00 to 0.14 with a mean of 0.03 for juvenile fishes and approximately 0.00 to 0.42 with a mean of 0.12 for adults.

Discussion

Our results suggest that transition zones between large rivers and their tributaries can result in complex habitat gradients with varying levels of biotic exchange among those habitats. In our basin wide study, after controlling for stream size and longitude there was an indication that proximity to a large river influenced assemblage structure; albeit this pattern was relatively weak with a high degree of variability among and within streams of different orders. This apparent influence of downstream habitats on stream fish assemblages is consistent with previous studies testing the effects of mainstem rivers (Hitt and Angermeier 2006, Hitt 2007) and reservoirs (Falke and Gido 2006b) downstream from sample reaches. However, in both of these studies, downstream habitats had the most notable influence on fish assemblages in medium size

tributaries. Hitt and Angermeier (2006) suggested that increased fish species richness and increased riverine species richness in 3rd order and larger tributaries of larger rivers were mediated through microhabitat complexity and channel shape. This is a plausible explanation for the relationship between fish assemblage structure (after controlling for stream size and easting) and proximity to the mainstem in 4th order streams. We also found increased species richness in 1st order streams with increasing distance from the mainstem. We hypothesize that the isolation of these streams or specific habitat requirement of riverine fishes may result in a reduction of obligate small river fish species. It seems apparent that fish species richness increases and assemblage structure is influenced by distance to a mainstem river, but these effects are often localized and dependent on factors other than simple proximity to the larger river. In general, we conclude that habitat structure has a stronger influence on fish assemblage structure than biotic exchange in prairie stream networks.

Because our study was based on correlations between fish assemblage structure and proximity to the mainstem it was not clear if responses of the fish assemblage were attributed to habitat changes, biotic exchanges or biotic interactions with the mainstem rivers. Patterns of distribution and abundance of individual species suggest biotic exchange from the mainstem to tributary rivers may be minimal. For example, we only found a slight decline in species that are typically found in large to medium sized rivers and distance in 5th order streams. This pattern was mainly attributed to the loss of one or two species that only occurred in streams near the mainstem river. These riverine fishes were likely constrained by habitat requirements to confluence zones and only persisted for short distances from the mainstem. In smaller order streams, there were < 4 of these species present, which were likely small-body species that were

wide-spread and evenly dispersed throughout the sample sites (e.g., *C. lutrensis*). The importance of connectivity for these generalist species is unknown.

The presence of riverine fishes in tributaries could be associated with reproduction and spawning migrations (Matthews 1998). Hitt (2007) noted that tributaries were used for nursery and spawning habitat by riverine species, such as catostomids and cyprinids, which were higher in abundance and more species rich in mainstem tributaries than in headwater tributaries. In contrast to this result, changes in assemblage structure in the Kansas basin were primarily driven by the lack of small stream fish (e.g., *Luxilus cornutus*, *E. spectabile*, *C. anomalum*) near mainstem rivers, rather than the presence of large river fishes. The one exception to this was the bullhead minnow, which generally decreased in abundance with distance from the mainstem river. The absence of these species near confluences with mainstem rivers may be due to increased turbidity, changes in habitat (e.g., substrate) or biotic interactions. There are abrupt changes in habitat between mainstem rivers and their tributaries with the lower portions made up of a more homogeneous floodplain habitat types. These deeper homogenous floodplain ecotones might allow predatory fishes to persist in the assemblage for a short distance in these transitional zones of tributaries and their mainstem. Whereas our data do not show a marked increase in these predatory species, they may have not been sampled effectively with our sampling methods.

In our three intensively monitored adventitious streams, there was a notable difference between the mainstem Kansas River and tributary fish assemblages. Within these tributaries, we found a slight decrease in variability and a decrease in similarity to the mainstem with increasing distance from the Kansas River. Gorman (1986) speculated that the impact of mainstem fish assemblages on adventitious tributaries is probably significant, but noted that these influences were likely temporal variable and synchronized with reproductive seasonal pulses of migrant

fishes. Schaefer and Kerfoot (2004) provided empirical evidence of greater species diversity and variability in fish assemblage over time at interface sites of Piasa Creek, IL with declining variability and diversity with increasing distance from the mainstem river over their approximate 60 km study area. Our study indicated a high degree of temporal variations in fish assemblage structure among sampling periods which was confounded by variable abundance of juvenile and adults. Moreover, the abundance of adult fishes was more structured along a gradient of distance from the mainstem than juvenile fishes. The more random distribution of juveniles along a longitudinal gradient could indicate that they are more prone to dispersal, which may be necessary to locate suitable rearing habitat (e.g., shallow, predator-free areas; Harvey 1987). Adults, however, may respond to habitat at larger spatial scales (i.e., longitudinal zonation) that is possibly driven by physical habitat (e.g., depth) or biotic interactions.

By characterizing patterns of assemblage structure at the basin and individual tributary scales, we developed a more complete evaluation of factors influencing local fish assemblage structure in the Kansas basin. The basin-wide analysis was coarse but gave us a greater number of samples and a wide variety of network combinations (e.g., probability of different order streams having their confluences with one another) to quantify the influence of connectivity and proximity on fish assemblage structure. At this large spatial scale we detected a weak influence of proximity and connectance to the mainstem, but study sites were relatively distant from mainstem rivers (10 - > 100 km). In general, the lack of a strong pattern at this spatial scale suggests either highly variable effects of proximity or localized effects smaller than the spatial extent of our study. When evaluated at a finer spatial scale (< 20 km from mainstem), we found fish assemblages at sites near the Kansas River to differ from the mainstem assemblage, but that differences associated with proximity to the source were related to the absence of small stream

fishes near tributary confluences. Combining these analyses suggest a relatively localized exchange of biota between mainstem rivers and their tributaries. This is not to say that periodic events or migrations that are important to the persistence of the species do not occur. However, long-term monitoring at a finer temporal scale may be necessary to evaluate the importance of these rare events.

Conservation implications

Quantifying the linkage between habitats within a stream network can help managers account for these influences when making decisions on the scale at which to conserve stream habitats. Although our results suggest many populations are localized and possibly independent from other habitats during normal conditions, a number of studies have reported the importance of connectance to refugia habitats after a disturbance in small to medium order streams (Detenbeck et al. 1992; Bayley and Osborne 1993; Sheldon and Meffe 1994; Lonzarich et al. 1998). Most studies have shown that recolonization of fish assemblages in lotic systems is fairly rapid (≤ 1 yr; Detenbeck et al. 1992; Bayley and Osborne 1993), this processes is dependent on distance from source populations (Sheldon and Meffe 1994; and Lonzarich et al. 1998). Moreover, the presence of barriers impedes recolonization (Detenbeck et al. 1992). Most of these studies were in small to medium order streams in which most fish assemblages are isolated from source populations of fish but are more adapted to rapid recolonization due the to the frequent disturbances from floods and droughts (Schlosser 1987). Larger tributary fish assemblages are more apt to be recolonized from emigration of source populations of fishes and be less adapted to highly stochastic habitats. Mainstem tributary fish assemblages may be more resilient to extinction risk by being less isolated and closer to source pools and rapidly

recolonized via emigration as predicted by island biogeography theory (MacArthur and Wilson 1967).

The importance of connectivity and location within a drainage network is likely to vary among species. In the Great Plains USA, many species that characterize mainstem river assemblages are in need of conservation, but the importance of tributaries to their conservation is not well understood. Given the recent threats to mainstem rivers, tributaries may be important refugia habitat from pulsed events in mainstem rivers. The role of mainstem rivers as corridors for tributary species seems clearer, as these habitats allow connectance of metapopulations and source populations for recolonization and maintaining allelic diversity (Sklaski et al. 2007). Although our results suggest biotic exchanges such as these may not be widespread, the temporal scale of our study was not adequate to evaluate the long-term importance of these network linkages. Long-term management and conservation of fishes will require further evaluation of the influence of connectivity in stream networks and how this influences metapopulation dynamics and over all resiliency of stream biota.

Figures

Figure 1. Conceptual diagram representing the hierarchical structuring of habitats and biotic exchanges with the mainstem river system.

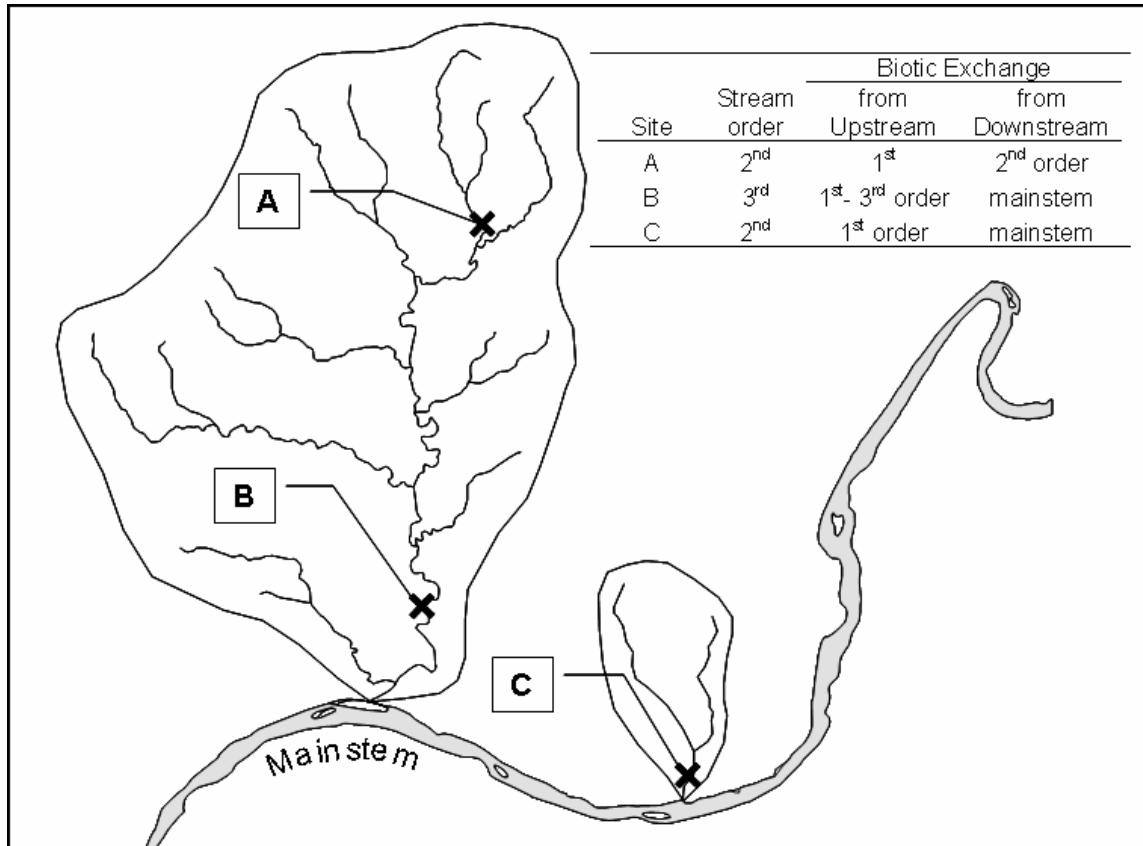


Figure 2. Fish collections sites by the Kansas Department of Wildlife and Parks during their annual stream monitoring and assessment survey of the Kansas River during Summer 1995 - 2006 (upper panel). Lower panel shows site locations within the three intensively monitored tributary streams (Clarks Creek, McDowell Creek and Wildcat Creek).

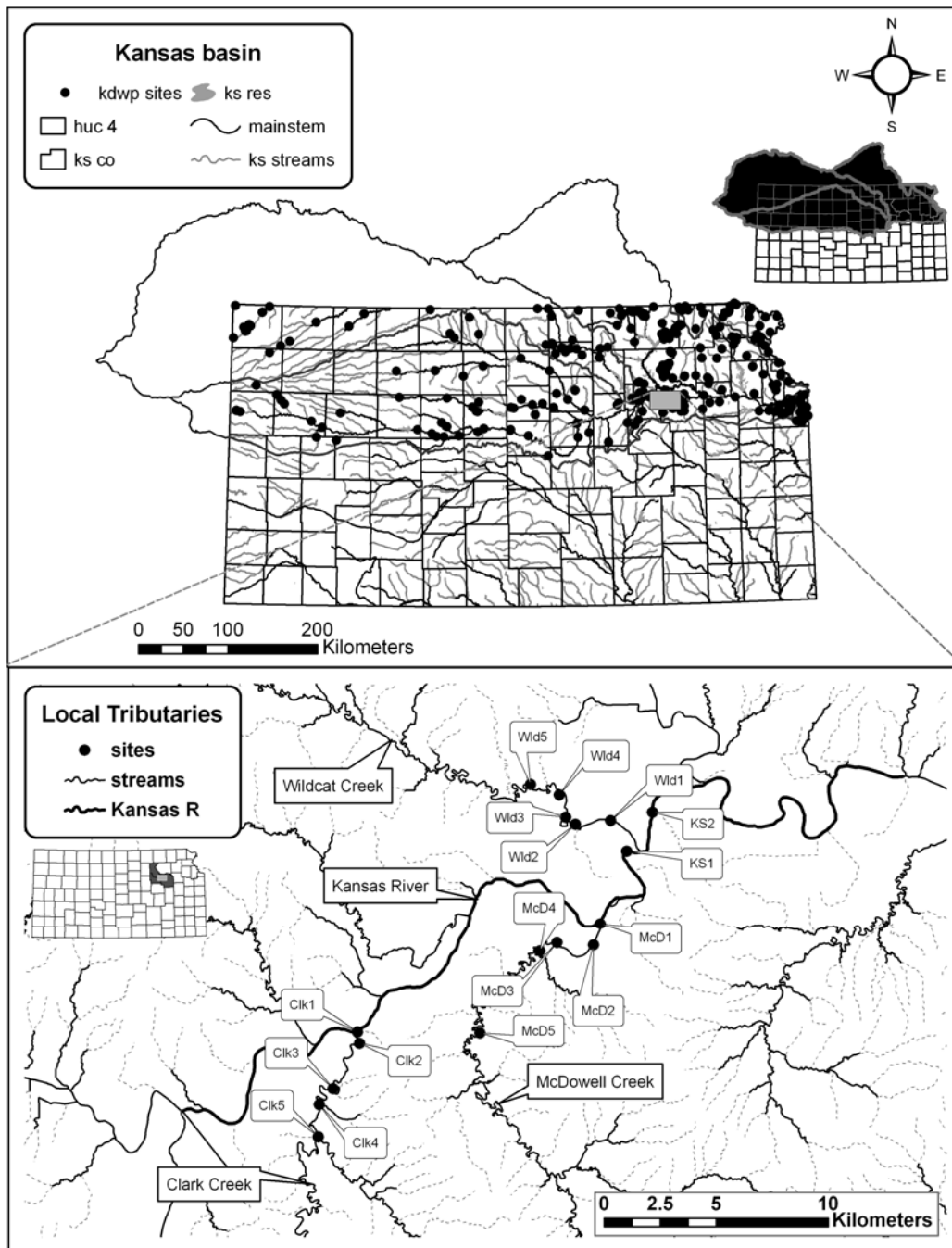


Figure 3. Number of species collected at sites as a function of drainage basin area for eastern (Big Blue and Kansas basins) and western (Republican and Smoky Hill basins) portions of the Kansas basin as well as several tributaries to the Missouri River (Lower Missouri-Blackwater and Missouri-Nishnabotna). Least-squared regression lines are drawn for significant relationships.

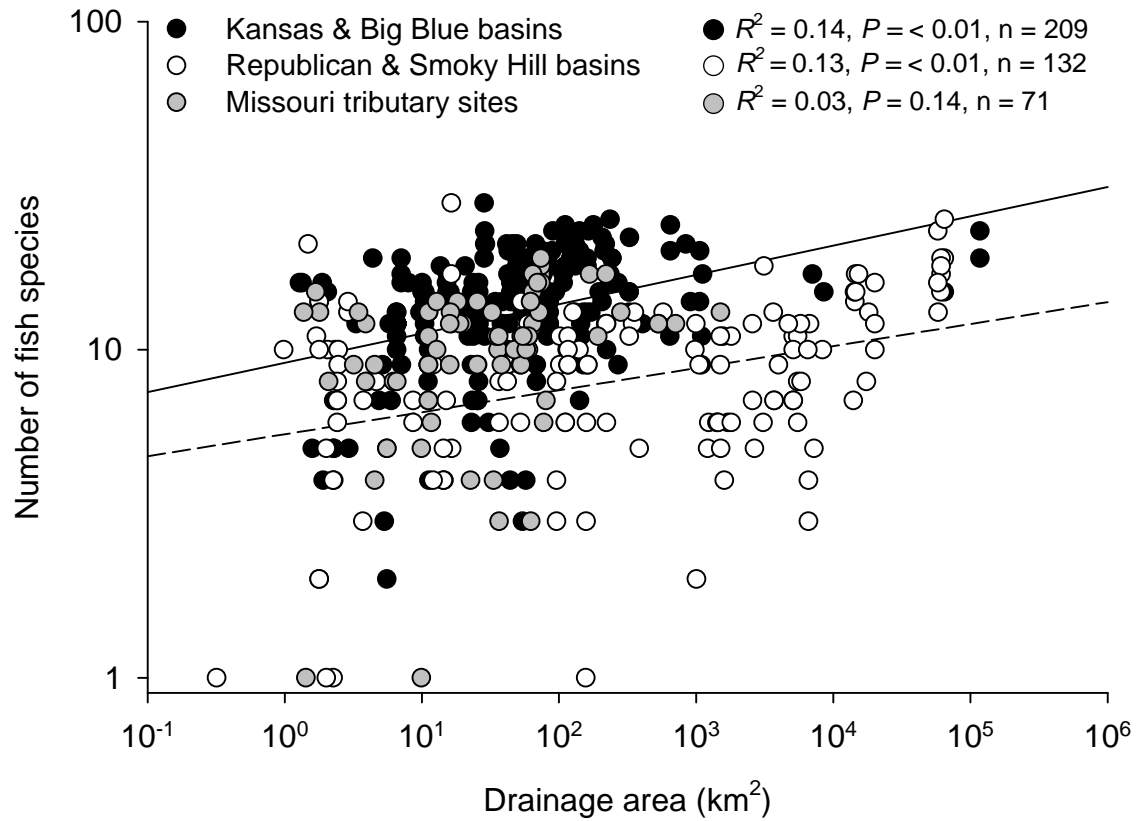


Figure 4. NMDS that summarized variation in the fish assemblage structure across sites in the Kansas basin (left panels) and associated species loadings (right panels). Axis 1 was graphed against the second and third axes and sites were coded by stream order. Species codes are the first 3 letters of the species genus followed by the first 3 letters of the species specific epithet. Three dimensional stress for the NMDS was 0.13.

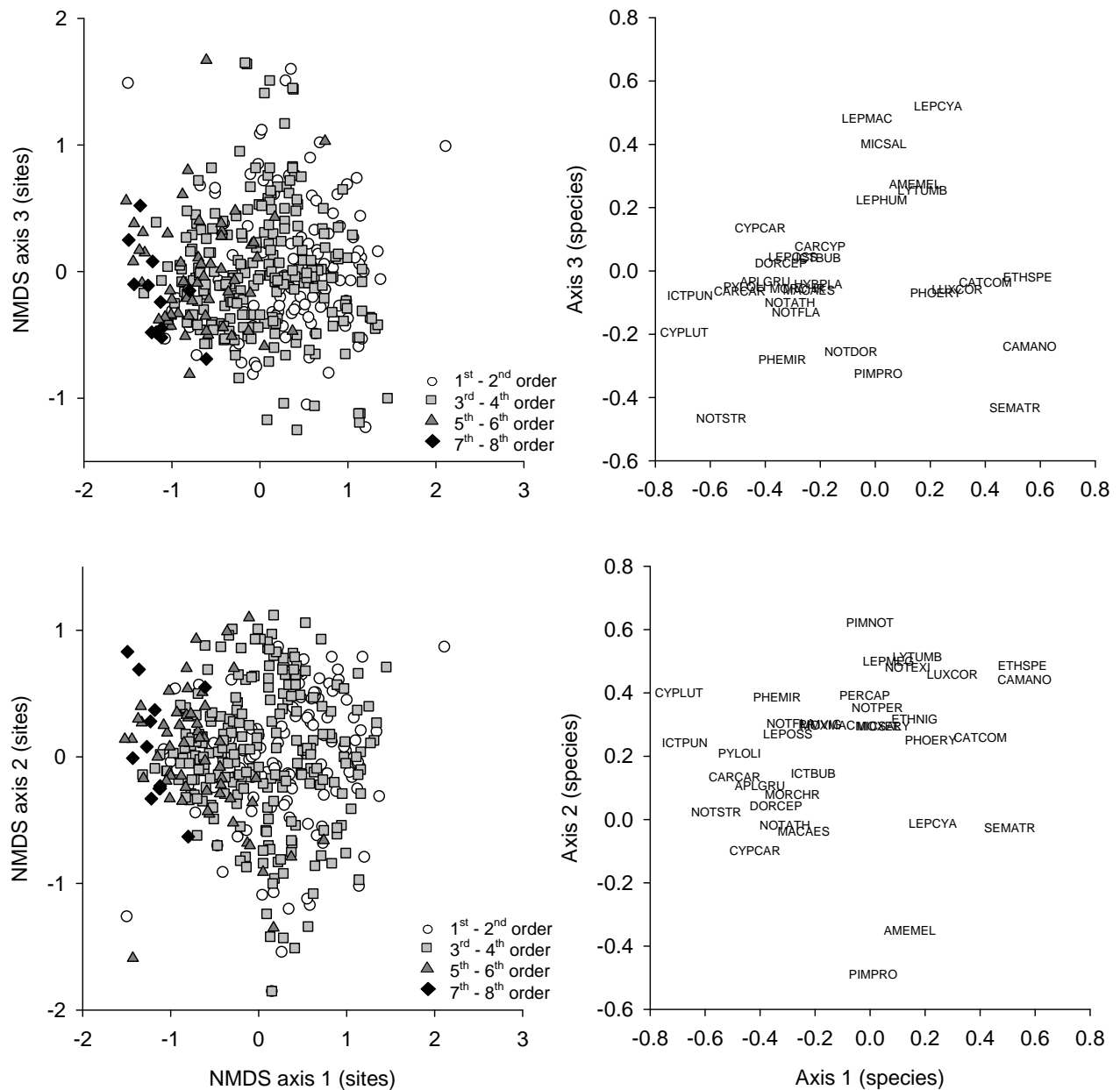


Figure 5. Regression analysis quantifying variance explained by distance from mainstem river on local fish species richness and assemblage structure (NMDS axis 1) in the Kansas basin by stream order.

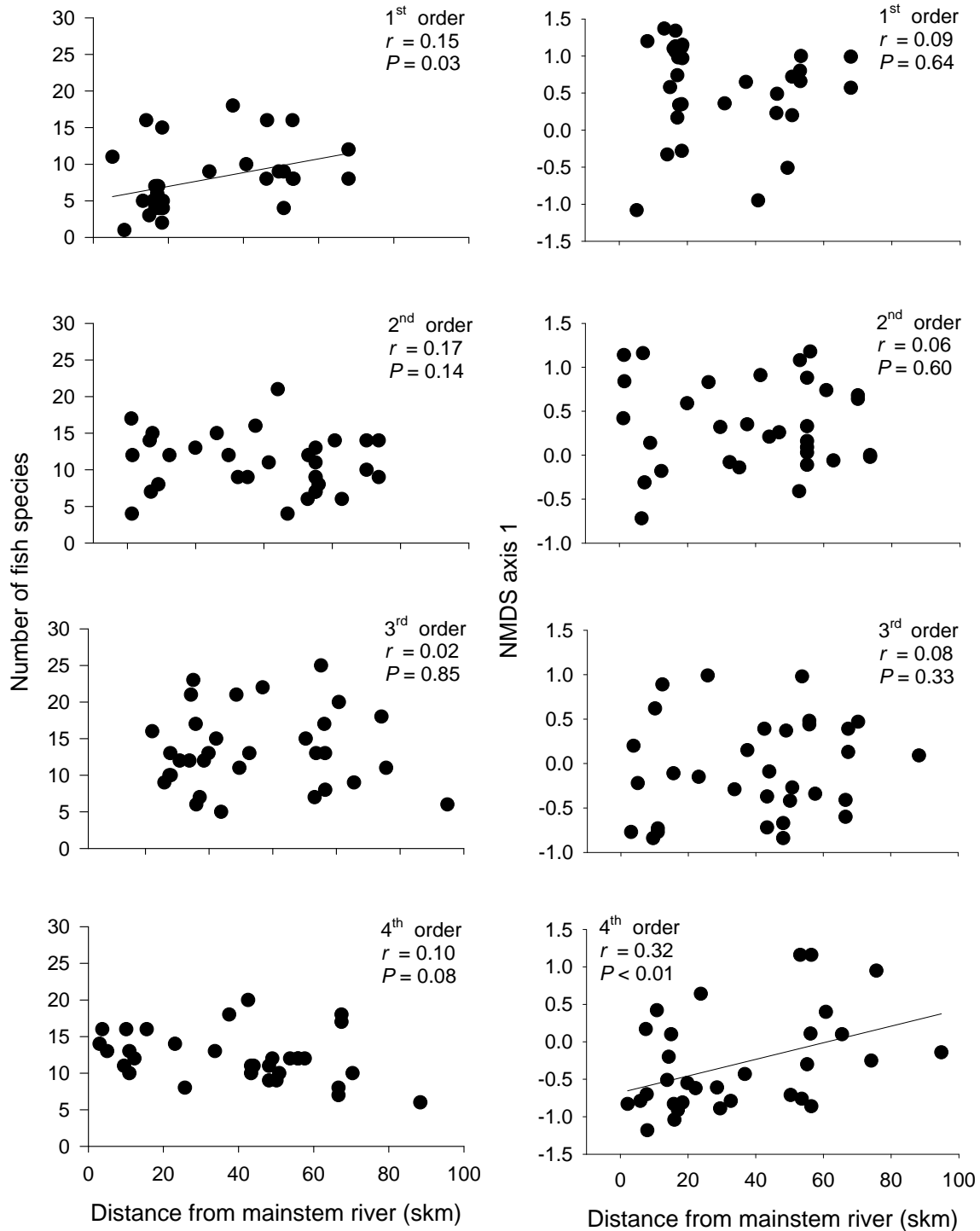


Figure 6. Regression analysis quantifying the association between distance from mainstem river and local fish species richness of medium to large rivers fishes in the Kansas basin. Analyses were run separately for different stream orders to control for stream size.

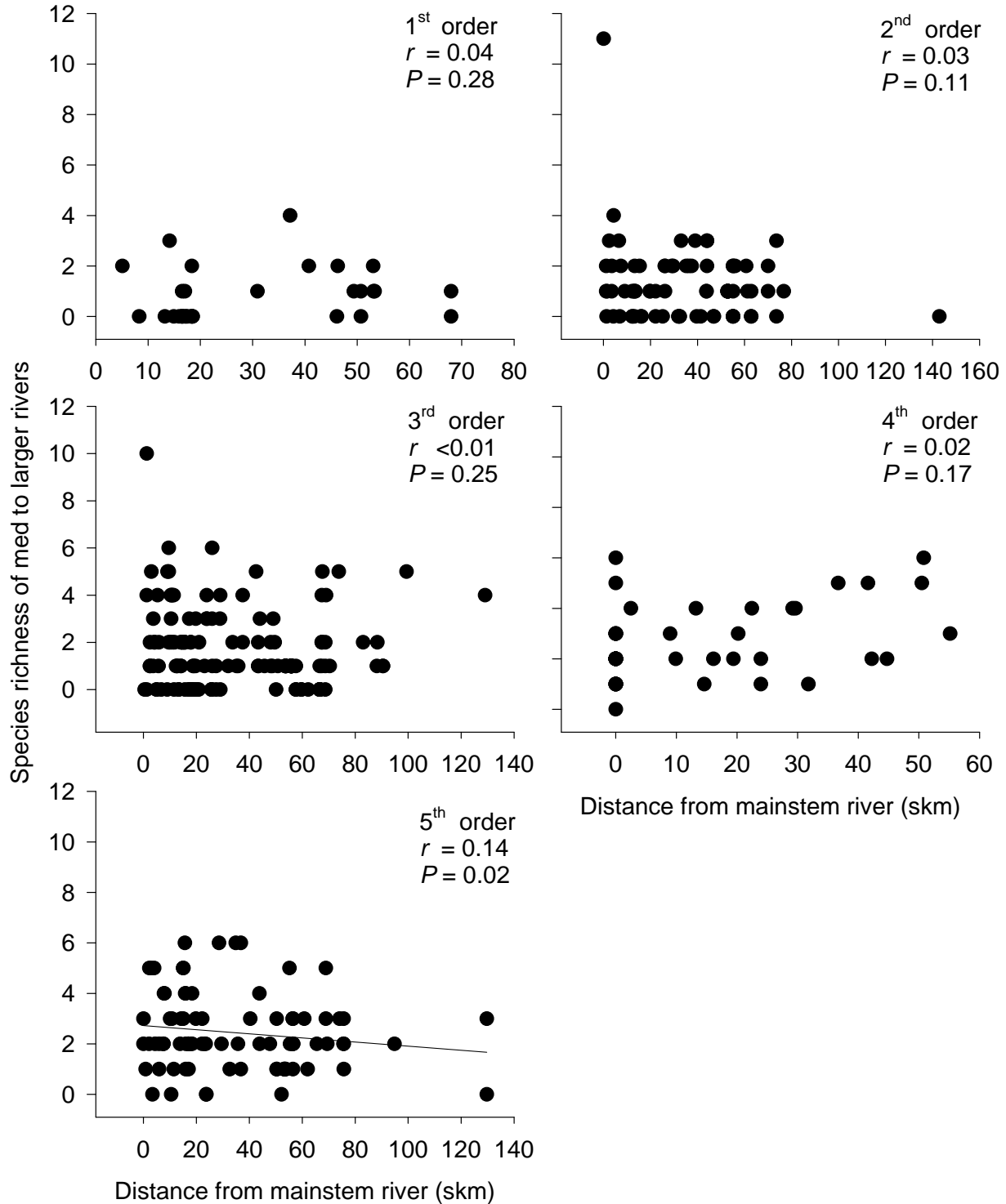


Figure 7. Residual analysis quantifying variance explained by distance from the mainstem river on fish species richness in the Kansas basin, while controlling for confounding network variables.

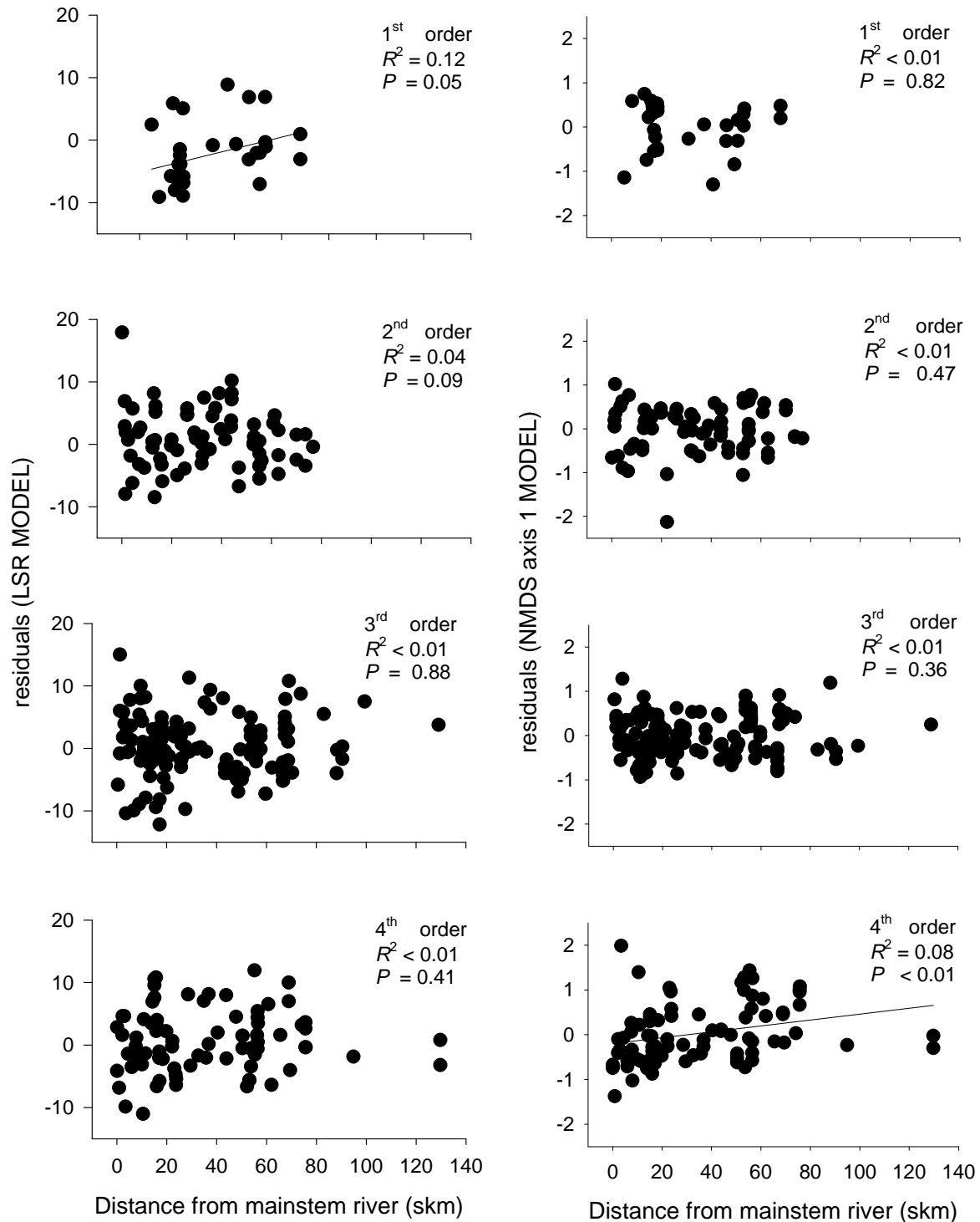


Figure 8. Fish species richness between streams of similar stream order with different downstream order. Different letters (a and b) represent significant ($\alpha = 0.05$) difference between mean species richness.

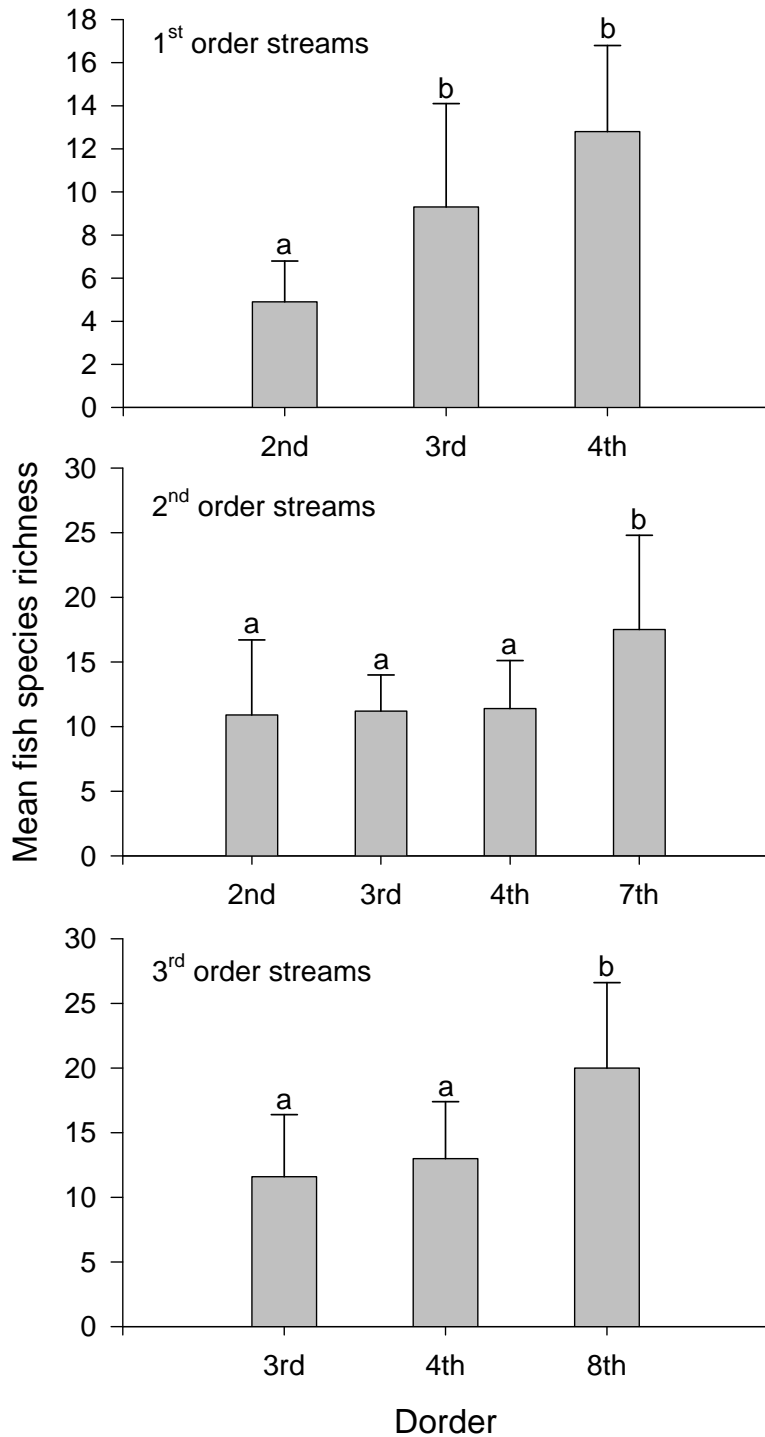


Figure 9. Residual analysis quantifying variance explained by downstream order on fish species richness in the Kansas basin, while controlling for confounding habitat variables.

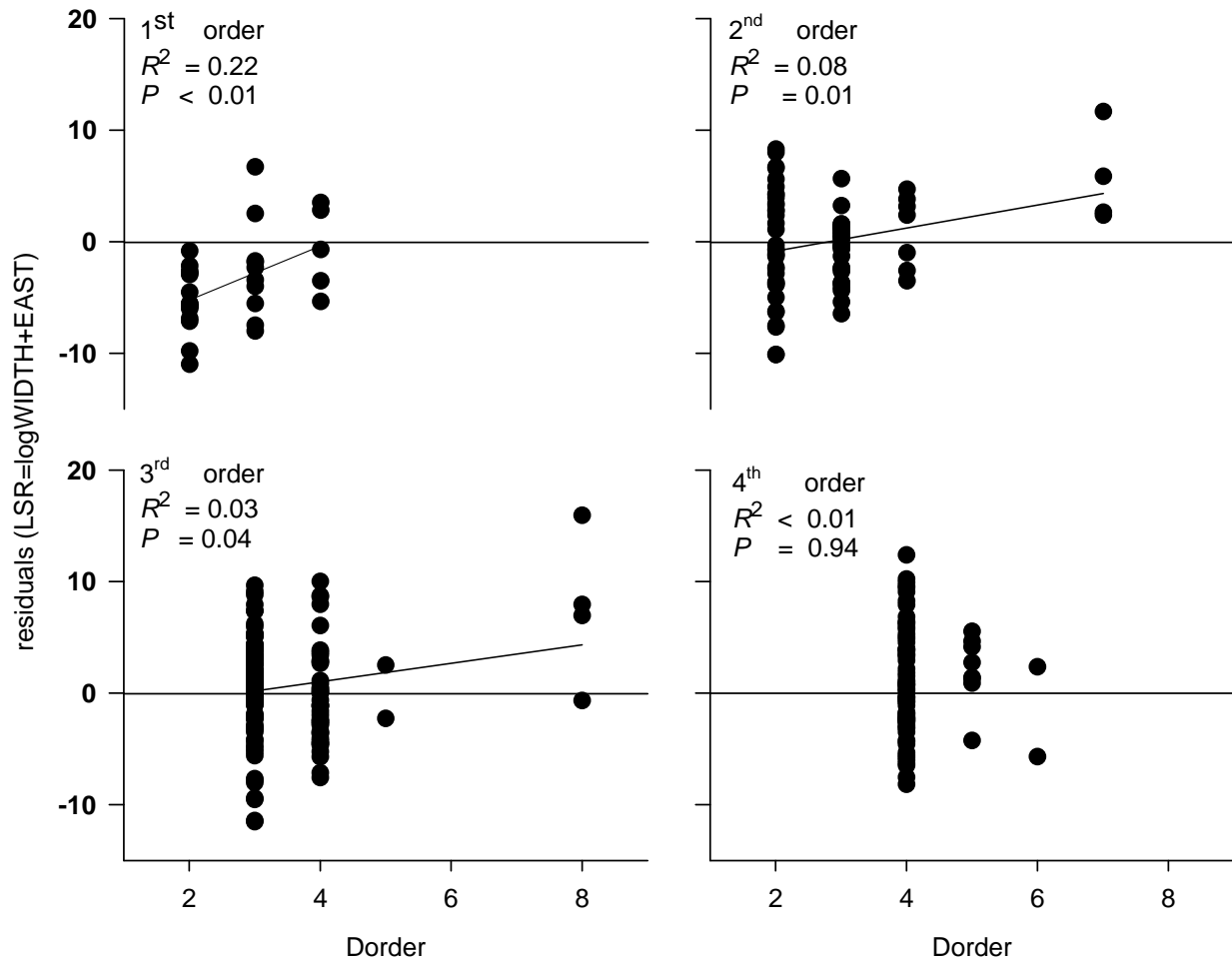


Figure 10. Residual analysis quantifying variance explained by downstream order on fish assemblage structure in the Kansas basin, while controlling for confounding habitat variables.

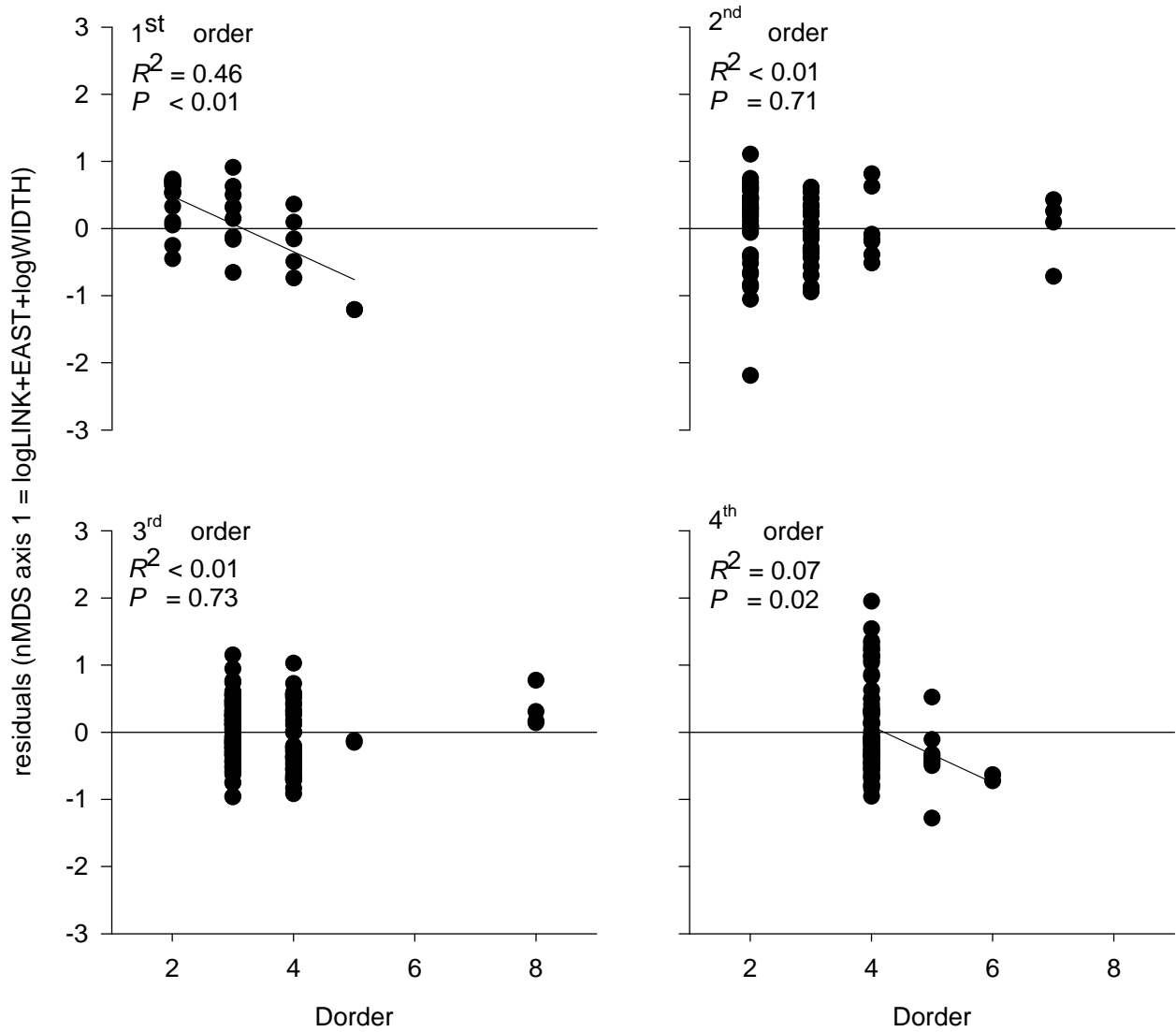


Figure 11. Fish species richness for three local scale tributary streams across all sampling periods. P-values from repeated measures ANOVA displayed. Kansas River represented here for reference.

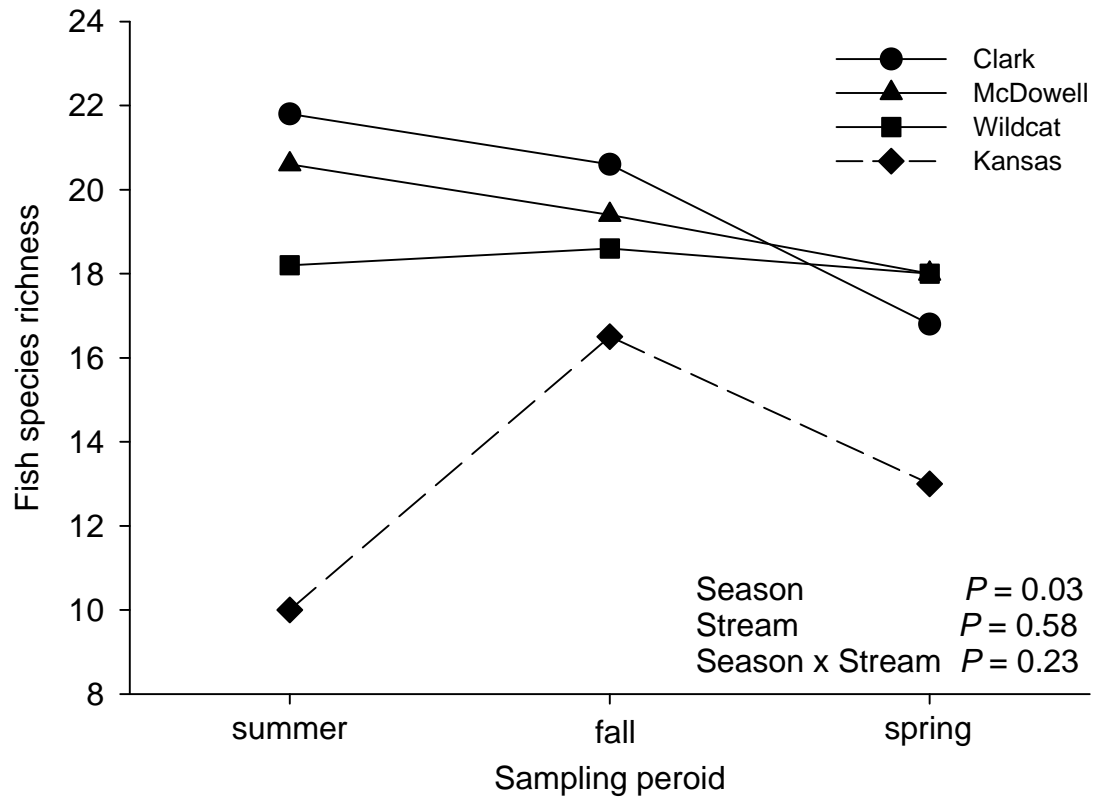


Figure 12. NMDS that summarized variation in the fish assemblage structure across sites in three tributaries of the Kansas River (left panels) and associated species loadings (right panels). Axis 1 and 2 plots were coded for streams and distance from mainstem and Axis 1 and 3 plots were coded for streams and sampling period. Species codes are as presented in Table 4. Three dimensional stress for the NMDS was 0.11.

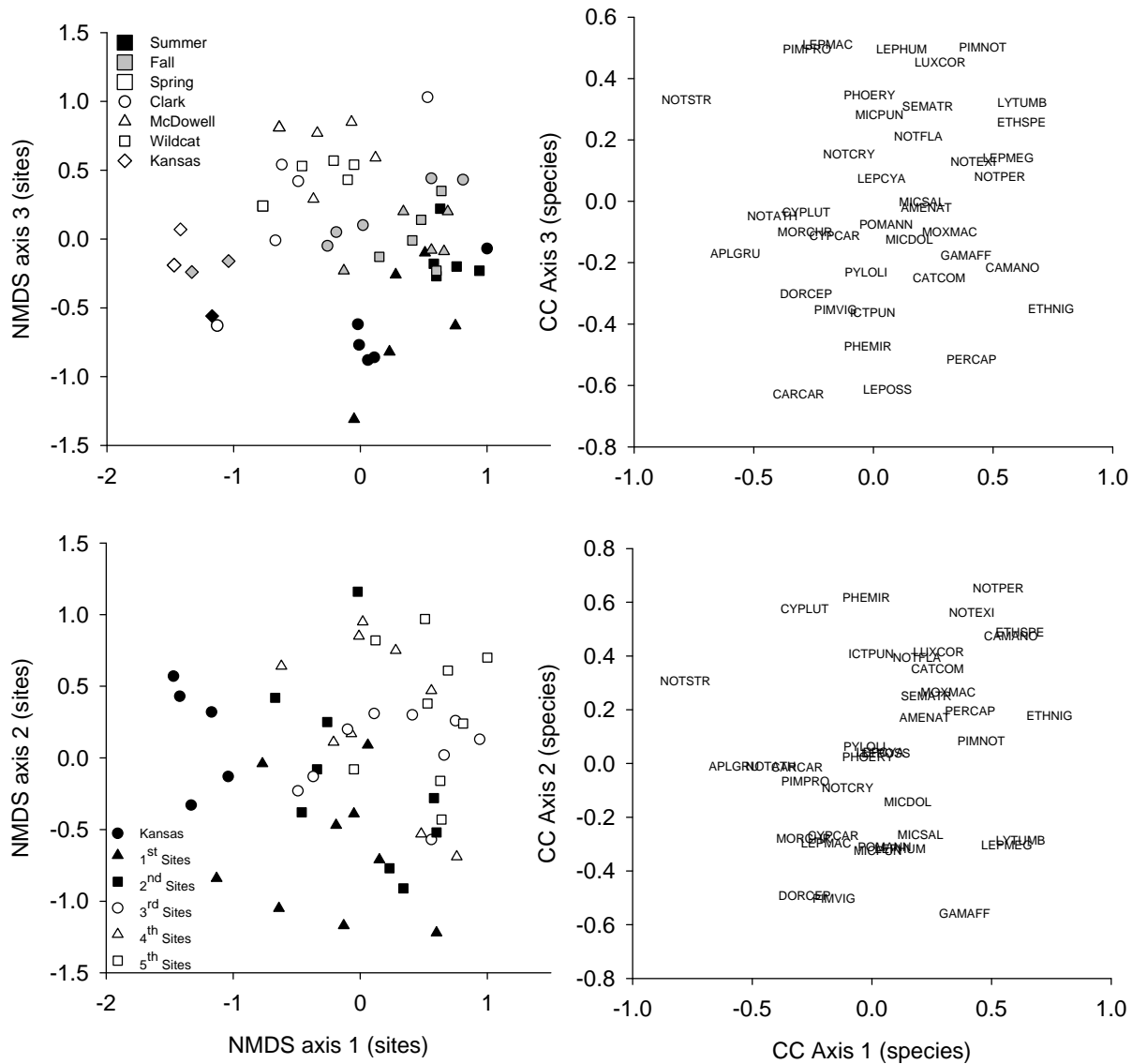


Figure 13. NMDS Axis 1 site scores from three tributaries of the Kansas River regressed against distance from the Kansas River.

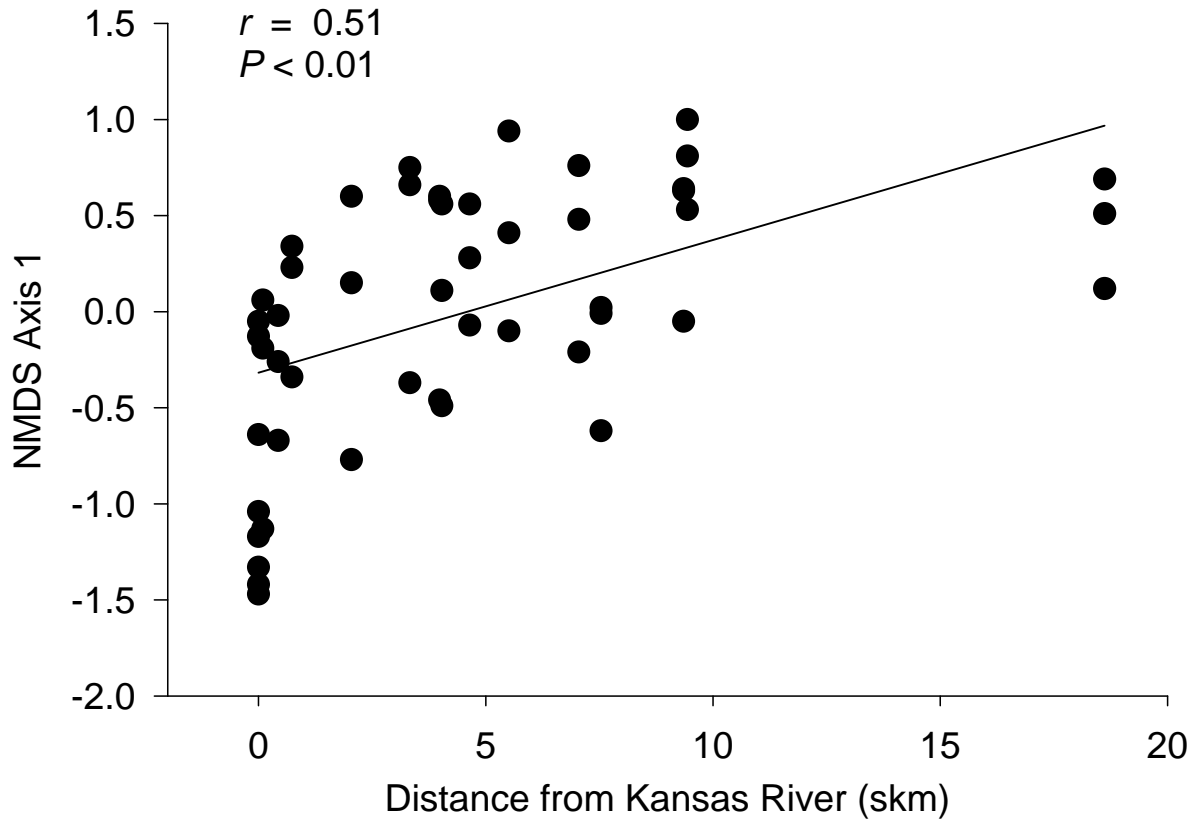


Figure 14. Regression analysis quantifying the relationship between distance from mainstem Kansas River and fish species richness of medium to large rivers fishes, small creek to small river fishes, and total fish species richness by sampling periods. Habitat affinities of species were classified by Goldstein and Meador (2004).

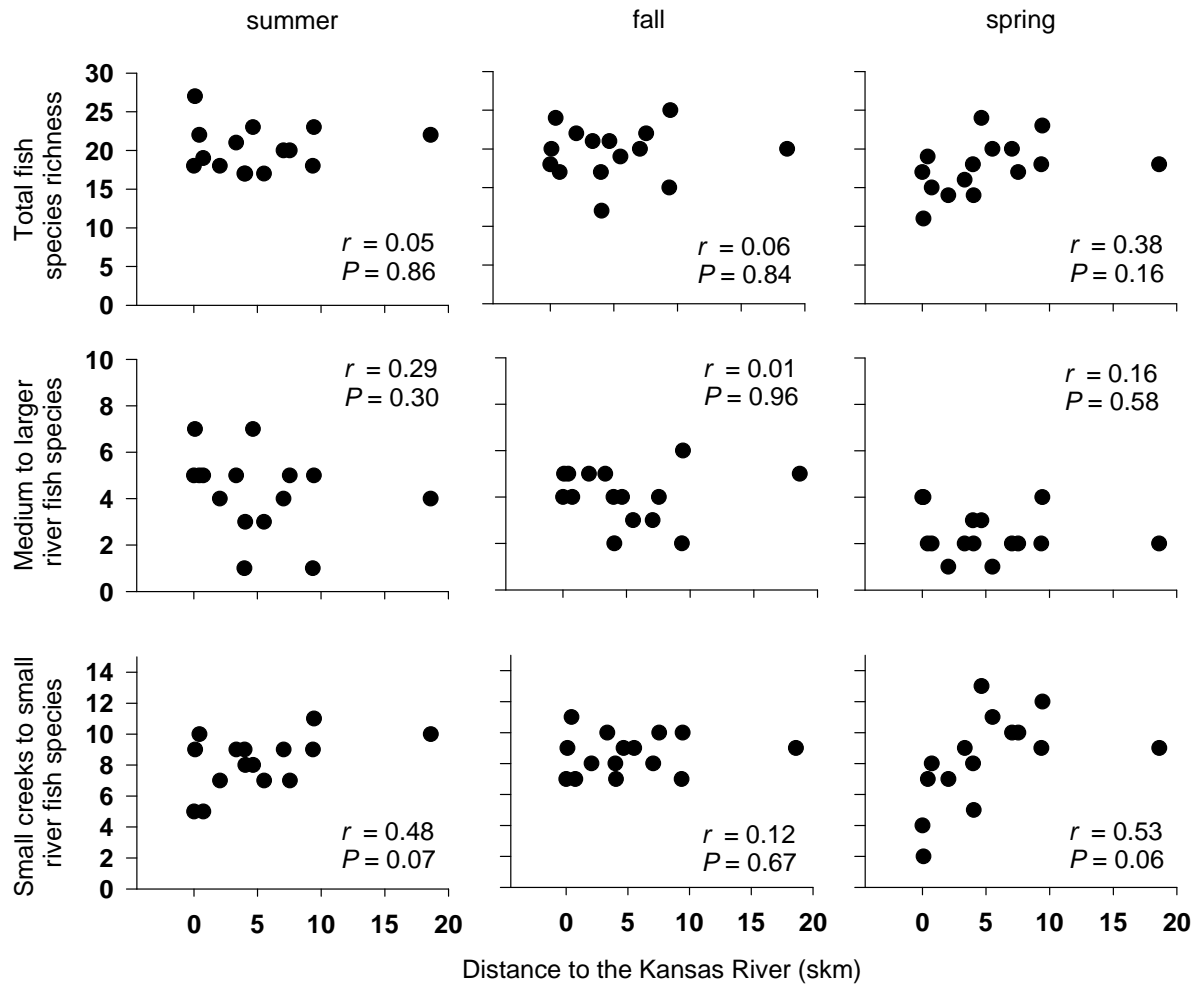


Figure 15. Similarity (Euclidian distances based on NMDS axis 1 and axis 2 site scores) of fish assemblages at sites within tributary streams and the mainstem Kansas River (closed circles). Euclidian distance scores were averaged across all sampling periods and means and standard deviations calculated. Open circles represent similarity of fish assemblage between the Kansas River sites.

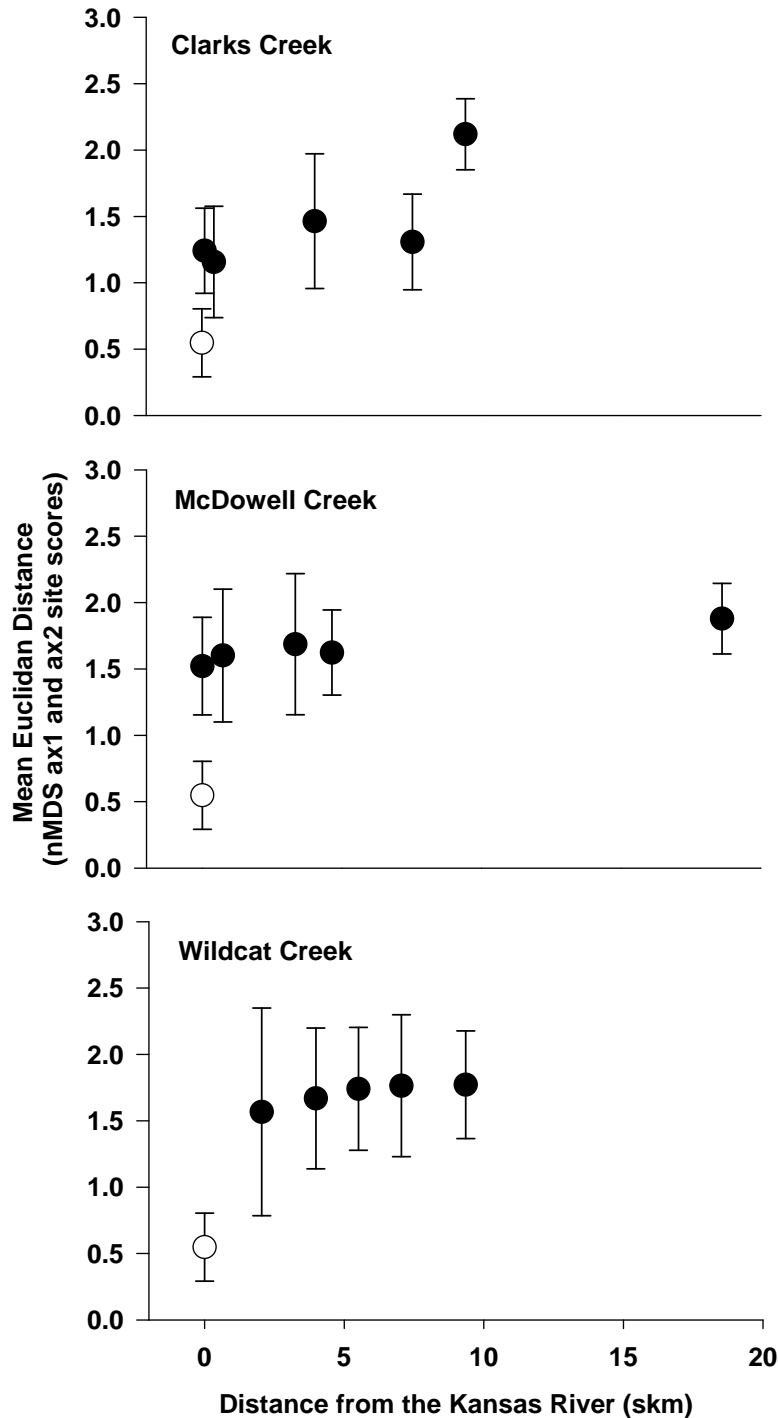
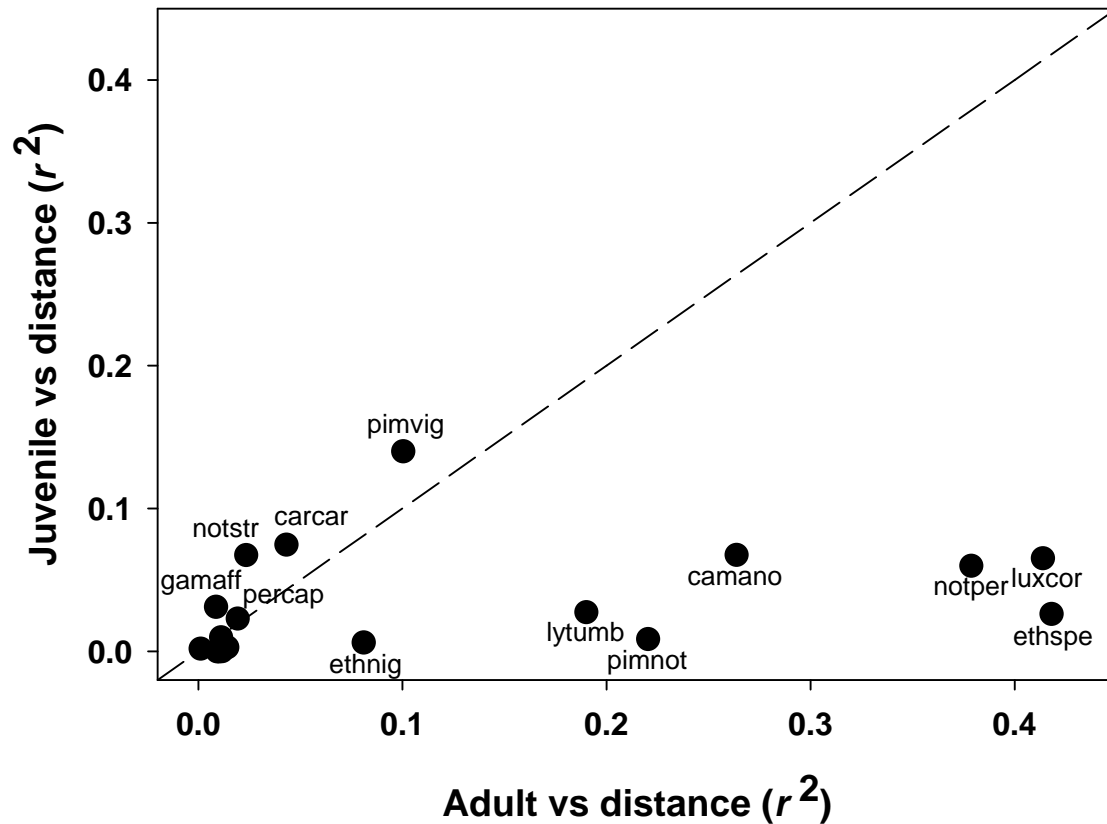


Figure 16. Paired comparisons of coefficients of determination (r^2) for juveniles and adults from regression analyses testing the association between 18 predominate fish species abundance in local tributaries (Clarks, McDowell, and Wildcat Creeks) and distance from the mainstem Kansas River. Species codes are the first 3 letters of the species genus followed by the first 3 letters of the species specific epithet.



Tables

Table 1. Descriptions of habitat variables used to quantify stream size or connectivity within the Kansas basin, KS.

Habitat variable	Variable discription	Author
Stream order	Strahler order of stream segment (order)	Strahler (1957)
Downstream order	Strahler order of downstream segment (dorder)	Grenouillet et al. (2004)
Link magnitude	Number of first-order segments upstream of a given point on a channel (link)	Shreve (1966)
Downstream link	Link magnitude of next downstream confluence (dlink)	Osborne and Wiley (1992)
Distance	Distance to downstream mainstem (stream km)	Horwitz (1978)
Confluence link	Number of confluences downstream from each stream segment to mainstem (clink)	Fairchild et al. (1998)
Basin area	Upstream catchment area of stream segment (km ²)	Horton (1945)

Table 2. Results from stepwise multiple regression analyses of the association between habitat on local fish species richness and fish assemblage structure in the Kansas basin. Dependent variables for these models are local species richness and axis one of a NMDS that represented variation in fish species abundances across sample sites.

Source	df	F-value	P-value	R ²	Variable	df	Standardized parameter estimate	t	P-value
<i>Local species richness</i>									
Model	1	49.5	<0.001	0.195	UTM easting	1	5.056	8.41	<0.001
Error	410				Stream order	1	4.713	7.94	<0.001
Total	411								
<i>Fish assemblage structure</i>									
Model	3	98.4	<0.001	0.422	Stream order	1	0.564	-9.288	<0.001
Error	405				UTM easting	1	0.539	-5.361	<0.001
Total	408				Stream width	1	0.522	-5.281	<0.001

Table 3. Number of fish collected and their relative abundance, percent of total individuals, and occurrences across 17 sample sites and three seasons from three tributaries of the Kansas River (Clarks, McDowell, and Wildcat Creeks).

Species	Scientific name	Species code	Total abundance	Relative abundance	Summer		Fall		Spring	
					abundance	Sites occupied	abundance	Sites occupied	abundance	Sites occupied
Yellow bullhead	<i>Ameiurus natalis</i>	AMENAT	1	< 0.0	1	1	-	-	-	-
Freshwater drum	<i>Aplodinotus grunniens</i>	APLGRU	68	0.1	1	1	19	4	48	3
Central stoneroller	<i>Campostoma anomalum</i>	CAMANO	2112	2.2	885	14	1193	14	34	10
River carpsucker	<i>Carpiodes carpio</i>	CARCAR	681	0.7	608	11	26	9	47	10
White sucker	<i>Catostomus commersoni</i>	CATCOM	23	< 0.0	20	6	3	2	-	-
Common carp	<i>Cyprinus carpio</i>	CYPCAR	102	0.1	32	5	7	4	63	4
Red shiner	<i>Cyprinella lutrensis</i>	CYPLUT	46973	48.8	13845	16	20950	17	12178	17
Gizzard shad	<i>Dorosoma cepedianum</i>	DORCEP	693	0.7	63	4	577	10	53	3
Johnny darter	<i>Etheostoma nigrum</i>	ETHNIG	599	0.6	339	15	236	14	24	8
Orangethroat darter	<i>E. spectabile</i>	ETHSPE	1562	1.6	541	11	745	12	276	10
Western mosquitofish	<i>Gambusia affinis</i>	GAMAFF	5237	5.4	1387	16	3641	17	209	14
Channel catfish	<i>Ictalurus punctatus</i>	ICTPUN	113	0.1	51	11	52	11	10	5
Green sunfish	<i>Lepomis cyanellus</i>	LEPCYA	227	0.2	55	15	51	11	121	10
Orangespotted sunfish	<i>L. humilis</i>	LEPHUM	3330	3.5	164	10	2446	17	720	17
Bluegill	<i>L. macrochirus</i>	LEPMAC	232	0.2	16	4	45	8	171	15
Longear sunfish	<i>L. megalotis</i>	LEPMEG	1262	1.3	406	15	607	15	249	12
Longnose gar	<i>Lepisosteus osseus</i>	LEPOSS	67	0.1	61	14	1	1	5	2
Common shiner	<i>Luxilus cornutus</i>	LUXCOR	232	0.2	19	4	77	8	136	7
Redfin shiner	<i>Lythrurus umbratilis</i>	LYTUMB	3889	4.0	1346	12	1991	14	552	15
Smallmouth bass	<i>Micropterus dolomieu</i>	MICDOL	15	< 0.0	13	3	2	1	-	-
Spotted bass	<i>M. punctulatus</i>	MICPUN	64	0.1	12	5	10	5	42	9
Largemouth bass	<i>M. salmoides</i>	MICSAL	9	< 0.0	3	3	5	3	1	1
White bass	<i>Morone chrysops</i>	MORCHR	8	< 0.0	-	-	-	-	8	2
Shorthead redhorse	<i>Moxostoma macrolepidotum</i>	MOXMAC	183	0.2	61	7	119	13	3	3
Emerald shiner	<i>Notropis atherinoides</i>	NOTATH	3	< 0.0	-	-	2	1	1	1
Golden shiner	<i>Notemigonus crysoleucas</i>	NOTCRY	1	< 0.0	-	-	-	-	1	1
Slender madtom	<i>Noturus exilis</i>	NOTEXI	111	0.1	64	9	24	8	23	6
Stoneroller	<i>N. flavus</i>	NOTFLA	662	0.7	22	5	12	4	628	5
Carmine shiner	<i>Notropis percobromis</i>	NOTPER	4873	5.1	287	10	4209	15	4246	17
Sand shiner	<i>N. stramineus</i>	NOTSTR	8742	9.1	1460	13	2795	15	618	10
Logperch	<i>Percina caprodes</i>	PERCAP	167	0.2	126	13	35	10	6	5
Suckermouth minnow	<i>Phenacobius mirabilis</i>	PHEMIR	1155	1.2	587	14	394	13	174	11
Southern redbelly dace	<i>Phoxinus erythrogaster</i>	PHOERY	94	0.1	1	1	1	1	92	3
Bluntnose minnow	<i>Pimephales notatus</i>	PIMNOT	9049	9.4	801	15	6415	17	1833	16
Fathead minnow	<i>P. promelas</i>	PIMPRO	129	0.1	1	1	-	-	128	12
Bullhead minnow	<i>P. vigilax</i>	PIMVIG	3527	3.7	537	16	2624	17	366	17
White crappie	<i>Pomoxis annularis</i>	POMANN	88	0.1	62	5	18	6	8	3
Flathead catfish	<i>Pylodictis olivaris</i>	PYLOLI	10	< 0.0	3	3	5	4	2	1
Creek chub	<i>Semotilus atromaculatus</i>	SEMATR	47	< 0.0	6	4	19	5	22	5
total			n = 96340		n = 23886	n = 16	n = 49356	n = 17	23098	n = 17

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Appendix A - Supplementary Material

Figures and Tables Appendices

Figure A.1. Local fish species richness (mean \pm standard deviation) by stream order.

Letters (a, b, and c) show significant ($\alpha = 0.05$) differences in species richness.

Figure 17

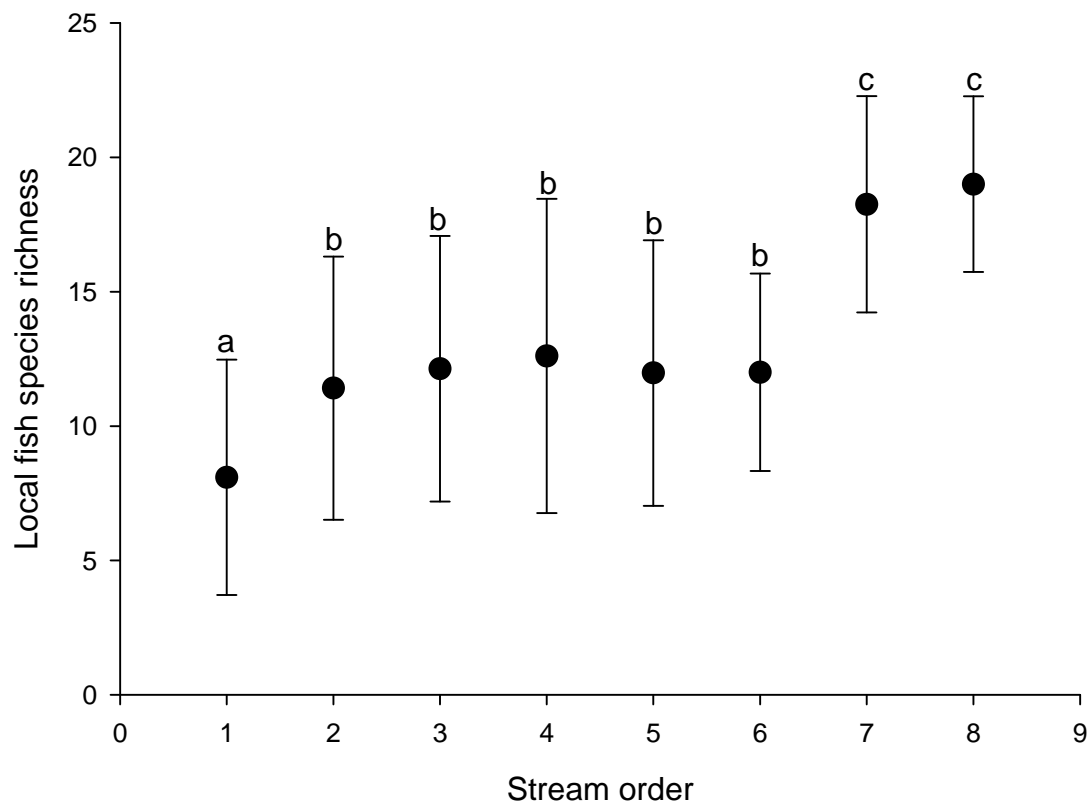


Table A.1. Area (km²) and percentage of area of Ecoregions and land use / land cover for each basin (Big Blue, Kansas, Lower Missouri-Blackwater, Missouri-Nishnabotna, Republican, and Smoky Hill in the study area.

Level 3 Ecoregions	Big Blue		Kansas		Lower Missouri-Blackwater		Missouri-Nishnabotna		Republican		Smoky Hill	
	total area	% total area	total area	% total area	total area	% total area	total area	% total area	total area	% total area	total area	% total area
Central Great Plains	19737	79.0%							27518	42.4%	39208	75.5%
Central Irregular Plains			5198	36.0%	412	99.8%	278	7.5%				
Flint Hills	1634	6.5%	5138	35.6%					519	0.8%	796	1.5%
High Plains									35403	54.6%	11949	23.0%
Nebraska Sand Hills									1456	2.2%		
Western Corn Belt Plains	3616	14.5%	4108	28.4%	1	0.2%	3414	92.5%				
National Land Use / Cover												
Grasses	4407	17.6%	3749	26.0%			348	9.4%	30957	47.7%	28017	53.9%
Agricultural	19291	77.2%	7926	54.9%			2793	75.7%	32459	50.0%	22176	42.7%
row crops	2687	10.8%	3945	27.3%			911	24.7%	2547	3.9%	3288	6.3%
small grains	15161	60.7%	3394	23.5%			1697	46.0%	14663	22.6%	6615	12.7%
pasture/hay	1440	5.8%	587	4.1%			185	5.0%	12098	18.6%	12035	23.2%
fallow	3	0.0%	0	0.0%			0	0.0%	3150	4.9%	239	0.5%
Shrub	50	0.2%	0	2.0%			4	0.1%	28	0.0%	437	0.8%
Forested	601	2.4%	1458	10.1%			338	9.2%	741	1.1%	392	0.8%
Urban, water, wetlands or barren lands	636	2.5%	1025	7.1%	413	100.0%	207	5.6%	711	1.1%	711	1.1%

Table A.2. Local habitat variables: distance to the Kansas River, mean depth, mean width, proportional stream morphology, and dominate substrate type for all seasons, summer, fall, and spring.

Stream	Reach	Season	Distance to Kansas River (skm)	Mean depth (cm)	Mean width (m)	Stream Morphology % Riffle	Stream Morphology % Run	Stream Morphology % Pool	Dominate substrate type
Clark Creek	1	Summer	0.1	53	22	2	98	0	bed rock
	2		0.4	21	53	41	41	18	bed rock
	3		4.0	104	18	0	78	22	cobble
	4		7.5	49	15	35	40	25	pebble, cobble
	5		9.4	52	6	21	75	4	cobble
McDowell Creek	1		0.0	64	20	0	100	0	silt
	2		0.7	69	13	0	100	0	silt
	3		3.3	39	9	17	38	45	silt, gravel
	4		4.6	32	6	30	50	20	pebble, gravel
	5		18.6	28	10	35	15	50	cobble
Wildcat Creek	1		2.0	61	11	0	80	20	silt
	2		4.0	40	10	20	75	5	pebble
	3		5.5	33	12	20	70	10	pebble, bed rock
	4		7.0	44	11	15	55	30	cobble
	5		9.4	55	12	10	65	25	pebble
Kansas River	1		0.0	32	92	0	100	0	sand
Clark Creek	1	Fall	0.1	56	20	2	98	0	gravel
	2		0.4	26	34	41	41	18	cobble
	3		4.0	102	25	0	78	22	cobble
	4		7.5	35	12	25	35	41	pebble
	5		9.4	39	5	16	84	0	silt
McDowell Creek	1		0.0	53	19	0	100	0	silt
	2		0.7	58	12	0	100	0	silt
	3		3.3	40	9	11	38	52	silt
	4		4.6	21	4	32	53	15	cobble
	5		18.6	25	10	31	0	69	pebble, silt
Wildcat Creek	1		2.0	44	11	0	80	20	silt
	2		4.0	26	11	19	76	5	pebble, cobble
	3		5.5	35	10	18	75	6	gravel
	4		7.0	56	13	1	56	44	gravel
	5		9.4	55	11	8	66	27	gravel
Kansas River	1		0.0	25	61	25	75	0	sand
	2		0.0	34	80	0	100	0	sand
Clark Creek	1	Spring	0.1	109	30	0	100	0	gravel, bed rock
	2		0.4	30	56	33	67	7	cobble
	3		4.0	116	18	0	100	0	cobble
	4		7.5	92	22	7	77	17	gravel, cobble
	5		9.4	87	10	3	97	0	gravel, clay
McDowell Creek	1		0.0	55	19	0	100	0	silt
	2		0.7	93	23	0	100	0	silt
	3		3.3	81	13	10	90	0	clay, gravel
	4		4.6	57	10	32	53	14	cobble, clay
	5		18.6	44	12	17	77	7	cobble
Wildcat Creek	1		2.0	111	21	0	100	0	silt
	2		4.0	70	12	0	100	0	gravel
	3		5.5	57	13	13	83	3	bed rock
	4		7.0	69	17	17	67	17	cobble
	5		9.4	63	13	10	80	10	gravel
Kansas River	1		0.0	68	102	0	100	0	sand
	2		0.0	60	120	0	100	0	sand

Table A.3. List of fish abundance and incidence collected across 413 sample sites in the Kansas basin, Kansas, US.

Species	Scientific name	Species codes	site occurrence	total abundance across sites	Abundance by stream order							
					1 st (n=32)	2 nd (n=76)	3 rd (n=151)	4 th (n=84)	5 th (n=40)	6 th (n=17)	7 th (n=8)	8 th (n=8)
Black bullhead	<i>Ameiurus melas</i>	AMEMEL	172	1671	49	453	558	226	44	341	-	-
Yellow bullhead	<i>A. natalis</i>	AMENAT	162	977	17	225	612	96	21	6	-	-
Freshwater drum	<i>Aplodinotus grunniens</i>	APLGRU	41	893	-	6	17	28	290	38	212	302
Central stoneroller	<i>Campostoma anomalum</i>	CAMANO	297	33353	1642	10476	13969	6240	695	164	167	-
River carpsucker	<i>Carpiodes carpio</i>	CARCAR	102	1406	12	32	240	348	65	113	313	283
Quillback	<i>C. cyprinus</i>	CARCYP	10	70	-	3	2	2	3	-	2	58
White sucker	<i>Catostomus commersoni</i>	CATCOM	152	1549	68	438	598	416	22	5	2	-
Red shiner	<i>Cyprinella lutrensis</i>	CYPLUT	343	95391	1436	5618	21957	24750	19271	11117	7170	4072
Common carp	<i>Cyprinus carpio</i>	CYPCAR	145	1835	11	139	783	302	273	208	79	40
Gizzard shad	<i>Dorosoma cepedianum</i>	DORCEP	48	1397	-	283	89	250	47	43	669	16
Johnny darter	<i>Etheostoma nigrum</i>	ETHNIG	66	921	230	195	272	211	9	-	3	1
Orangethroat darter	<i>E. spectabile</i>	ETHSPE	191	6766	547	1601	2898	1253	406	61	-	-
Plains killifish	<i>Fundulus zebrinus</i>	FUNZEB	24	419	-	-	250	128	38	1	2	-
Western mosquitofish	<i>Gambusia affinis</i>	GAMAFF	32	605	1	24	64	347	37	3	106	23
Brassy minnow	<i>Hybognathus hankinsoni</i>	HYBHAN	10	172	-	10	5	157	-	-	-	-
Plains minnow	<i>H. placitus</i>	HYBPLA	9	101	-	1	-	3	-	-	97	-
Channel catfish	<i>Ictalurus punctatus</i>	ICTPUN	180	2775	105	67	312	910	527	416	244	194
Smallmouth buffalo	<i>Ictiobus bubalus</i>	ICTBUB	15	92	-	21	11	3	-	30	6	21
Bigmouth buffalo	<i>I. cyprinellus</i>	ICTCYP	10	550	-	5	23	518	1	1	2	-
Longnose gar	<i>Lepisosteus osseus</i>	LEPOSS	38	111	1	6	21	32	9	10	8	24
Green sunfish	<i>Lepomis cyanellus</i>	LEPCYA	349	11357	1234	2397	6124	1005	382	174	38	3
Orangespotted sunfish	<i>L. humilis</i>	LEPHUM	121	2797	43	478	1142	552	567	12	3	-
Bluegill	<i>L. macrochirus</i>	LEPMAC	183	3545	280	970	1015	975	138	133	34	-
Longear sunfish	<i>L. megalotis</i>	LEPMEG	63	2068	3	230	1287	435	104	-	7	2
Common shiner	<i>Luxilus cornutus</i>	LUXCOR	91	6785	390	1876	3962	466	91	-	-	-
Redfin shiner	<i>Lythrurus umbratilis</i>	LYTUMB	74	14817	65	1497	9131	4001	123	-	-	-
Speckled chub	<i>Macrhybopsis aestivalis</i>	MACAES	9	102	-	-	-	-	-	-	96	6
Smallmouth bass	<i>Micropterus dolomieu</i>	MICDOL	2	46	-	41	-	-	-	-	5	-
Largemouth bass	<i>M. salmoides</i>	MICSAL	194	1661	65	301	914	285	61	32	3	-
White bass	<i>Morone chrysops</i>	MORCHR	17	266	1	48	63	50	55	27	16	6
Golden redbreast	<i>Moxostoma erythrurum</i>	MOXERY	18	207	-	55	103	28	5	-	16	-
Shorthead redbreast	<i>M. macrolepidotum</i>	MOXMAC	44	322	21	54	74	87	38	32	6	10
Golden shiner	<i>Notemigonus crysoleucas</i>	NOTCRY	39	227	9	123	49	46	-	-	-	-
Emerald shiner	<i>Notropis atherinoides</i>	NOTATH	18	969	7	-	21	12	192	25	661	51
Bigmouth shiner	<i>N. dorsalis</i>	NOTDOR	33	3455	515	712	1694	446	82	-	6	-
Carmine shiner	<i>N. percobromis</i>	NOTPER	25	3332	-	290	641	308	2090	-	3	-
Sand shiner	<i>N. stramineus</i>	NOTSTR	235	25393	1362	3674	7130	5887	2204	1465	3071	600
Topeka shiner	<i>N. topeka</i>	NOTTOP	22	934	-	28	863	39	4	-	-	-
Slender madtom	<i>Noturus exilis</i>	NOTEXI	75	1427	13	401	801	178	34	-	-	-
Stonecat	<i>N. flavus</i>	NOTFLA	82	524	4	17	90	215	117	50	5	26
Logperch	<i>Percina caprodes</i>	PERCAP	40	145	1	10	60	32	38	4	-	-
Suckermouth minnow	<i>Phenacobius mirabilis</i>	PHEMIR	191	4559	106	558	1203	1100	525	153	715	199
Southern redbelly dace	<i>Phoxinus erythrogaster</i>	PHOERY	24	1588	103	651	834	-	-	-	-	-
Bluntnose minnow	<i>Pimephales notatus</i>	PIMNOT	195	12377	819	2846	5052	2190	1238	130	61	41
Fathead minnow	<i>P. promelas</i>	PIMPRO	275	14455	859	2095	7493	2578	901	132	397	-
Bullhead minnow	<i>P. vigilax</i>	PIMVIG	36	1547	12	27	27	97	134	80	27	1143
White crappie	<i>Pomoxis annularis</i>	POMANN	52	142	4	20	41	51	17	-	9	-
Flathead catfish	<i>Pylodictis olivaris</i>	PYLOLI	64	280	6	2	8	50	92	67	18	37
Shovelnose sturgeon	<i>Scaphirhynchus platyrhynchus</i>	SCAPLA	4	226	-	-	-	-	-	-	-	226
Creek chub	<i>Semotilus atromaculatus</i>	SEMATR	292	16159	1874	4820	6517	2538	368	35	7	-