SEASONAL FISH COMMUNITY AND REPRODUCTIVE BIOLOGY OF FISHES IN TWO TRIBUTARIES OF THE LOWER MISSOURI RIVER, USA

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the

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Seasonal fish community and reproductive biology of fishes in two tributaries of the lower Missouri River, USA

Emily K. Pherigo

Dr. Craig Paukert, Thesis Advisor

ABSTRACT

Tributaries provide important habitats for spawning, rearing and feeding of fish in connected river systems. Regulation of rivers may alter the fish communities and environmental variables triggering fish use. Habitat destruction from dam construction is one of the leading causes for the decline of aquatic species, including big-river fishes. The influence of larger dams on fishes is well-documented and low-head dams (<15 meters in height) are receiving increased attention as removal of these structures occurs because of an emphasis on restoring rivers for aquatic fauna and public safety. However, the distribution of mainstem big-river fishes in tributaries and the contribution of tributaries to large river systems (LRS; systems with a mean annual discharge of at least 350 cms) remains unclear. Therefore, this study investigated the seasonal patterns of fish abundance, species richness, and big-river fish presence upstream and downstream of a low-head dam (LD1) on the Osage River, a regulated tributary of the Lower Missouri River in central Missouri, as well as in comparison to the geographically and biologically similar free-flowing Gasconade River, another tributary to the Lower Missouri River. Furthermore, this study investigated the influence of river regulation in the Osage River on reproductive biology of fishes by comparing sex and reproductive readiness of Golden Redhorse and Spotted Bass in the two tributaries.

Fish community metrics and non-metric multidimensional scaling as well as an information-theoretic approach were used to evaluate the relative support of models relating presence of big-river fishes to tributary, season, discharge, water temperature, and tributary longitudinal position for September through August 2012–2013. Our results suggest that the lowermost 19 river kilometers (rkm) of the Osage River had lower overall species richness, fewer species of conservation concern, fewer big-river species, and fewer juvenile life stages of fish compared to the unregulated lowermost 19 rkm of the Gasconade River. The factors contributing to the occurrence of big-river fishes in these tributaries varied depending on the species and life stage. There was not one abiotic variable that was best at predicting the presence the seven big-river species investigated (Chestnut lamprey, adult and juvenile Flathead Catfish, adult and juvenile Longnose Gar, juvenile Goldeye, and Sand Shiners). Instead, certain species or life stages had an affinity for the Gasconade River, responded to increased water temperature or above average discharge, or a combination of these factors. Our findings suggest that species turnover in the lowermost sections of tributaries near confluences with LRS is seasonally influenced and provides habitats for a variety of life stages, including some big-river species.

Boat electrofishing, benthic trawls, and beach seines collected 15,619 fish representing 71 species in the lower 30 rkm of the Osage River, September 2012 through July 2013. Of the 71 species collected, 48 species were captured both upstream and downstream of LD1, 13 species were only captured upstream of the structure, and ten species were only captured downstream of the structure. Half of the species only captured downstream of LD1 were big-river species - Skipjack Herring, Speckled Chub, Stonecat, White Bass, and Yellow Bass. Overall, species richness did not differ upstream and downstream of LD1; however, there were differences in the proportion of big-river species depending on what sampling technique was used. Summer 2013 resulted in diverse and distributed big-river species with Flathead Catfish, Longnose Gar, and Goldeye detected both upstream and downstream of LD1, most likely due to high water overtopping LD1 allowing upstream passage in the month preceding summer sampling. Reaches downstream of LD1 were more similar to each other than to sites upstream of the structure and downstream sites within eight kilometers of the confluence with the Missouri River were also similar to each other.

Gonadosomatic index and histological observation of gonads were used as indicators of reproductive readiness to investigate the influence of river regulation on reproductive biology of Golden Redhorse and Spotted Bass in the Osage River and the neighboring Gasconade River. Gonadosomatic indices did not differ between rivers for female Golden Redhorse, male Golden Redhorse, female Spotted Bass, or male Spotted Bass. For all species and sex combinations except male Spotted Bass, GSI was significantly higher at phase III as identified through histology than other reproductive phases observed. Linear regression models explaining patterns of female Golden Redhorse GSI suggested that cooler water temperatures and discharge slightly higher than average best predicted reproductive readiness regardless of river. The top-ranked model for predicting female Spotted Bass GSI indicated that average discharge in early summer best predicted reproductive readiness in the regulated Osage River. One intersex Spotted Bass caught in the Gasconade River was identified by histology.

These results will provide a baseline should modifications occur to LD1 in the Osage River, and provides evidence that big-river fishes seasonally use Missouri River tributaries and that LD1 is a semi-permeable barrier to big-river fish in the Osage River. Our findings suggest that species change in the lowermost sections of tributaries near confluences with LRS is seasonally influenced and provides habitats for a variety of life stages, including nursery habitat. Managers and researchers should incorporate tributaries of various sizes into investigations of this nature for big-river species and that this use may be limited to the lowermost reaches. The cues for reproductive readiness in the regulated Osage River and the free-flowing Gasconade River do not differ for Golden Redhorse yet river regulation (i.e., Osage River) was a substantial predictor of Spotted Bass reproductive readiness.

DESCRIPTION OF CHAPTERS

The following chapters were written as independent manuscripts for submission into peer-reviewed journals. Subsequently, some material is repeated across chapters and each chapter contains an independent literature cited.

CHAPTER 1 SEASONAL FISH COMMUNITY IN A REGULATED AND A FREE-FLOWING LOWER MISSOURI RIVER TRIBUTARY

Abstract

Tributaries contribute to stream networks by providing habitat for specific life events and supplemental resources, but river regulation may alter the fish communities and use by big-river fishes. Our objectives were to (1) determine how the fish community and presence of big-river fishes differed between a regulated and free-flowing tributary of the Lower Missouri River and (2) what factors contributed to the occurrence of big-river fishes. Our results suggest that the fish assemblages in the lowermost 19 river kilometers of the Osage and Gasconade rivers differed with the regulated Osage River having lower overall species richness, fewer species of conservation concern, fewer big-river species, and fewer juvenile life-stages of fish compared to the unregulated Gasconade River. The factors contributing to the occurrence of big-river fishes in these tributaries varied depending on the species and life stage. There was not one abiotic variable that was best at predicting the presence of fish species in the big-river guild. Instead, certain species or life stages had an affinity for the Gasconade River, responded to increased water temperature or above average discharge, or a combination of these factors. For example, adult and juvenile Flathead Catfish as well as juvenile Goldeye were most associated with higher water temperatures. These big-river fish species may be using these tributaries for feeding, nursery habitat or other unexplained purposes. Whereas Chestnut Lamprey were most associated with the Gasconade River in spring and may have been evidence of spawning aggregations. Sand Shiners were ubiquitous in these tributaries and detections were not strongly associated with any set of environmental variables. Our

findings suggest that species turnover in the lowermost sections of tributaries near confluences with large river systems is seasonally influenced and provides habitats for a variety of life stages. Managers and researchers may need to incorporate tributaries of various sizes into investigations of this nature for big-river species. The information provided here may help inform future investigations on the biology and management of these species as well as the role of tributaries in the larger connected stream network.

Introduction

An unaltered, connected stream network may provide the large spatial scale necessary to support a diverse native aquatic community (Fullerton et al. 2010). Tributaries contribute to stream networks by providing habitat for specific life-stage events and supplemental resources (Dunning 1992). Some long-distance migratory fish seek tributaries for spawning, ensuring progeny have suitable habitat for incubation and early life and the larvae can drift into habitats suitable for later life stages (Pflieger 1997, Vokoun et al. 2003, Firehammer et al. 2006, Grabowski and Isely 2006, Lucas and Baras 2001). Tributaries in large river systems (LRS; systems with a mean annual discharge of at least 350 cubic meters per second, cms; Dynesius and Nilsson 1994) have also been identified as nursery habitat for some species, including Paddlefish *Polyodon spathula* (Miller et al. 2011; Pracheil et al. 2009), Blue Suckers *Cycleptus elongatus*, Flathead Catfish *Pylodictus olivaris*, and Mooneyes *Hiodon tergisus* (Brown and Coon 1994). These big-river species and other adult migratory fish might also move into tributaries as a refuge en route to a more distant location (Goniea et al. 2006) or to feed on the increased aquatic biota often found at confluences (Benda et al. 2004). Therefore, tributaries can be critical areas for mainstem riverine fishes.

Biotic organization in lotic systems has been theorized as a continuous gradient (Vannote et al. 1980) as well as a more complex patchy distribution influenced by human alteration, biology, and environmental variability (Ward and Stanford 1983; Gorman 1986; Taylor and Warren 2001; Thorp et al. 2006; Roberts and Hitt 2010). The serial discontinuity concept theorizes dam placement in a watershed, in addition to tributary influences and lateral connectivity, may affect abiotic variables, such as substrate size, habitat heterogeneity, and temperature (Ward and Stanford 1983). These regulated rivers thereby disrupt patterns in biotic communities, including fish (Ward and Stanford 1983; Ellis and Jones 2013). The immigrant accessibility model (IAM) predicts a positive relationship between species richness and larger stream size and that these patterns are lessened during flood events (Roberts and Hitt 2010). For example, high discharge would allow upstream movement thereby homogenizing the distribution. Even semi-permeable barriers such as diversion weirs, lock and dams, and low-head dams cause disjunct fish assemblages or altered movement patterns (Zigler et al. 2003; Santucci et al. 2005; Eitzmann and Paukert 2010; Helms et al. 2011). Many LRS are impounded and longitudinal patterns do not match reference conditions but instead show some variation of the expected natural condition. Depending on size, scope, operations, locations and the biotic communities present, dams can have direct influences on the habitat or the fish community in rivers and streams.

Midwestern lotic systems have naturally high levels of diversity yet are affected by manipulation and alteration (Karr et al. 1985; Galat et al. 2005). Multiple studies investigating fish assemblages in relation to anthropogenic disturbances and longitudinal position have taken place in large Midwestern rivers including the Kansas River, tributaries of the Mississippi River in Iowa, and Wisconsin rivers (Lyons 2005; Paukert et al. 2008; Thornbrugh and Gido 2009; Eitzmann and Paukert 2010; White et al. 2010; Fischer et al. 2012; Parks et al. 2014). Large-scale monitoring programs are important to assess the effect of habitat on fish communities, the status of imperiled species, and develop restoration and recovery plans to address the ecological stressors affecting aquatic ecosystems (U.S. Fish and Wildlife Service 2014; Galat et al. 2005).

In the altered Missouri River where backwater habitats have been greatly reduced because of channelization (National Research Council 2002), tributary confluences may be important sources of deep, slow water and therefore serve as critical habitat for certain species and life stages of fish (Brown and Coon 1994). River confluences are characterized by changes in substrate, channel morphology, water chemistry, and flow patterns (Benda et al. 2004, Fullerton et al. 2010). However, the spatial scale of the converging systems varies with stream size, relative discharge, and geomorphology. The interaction of physical properties and biological components present at confluences leads to increased species richness (Hitt and Angermeier 2008; Czegledi et al. 2016) and distinctive community structures (Benda et al. 2004; Thorp et al. 2006; Naus and Adams 2016).

How far big-river fishes move upstream into the tributaries may depend on season, discharge, temperature, and physical habitat of the river reaches. Fish movement is typically most active in the spring and fall (Porto et al. 1999; Zigler et al. 2003; Grabowski and Isely 2006; Neely et al. 2009) with some combination of temperature and flow thought to trigger distribution, movement, and spawning of fish (Bramblett et al. 2002; Goniea et al. 2006; Thornbrugh and Gido 2009). Tributaries may provide these environmental cues at different times than mainstem rivers and, as a result, migratory fish may use these tributaries (Paukert and Fisher 2001). Understanding how mainstem fishes use tributaries will aid the incorporation of tributaries into LRS recovery, such as those efforts in the Missouri River Basin.

The objective of this study was to characterize the seasonal fish community of a free-flowing and regulated tributary of the Lower Missouri River to identify how tributaries of LRS contribute to mainstem aquatic biota. Our objectives were to (1) determine overall and longitudinal species richness in the Osage and Gasconade rivers throughout the four seasons; (2) define the overall and longitudinal fish community using species abundances and relate the community to water temperature, discharge, and seasonality, all of which may be affected by the degree of regulation, in two tributaries of the Lower Missouri River; and (3) model the likelihood of big-river fish species presence using environmental and habitat variables. The documented use of tributaries by big-river fish, seasonal and life-stage habitat use by fish in connected river systems, and the numerous theories on longitudinal fish community organization in lotic systems led us to hypothesize that there would be increased species richness near the confluences with the Missouri River and that community structure would change in the lower 19 river kilometers (rkm) of both tributaries as one moved upstream of the confluence areas. Furthermore, we hypothesized that variation in longitudinal patterns in species richness and the fish community would become less distinct in the lower 19 rkm in spring due to high discharge flushing fish downstream while simultaneously allowing upstream movement. The potential effects of altered rivers on aquatic species led us to hypothesize that species richness would be greater in the free-flowing Gasconade River; however, big-river fish would be present in higher proportions in the larger, regulated Osage River, especially in spring when discharge was consistently higher.

Methods

Study area and reaches

The Osage and Gasconade rivers, an eighth-order stream and a sixth-order stream at their respective confluences with the Lower Missouri River, enter the mainstem Missouri River approximately 40 rkm apart in central Missouri, with the Osage River confluence upstream of the Gasconade (Figure 1-1). Four major reservoirs, including Truman Reservoir and Lake of the Ozarks, have inundated 970 rkm of the mainstem Osage River (Duchrow 1984), leaving 130 rkm between Bagnell Dam, the lowest dam on the Osage River, and the Missouri River. Lock and Dam #1 (LD1) located at rkm 19 was constructed in 1906 by the U.S. Army Corps of Engineers as part of a navigation plan, which included the construction of numerous wing dikes throughout the lower 130 rkm of the Osage River. LD1 originally created a 32 rkm pool upstream but was removed from service in 1951. Today the structure is dilapidated with gravel and sediment filling in the upstream side, but still remains a semi-permeable barrier to fish passage (Lallaman 2012).

Bagnell Dam, a 45-meter (m) tall, bottom-release, hydroelectric facility was built in 1931, and impounds the 22,000 hectares Lake of the Ozarks Reservoir. The current Federal Energy Regulatory Commission license dictates a minimum discharge of 25.5 cms from the dam, with seasonally varying caps limiting the minimum flow and rules for post-flood ramp down and re-aeration flows following power generation. Regulation of Bagnell Dam has altered the downstream water temperature so the Osage River warms up slower in the spring, is cooler in summer, warmer in winter, and less daily variability when compared to the Gasconade River (Figure 1-2).

In contrast to the Osage River Basin, the mainstem Gasconade River is free-flowing for nearly 500 rkm with no major reservoirs in the basin. The Gasconade River exhibits a natural flow regime with high water events more frequent in the spring tapering off to seasonally low flows whereas the Osage River exhibits highly fluctuating flows of up to 2 m per day. Although geographically close, the Osage River drainage area is four times the size of the Gasconade. The percent land use/land cover are comparable between the two basins (Table 1-1). Notwithstanding the dissimilarity in size, we believe that the proximity of the basins and similar aquatic biota, including multiple fish and mussel species, provides an informative opportunity for comparison.

Fish collections

Standardized sampling began in September 2012 and extended through August 2013. Sampling was conducted in the lower 19 rkm of the Osage and Gasconade rivers, upstream of their confluences with the Missouri River, in central Missouri (Figure 1-1). Study reaches were delineated every other 1.6 rkm (approximately 1 river mile, RM) in each tributary except at their respective confluences with the Missouri River where we sampled two consecutive 1.6 rkm reaches for a total of seven study reaches in each tributary. To collect the entire fish community we deployed three random samples of boat electrofishing, beach seines, and benthic trawls in each reach during the four seasons. Fall sampling occurred September 13 - November 8, 2012, winter was December 18, 2012 – March 16, 2013, spring was March 26 - May 20, 2013, and summer sampling occurred June 21 - August 16, 2013. Due to the variability in sampling techniques, each sampling gear was analyzed separately.

The majority of captured fish were identified to species, measured to the nearest millimeter (mm) and returned to the river. However, some fish were retained for lab identification. If more than 25 of a single species were captured, 25 were randomly chosen to be measured while the remaining fish were counted. Upon completion of the sampling transect, depth was determined at the beginning and end of the transect by a boat-mounted Lowrance depth sounder (Navico, Inc.) and all data was recorded on an Archer global positioning system unit (Juniper Systems, Inc., Logan, Utah).

Boat electrofishing. Collections were made by boat electrofishing during daylight hours by a crew of one boat operator and two netters outfitted with 3 mm mesh, long-handled dip nets. A Midwest Lake Electrofishing Systems (Polo, MO) Infinity electrofishing box with pulsed direct current at 60 Hz and 40% duty cycle was used to target the power (watts) and amps to the recommended levels by Miranda (2009) for the ambient conductivity of the water at sampling time. Three, five-minute downstream longitudinal transects sampled bankline, bar, and channel border habitats less than three meters (m) deep in each river reach. Catch per unit effort (CPUE) is the number of fish per five minutes electrofishing.

Beach seines. Near-shore wadeable habitats less than 1.2 m were sampled with a 3 mm dipped mesh bag seine measuring 9 m X 1.8 m with a 1.8 m bag. Standard seine hauls were conducted with both ends on the shore, the upstream end arching off the bank to move parallel to the bank and then arching back in to the shore at the conclusion of 30 m. CPUE was calculated as fish per 30 m seine haul.

Benthic trawls. A customized benthic Gerken Siamese Trawl (Greg Faulkner, Innovative Nets, Milton, Louisiana) measuring 2.5 meters (m) long with 6 mm mesh, a 2.5 m headrope and a 3 m footrope was used in all reaches during all seasons. Larger 38 mm mesh inside the 6 mm mesh in the cod-end separates the larger fish from the smaller fish. The length of the trawl towlines were about 3 times the water depth and the trawl doors were 50 cm in length to ensure that the trawl mouth opened properly and maintained contact with the bottom. Benthic trawl hauls were towed off the bow in reverse a minimum of 75 m and a maximum of 200 m in main channel, channel border, and pool habitat greater than 1.2 m deep at a speed slightly faster than the water. Catch per unit effort (CPUE) is the number of fish per 100 m trawled.

Data analysis

To account for ontogentic shifts, large-bodied species captured were identified as adults or juveniles based on published lengths at maturity (Table 1-2; Pflieger 1997; Becker 1983; Jenkins and Burkhead 1994; Fischer et al. 2012). We analyzed juveniles and adults of the same species as separate because tributary use varies ontogenetically for many stream fishes (Schlosser 1982; Gelwick 1990; Gido and Propst 1999; Gillette et al. 2005). We calculated species richness, or the total number of species represented, for each river, reach, season and gear.

Fluvial dependent and fluvial specialist species were classified by Galat et al. (2005) with modifications made to remove the “tributary stragglers” as designated by

Pflieger and Grace (1987). These species will be referred to as big-river species from here on out (Table 1-2). Eighteen fish species captured were identified as members of the big-river fish guild (Cross et al. 1986; Pflieger 1997; Galat et al. 2005; Table 1-2). The big-river species richness, or the total number of big-river species represented, was calculated for each reach, river, season and sampling gear. The proportion of big-river species captured was calculated using big-river species richness divided by total species richness for each combination listed previously.

We used nonmetric multidimensional scaling (NMDS) to assess differences in the fish community between the two rivers and longitudinally among reaches as well as seasonally. For each sampling technique, species abundance data at each river-reach combination and then each season-river-reach combination was used to perform NMDS ordinations. Environmental variables were fit to the season-river-reach NMDS ordinations to correlate fish community with river, distance from Missouri River confluence, depth, discharge, water temperature, and season. The ordination analyses were performed in R (version 2.15.0; R Development Core Team 2011) using the vegan package for descriptive community ecology (Oksanen et al. 2013).

We developed 13 *a priori* models to evaluate factors that predict presence of big-river fish species based on previous research and theories of big-river fish distribution, fish biological reactions to environmental variables, and our own biological intuition (Table 1-3). We only predicted presence of big-river fish with greater than ten occurrences by boat electrofishing and trawling in the lower 19 rkm of each river. We did not include seining data because seining was not conducted in all reaches and all seasons. We fit generalized linear mixed-effects models to our data using the glmer function in the lme4 package (Bates et al. 2018) in R statistical software version 3.5.2 (R Development Core Team 2018). We defined our response variable as a binomial distribution with a logit link and used the Nelder-Mead optimization of parameters. We used study reach as a random effect in all models to account for any autocorrelation resulting from repeated sampling. Fixed effects included metrics representing water temperature, river discharge, season, depth, longitudinal river position, and river as parameters to explain presence of big-river fishes in the regulated Osage River and the unregulated Gasconade River (Table 1-3 and 1-4).

Water temperature measurements included mean daily water temperature (based on recording every 15 minutes) as collected by temperature loggers at rkm 5 on the Osage River and rkm 7 on the Gasconade River deployed by USGS Columbia Environmental Research Center and, when necessary, temperature taken at the time of sample. The three-day prior water temperature coefficient of variation (CV) of the mean daily water temperature was also included as a variable in models to determine if the variation in water temperature was indicative of big-river fish presence. The temperature CV over the 5-, 7-, and 10-day period were considered, however, 3-day was chosen due to a lack of difference in preliminary analysis and the believed biological relevance of the 3-day time period.

The daily mean river discharge was calculated using data obtained from waterwatch.usgs.gov for the following stream gages: 06926510 at St. Thomas, Missouri for the Osage River; 06934000 at Rich Fountain, Missouri for the Gasconade River; and 06909000 at Boonville, Missouri for the Missouri River. To account for varying scales of discharge among the Osage, Gasconade, and Missouri rivers, the daily mean discharge was converted to the proportion of the 17-year annual mean discharge (1996-2013) and scaled using the mean-centering scale function in R statistical software (version 2.15.0; R Development Core Team 2011). This function subtracts the parameter mean and then divides by the standard deviation. To account for the bell curve shape of the raw mean daily discharge data over the year, a parabolic form of the discharge measurement was included in the models.

The three-day prior discharge CV was included as a model parameter to account for flow variability. Flow variability has been related to the occurrence of opportunistic, periodic, and equilibrium life history strategies of fish across the united states (Mims and Olden 2012). We chose the CV prior to capture because our hypothesis was that flow variability, or the lack thereof, may be giving some indication of habitat preference to these big-river fish. We chose 3 days prior to capture after exploring multiple time frames (i.e., 2,3,5,7,10 days prior).

Other model parameters included season, depth, longitudinal river position, and river. Season was a categorical variable (spring, summer, fall, or winter) defined using the date the sample occurred. Depth was a continuous variable and represented the depth of the sample, in meters. The longitudinal river position was a categorical variable representing the river mile where the sample occurred. A lower river mile meant it was closer to the Missouri River confluence. To determine if these patterns differ by river, Gasconade and Osage were used as covariates in all analyses.

Models were compared using Akaike's Information Criterion for small sample sizes (AICc) using the aictab function in the AICcmodavg package (Mazerolle 2017) and the model select function (mod.sel) in the multi-model inference (MuMIn) package (Bartón 2018) in R (version 3.5.2; R Development Core Team 2018).

There were instances where the lowest AICc model was not strongly weighted making the inference on the best predictors of big-river fish species presence in the Osage and Gasconade rivers unclear. Therefore, full-model averaging was employed to create parameter estimates for all variates of the global model for each species using all models in the candidate set (Symonds and Moussalli 2011). This was done using the multi-model inference (MuMIn) package (Bartón 2018) in R (version 3.5.2 patched, R development Core Team 2018) and an 85% confidence interval was used to include parameters that were supported across models (Van Dyke et al. 2017). Following Van Dyke et al. (2017), we focused only on those model-averaged parameter estimates whose 85% confidence intervals do not include 0 and thus indicate particularly strong support for a non-0 parameter estimate.

Results

Fall 2012 occurred during a drought year and discharges in the two tributaries were the lowest observed throughout the study (Figure 1-3, Table 1-5). The season with the highest mean discharge was spring 2013 when discharge in the Osage River was 6, 10, and 22 times that in summer, winter, and fall respectively and discharge in the Gasconade was 5, 5, and 9 times the discharge in summer, winter and fall (Figure 1-3, Table 1-5). A flood occurred in early August 2013 when discharges exceeded 4,199 cms in the Osage River and 2,832 cms on the Gasconade River (Figure 1-3). The lowest water temperatures were observed in winter in both tributaries and the highest in summer 2013 (Table 1-5). The mean Osage water temperature in spring 2013 was only 4.3°C higher than the winter temperature whereas the Gasconade spring water temperature was 8.4°C warmer (Table 1-5, Figure 1-2).

Sampling was conducted between September 13, 2012, and August 16, 2013. Three boat electrofishing samples were deployed in each reach and season except at reaches three and seven in the Gasconade River during fall due to low water and the inability to access these sites. Beach seines were not deployed at reach one in the Gasconade or Osage rivers except in winter when samples were successfully collected at reach one in the Osage River. No seining was completed at Osage reach six in winter, Gasconade reaches two and three in spring, any Osage reaches in spring, or Gasconade reach two in summer. Benthic trawls were successfully deployed in all reaches and seasons.

In total, 30,355 fish representing 86 species were captured. Large-bodied fish were separated into adults or juveniles based on published length at maturity recognizing 39 species in juvenile life stages (Table 1-2). Regardless of river or gear, 41% of the species captured were represented in the juvenile life stage. All gears detected juveniles, but proportions varied by season. Benthic trawls captured the highest proportion of juveniles in fall, beach seines in summer, and electrofishing caught the highest proportion in the Osage River in winter and in the Gasconade River in spring (Tables 1-6, 1-7, & 1-8).

The unregulated Gasconade was more speciose at 82 while the regulated Osage had 57 species. This trend was consistent for all three gears and in all seasons (Tables 1-6, 1-7, & 1-8). Seasonal species richness in the tributaries was not highest in spring as hypothesized (Tables 1-6, 1-7, & 1-8). Instead, spring 2013 exhibited the lowest species richness in the Osage River for trawls and boat electrofishing (no seining was conducted) while summer 2013 had the highest species richness for many river and gear combinations - seines and trawls in both the Gasconade and Osage rivers and electrofishing in the Gasconade River. Seasonal species richness fluctuated from a low of 8 species captured by beach seine in the Osage River in winter to a high of 47 species captured by boat electrofishing in the Gasconade River in summer. Each river and season, individually and in combination, contributed unique species to the cumulative species richness**.** These were usually rare species, juvenile life stage, and/or big-river fish.

Longitudinal species richness was not highest closer to the Missouri River confluence as had been hypothesized (Figure 1-4). Cumulative species richness increased in reaches upstream of the Missouri River confluence for seining on the Osage River and benthic trawls in the Gasconade River. There was not a consistent longitudinal species richness pattern among seasons for the river and gear combinations.

Big-river fish species accounted for 21% percent of all species captured. Eight of the big-river species were captured in both rivers (Chestnut Lamprey *Ichthyomyzon castaneus*, Channel Shiner *Notropis wickliffi*, Flathead Catfish, Goldeye *Hiodon alosoides*, Longnose Gar *Lepisosteus osseus*, Speckled Chub *Macrhybopsis aestivalis*, Sand Shiner *Notropis stramineus*, and White Bass *Morone chrysops*), seven were only captured in the Gasconade River (Alabama Shad *Alosa alabamae*, Blue Catfish *Ictalurus furcatus*, Highfin Carpsucker *Carpiodes velifer*, Lake Sturgeon *Acipenser fulvescens*, Mooneye, Paddlefish, and River Shiner *Notropis blennius*), and three were only captured in the Osage River (Skipjack Herring *Alosa chrysochloris*, Stonecat *Noturus flavus*, and Yellow Bass *Moronid mississippiensis*). Multiple Paddlefish were captured in the Osage River during non-standardized sampling, whereas only one juvenile Paddlefish was captured in the Gasconade River during standard sampling.

The proportion of big-river species captured by each gear was consistent between the two rivers. Although spring was hypothesized to have the most big-river species, only benthic trawls had the highest proportion of big-river species captured in spring when 22% (4 of the 18) species captured in the Gasconade and 20% (2 of the 10) in the Osage were big-river species (Table 1-8).

Despite species richness and proportion of big-river species patterns not supporting the preliminary hypotheses, there were distinct differences between the regulated Osage River and the free-flowing Gasconade River. The two rivers had 53 species in common while 29 species were only captured in the Gasconade River and four species were only captured in the Osage River (Skipjack Herring, Stonecat, White Crappie *Pomoxis annularis*, and Yellow Bass). Of the 29 species only captured in the Gasconade River, two were classified as Missouri State Endangered, Lake Sturgeon and Crystal Darter *Crystallaria asprella*, with an additional two listed as imperiled in Missouri: Alabama Shad and Highfin Carpsucker. The Lake Sturgeon, Alabama Shad, and Highfin Carpsucker were found in juvenile size classes. The Lake Sturgeon were stocked into the Gasconade and Osage rivers in September 2012 and the fish we collected were likely from these stockings. The Osage stocking site was in reach two, approximately 3 rkm upstream of the Missouri River confluence. The Gasconade stocking site was in reach seven, approximately 14 rkm upstream of the Missouri River confluence. No stocked juvenile Lake Sturgeon were captured in the Osage River, however, three were captured by benthic trawl in the Gasconade River; one upstream and two downstream of the stocking site. The two Crystal Darters were captured by benthic trawls in the summer. All four Alabama Shad were captured in fall: three by boat electrofishing and one by benthic trawl. The one Highfin Carpsucker was captured in summer by seine.

The NMDS ordinations of species abundance at the river-reach combination differentiated the two rivers and longitudinal patterns (Figure 1-5). Electrofishing NMDS detected differences between the two rivers with Bleeding Shiners *Luxilus zonatus*, Black Redhorse *Moxostoma duquesnei*, and Northern Hogsucker *Hypentelium nigricans* more common in the Gasconade River, and Skipjack Herring, juvenile Sauger *Sander canadense*, and White Crappie in the Osage River (Figure 1-5A). In addition, Gasconade River reaches closest to the Missouri River confluence (reaches G1, G2, & G3) were more similar to each other and the Osage River sites than the upper reaches of the Gasconade River. Seining NMDS separated the rivers and detected longitudinal differences with sites in the lower Osage River (O2, O3, O4, and O5) characterized by juvenile River Carpsucker *Carpiodes carpio*, Mimic Shiners *Notropis volucellus* and Emerald Shiners *Notropis atherinoides* (Figure 1-5B). Benthic trawl NMDS did not detect differences between the two rivers but did detect longitudinal differences in the fish community (Figure 1-5C). Fish collected with trawls indicated the reaches in the lower Gasconade and Osage rivers were somewhat similar and associated with River Carpsucker, juvenile Goldeye, and juvenile Silver Chub *Macrhybopsis storeriana*, while reaches further upstream of the Missouri River confluence (reaches 5, 6, & 7) were more similar and typified by Crystal Darters, Longear Sunfish *Lepomis megalotis*, and Logperch *Percina caprodes* (Figure 1-5C).

Environmental variables and big-river species scores projected on NMDS plots of species abundance at the season-river-reach combination further explains fish community differences (Figure 1-6). Fish communities in the Osage River sites sampled by boat electrofishing were associated with deeper water and higher and more variable discharge while the Gasconade River sites were typified by fish communities more common upstream of the Missouri River confluence, including juvenile Alabama Shad and higher proportions of small Ozark stream fish (Figure 1-5A & 1-6A). The spring season was associated with variables related to an increase in discharge and a few big-river fish species, including juvenile Paddlefish, juvenile Blue Catfish, and Longnose Gar (Figure 1-6A).

The longitudinal patterns and differences in fish community sampled by beach seines in the two rivers can be explained by the juvenile life stages of big-river fishes as well as habitat and environmental variables (Figure 1-6B). Juvenile White Bass, Longnose Gar and Highfin Carpsucker were associated with the deeper, warmer waters of the Gasconade River in summer while the more common shiners were associated with the Osage River in fall and winter when water temperatures fluctuated.

Benthic trawls detected longitudinal differences rather than differences between the two rivers in the NMDS ordination plots of river-reach combinations (Figure 1-5C). Incorporating season into the species abundance site scores and fitting big-river species abundance, habitat and environmental variables to the NMDS ordination showed that juvenile big-river species associated more with the Gasconade River than the Osage River (Figure 1-6C). Although season did not define the fish community in the two Missouri River tributaries, fluctuating discharges (Discharge CV), increased water temperatures and increased flow in the mainstem Missouri River correlate with the fish community sampled in the Osage River, which included adult Flathead Catfish, Stonecat, and Channel Shiners (Figure 1-6C).

In the Gasconade River, over half of the big-river species were only represented in the juvenile stage (Alabama Shad, Blue Catfish, Goldeye, Highfin Carpsucker, Lake Sturgeon, Mooneye, Paddlefish, and White Bass) while the Flathead Catfish and the Longnose Gar were captured in both adult and juvenile life stages. In the Osage River, both adult and juvenile Flathead Catfish, Longnose Gar, Skipjack Herring, and White Bass were captured while Goldeye were only captured in the juvenile life stage. To understand more about habitat and environmental variables that may predict big-river fish occurrence in the Osage and Gasconade rivers, the presence/absence data for big-river species with ten or more captures – Chestnut Lamprey, Flathead Catfish, juvenile Flathead Catfish, Longnose Gar, juvenile Longnose Gar, juvenile Goldeye, and Sand Shiners – were used in generalized linear mixed-effects models.

The top models (those with $\Delta AIC_c \leq 2$) explained 17-81% of the presence of big-river species with ten or more captures (Table 1-9 and Appendix A). Chestnut Lamprey, adult Flathead Catfish, and juvenile Flathead Catfish each had one top model while juvenile Goldeye and Sand Shiners each had two, and adult and juvenile Longnose Gar each had three top models. The "tributary conditions" model was among the top models predicting the presence of juvenile Flathead Catfish, juvenile Goldeye, and adult and juvenile Longnose Gar explaining 69%, 46%, 44%, and 19%, respectively, of their presence in the Gasconade and Osage rivers (Table 1-9).

The “tributary conditions” model considers the mean daily water temperature and the mean daily discharge on the day sampling occurred as well as the river. Of the four species for which this was the top model or among the top models, three of them (juvenile Flathead Catfish, juvenile Goldeye, and juvenile Longnose Gar) had mean daily water temperature as a substantial variable while adult Longnose Gar had mean daily discharge as a substantial variable. For all the juvenile life stage of species that were modeled, the probability of presence increased with warmer tributary water temperatures (Table 1-9).

Models with only mean daily water temperature or mean daily discharge were found to be top predictors for three of the big-river fish species modeled. The “tributary temp” model, which considers the mean daily water temperature on the day of sampling and the river, explained 81% of the adult Flathead Catfish presence and 34% of the juvenile Goldeye presence (Table 1-9). The “tributary discharge” model, which considers the mean daily discharge on the day of sampling and the river, explained 24% of adult Longnose Gar presence. Adult Longnose Gar also had the “tributary variability” model, which contained daily means and CVs of water temperature and discharge, among it’s top-ranked models explaining 19% of its presence in these Missouri River tributaries.

The “season” model explained 48% of the juvenile Longnose Gar and 76% of the Chestnut Lamprey presence. Of the 59 juvenile Longnose Gar captured during our study, 91% of them were captured in spring and summer and these seasons were important for explaining the presence of juvenile Longnose Gar in the top model (Table 1-9). For the 51 Chestnut Lamprey captured in this study, 98% were captured in the Gasconade River and 76% were captured in the Gasconade River in spring. River was the substantial variable in the Chestnut Lamprey top model because we were more likely to detect them in the Gasconade River rather than the Osage River. The Gasconade River harbored other big-river species, including juvenile Alabama Shad, juvenile Blue Catfish, juvenile Mooneye, juvenile Paddlefish, River Shiners, and juvenile Highfin Carpsucker. The Osage River was host to big-river species not captured in the Gasconade River including adult and juvenile Skipjack Herring, Yellow Bass, and Stonecat.

Sand Shiners were ubiquitous in these tributaries and detections were not strongly associated with any set of environmental variables. Other variables tested but not important in predicting big-river fish presence included Missouri River discharge, water depth, distance from the Missouri River, and the variability of water temperature and discharge.

Full-model averaging further supported the importance of parameters for predicting Chestnut Lamprey, adult and juvenile Flathead Catfish, juvenile Goldeye, and adult Longnose Gar but did not identify any substantial predictors for juvenile Longnose Gar or Sand Shiners (Table 1-10). Full-model averaging of Chestnut lamprey further supported the importance of the Gasconade River in predicting Chestnut Lamprey presence, which was also identified in the top model. Increased water temperature was the substantial predictor for adult and juvenile Flathead Catfish, which was also identified by their top models of "tributary temp" and "tributary conditions," respectively. Mean daily water temperature was the only substantial variable identified in the top models for predicting juvenile Goldeye, but full-model averaging substantiated the importance of increased water temperature and the Gasconade River for predicting the presence of the juvenile life-stage of this big-river fish species. Full-model averaging for adult Longnose Gar supported the importance of above-average discharge which was identified in top models predicting this big-river species and added the Gasconade River as an important predictor.

Discussion

Our results suggest that the fish assemblages in the lowermost 19 rkm of the Osage and Gasconade rivers, two Lower Missouri River tributaries, were different from each other and that these differences may be associated with season, river regulation, network position (proximity to the larger Missouri River/longitudinal position), and the presence of uncommon species such as big-river fishes.

Our results suggest that the fish assemblage in the lowermost 19 rkm of the regulated Osage River where it enters the larger mainstem Missouri River is still affected by the regulation in the upper basin. The Osage River had lower overall species richness, fewer species of conservation concern, fewer big-river species, and fewer juvenile life stages of fish compared to the unregulated Gasconade River. Research in the regulated Murray-Darling River system of Australia, found species diversity and abundance of native fish were reduced due to the desynchronization of environmental cycles and fish reproductive cycles (Gehrke et al. 1995), and this also may have occurred in the Osage River. In the hydro-peaking Osage River, higher flows could be influencing spawning strategies and flushing juvenile fish out of the system, which has been shown in the

Oconee River in Georgia, the Colorado River, and streams in France (Bunn and Arthington 2002; Cattaneo 2005; Peterson et al. 2013).

The differences in the fish community between the Osage and Gasconade rivers were less noticeable within 8 rkm of their confluences with the Missouri River. The fish community in the Gasconade River reaches closest to the Missouri River confluence (reaches G1, G2, & G3) were more similar to each other and the Osage River sites than the upper reaches of the Gasconade River. Thornbrugh and Gido (2009) found that stream order explained longitudinal change in fish assemblage for smaller streams connected to large mainstem rivers, which in our study occurred in the lower order Gasconade River (stream order 6), and not the larger Osage River (stream order 8). The Gasconade River has an average annual discharge of 87 cms at the Rich Fountain gage upstream of its confluence with the Missouri River. The Missouri River is stream order 11 and has an average annual discharge of 1,959 cms at the Boonville gage. This difference in discharge would cause water flowing from the Gasconade River to slow down as it joins the Missouri River and create backwater habitat. Our data suggest this backwater habitat and the influence on the fish assemblage in the Gasconade River is within 8 rkm of the confluence with the larger Missouri River. As with many other studies investigating the role of tributaries in relation to mainstem habitats, stream size and network position have substantial effects on the fish assemblages and the scale of the interaction between these two systems (Gorman 1986; Brown and Coon 1994; Hitt and Angermeier 2008; Thornbrugh and Gido 2009; Czegledi et al. 2016; Naus and Adams 2016).

Despite the longitudinal change in the fish assemblage, longitudinal species richness was relatively consistent in the respective tributaries further indicating that species turnover occurred throughout the study areas. We hypothesized that study reaches closer to the Missouri River would lead to increased species richness (Benda et al. 2004; Fullerton et al. 2010; Hitt and Angermeier 2008; Czegledi et al. 2016). However, the area of tributary/mainstem interaction varies with stream size, discharge, and geomorphology. Although the species richness pattern did not match our hypothesis or the patterns theorized or observed in wadeable systems (Benda et al. 2004; Hitt and Angermeier 2008; Czegledi et al. 2016) it was similar to that observed by Thornbrugh and Gido (2009) in the Kansas Basin where proximity to a mainstem river explained little additional variation in species richness yet clarified differences in fish community, particularly the abundance of stream fish species. Our results support what these studies emphasize: stream order, scale, and network position are important when evaluating community metrics in connected river systems.

In the 19 rkm upstream of their respective confluences with the Missouri River, the fish assemblages of the Gasconade and Osage rivers appear to be strongly influenced by season. Each river and season, individually and in combination, contributed species to the cumulative species richness and therefore the fish community. These were usually rare species, juvenile life stage, and/or big-river fish. We hypothesized that the Osage and Gasconade rivers would have the greatest species richness in spring because fish are very active in the spring (Porto et al. 1999; Zigler et al. 2003; Grabowski and Isely 2006; Neely et al. 2009) and those fish exhibiting a migratory reproductive behavior are more often associated with large rivers (Goldstein and Meador 2004). It was thought that migratory fish of the big-river guild would be more likely to move into the Osage and Gasconade rivers in spring due to the warming water temperatures and increased discharge making the tributaries seemingly less distinguishable from the Missouri River. However, summer followed by fall was the most speciose and big-river fishes were not overwhelmingly detected in spring. Thornbrugh and Gido (2009) observed the same pattern in tributaries of the Kansas River where species richness varied by season with richness lower in spring than in summer and fall. In our study, summer and fall saw overall increase in numbers of fish, especially small-bodied fishes such as shiners or juvenile life stages.

Full-model averaging of generalized linear mixed-effects models predicting select big-river species presence further clarified the abiotic variables associated with the presence of big-river species with greater than ten captures during our sampling. There was not one abiotic variable that was best at predicting the presence of fish species in the big-river guild. Instead, certain species or life stages had an affinity for the Gasconade River, responded to increased water temperature or above average discharge, or a combination of these factors. Therefore, summarizing the abiotic variables to use in predicting multiple species of the big-river guild may not be justifiable. However, we were able to determine substantial predictors for the presence of adult and juvenile Flathead Catfish, juvenile Goldeye, Chestnut Lamprey, and adult Longnose Gar. These findings may help biologists and managers in LRS to detect and understand life history needs for these species.

Increased mean daily water temperature best predicted adult and juvenile Flathead Catfish presence. In our study, Flathead Catfish were detected in the Gasconade and Osage rivers in summer and fall, the seasons with the warmest water temperatures. This period of detection coincides with summer/fall movement patterns observed in the Grand River, another tributary of the Lower Missouri River, and the Cuivre River, a tributary of the Mississippi River (Vokoun and Rabeni 2005). Flathead Catfish may have moved into these systems during or following spates as they are highly mobile species known to move into smaller order streams following high water events to take advantage of the increased food availability (Vokoun and Rabeni 2005; Stanley et al. 2012).

An increase in mean daily water temperature was also a strong predictor of juvenile Goldeye presence. The association between juvenile Goldeye and increased water temperature may be due to the life cycle strategy of Goldeye. The Goldeye spawns in spring and has a semi-buoyant egg that develops as it drifts and eventually settles out either by swimming to an area of less flow or by being deposited in such areas (Pflieger 1997). With the converging flows and slack water found at tributary confluences, these areas have been identified as important nursery habitats for Goldeye and other big-river fishes in highly-modified river-floodplain systems such as the Lower Missouri River (Brown and Coon 1994; Naus and Adams 2016). Low summer flows and a constant connection to the Lower Missouri River creates slackwater that provides nursery habitat for developing fishes at tributary confluences. This information indicates that sampling these habitats when water temperatures are above average is a good time for detecting this life stage of Goldeye.

Recommendation for studies on Chestnut Lamprey detection and monitoring differ in that they would be best planned for early spring in the Gasconade River. Large numbers of Chestnut Lamprey, referred to as "groups" by Cochran (2014), were captured in the Gasconade River in spring with individuals captured in both rivers in other seasons. Chestnut Lamprey are spring spawners and these groups of Chestnut Lamprey may have been spawning aggregations similar to those captured in Michigan streams (Pflieger 1997; Cochran 2014). Seasonal changes in big-river species presence may be associated with life-stage traits such as spawning or migration as was found by Sommer et al. (2014) in the Sacramento River where seasonal variation in water temperature and flood stage were important factors affecting the fish assemblage structure and the presence of migratory species.

Adult Longnose Gar affinity for the Gasconade River and higher than average mean daily discharge was driven by approximately 50% of the total captures happening by electrofishing in the Gasconade River in spring, the season with the highest discharge. This finding was unexpected and is most likely attributed to Longnose Gar using the bankline and low-flow habitats that were sampled by electrofishing in spring 2013. Longnose Gar use of these habitats was most likely to avoid the higher flow occurring in mid-channel areas (Sutton et al. 2009). Regardless, our study shows that Longnose Gar are residents of these Lower Missouri River tributaries despite environmental conditions. Consistent with other results of our study, this finding is different than would be expected in wadeable systems where Longnose Gar are associated with low stream flow (Stanley et al. 2012). Larger tributaries of LRS, such as the Osage and Gasconade rivers are to the

Lower Missouri River, provide consistent habitat for big-river species, unlike smaller systems which provide opportunistic habitats for these species.

In conclusion, this study found the fish assemblage in the lowermost 19 rkm of the regulated Osage River where it enters the larger mainstem Missouri River is still affected by the regulation in the upper basin. The Osage River had lower overall species richness, fewer species of conservation concern, fewer big-river species, and fewer juvenile life stages of fish compared to the unregulated Gasconade River. At the relatively small spatial scale of 19 rkm upstream of confluences with the large Missouri River there was a longitudinal pattern in fish community in two mid-sized rivers and within 8 rkm of their respective confluences with the Missouri River the fish communities were similar to each other. Seasonal shifts in the fish communities show the many roles that medium sized tributaries play in the connected river system. Probable reasons for these shifts include spawning, feeding, nursery habitat or random movements by mobile fish species (Koster et al. 2014; Czegledi et al. 2016). However, a more extensive study to determine the hydrologic components relevant to the fish species of interest would be beneficial to further identify the mechanisms for the fish community differences. Other future studies focused on temporal (summer and fall), spatial (greater than 20 rkm), and tributary size are suggested to refine the use of these tributaries by big-river fish species and the juvenile life stages of fishes. Our findings suggest that the species turnover in the lowermost sections of tributaries near confluences with big rivers is seasonally influenced and this area provides habitats for a variety of life stages, including spawning and nursery habitat. Managers and researchers should incorporate tributaries of various sizes into investigations of this nature for big-river species and that this use may be limited to the lowermost reaches (within 8 rkm).

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Table 1-1. Land use and basin information of the Gasconade and Osage rivers.

	Osage	Gasconade
Stream order	8	6
Number of mainstem reservoirs	4	0
Basin area (km^2)	39,627	9,258
Mean Annual Discharge (cms)	348	86.65
Grassland/Pasture	44%	38%
Forest	30%	51%
Cropland	14%	3%
Impervious/Urban	3%	2%

Table 1-2. Total length at maturity for species collected in the Gasconade and Osage rivers, 2012-2013. Species which were not distinguished as adult or juvenile are denoted with a "na." Species identified as big-river fishes are indicated by an asterisk.

Species	Species Code	Length at Maturity (mm)
*Alabama shad, *Alosa alabamae*	ALSD	228[a]
Banded darter, *Etheostoma zonale*	BDDR	na
Bigeye shiner, *Notropis boops*	BESN	na
Bighead carp, *Hypopthalmichthys nobilis*	BHCP	620[b]
Bigmouth buffalo, *Ictiobus cyprinellus*	BMBF	380[b]
Black crappie, *Pomoxis nigromaculatus*	BKCP	180[b]
Black redhorse, *Moxostoma duquesnei*	BKRH	236[c]
Blackspotted topminnow, *Fundulus olivaceus*	BPTM	na
Bleeding shiner, *Luxilus zonatus*	BDSN	na
*Blue catfish, *Ictalurus furcatus*	BLCF	500[b]
Bluegill, *Lepomis macrochirus*	BLGL	80[b]
Bluntnose minnow, *Pimephales notatus*	BNMW	na
Brook silverside, *Labidesthes sicculus*	BKSS	63[c]
Bullhead minnow, *Pimephales vigilax*	BHMW	na
Central stoneroller, *Campostoma anomalum*	CLSR	na
Channel catfish, *Ictalurus punctatus*	CNCF	250[b]
*Channel Shiner, *Notropis wickliffi*	CNSN	na
*Chestnut lamprey, *Ichthyomyzon castaneus*	CNLP	na
Common carp, *Cyprinus carpio*	CARP	300[b]
Creek chub, *Semotilus atromaculatus*	CKCB	na
Crystal darter, *Ammocrypta asprella*	CLDR	na

Species	Species Code	Length at Maturity (mm)
Emerald shiner, *Notropis atherinoides*	ERSN	na
Fathead minnow, *Pimephales promelas*	FHMW	na
*Flathead catfish, *Pylodictus olivaris*	FHCF	380[b]
Freckled madtom, *Noturus nocturnus*	FKMT	na
Freshwater drum, *Aplodinotus grunniens*	FWDM	275[b]
Gilt darter, *Percina evides*	GLDR	na
Gizzard shad, *Dorosoma cepedianum*	GZSD	200[b]
Golden redhorse, *Moxostoma erythrurum*	GDRH	218[c]
*Goldeye, *Hiodon alosoides*	GDEY	350[b]
Grass carp, *Ctenopharyngodon idella*	GSCP	510[b]
Gravel chub, *Erimystax punctatus*	GVCB	na
Green sunfish, *Lepomis cyanellus*	GNSF	64[b]
Greenside darter, *Etheostoma blennioides*	GSDR	na
*Highfin carpsucker, *Carpiodes velifer*	HFCS	229[c]
Johnny darter, *Etheostoma nigrum*	JYDR	na
*Lake sturgeon, *Acipenser fulvescens*	LKSG	1140[d]
Largemouth bass, *Micropterus salmoides*	LMBS	250[b]
Largescale stoneroller, *Campostoma oligolepis*	LSSR	na
Logperch, *Percina caprodes*	LGPH	na
Longear sunfish, *Lepomis megalotis*	LESF	40[b]
*Longnose gar, *Lepisosteus osseus*	LNGR	700[b]
Mimic shiner, *Notropis volucellus*	MMSN	na
Missouri saddled darter, *Etheostoma tetrazonum*	MSDR	na

Species	Species Code	Length at Maturity (mm)
*Mooneye, *Hiodon tergisus*	MNEY	229[c]
Northern hog sucker, *Hypentelium nigricans*	NHSK	203[c]
Orangespotted sunfish, *Lepomis humilis*	OSSF	45[b]
Orangethroat darter, *Etheostoma spectabile*	OTDR	na
Ozark minnow, *Notropis nubilus*	OZMW	na
*Paddlefish, *Polyodon spathula*	PDFH	1400[d]
Pumpkinseed, *Lepomis gibbosus*	PNSD	na
Quillback, *Carpiodes cyprinus*	QLBK	275[b]
Rainbow darter, *Etheostoma caeruleum*	RBDR	na
Red shiner, *Cyprinella lutrensis*	RDSN	na
Redear Sunfish, *Lepomis microlophus*	RESF	na
Redfin Shiner, *Lythrurus umbratilus*	RFSN	na
River carpsucker, *Carpiodes carpio*	RVCS	275[b]
River redhorse, *Moxostoma carinatum*	RVRH	264[c]
*River shiner, *Notropis blennius*	RVSN	na
Rock bass, *Ambloplites rupestris*	RKBS	na
Rosyface shiner, *Notropis rubellus*	RYSN	na
*Sand shiner, *Notropis stramineus*	SNSN	na
Sauger, *Sander canadense*	SGER	250[e]
Shorthead redhorse, *Moxostoma macrolepidotum*	SHRH	225[b]
Shortnose gar, *Lepisosteus platostomus*	SNGR	375[b]
Silver carp, *Hypopthalmichthys molitrix*	SVCP	530[b]
Silver chub, *Macrhybopsis storeriana*	SVCB	88[c]

Species	Species Code	Length at Maturity (mm)
Silver lamprey, *Ichthyomyzon unicuspis*	SVLP	na
Silver redhorse, *Moxostoma anisurum*	SVRH	270[c]
*Skipjack herring, *Alosa chrysochloris*	SJHR	305[c]
Slenderhead darter, *Percina phoxocephala*	SHDR	na
Smallmouth bass, *Micropterus dolomieu*	SMBS	250[b]
Smallmouth buffalo, *Ictiobus bubalus*	SMBF	375[b]
*Speckled chub, *Macrhybopsis aestivalis*	SKCB	na
Spotfin shiner, *Cyprinella spiloptera*	SFSN	na
Spotted bass, *Micropterus punctulatus*	STBS	250[c]
*Stonecat, *Noturus flavus*	STCT	na
Striped bass x White bass, *Morone saxatilis x Morone chrysops*	SBWB	225[b]
Striped shiner, *Luxilus chrysocephalus*	SPSN	na
Walleye, *Sander vitreum*	WLYE	300[b]
Warmouth, *Lepomis gulosus*	WRMH	na
Wedgespot shiner, *Notropis greenei*	WSSN	na
Western Mosquitofish, *Gambusia affinis*	MQTF	na
*White bass, *Morone chrysops*	WTBS	225[b]
White crappie, *Pomoxis annularis*	WTCP	180[b]
*Yellow bass, *Morone mississippiensis*	YWBS	na

[a]Meadows et al. 2007; [b]Fischer et al. 2012; [c]Pflieger 1997; [d]Becker 1983; [e]Bozek et al. 2011

Table 1-3. Candidate set of a priori models developed to explain the presence of big-river fish species in the Osage and Gasconade rivers September 2012-August 2013. Variables listed in the table were included as fixed effects. Site was included in all models as a random effect to account for any autocorrelation as a result of repeated sampling. MOR=Missouri River. Variable acronyms are defined in Table 1-4.

Model Name	Model Equation
Intercept Only	
Tributary Null	β(RIV)
Tributary Temp	β(TEM) + β(RIV)
Tributary Discharge	β(FLO) + β(FLO2) + β(RIV)
MOR Discharge	β(FLO_MO) + β(RIV)
Season	β(FAL) + β(SPR) + β(SUM) + β(RIV)
Depth	β(DEP) + β(RIV)
Longitudinal Position	β(RM) + β(RIV)
Tributary Conditions	β(FLO) + β(FLO2) + β(TEM) + β(RIV)
Tributary Variability	β(FLO) + β(FLO2) + β(FLO_CV) + β(TEM) + β(TEM_CV) + β(RIV)
Refuge	β(DEP) + β(FLO) + β(FLO2) + β(FLO_CV) + β(FLO_MO)
Seasonal Habitat	β(FAL) + β(SPR) + β(SUM) + β(DEP) + β(FLO) + β(FLO2) + β(FLO_CV) + β(TEM) + β(TEM_CV) + β(RIV)
Global	β(FAL) + β(SPR) + β(SUM) + β(DEP) + β(FLO) + β(FLO2) + β(FLO_CV) + β(TEM) + β(TEM_CV)+ β(FLO_MO) + β(RM) + β(RIV)

Table 1-4. Model variables and definitions used to predict presence of big-river fishes in the Osage and Gasconade rivers near their confluence with the Missouri River in central Missouri September 2012 through August 2013.

Variable	Definition
RIV	Osage River was the default, Gasconade was "not Osage River"
FAL	fall season (September 13 through November 8, 2012); default/intercept is winter in models
SPR	spring season (March 26 through May 20, 2013)
SUM	summer season (June 21 through August 16, 2013)
DEP	average depth of sample, in meters
RM	tributary river mile; lower tributary RM means closer to the MOR
TEM	mean daily water temperature in degrees Celsius calculated from 15 minute temperature data collected by temp loggers deployed by USGS-CERC; if 15 minute data was not available, mean water temperature collected during sampling was used
TEM_CV	coefficient of variation of water temperature three days prior to sample date; calculated using 15 minute temp logger data collected by USGS-CERC
FLO	mean daily discharge from USGS gages on Osage and Gasconade rivers converted to a proportion of the mean annual discharge from 1996 to 2013
FLO^2	mean daily discharge from USGS gages on Osage and Gasconade rivers converted to a proportion of the mean annual discharge from 1996 to 2013 squared to account for distribution of raw data
FLO_MO	mean daily discharge from USGS gage at Boonville on Missouri River converted to a proportion of the mean annual discharge from 1996 to 2013
FLO_CV	discharge coefficient of variation of three previous days to sample date; calculated using 15 min discharge data downloaded from USGS website for Rich Fountain gage on Gasconade River and St. Thomas Gage on Osage River.

Table 1-5. Mean (range and standard error in parentheses) environmental variables for sampling conducted in the Gasconade and Osage rivers, September 2012-August 2013. TEM = water temperature, TEM_CV = coefficient of variation of water temperature, FLO = Proportion 17 year annual mean discharge (1996-2013), FLO_CV = coefficient of variation of the mean annual discharge, DEP = sample depth.

	Fall12		Winter1213		Spring13		Summer13	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
Begin date	10/11/2012	9/13/2012	12/19/2012	12/18/2012	3/26/2013	3/27/2013	6/25/2013	7/8/2013
End date	11/8/2012	10/28/2012	3/9/2013	3/7/2013	5/20/2013	4/25/2013	8/16/2013	7/29/2013
TEM	13.37 (9.54 - 19.13; 0.95)	18.33 (13.91 - 24.41; 0.78)	5.45 (1.82 - 7.73; 0.47)	4.34 (3.22 - 7.41; 0.35)	14.09 (6.41 - 23.91; 1.5)	8.69 (5.66 - 11.8; 0.59)	27.66 (21.67 - 29.26; 0.51)	27.26 (25.59 - 27.83; 0.2)
TEM_CV	0.05 (0.01 - 0.13; 0.01)	0.04 (0.01 - 0.14; 0.01)	0.17 (0.02 - 0.45; 0.04)	0.08 (0.02 - 0.13; 0.01)	0.05 (0.01 - 0.09; 0.01)	0.06 (0.02 - 0.08; 0.01)	0.01 (0.01 - 0.03; 0)	0.03 (0.02 - 0.04; 0)
FLO	0.28 (0.22 - 0.34; 0.01)	0.1 (0.09 - 0.12; 0)	0.58 (0.24 - 1.52; 0.09)	0.21 (0.1 - 1.69; 0.08)	2.64 (0.89 - 7.26; 0.52)	2.34 (1.47 - 3.02; 0.15)	0.52 (0.27 - 2.13; 0.13)	0.4 (0.13 - 1.19; 0.09)
FLO_CV	0.04 (0.02 - 0.07; 0)	0.1 (0.03 - 0.4; 0.03)	0.08 (0.01 - 0.31; 0.03)	0.08 (0.01 - 0.63; 0.03)	0.15 (0.06 - 0.43; 0.03)	0.16 (0.07 - 0.29; 0.03)	0.16 (0.04 - 0.74; 0.05)	0.53 (0.14 - 0.78; 0.06)
DEP	1.28 (0.16 - 3.18; 0.22)	1.38 (0.11 - 2.88; 0.19)	1.35 (0.16 - 3.13; 0.21)	1.28 (0.1 - 3.28; 0.22)	1.71 (0.15 - 3.46; 0.25)	2.93 (1.65 - 4.93; 0.22)	1.39 (0.16 - 3.15; 0.21)	1.59 (0.1 - 4.03; 0.28)

Table 1-6. Species and number of fish captured (percent abundance) with boat electrofishing from the Gasconade and Osage rivers, September 2012-August 2013. Species codes in bold-italics are big-river species while those followed by "_J" were the juvenile life stage. Percent abundance calculated by dividing number of individuals of each species by total fish captured in each column (river-season combination) and multiplying by 100. Species codes are listed in Table 1-2.

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
ALSD_J	3 (0.1)		3 (0.5)							
BDDR	1 (<0.1)		1 (0.2)							
BDSN	18 (0.6)				2 (0.3)		2 (0.2)		14 (2.3)	
BHCP	1 (<0.1)								1 (0.2)	
BHMW	107 (3.8)	260 (7.2)	28 (4.5)	147 (25.7)	61 (7.7)	107 (12)	16 (2)		2 (0.3)	6 (0.9)
BKCP	8 (0.3)	4 (0.1)		1 (0.2)	7 (0.9)	2 (0.2)	1 (0.1)			1 (0.2)
BKCP_J	4 (0.1)	11 (0.3)			3 (0.4)	11 (1.2)			1 (0.2)	
BKRH	3 (0.1)						1 (0.1)		2 (0.3)	
BKRH_J	5 (0.2)		1 (0.2)				3 (0.4)		1 (0.2)	
BKSS	19 (0.7)	49 (1.4)	4 (0.6)	4 (0.7)	11 (1.4)	44 (4.9)	3 (0.4)		1 (0.2)	1 (0.2)
BKSS_J	3 (0.1)	8 (0.2)	1 (0.2)			8 (0.9)	2 (0.2)			
BLCF_J	1 (<0.1)						1 (0.1)			
BLGL	195 (6.8)	135 (3.8)	24 (3.9)	38 (6.6)	117 (14.7)	20 (2.2)	35 (4.3)	10 (2.3)	19 (3.1)	67 (10.6)
BLGL_J	69 (2.4)	127 (3.5)	9 (1.5)	36 (6.3)	35 (4.4)	66 (7.4)	12 (1.5)	10 (2.3)	13 (2.1)	15 (2.4)

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
BMBF	8 (0.3)	4 (0.1)	1 (0.2)				7 (0.9)	3 (0.7)		1 (0.2)
BMBF_J	7 (0.2)						6 (0.7)		1 (0.2)	
BNMW	82 (2.9)	19 (0.5)	38 (6.1)	19 (3.3)	34 (4.3)		9 (1.1)		1 (0.2)	
BPTM	3 (0.1)						1 (0.1)		2 (0.3)	
CARP	22 (0.8)	18 (0.5)	3 (0.5)	9 (1.6)			7 (0.9)	2 (0.5)	12 (2)	7 (1.1)
CARP_J		1 (<0.1)								1 (0.2)
CKCB	1 (<0.1)		1 (0.2)							
CLSR	2 (<0.1)		2 (0.3)							
CNCF	53 (1.9)	13 (0.4)	14 (2.3)	3 (0.5)	3 (0.4)	2 (0.2)	22 (2.7)		14 (2.3)	8 (1.3)
CNCF_J	9 (0.3)		1 (0.2)				3 (0.4)		5 (0.8)	
CNLP	49 (1.7)	1 (<0.1)		1 (0.2)	10 (1.3)		38 (4.6)		1 (0.2)	
CNSN	1 (<0.1)	3 (<0.1)					1 (0.1)	3 (0.7)		
ERSN	155 (5.4)	159 (4.4)	14 (2.3)	57 (10)	110 (13.8)	13 (1.5)	20 (2.4)	85 (19.3)	11 (1.8)	4 (0.6)
FHCF	4 (0.1)	6 (0.2)							4 (0.7)	6 (0.9)
FHCF_J	7 (0.2)	8 (0.2)	1 (0.2)						6 (1)	8 (1.3)
FWDM	72 (2.5)	24 (0.7)		5 (0.9)	2 (0.3)	7 (0.8)	61 (7.5)	6 (1.4)	9 (1.5)	6 (0.9)
FWDM_J	148 (5.2)	82 (2.3)	4 (0.6)	21 (3.7)	4 (0.5)	10 (1.1)	117 (14.3)	1 (0.2)	23 (3.7)	50 (7.9)

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
GDEY_J	5 (0.2)	7 (0.2)		3 (0.5)		1 (0.1)	3 (0.4)		2 (0.3)	3 (0.5)
GDRH	21 (0.7)	2 (<0.1)		2 (0.3)	1 (0.1)		13 (1.6)		7 (1.1)	
GDRH_J	7 (0.2)	2 (<0.1)					4 (0.5)		3 (0.5)	2 (0.3)
GLDR	8 (0.3)	1 (<0.1)	8 (1.3)							1 (0.2)
GNSF	12 (0.4)	22 (0.6)	6 (1)	9 (1.6)	5 (0.6)	7 (0.8)		6 (1.4)	1 (0.2)	
GNSF_J	10 (0.4)	6 (0.2)	3 (0.5)		1 (0.1)	6 (0.7)	6 (0.7)			
GSCP	7 (0.2)	3 (<0.1)					6 (0.7)	3 (0.7)	1 (0.2)	
GVCB	5 (0.2)	1 (<0.1)	2 (0.3)			1 (0.1)			3 (0.5)	
GZSD	341 (12)	572 (15.9)	88 (14.2)	8 (1.4)	30 (3.8)	327 (36.8)	42 (5.1)	13 (3)	181 (29.5)	224 (35.3)
GZSD_J	60 (2.1)	173 (4.8)	10 (1.6)	22 (3.8)	1 (0.1)	53 (6)	2 (0.2)	45 (10.2)	47 (7.7)	53 (8.3)
JYDR	1 (<0.1)		1 (0.2)							
LESF	133 (4.7)	90 (2.5)	82 (13.2)	27 (4.7)	11 (1.4)	20 (2.2)	18 (2.2)	7 (1.6)	22 (3.6)	36 (5.7)
LESF_J	2 (<0.1)	4 (0.1)	2 (0.3)	1 (0.2)		3 (0.3)				
LGPH	14 (0.5)	3 (<0.1)	13 (2.1)	3 (0.5)	1 (0.1)					
LMBS	10 (0.4)	9 (0.3)	3 (0.5)		3 (0.4)	2 (0.2)	3 (0.4)	2 (0.5)	1 (0.2)	5 (0.8)
LMBS_J	3 (0.1)	9 (0.3)	1 (0.2)	4 (0.7)	1 (0.1)	4 (0.4)			1 (0.2)	1 (0.2)
LNGR	24 (0.8)	7 (0.2)			3 (0.4)		14 (1.7)	3 (0.7)	7 (1.1)	4 (0.6)

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
LNGR_J	42 (1.5)	17 (0.5)		2 (0.3)	3 (0.4)		26 (3.2)	5 (1.1)	13 (2.1)	10 (1.6)
LSSR	21 (0.7)		3 (0.5)		3 (0.4)		8 (1)		7 (1.1)	
MMSN	24 (0.8)	104 (2.9)	1 (0.2)	6 (1)	2 (0.3)	63 (7.1)	4 (0.5)	20 (4.5)	17 (2.8)	15 (2.4)
MNEY_J	1 (<0.1)								1 (0.2)	
MSDR	9 (0.3)		9 (1.5)							
NHSK	8 (0.3)		4 (0.6)						4 (0.7)	
NHSK_J	3 (0.1)		2 (0.3)						1 (0.2)	
OSSF	5 (0.2)				4 (0.5)		1 (0.1)			
OSSF_J	1 (<0.1)				1 (0.1)					
OTDR	1 (<0.1)				1 (0.1)					
OZMW	2 (<0.1)				1 (0.1)		1 (0.1)			
PDFH_J	1 (<0.1)						1 (0.1)			
QLBK	12 (0.4)	1 (<0.1)			4 (0.5)		8 (1)	1 (0.2)		
QLBK_J	12 (0.4)		8 (1.3)				4 (0.5)			
RDSN	37 (1.3)	54 (1.5)	14 (2.3)	5 (0.9)	6 (0.8)	17 (1.9)	13 (1.6)	17 (3.9)	4 (0.7)	15 (2.4)
RESF	9 (0.3)				3 (0.4)				6 (1)	
RKBS	2 (<0.1)						1 (0.1)		1 (0.2)	

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
RVCS	44 (1.5)	36 (1)		7 (1.2)	1 (0.1)	4 (0.4)	40 (4.9)	23 (5.2)	3 (0.5)	2 (0.3)
RVCS_J	26 (0.9)	21 (0.6)		7 (1.2)	4 (0.5)	10 (1.1)	17 (2.1)	1 (0.2)	5 (0.8)	3 (0.5)
RVRH	18 (0.6)		1 (0.2)				3 (0.4)		14 (2.3)	
RVRH_J	5 (0.2)				3 (0.4)		1 (0.1)		1 (0.2)	
RVSN	4 (0.1)		1 (0.2)						3 (0.5)	
RYSN	315 (11.1)	31 (0.9)	45 (7.3)	8 (1.4)	168 (21.1)		95 (11.6)	23 (5.2)	7 (1.1)	
SBWB	1 (<0.1)	2 (<0.1)				1 (0.1)			1 (0.2)	1 (0.2)
SFSN	107 (3.8)	7 (0.2)	6 (1)	7 (1.2)	81 (10.2)		9 (1.1)		11 (1.8)	
SGER		1 (<0.1)		1 (0.2)						
SGER_J		1 (<0.1)		1 (0.2)						
SHDR	8 (0.3)	4 (0.1)	5 (0.8)	3 (0.5)					3 (0.5)	1 (0.2)
SHRH	13 (0.5)	1 (<0.1)	7 (1.1)	1 (0.2)	1 (0.1)				5 (0.8)	
SHRH_J	27 (0.9)	2 (<0.1)	24 (3.9)	1 (0.2)			3 (0.4)			1 (0.2)
SJHR		1 (<0.1)				1 (0.1)				
SJHR_J		6 (0.2)		3 (0.5)		1 (0.1)				2 (0.3)
SMBF	37 (1.3)	3 (<0.1)	3 (0.5)			1 (0.1)	14 (1.7)	2 (0.5)	20 (3.3)	
SMBF_J	26 (0.9)	9 (0.3)		4 (0.7)		2 (0.2)	16 (2)	1 (0.2)	10 (1.6)	2 (0.3)

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
SMBS_J	13 (0.5)		8 (1.3)		1 (0.1)		1 (0.1)		3 (0.5)	
SNGR	33 (1.2)	26 (0.7)			3 (0.4)		22 (2.7)	8 (1.8)	8 (1.3)	18 (2.8)
SNSN	21 (0.7)	9 (0.3)	6 (1)	6 (1)	2 (0.3)	1 (0.1)	1 (0.1)	2 (0.5)	12 (2)	
STBS	15 (0.5)	20 (0.6)	1 (0.2)	9 (1.6)	3 (0.4)	2 (0.2)	7 (0.9)		4 (0.7)	9 (1.4)
STBS_J	177 (6.2)	146 (4.1)	75 (12.1)	51 (8.9)	44 (5.5)	32 (3.6)	31 (3.8)	20 (4.5)	27 (4.4)	43 (6.8)
SVCB	13 (0.5)	4 (0.1)	12 (1.9)	3 (0.5)		1 (0.1)			1 (0.2)	
SVCB_J		1 (<0.1)		1 (0.2)						
SVCP	10 (0.4)	46 (1.3)	1 (0.2)				7 (0.9)	46 (10.5)	2 (0.3)	
SVCP_J	17 (0.6)	66 (1.8)	15 (2.4)			14 (1.6)	1 (0.1)	52 (11.8)	1 (0.2)	
SVLP	1 (<0.1)						1 (0.1)			
WLYE	1 (<0.1)						1 (0.1)			
WRMH	3 (0.1)				1 (0.1)		2 (0.2)			
WSSN		62 (1.7)		25 (4.4)		17 (1.9)		20 (4.5)		
WTBS		1 (<0.1)								1 (0.2)
WTCP		7 (0.2)		1 (0.2)		5 (0.6)				1 (0.2)
WTCP_J		3 (<0.1)				3 (0.3)				
YWBS		1 (<0.1)								1 (0.2)

Species Code	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
Fish Captured	2,848	2,536	620	572	796	889	818	440	614	634
Species Richness	65	45	41	33	35	25	46	23	47	30
Proportion Juvenile	0.44	0.49	0.41	0.42	0.34	0.60	0.46	0.35	0.43	0.47
Proportion Big-River	0.17	0.20	0.10	0.15	0.09	0.12	0.15	0.13	0.15	0.20
Total Species Richness	71		51		44		47		52	

Table 1-7. Species and number of fish captured (percent abundance) with beach seines from the Gasconade and Osage rivers, September 2012-August 2013. Species codes in bold-italics are big-river species while those followed by "_J" were the juvenile life stage. Percent abundance calculated by dividing number of individuals of each species by total fish captured in each column (river-season combination) and multiplying by 100. Species codes are listed in Table 1-2.

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
BDDR	1 (<0.1)				1 (<0.1)					
BDSN	912 (6.3)	793 (11.4)	25 (0.6)	7 (0.2)	19 (0.5)		21 (0.7)		847 (27.6)	786 (27.7)
BESN	164 (1.1)	1 (<0.1)	35 (0.8)		4 (0.1)		109 (3.4)		16 (0.5)	1 (<0.1)
BHMW	1106 (7.7)	386 (5.5)	521 (12.5)	361 (9.1)	520 (13)	16 (10.4)	56 (1.7)		9 (0.3)	9 (0.3)
BKRH_J	2 (<0.1)								2 (<0.1)	
BKSS	30 (0.2)	45 (0.6)	26 (0.6)	44 (1.1)	1 (<0.1)		2 (<0.1)		1 (<0.1)	1 (<0.1)
BKSS_J	51 (0.4)	48 (0.7)	16 (0.4)	13 (0.3)					35 (1.1)	35 (1.2)
BLGL	8 (<0.1)	4 (<0.1)	7 (0.2)	2 (<0.1)					1 (<0.1)	2 (<0.1)
BLGL_J	85 (0.6)	19 (0.3)	30 (0.7)	16 (0.4)	20 (0.5)		15 (0.5)		20 (0.7)	3 (0.1)
BNMW	343 (2.4)	29 (0.4)	163 (3.9)		122 (3)		57 (1.8)		1 (<0.1)	29 (1)
BPTM	42 (0.3)	3 (<0.1)	22 (0.5)	3 (<0.1)			14 (0.4)		6 (0.2)	
CKCB	1 (<0.1)								1 (<0.1)	
CLSR	3 (<0.1)								3 (<0.1)	
CNSN	107 (0.7)	1 (<0.1)			107 (2.7)					1 (<0.1)

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
ERSN	454 (3.1)	436 (6.3)	168 (4)	361 (9.1)	5 (0.1)	7 (4.5)	3 (<0.1)		278 (9.1)	68 (2.4)
FHMW	1 (<0.1)		1 (<0.1)							
GDRH_J	1 (<0.1)	2 (<0.1)					1 (<0.1)			2 (<0.1)
GLDR	2 (<0.1)								2 (<0.1)	
GNSF	1 (<0.1)	3 (<0.1)	1 (<0.1)	3 (<0.1)						
GNSF_J	13 (<0.1)	11 (0.2)	11 (0.3)	11 (0.3)	2 (<0.1)					
GVCB	28 (0.2)	66 (0.9)		62 (1.6)	1 (<0.1)		3 (<0.1)		24 (0.8)	4 (0.1)
GZSD		1297 (18.6)								1297 (45.7)
GZSD_J		118 (1.7)								118 (4.2)
HFCS_J	1 (<0.1)								1 (<0.1)	
LESF	7 (<0.1)	37 (0.5)	3 (<0.1)	34 (0.9)	1 (<0.1)				3 (<0.1)	3 (0.1)
LGPH	1 (<0.1)								1 (<0.1)	
LNGR_J	1 (<0.1)								1 (<0.1)	
LSSR	25 (0.2)		3 (<0.1)		5 (0.1)		11 (0.3)		6 (0.2)	
MMSN	359 (2.5)	1485 (21.4)	29 (0.7)	1314 (33.2)	173 (4.3)	100 (64.9)	139 (4.3)		18 (0.6)	71 (2.5)
MQTF	427 (3)	440 (6.3)	249 (6)	412 (10.4)	46 (1.2)	11 (7.1)	20 (0.6)		112 (3.6)	17 (0.6)
MSDR	2 (<0.1)		2 (<0.1)							

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
NHSK_J	3 (<0.1)								3 (<0.1)	
OTDR	4 (<0.1)		4 (<0.1)							
OZMW	7 (<0.1)	3 (<0.1)	1 (<0.1)	1 (<0.1)			5 (0.2)		1 (<0.1)	2 (<0.1)
QLBK_J	3 (<0.1)	2 (<0.1)							3 (<0.1)	2 (<0.1)
RBDR	3 (<0.1)		3 (<0.1)							
RDSN	2006 (13.9)	546 (7.9)	142 (3.4)	208 (5.3)	641 (16)	11 (7.1)	1011 (31.5)		212 (6.9)	327 (11.5)
RESF	11 (<0.1)		3 (<0.1)						8 (0.3)	
RFSN	73 (0.5)				72 (1.8)				1 (<0.1)	
RVCS		81 (1.2)		81 (2)						
RVCS_J	7 (<0.1)	87 (1.3)	1 (<0.1)	86 (2.2)	2 (<0.1)	1 (0.6)	4 (0.1)			
RVRH_J	1 (<0.1)		1 (<0.1)							
RVSN	1020 (7.1)		1 (<0.1)		970 (24.2)		37 (1.2)		12 (0.4)	
RYSN	2990 (20.7)	148 (2.1)	1080 (25.9)	104 (2.6)	342 (8.6)	7 (4.5)	230 (7.2)		1338 (43.6)	37 (1.3)
SFSN	3475 (24)	133 (1.9)	1358 (32.6)	132 (3.3)	831 (20.8)		1231 (38.3)		55 (1.8)	1 (<0.1)
SHDR	1 (<0.1)		1 (<0.1)							
SMBS_J	1 (<0.1)								1 (<0.1)	
SNSN	600 (4.2)	54 (0.8)	255 (6.1)	46 (1.2)	102 (2.6)	1 (0.6)	225 (7)		18 (0.6)	7 (0.2)

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
SPSN	2 (<0.1)								2 (<0.1)	
STBS_J	28 (0.2)	18 (0.3)	3 (<0.1)	5 (0.1)					25 (0.8)	13 (0.5)
SVRH_J	3 (<0.1)	1 (<0.1)							3 (<0.1)	1 (<0.1)
WSSN	38 (0.3)	655 (9.4)	7 (0.2)	654 (16.5)	13 (0.3)		18 (0.6)			1 (<0.1)
WTBS_J	1 (<0.1)	2 (<0.1)							1 (<0.1)	2 (<0.1)
WTCP_J		1 (<0.1)								1 (<0.1)
Fish Captured	14,455	6,955	4,172	3,960	4,000	154	3,212	0	3,071	2,841
Species Richness	47	28	29	19	23	8	21	0	35	25
Proportion Juvenile	0.32	0.39	0.21	0.26	0.13	0.12	0.14	0.00	0.31	0.36
Proportion Big-River	0.13	0.11	0.07	0.05	0.13	0.13	0.10	0.00	0.14	0.12
Total Species Richness	49		30		23		21		40	

Table 1-8. Species and number of fish captured (percent abundance) with benthic trawls from the Gasconade and Osage rivers, September 2012-August 2013. Species codes in bold-italics are big-river species while those followed by "_J" were the juvenile life stage. Percent abundance calculated by dividing number of individuals of each species by total fish captured in each column (river-season combination) and multiplying by 100. Species codes are listed in Table 1-2.

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
ALSD_J	1 (<0.1)		1 (0.4)							
BDDR	8 (0.4)	1 (<0.1)	2 (0.7)		2 (1.4)	1 (0.6)			4 (0.3)	
BDSN	1 (<0.1)						1 (0.4)			
BHMW	112 (5.7)	74 (4.6)	44 (16.4)	42 (33.3)	23 (15.6)	24 (13.8)	1 (0.4)	8 (1.2)	44 (3.4)	
BKCP_J	2 (0.1)								2 (0.2)	
BKRH_J	2 (0.1)				2 (1.4)					
BLGL	40 (2)	9 (0.6)		7 (5.6)	36 (24.5)		1 (0.4)		3 (0.2)	2 (0.3)
BLGL_J	9 (0.5)	5 (0.3)	1 (0.4)	2 (1.6)		2 (1.1)			8 (0.6)	1 (0.2)
BNMW	8 (0.4)	2 (0.1)	1 (0.4)		5 (3.4)		1 (0.4)		1 (<0.1)	2 (0.3)
CARP		3 (0.2)		2 (1.6)				1 (0.1)		
CLDR	2 (0.1)								2 (0.2)	
CLSR	1 (<0.1)						1 (0.4)			
CNCF	6 (0.3)	5 (0.3)	1 (0.4)	3 (2.4)	1 (0.7)	2 (1.1)	1 (0.4)		3 (0.2)	
CNCF_J	41 (2.1)	12 (0.7)	2 (0.7)			1 (0.6)	1 (0.4)		38 (2.9)	11 (1.7)

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
CNLP	1 (<0.1)						1 (0.4)			
CNSN	16 (0.8)	16 (1)							16 (1.2)	16 (2.5)
ERSN	6 (0.3)				1 (0.7)				5 (0.4)	
FHCF		2 (0.1)		1 (0.8)						1 (0.2)
FHCF_J	2 (0.1)	1 (<0.1)	1 (0.4)	1 (0.8)					1 (<0.1)	
FHMW		1 (<0.1)						1 (0.1)		
FKMT	2 (0.1)								2 (0.2)	
FWDM_J	187 (9.6)	3 (0.2)		2 (1.6)					187 (14.5)	1 (0.2)
GDEY_J	25 (1.3)								25 (1.9)	
GDRH	3 (0.2)								3 (0.2)	
GDRH_J	8 (0.4)		1 (0.4)						7 (0.5)	
GLDR	358 (18.3)	61 (3.8)	179 (66.8)	24 (19)	6 (4.1)	6 (3.4)	123 (50)	19 (2.8)	50 (3.9)	12 (1.9)
GNSF_J		1 (<0.1)				1 (0.6)				
GSDR	1 (<0.1)								1 (<0.1)	
GVCB	24 (1.2)	5 (0.3)			1 (0.7)	2 (1.1)	8 (3.3)		15 (1.2)	3 (0.5)
GZSD_J		41 (2.5)								41 (6.4)

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
JYDR	3 (0.2)	1 (<0.1)	1 (0.4)		1 (0.7)	1 (0.6)			1 (<0.1)	
LESF	2 (0.1)	2 (0.1)		2 (1.6)					2 (0.2)	
LGPH	23 (1.2)	2 (0.1)	8 (3)	1 (0.8)			7 (2.8)		8 (0.6)	1 (0.2)
LKSG_J	3 (0.2)		2 (0.7)		1 (0.7)					
LNGR_J	1 (<0.1)	1 (<0.1)					1 (0.4)	1 (0.1)		
MMSN	826 (42.3)	588 (36.6)	8 (3)	3 (2.4)	32 (21.8)	30 (17.2)	52 (21.1)	239 (35.6)	734 (56.8)	316 (49.7)
MQTF		1 (<0.1)				1 (0.6)				
MSDR	10 (0.5)		2 (0.7)		7 (4.8)				1 (<0.1)	
NHSK_J	1 (<0.1)						1 (0.4)			
PNSD	1 (<0.1)								1 (<0.1)	
QLBK_J	1 (<0.1)	1 (<0.1)						1 (0.1)	1 (<0.1)	
RBDR	1 (<0.1)				1 (0.7)					
RVCS	1 (<0.1)	6 (0.4)		1 (0.8)				1 (0.1)	1 (<0.1)	4 (0.6)
RVCS_J	5 (0.3)	5 (0.3)		1 (0.8)					5 (0.4)	4 (0.6)
RVRH	1 (<0.1)				1 (0.7)					
RVRH_J	1 (<0.1)	1 (<0.1)	1 (0.4)	1 (0.8)						
RYSN	13 (0.7)								13 (1)	

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
SFSN	1 (<0.1)								1 (<0.1)	
SGER_J	2 (0.1)								2 (0.2)	
SHDR	101 (5.2)	1 (<0.1)	8 (3)				33 (13.4)		60 (4.6)	1 (0.2)
SHRH	1 (<0.1)						1 (0.4)			
SHRH_J		1 (<0.1)								1 (0.2)
SKCB	8 (0.4)	2 (0.1)	2 (0.7)		2 (1.4)	1 (0.6)	4 (1.6)	1 (0.1)		
SMBS_J	2 (0.1)								2 (0.2)	
SNGR	2 (0.1)	1 (<0.1)							2 (0.2)	1 (0.2)
SNSN	4 (0.2)	4 (0.2)		2 (1.6)	2 (1.4)	2 (1.1)	2 (0.8)			
STBS_J	5 (0.3)	8 (0.5)		7 (5.6)					5 (0.4)	1 (0.2)
STCT		1 (<0.1)								1 (0.2)
SVCB	13 (0.7)	17 (1.1)	2 (0.7)	8 (6.3)	3 (2)	1 (0.6)			8 (0.6)	8 (1.3)
SVCB_J	11 (0.6)	2 (0.1)	1 (0.4)	2 (1.6)					10 (0.8)	
WLYE_J	10 (0.5)								10 (0.8)	
WSSN	26 (1.3)	721 (44.8)		14 (11.1)	20 (13.6)	99 (56.9)	6 (2.4)	400 (59.5)		208 (32.7)
WTBS_J	8 (0.4)								8 (0.6)	

Species	Cumulative		Fall		Winter		Spring		Summer	
	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage	Gasconade	Osage
Fish Captured	1,953	1,608	268	126	147	174	246	672	1,292	636
Species Richness	49	32	18	16	19	14	18	10	35	19
Proportion Juvenile	0.43	0.41	0.44	0.44	0.11	0.21	0.17	0.20	0.43	0.37
Proportion Big-River	0.20	0.19	0.22	0.13	0.16	0.14	0.22	0.20	0.11	0.16
Total Species Richness	55		25		21		22		39	

Table 1-9. Top models ($\Delta AIC_c \leq 2$), model weights, and substantial variables explaining big-river species presence in the Gasconade and Osage rivers, September 2012 - August 2013.

Species	Top Model(s)	Model Weight	Substantial Variables
Chestnut Lamprey	Season	0.76	river
Adult Flathead Catfish	Tributary temp	0.81	mean daily water temperature
Juvenile Flathead Catfish	Tributary conditions	0.69	mean daily water temperature
Juvenile Goldeye	Tributary conditions	0.46	mean daily water temperature
	Tributary temp	0.34	mean daily water temperature
Adult Longnose Gar	Tributary conditions	0.44	mean daily discharge
	Tributary discharge	0.24	mean daily discharge
	Tributary variability	0.19	mean daily discharge
Juvenile Longnose Gar	Season	0.48	spring & summer
	Tributary conditions	0.19	mean daily water temperature
	Global	0.18	
Sand Shiners	Intercept only	0.41	
	Tributary null	0.17	

Table 1-10. β-coefficients ± 85% confidence intervals (CI) for final averaged models explaining the probability of presence of seven big-river fish species captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. Values in bold, italic text indicate these coefficients have 85% confidence intervals that do not include zero and thus have particularly strong support across all models. Table 1-4 defines covariate abbreviations.

	CNLP		FHCF		FHCFJ		GDEYJ		LNGR		LNGRJ		SNSN	
Covariate	β	85% CI	β	85% CI	β	85% CI	β	85% CI	β	85% CI	β	85% CI	β	85% CI
Intercept	***-1.67***	***0.91***	***-5.91***	***2.10***	***-2.90***	***1.62***	***-3.39***	***1.22***	***-2.69***	***0.52***	***-3.98***	***2.06***	***-2.98***	***0.65***
RIV[a]	***-3.25***	***1.53***	0.93	1.26	-0.31	1.00	***-1.02***	***1.01***	***-0.96***	***0.86***	-0.17	0.74	-0.17	0.66
SPR[b]	0.55	1.02					0.02	0.31			1.89	2.26	-0.02	0.39
SUM[b]	-1.88	2.37					0.05	0.55			2.38	3.19	-0.02	0.35
FAL[b]	-1.63	1.90					0.02	0.32			0.84	1.96	-0.01	0.22
DEP	-0.05	0.26	0.00	0.07	0.00	0.01	0.00	0.02	0.00	0.15	0.06	0.22	0.00	0.10
FLO	0.38	1.14	-0.35	2.70	-0.25	2.73	-0.42	1.19	***1.26***	***0.78***	0.23	1.12	0.03	0.38
FLO^2	-0.06	0.20	-0.37	5.58	-4.95	7.53	0.16	0.33	-0.17	0.17	0.01	0.21	-0.02	0.30
FLO_CV	-0.06	0.41	0.00	0.12	0.01	0.22	0.00	0.15	0.15	0.37	0.05	0.28	-0.02	0.23
TEM	0.07	0.81	***2.07***	***1.16***	***1.69***	***0.81***	***0.91***	***0.74***	0.33	0.59	0.05	1.10	0.00	0.23
TEM_CV	0.03	0.20	0.01	0.32	0.01	0.46	0.00	0.23	0.03	0.30	-0.09	0.57	0.01	0.13
RM	0.00	0.02	0.00	0.00	0.00	0.00	-0.03	0.12	0.00	0.00	-0.03	0.10	0.01	0.05
FLO_MO	-0.03	0.24	0.00	0.06	0.00	0.04	0.00	0.03	-0.01	0.18	-0.15	0.57	0.00	0.11

[a] river is a categorical variable interpreted relative to a reference category (Gasconade River) that is represented by the intercept. For all models, the variable estimate represents the Osage River.

[b] season is a categorical variable interpreted relative to a reference category (winter) that is represented by the intercept. For FHCF, FHCFJ, and LNGR, models containing season were removed from analysis due to a lack of convergence.

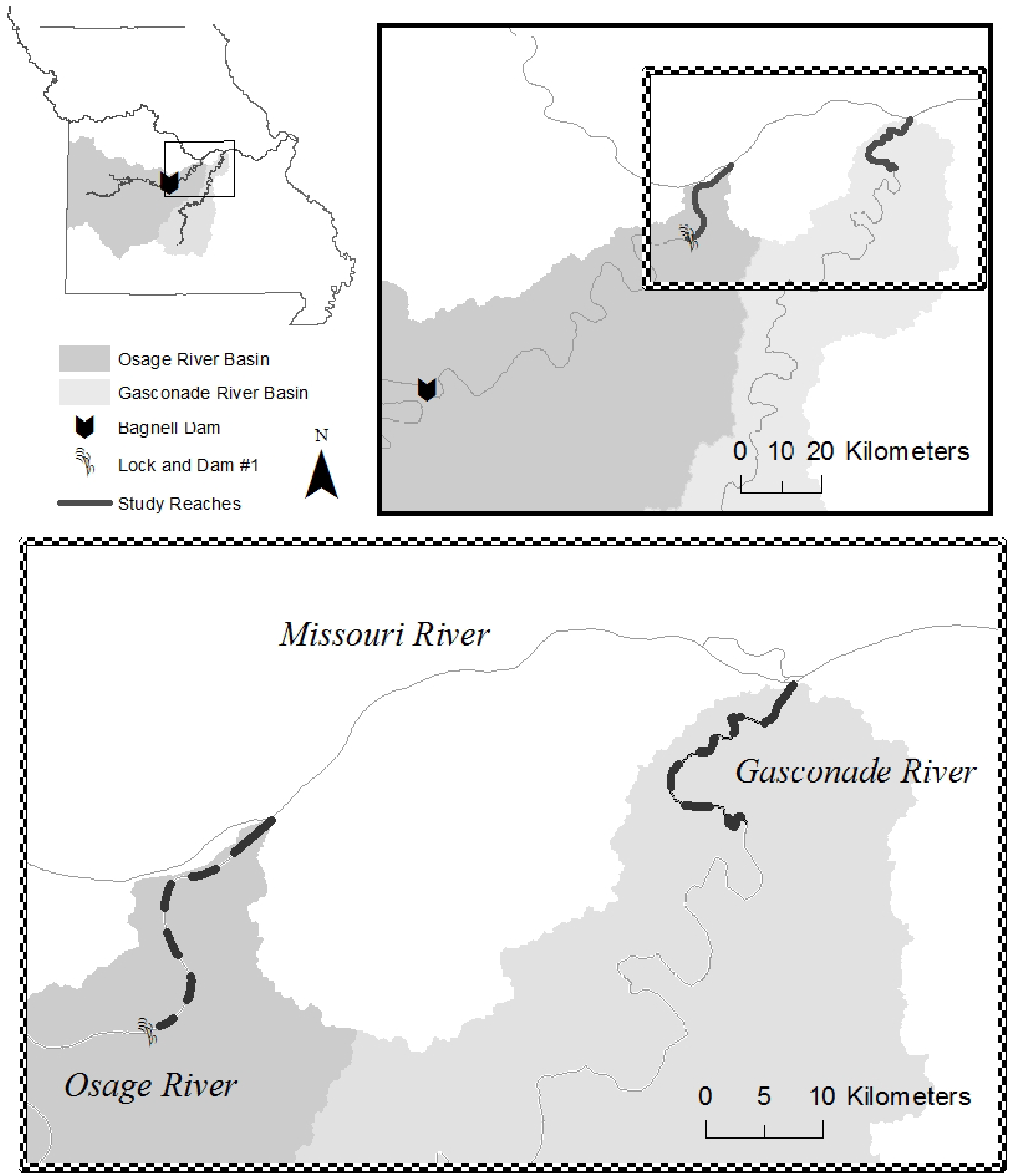

Figure 1-1. Study area location in central Missouri. Sampling was conducted in the lower 19 rkm of the Osage and Gasconade rivers, upstream of their confluences with the Missouri River. Study reaches were every other 1.6 rkm except at their respective confluence with the Missouri River where there were two consecutive study reaches.

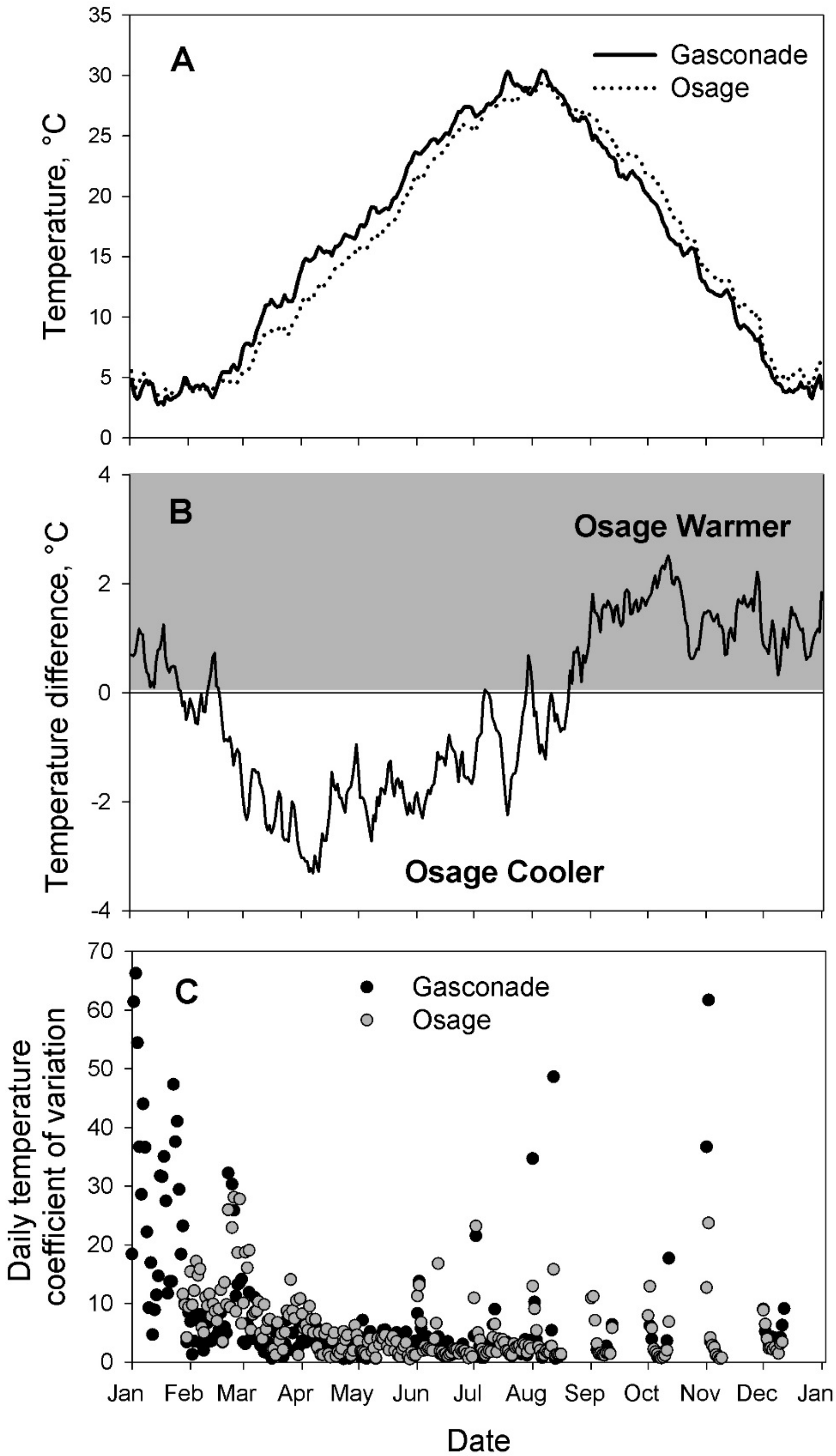

Figure 1-2. (A) Mean water temperature in the Gasconade and Osage rivers, 2006-2013. (B) Difference between Gasconade River and Osage River mean daily water temperatures, 2006-2013. (C) Mean of daily water temperature coefficient of variation for the Gasconade and Osage rivers, 2006-2013. Temperature data collected every 15 minutes from USGS-CERC deployed temperature loggers.

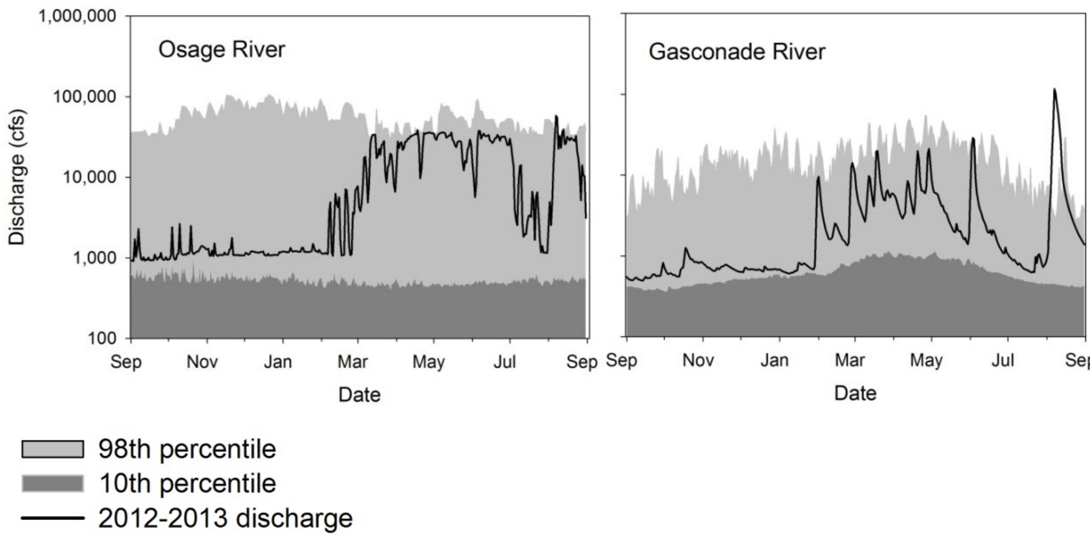

Figure 1-3. Flow duration hydrographs for the Gasconade and Osage rivers for record period 1923-2013 with the hydrograph of the sampling period, September 2012 - August 2013.

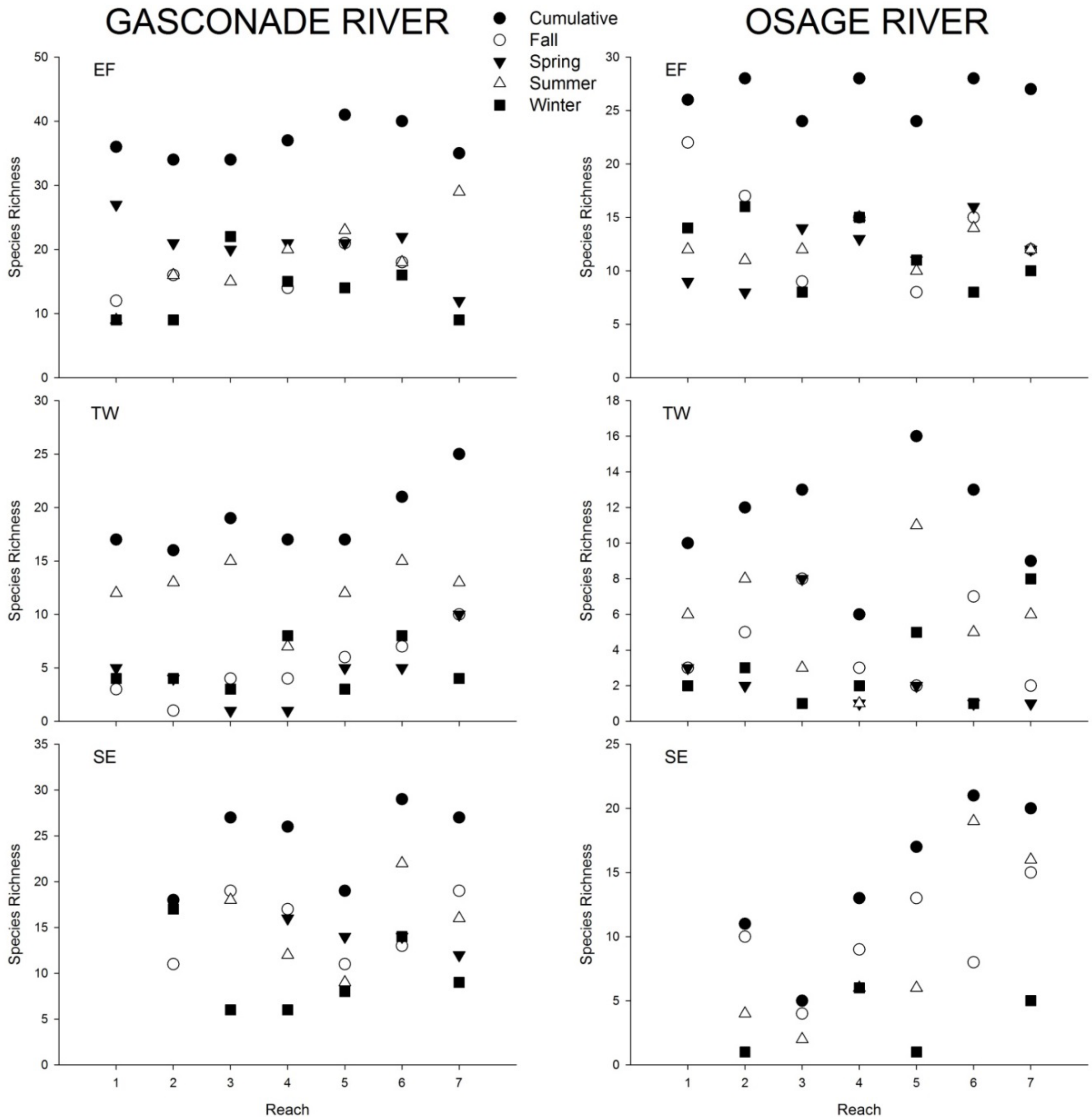

Figure 1-4. Cumulative and seasonal longitudinal species richness collected by boat electrofishing (EF), benthic trawls (TW), and beach seines (SE) in the Gasconade (left column) and Osage (right column) rivers, September 2012 – August 2013.

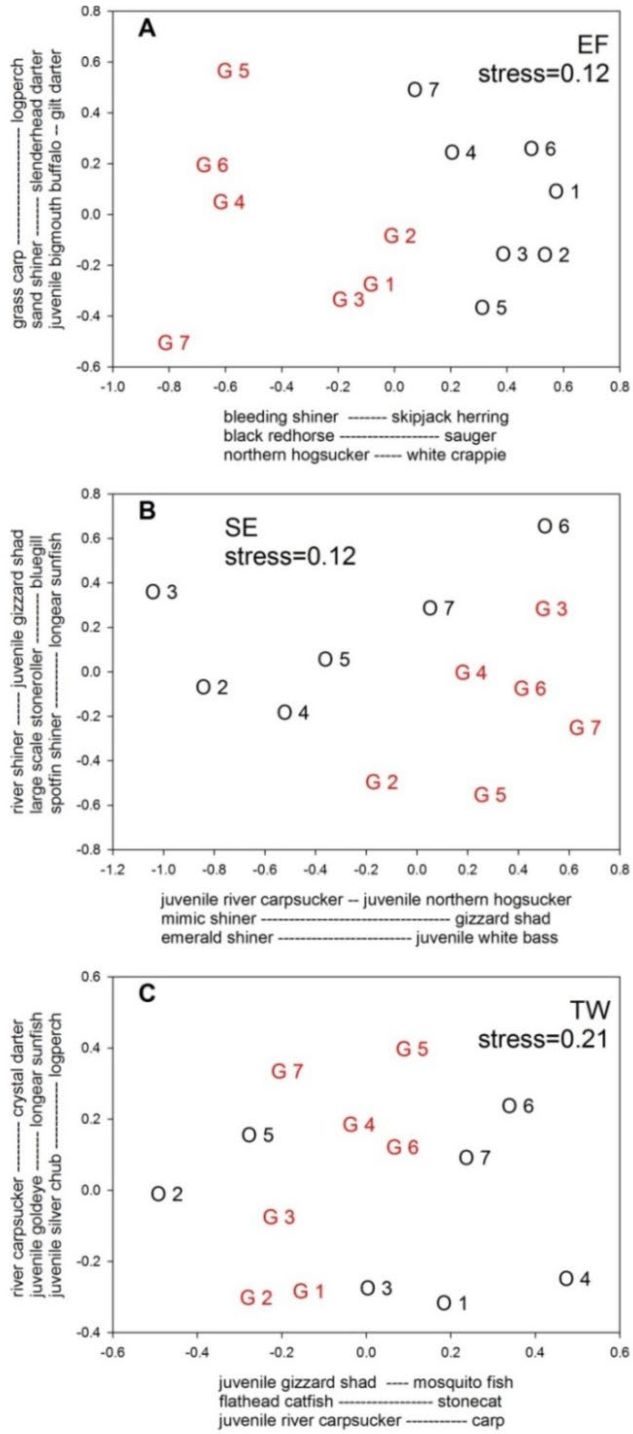

Figure 1-5. Non-metric multi-dimensional scaling ordination plots of site scores for boat electrofishing (EF), beach seines (SE), and benthic trawls (TW) conducted in the Gasconade and Osage rivers, September 2012 – August 2013. Gasconade River reaches are red print and are indicated by the letter "G." Osage River sites are black print and start with "O." Species names on the axes identify those fishes with the strongest correlations with the site scores.

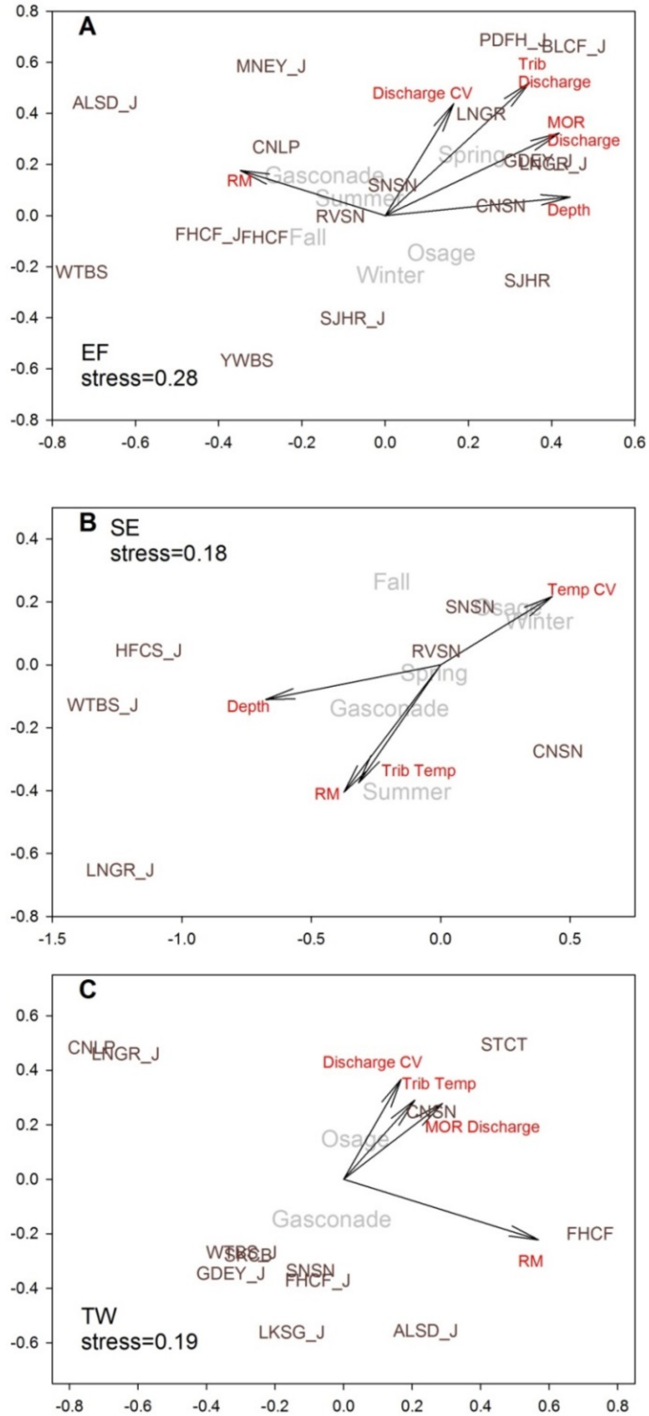

Figure 1-6. Non-metric multi-dimensional scaling ordination plots of species abundance across rivers, reaches, and seasons with big-river species and significant environmental variables projected for boat electrofishing (EF), beach seines (SE), and benthic trawls (TW) conducted in the Gasconade and Osage rivers, September 2012 – August 2013. Centroids (light grey print) and vectors (black arrows to red print) found to be significant are included with big-river species scores for all river, reach, and season combinations.

Appendix A

Model results and rankings

Table A.1. Generalized linear mixed-effects model results explaining the probability of presence of Chestnut Lamprey captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC$_c$). The number of parameters (K), differences in AIC$_c$ (ΔAIC$_c$), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of Chestnut Lamprey presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below												
Model name	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Season	6	129.4	0.00	1.00	0.76	-58.55	0.76	***-1.66***	***-3.31***	-1.94	0.79	-2.09								
								0.41	***1.04***	1.09	0.53	1.09								
Tributary conditions	6	134.1	4.78	0.09	0.07	-60.94	0.82	***-2.12***	***-3.31***					***1.25***	***-0.21***		-0.50			
								0.31	***1.05***					***0.44***	***0.10***		0.33			
Tributary discharge	5	134.6	5.20	0.07	0.06	-62.19	0.88	***-1.98***	***-3.27***					***1.35***	***-0.24***					
								0.27	***1.05***					***0.43***	***0.10***					
Refuge	8	134.9	5.53	0.06	0.05	-59.22	0.93	***-2.39***	***-2.77***				-0.49	***2.13***	***-0.33***	-0.83				-0.40
								0.38	***1.06***				0.30	***0.59***	***0.11***	0.53				0.37
Seasonal habitat	12	135.1	5.74	0.06	0.04	-55.06	0.97	-0.28	***-2.77***	***-3.14***	-0.73	***-5.40***	-0.47	1.38	-0.27	-0.23	1.75	0.39		
								1.01	***1.08***	***1.56***	1.30	***2.32***	0.34	1.09	0.20	0.72	0.95	0.35		
Tributary variability	8	137.2	7.82	0.02	0.02	-60.36	0.99	***-2.21***	***-3.25***					***1.58***	***-0.25***	-0.38	-0.22	0.17		
								0.33	***1.06***					***0.58***	***0.12***	0.44	0.47	0.28		
Global	14	138.0	8.65	0.01	0.01	-54.34	1.00	0.67	-2.29	-3.26	-1.27	-6.95	-0.48	3.07	-0.59	-0.52	3.09	0.68	-0.09	-0.75
								1.33	1.20	1.62	1.35	2.84	0.35	1.91	0.36	0.85	1.68	0.47	0.10	0.89
Tributary temp	4	141.5	12.10	0.00	0.00	-66.67	1.00	***-2.00***	***-3.22***								-0.49			
								0.25	***1.03***								0.27			

Model name	Model results							Covariate coefficient estimates and standard errors below												
	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary null	3	143.3	13.92	0.00	0.00	-68.60	1.00	***-1.90*** ***0.23***	***-3.21*** ***1.03***											
MOR discharge	4	143.7	14.32	0.00	0.00	-67.78	1.00	***-1.90*** ***0.24***	***-3.36*** ***1.05***											0.36 0.28
Depth	4	144.9	15.53	0.00	0.00	-68.38	1.00	***-1.93*** ***0.24***	***-3.18*** ***1.03***				-0.17 0.26							
Longitudinal position	4	145.2	15.86	0.00	0.00	-68.55	1.00	***-2.00*** ***0.39***	***-3.22*** ***1.03***										0.02 0.06	
Intercept only	2	163.1	33.71	0.00	0.00	-79.52	1.00	-2.90 0.39												

Table A.2. Generalized linear mixed-effects model results explaining the probability of presence of Flathead Catfish captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. The Season, Seasonal habitat, and Global models failed to converge and were eliminated from analysis. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC_c). The number of parameters (K), differences in AIC_c (ΔAIC_c), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of Flathead Catfish presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below									
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary temp	4	76.3	0.00	1.00	0.81	-34.10	0.81	***-5.87*** ***1.30***	0.92 0.82					***2.11*** ***0.76***			
Tributary conditions	6	79.6	3.22	0.20	0.16	-33.65	0.98	***-6.08*** ***2.00***	1.00 1.00		-1.83 4.05	-1.99 8.84		***1.96*** ***0.91***			
Tributary variability	8	83.6	7.31	0.03	0.02	-33.60	1.00	***-6.18*** ***2.03***	0.79 1.41		-1.77 3.23	-1.06 7.32	0.08 0.53	2.03 1.20	0.33 1.50		
Refuge	8	88.8	12.45	0.00	0.00	-36.17	1.00	***-4.35*** ***1.25***	0.35 1.72	-0.95 0.55	-3.95 5.26	-6.07 12.26	0.76 0.54				0.72 0.78
Tributary discharge	5	89.6	13.30	0.00	0.00	-39.72	1.00	***-3.35*** ***0.95***	1.84 1.04		-6.28 4.80	-14.70 9.69					
Intercept only	2	93.5	17.21	0.00	0.00	-44.75	1.00	***-3.57*** ***0.46***									
Depth	4	93.5	17.21	0.00	0.00	-42.71	1.00	***-4.24*** ***0.70***	0.95 0.73	-0.63 0.42							
Tributary null	3	94.1	17.82	0.00	0.00	-44.04	1.00	***-3.98*** ***0.69***	0.84 0.70								
Longitudinal position	4	96.2	19.86	0.00	0.00	-44.03	1.00	***-4.01*** ***0.81***	0.83 0.70							0.01 0.09	

	Model results							Covariate coefficient estimates and standard errors below									
Model name	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
MOR discharge	4	96.2	19.87	0.00	0.00	-44.04	1.00	***-3.98*** ***0.69***	0.83 0.71								0.01 0.30

Table A.3. Generalized linear mixed-effects model results explaining the probability of presence of juvenile Flathead Catfish captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. The Season, Seasonal habitat, and Global models failed to converge and were eliminated from analysis. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC_c). The number of parameters (K), differences in AIC_c (ΔAIC_c), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of juvenile Flathead Catfish presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates with standard errors below									
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary conditions	6	102.2	0.00	1.00	0.69	-44.98	0.69	***-2.52*** ***0.89***	-0.26 0.63		-0.30 2.15	-6.38 5.17		***1.62*** ***0.51***			
Tributary temp	4	104.5	2.31	0.31	0.22	-48.20	0.91	***-4.28*** ***0.76***	-0.37 0.55					***1.96*** ***0.52***			
Tributary variability	8	106.3	4.04	0.13	0.09	-44.90	1.00	***-2.53*** ***0.87***	-0.61 1.18		-0.37 1.98	-5.87 4.64	0.16 0.48	***1.61*** ***0.76***	0.08 1.04		
Refuge	8	116.3	14.11	0.00	0.00	-49.94	1.00	***-1.62*** ***0.62***	-0.80 1.18	0.26 0.30	-2.33 2.15	-7.30 5.89	0.46 0.40				0.89 0.48
Tributary discharge	5	120.2	18.02	0.00	0.00	-55.02	1.00	***-1.29*** ***0.51***	0.68 0.65		-3.47 2.36	***-13.01*** ***5.43***					
Intercept only	2	132.1	29.88	0.00	0.00	-64.03	1.00	***-2.98*** ***0.26***									
Tributary null	3	133.8	31.58	0.00	0.00	-63.86	1.00	***-2.83*** ***0.34***	-0.30 0.52								
MOR discharge	4	134.5	32.34	0.00	0.00	-63.21	1.00	***-2.83*** ***0.34***	-0.39 0.53								0.27 0.23
Depth	4	134.8	32.57	0.00	0.00	-63.33	1.00	***-2.83*** ***0.34***	-0.37 0.52	0.25 0.24							

	Model results							Covariate coefficient estimates with standard errors below									
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Longitudinal position	4	135.7	33.53	0.00	0.00	-63.81	1.00	***-2.73***	-0.30							-0.02	
								0.47	0.52							0.07	

Table A.4. Generalized linear mixed-effects model results explaining the probability of presence of juvenile Goldeye captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. The Seasonal habitat and Global models failed to converge and were eliminated from analysis. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC_c). The number of parameters (K), differences in AIC_c (ΔAIC_c), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of juvenile Goldeye presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below												
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary conditions	6	108.3	0	1.00	0.46	-48.04	0.46	***-3.75***	-0.96					-0.80	0.30		***1.07***			
								0.63	0.65					0.97	0.23		***0.39***			
Tributary temp	4	109.0	0.61	0.74	0.34	-50.42	0.80	***-3.27***	-1.13								***1.01***			
								0.55	0.73								***0.33***			
Longitudinal position	4	111.4	3.06	0.22	0.10	-51.64	0.91	***-1.77***	-1.01										***-0.27***	
								0.41	0.61										***0.10***	
Tributary variability	8	112.5	4.16	0.13	0.06	-48.03	0.96	***-3.77***	-0.85					-0.68	0.28	-0.07	1.15	0.09		
								0.65	0.90					1.18	0.26	0.42	0.61	0.65		
Season	6	114.4	6.09	0.05	0.02	-51.09	0.99	***-4.17***	-1.05	0.83	0.71	***2.35***								
								1.08	0.70	1.24	1.24	***1.07***								
Tributary discharge	5	116.7	8.39	0.02	0.01	-53.27	0.99	***-3.36***	-1.01					-1.36	0.40					
								0.52	0.64					0.86	0.21					
Tributary null	3	118.7	10.37	0.01	0.00	-56.32	0.99	***-2.82***	-1.01											
								0.44	0.67											
Intercept only	2	119.0	10.65	0.00	0.00	-57.48	1.00	***-3.33***												
								0.44												
MOR discharge	4	120.5	12.11	0.00	0.00	-56.17	1.00	***-2.82***	-1.06											0.17
								0.45	0.68											0.29

	Model results							Covariate coefficient estimates and standard errors below												
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Depth	4	120.7	12.34	0.00	0.00	-56.28	1.00	***-2.85***	-1.00				-0.09							
								0.46	0.68				0.32							
Refuge	8	120.7	12.35	0.00	0.00	-52.12	1	***-3.33***	-1.48				0.09	-1.91	***0.48***	0.39				0.32
								0.55	0.80				0.33	0.99	***0.23***	0.34				0.46

Table A.5. Generalized linear mixed-effects model results explaining the probability of presence of Longnose Gar captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. The Intercept Only, Season, Seasonal Habitat and Global models failed to converge and were eliminated from analysis. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC_c). The number of parameters (K), differences in AIC_c (ΔAIC_c), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of Longnose Gar presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below									
Model name	K	AIC_c	ΔAIC_c	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary conditions	6	133.4	0.00	1.00	0.44	-60.55	0.44	***-2.73*** ***0.36***	-0.90 0.57		***1.44*** ***0.49***	-0.20 0.11		0.59 0.33			
Tributary discharge	5	134.6	1.25	0.54	0.24	-62.21	0.67	***-2.65*** ***0.34***	-0.91 0.57		***1.09*** ***0.43***	-0.12 0.10					
Tributary variability	8	135.1	1.70	0.43	0.19	-59.31	0.86	***-2.67*** ***0.37***	-1.11 0.61		***1.25*** ***0.62***	-0.18 0.13	0.39 0.28	0.39 0.49	0.15 0.45		
Refuge	8	135.7	2.34	0.31	0.14	-59.63	1.00	***-2.66*** ***0.37***	-1.07 0.67	-0.03 0.29	1.06 0.55	-0.14 0.11	***0.52*** ***0.23***				-0.09 0.33
MOR discharge	4	145.6	12.23	0.00	0.00	-68.73	1.00	***-2.36*** ***0.28***	***-1.29*** ***0.56***								0.40 0.23
Tributary null	3	146.4	13.02	0.00	0.00	-70.15	1.00	***-2.36*** ***0.28***	***-1.13*** ***0.53***								
Longitudinal position	4	147.7	14.31	0.00	0.00	-69.77	1.00	***-2.09*** ***0.40***	***-1.13*** ***0.53***							-0.06 0.06	
Tributary temp	4	147.9	14.53	0.00	0.00	-69.88	1.00	***-2.37*** ***0.28***	***-1.14*** ***0.53***					0.17 0.24			
Depth	4	148.2	14.84	0.00	0.00	-70.04	1.00	***-2.35*** ***0.28***	***-1.16*** ***0.54***	0.11 0.23							

Table A.6. Generalized linear mixed-effects model results explaining the probability of presence of juvenile Longnose Gar captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC$_c$). The number of parameters (K), differences in AIC$_c$ (ΔAIC$_c$), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of juvenile Longnose Gar presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below												
Model name	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Season	6	178.9	0.00	1.00	0.48	-83.32	0.48	***-4.29***	-0.27	0.79	***2.53***	***2.72***								
								1.02	0.41	1.24	***1.06***	***1.05***								
Tributary conditions	6	180.7	1.84	0.40	0.19	-84.23	0.67	***-2.67***	-0.02					0.74	-0.05		***0.74***			
								0.34	0.44					0.40	0.10		***0.26***			
Global	14	180.8	1.92	0.38	0.18	-75.74	0.85	***-4.24***	0.10	1.68	2.19	3.49	0.21	0.84	-0.06	0.07	-0.06	-0.33	-0.15	-0.81
								1.68	0.63	1.64	1.52	2.79	0.24	1.13	0.22	0.32	1.18	0.74	0.08	0.55
Seasonal habitat	12	182.3	3.42	0.18	0.09	-78.67	0.93	***-5.73***	-0.43	1.87	***3.38***	***5.20***	0.18	-0.98	0.29	0.27	-1.22	-0.23		
								1.55	0.58	1.61	***1.50***	***2.51***	0.23	0.82	0.16	0.28	0.89	0.58		
Tributary variability	8	183.7	4.82	0.09	0.04	-83.63	0.98	***-2.58***	-0.25					0.51	-0.02	0.25	0.51	-0.12		
								0.35	0.49					0.48	0.10	0.23	0.37	0.47		
Refuge	8	186.9	8.01	0.02	0.01	-85.23	0.98	***-2.46***	-0.45				0.21	0.05	0.07	***0.48***				-0.02
								0.33	0.50				0.22	0.44	0.10	***0.18***				0.26
Tributary discharge	5	187.9	8.97	0.01	0.01	-88.84	0.99	***-2.54***	-0.03					0.29	0.04					
								0.32	0.43					0.34	0.09					
Longitudinal position	4	188.3	9.45	0.01	0.00	-90.11	0.99	***-1.68***	-0.28										***-0.14***	
								0.34	0.41										***0.06***	
Tributary temp	4	189.0	10.14	0.01	0.00	-90.45	1.00	***-2.36***	-0.31								***0.47***			
								0.28	0.41								***0.20***			

Model name	Model results							Covariate coefficient estimates and standard errors below												
	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Intercept only	2	190.9	12.05	0.00	0.00	-93.45	1.00	***-2.42*** ***0.20***												
Tributary null	3	192.5	13.59	0.00	0.00	-93.21	1.00	***-2.28*** ***0.27***	-0.28 0.40											
MOR discharge	4	193.0	14.08	0.00	0.00	-92.43	1.00	***-2.27*** ***0.27***	-0.35 0.41											0.24 0.19
Depth	4	193.2	14.30	0.00	0.00	-92.53	1.00	***-2.27*** ***0.27***	-0.34 0.41				0.22 0.19							

Table A.7. Generalized linear mixed-effects model results explaining the probability of presence of Sand Shiners captured by boat electrofishing and benthic trawl in the Gasconade and Osage rivers, September 2012-August 2013. Models were ranked using Akaike's Information Criterion with a small sample size correction (AIC$_c$). The number of parameters (K), differences in AIC$_c$ (ΔAIC$_c$), model likelihood, model weight, log likelihood, and cumulative weight are provided as supporting evidence for the ranking. Model covariate coefficient estimates and standard errors are presented with values in bold, italic text indicating a substantial influence on the probability of Sand Shiner presence as estimated by that particular model. Variable acronyms are defined in Table 1-4 of the main document.

	Model results							Covariate coefficient estimates and standard errors below												
Model name	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Intercept only	2	132.0	0.00	1.00	0.41	-63.99	0.41	***-3.02*** ***0.33***												
Tributary null	3	133.7	1.72	0.42	0.17	-63.84	0.58	***-2.87*** ***0.40***	-0.30 0.54											
Longitudinal position	4	134.3	2.27	0.32	0.13	-63.09	0.71	***-3.31*** ***0.54***	-0.31 0.52										0.08 0.07	
Tributary temp	4	135.5	3.48	0.18	0.07	-63.69	0.78	***-2.88*** ***0.40***	-0.30 0.54								-0.14 0.27			
Depth	4	135.7	3.71	0.16	0.06	-63.81	0.85	***-2.86*** ***0.40***	-0.32 0.54				0.06 0.26							
MOR discharge	4	135.8	3.76	0.15	0.06	-63.83	0.91	***-2.86*** ***0.40***	-0.31 0.54											0.02 0.26
Tributary discharge	5	137.1	5.06	0.08	0.03	-63.45	0.94	***-2.76*** ***0.44***	-0.33 0.54					0.03 0.48	-0.13 0.27					
Tributary variability	8	138.1	6.09	0.05	0.02	-60.83	0.96	***-3.06*** ***0.55***	0.38 0.72					0.75 0.82	-0.46 1.07	-0.75 0.54	0.49 0.44	0.49 0.29		
Season	6	138.4	6.38	0.04	0.02	-63.07	0.98	***-2.46*** ***0.53***	-0.31 0.54	-0.33 0.67	-0.73 0.73	-0.73 0.73								

Model name	Model results							Covariate coefficient estimates and standard errors below												
	K	AIC$_c$	ΔAIC$_c$	Model likelihood	Model weight	Log likelihood	Cumulative weight	Intercept	RIV	FAL	SPR	SUM	DEP	FLO	FLO^2	FLO_CV	TEM	TEM_CV	RM	FLO_MO
Tributary conditions	6	138.8	6.82	0.03	0.01	-63.29	0.99	***-2.79***	-0.33					-0.03	-0.12		-0.15			
								0.44	0.54					0.49	0.27		0.26			
Refuge	8	140.8	8.77	0.01	0.01	-62.18	1.00	***-2.94***	-0.10				0.04	0.14	-0.29	-0.61				0.11
								0.57	0.63				0.28	0.67	0.97	0.49				0.36
Seasonal habitat	12	141.9	9.84	0.01	0.00	-58.44	1.00	-1.38	0.82	-1.06	-3.61	-2.05	0.00	2.83	-0.90	-1.19	1.29	0.53		
								1.25	0.84	1.73	1.82	2.78	0.28	1.41	1.23	0.66	1.11	0.32		
Global	14	145.6	13.53	0.00	0.00	-58.11	1.00	-1.50	0.81	-1.17	-3.44	-1.96	-0.03	2.40	-1.39	-1.16	0.98	0.48	0.05	0.41
								1.40	0.85	1.74	1.82	2.74	0.28	1.53	1.46	0.66	1.13	0.33	0.08	0.63

CHAPTER 2 SEASONAL FISH COMMUNITY UPSTREAM AND DOWNSTREAM OF A LOW-HEAD DAM ON A LOWER MISSOURI RIVER TRIBUTARY

Abstract

Habitat destruction from dam construction in one of the leading causes for the decline of aquatic species, including big-river fishes. The influence of larger dams on fishes in well documented and low-head dams (<15 meters in height) are receiving increased attention as removal of these structures accelerates because of an emphasis on restoring rivers for aquatic fauna and public safety. The distribution of mainstem big-river fishes in tributaries and the contribution of tributaries to big-river ecosystems remains unclear. Therefore, this study investigates the seasonal patterns of fish abundance, species richness, and big-river fish presence upstream and downstream of a low-head dam on the Osage River (LD1), a regulated tributary of the Lower Missouri River in central Missouri. Boat electrofishing, benthic trawls, and beach seines collected 15,619 fish representing 71 species in the lower 30 river kilometers of the Osage River, September 2012 through July 2013. Of the 71 species collected, 48 species were captured both upstream and downstream of LD1, 13 species were only captured upstream of the structure, and ten species were only captured downstream of the structure. Half of the species only captured downstream of LD1 were big-river species - Skipjack Herring *Alosa chrysochloris*, Speckled Chub *Macrhybopsis aestivalis*, Stonecat *Noturus flavus*, White Bass *Morone chrysops*, and Yellow Bass *Morone mississippiensis.* Overall, species richness did not differ upstream and downstream of LD1; however, there were differences in the proportion of big-river species depending on what sampling technique was used. Summer 2013 resulted in diverse and distributed big-river species with

Flathead Catfish *Pylodictis olivaris*, Longnose Gar *Lepisosteus osseus*, and Goldeye *Hiodon alosoides* detected both upstream and downstream of LD1. This distribution was most likely due to high water overtopping LD1 allowing upstream passage in the month preceding summer sampling. Nonmetric multidimensional scaling (NMDS) using species abundance revealed that regardless of season or gear, reaches downstream of LD1 were more similar to each other than to sites upstream of the structure and sites within four miles of the confluence with the Missouri River were also similar to each other. This study provides evidence that LD1 is a semi-permeable barrier to big-river fish in the Osage River and to the seasonal use of Missouri River tributaries by big-river fishes. This information will provide a baseline should modifications occur to LD1 in the Osage River.

Introduction

Humans have modified rivers since early civilization but activities intensified in the 20th century with engineering improvements and growing demands for navigation, flood control, irrigation, recreation, and power generation (Dynesius and Nilsson 1994; Nilsson et al. 2005). Alterations such as these and habitat destruction are the leading cause for the decline of aquatic species and listing of aquatic species as endangered (Carpenter et al. 2011; Wilcove et al. 1998). The influence of larger dams on fishes is well documented (Ward and Stanford 1979; Petts 1984; Ligon et al. 1995; Poff and Hart 2002; Brenkman et al. 2012; Kiraly et al. 2014). Low-head dams (<15 meters in height) have received increased attention as removal of these structures occurs because of an emphasis on restoring rivers for aquatic fauna and public safety (Born 1998; Porto et al. 1999; Tiemann et al. 2004; Gardner et al. 2011; Hogg et al. 2013; Raabe and Hightower 2014). Many of the low-head dams in central United States are in disrepair increasing chances for dam failure leading to safety concerns and habitat destruction (Poff and Hart 2002). To quantify the influence of these low-head structures on aquatic biota and assist in the decision-making process about dam removal projects, efforts are being made to research rivers before and after low-head dam removal projects (Kanehl et al. 1997; Poff and Hart 2002; Catalano et al. 2007; Gardner et al. 2011; Helms et al. 2011; Brenkman et al. 2012; Kiraly et al. 2014; Poulos et al. 2014).

Many theories have been developed to explain longitudinal fish community organization in lotic systems (Vannote 1980; Ward and Stanford 1983; Gorman 1986; Taylor and Warren 2001; Thorp et al. 2006; Roberts and Hitt 2010). Regulated rivers have disrupted patterns in biotic communities, including fish, which are dependent on where in the watershed the disturbance is located (Ward and Stanford 1983; Ellis and Jones 2013). This serial discontinuity concept theorizes that dam placement in a watershed in addition to tributary influences and lateral connectivity affect abiotic parameters, such as substrate size, habitat heterogeneity, and temperature (Ward and Stanford 1983). Even semi-permeable barriers such as diversion weirs, lock and dams, and low-head dams cause disjunct fish assemblages or altered movement patterns (Zigler et al. 2003; Santucci et al. 2005; Eitzmann and Paukert 2010; Helms et al. 2011). Since many large river systems (systems with a mean annual discharge of at least 350 cubic meters per second, cms; Dynesius and Nilsson 1994) are impounded, longitudinal patterns do not match reference conditions but instead show some variation of the expected pattern. Whether due to direct effects to the fish community or the habitat, dams alter fish composition in rivers and streams. Understanding these effects will help decision-makers evaluate the ecological value of dam removals.

Midwestern lotic systems have high levels of fish diversity, a history of manipulation and degradation, and a growing list of imperiled species (Karr et al. 1985; Galat et al. 2005). Studies in large Midwestern rivers, including the Kansas River, tributaries of the Mississippi River in Iowa, and Wisconsin rivers, have investigated fish assemblages in relation to anthropogenic disturbances and longitudinal position (Lyons 2005; Paukert et al. 2008; Eitzmann and Paukert 2010; White et al. 2010; Fischer et al. 2012; Parks et al. 2014). Research such as these and large-scale monitoring programs are important to assess the status of imperiled species, the effect of habitat on fish communities, and to develop restoration and recovery plans to address the ecological issues affecting aquatic ecosystems (Dryer and Sandvol 1993; Galat et al. 2005).

Fish movement between tributaries and mainstem rivers is common, but varies by species, life-stage, seasons, discharge, water temperature, and spatial position (Bramblett et al. 2002; Goniea et al. 2006; Thornbrugh and Gido 2009). The movement of big-river fishes into the lower reaches of larger tributaries is expected since these fish are highly mobile, capable of swimming long-distances, and the low gradient portions of these tributaries may closely resemble the mainstem rivers or, in fact, be mainstem river backwater for many miles. Fish movement may be most active in the spring and fall (Porto et al. 1999; Zigler et al. 2003; Grabowski and Isely 2006; Neely et al. 2009), and fish exhibiting a migratory reproductive behavior are more often associated with large rivers (Goldstein and Meador 2004). Since spawning is often correlated with spring when water temperatures are warming and discharge is higher than average, these conditions make the larger tributaries seemingly less distinguishable from the mainstem rivers and thus more likely for fishes to move into tributaries.

The distribution of mainstem big-river fishes in tributaries and the contribution of tributaries to big-river ecosystems remains unclear. Therefore, this study aims to characterize the longitudinal and seasonal fish community of the Osage River, a regulated tributary of the Lower Missouri River. Specifically, our goal was to characterize fish assemblage structure in the lower Osage River by focusing on longitudinal patterns of species richness, presence of big-river fishes, and diversity indices upstream and downstream of a low-head dam known as Osage Lock and Dam #1 (LD1) located 19 river kilometers (rkm) upstream from the confluence of the Missouri River.

I hypothesize that species richness and diversity indices will be greatest at the reaches closest to the Missouri River confluence during all seasons except spring when water temperatures are warming and discharge is high, I predict species richness and diversity indices in the lower 32 rkm of the Osage River will be the same due to high discharge flushing fish downstream and allowing upstream movement over LD1, therefore homogenizing the assemblage in the lower portions of the river. Similarly, I hypothesize big-river fishes will be present in the lower 19 rkm of the Osage River during all times of year, however the presence of big-river fishes upstream of LD1 on the Osage River will be limited to springs when discharge is high and passage over LD1 is feasible (Figure 2-1).

Methods

Study area and reaches

The Osage River, an eighth-order stream at its confluence with the Lower Missouri River, enters the mainstem Missouri River in central Missouri (Figure 2-2). Four major reservoirs, including Truman Reservoir and Lake of the Ozarks, have inundated 970 rkm of the mainstem Osage River (Duchrow 1984), leaving 130 rkm between Bagnell Dam, the lowest dam on the Osage River, and the Missouri River. LD1 is a low-head dam located at rkm 19 on that Osage River that was constructed in 1906 by the U.S. Army Corps of Engineers as part of a navigation plan, which included the construction of numerous wing dikes throughout the lower 130 rkm of the Osage River (Herman and Hill 2012). LD1 originally created a 32 rkm pool upstream but the dam was removed from service in 1951. Today the structure is dilapidated with gravel and sediment filling in the upstream side (Figure 2-3). Telemetry of paddlefish during spring migration at LD1 between 2007-2009 concluded that successful upstream passage is dependent on a combined Osage and Missouri River discharge greater than 2,975 cms indicating that it is a semi-permeable barrier (Lallaman 2012).

Bagnell Dam is a 45 meter (m) tall, bottom-release, hydroelectric facility completed in 1931 and impounds Lake of the Ozarks Reservoir which has a surface area of 22,000 hectares (ha) about 130 rkm upstream of the Missouri River confluence. The current Federal Energy Regulatory Commission license dictates Bagnell Dam will have a regulated minimum discharge of 25.5 cms, but also includes seasonally varying caps limiting the prescribed minimum flow and rules for post-flood ramp down and re-aeration flows following power generation, which can make the river water levels fluctuate up to 2 m per day. This regulation has altered the downstream water temperature so the Osage River warms up slower in the spring, is cooler in summer, warmer in winter, and less variable throughout the day when compared to similar streams in central Missouri.

Sampling was conducted in the lower 32 rkm of the Osage River, upstream of the Missouri River confluence in central Missouri (Figure 2-2). Eleven 1.6 rkm reaches were systematically established every 3.2 rkm except at the confluence with the Missouri River where two consecutive 1.6 rkm reaches were sampled. There were seven reaches in the 19 rkm downstream of LD1 and four reaches extending 13 rkm upstream of the structure. Within each reach, three random samples of each standard gear were deployed during each of the four seasons (see below) when suitable habitat was available**.**

Fish collections

A suite of standard gears including boat electrofishing, benthic trawls, and beach seines was used to sample the fish community beginning in September 2012 and was repeated in each season (fall, winter, spring, and summer) through July 2013 (Table 2-1). These gears target different aspects of the fish community and, when used in conjunction with one another, cover the variety of habitats and fishes found in the mid-sized rivers.

Boat electrofishing. Boat electrofishing was conducted during daylight hours by a crew of one boat operator and two netters outfitted with 3 mm mesh, long-handled dip nets. A Midwest Lake Electrofishing Systems Infinity electrofishing box with pulsed direct current at 60 Hz and 40% duty cycle was used to target the power (watts) and amps to the recommended levels by Miranda (2009) for the ambient conductivity of the water at sampling time. Five-minute downstream longitudinal transects sampled bankline, bar, and channel border habitats less than three meters deep. Catch per unit effort (CPUE) is the number of fish per five minutes electrofishing.

Benthic trawls. We used a Gerken Siamese Trawl (Greg Faulkner, Innovative Nets, Milton, Louisiana) with 6 mm mesh, 2.5 meters (m) long with a 2.5 m headrope and a 3 m footrope. Larger 38 mm mesh in the cod-end separates the larger fish from the smaller fish which filter through the large mesh and are deposited in the 6 mm mesh codend. The length of the trawl towlines were about 3 times the water depth and the trawl doors were 50 cm in length to ensure that the trawl mouth opened properly and maintained contact with the bottom at a proper opening. Benthic trawl hauls were towed off the bow in reverse a minimum of 75 m and a maximum of 200 m in main channel, channel border, and pool habitat greater than 1.2 meters deep at a speed slightly faster than the water. Catch per unit effort (CPUE) is the number of fish per 100 m trawled.

Beach seines. Near-shore wadeable habitats less than 1.2 m were sampled with a 9 m X 1.8 m dipped seine with a 1.8 m, 3 mm mesh bag. Standard seine hauls were conducted with both ends on the shore, the upstream end arching off the bank to move parallel to the bank downstream and then arching back in to the shore at the conclusion of 30 m. CPUE was calculated as fish per 30 m seine haul.

Data analysis

The majority of captured fish was identified, measured and returned to the river at point of capture. However, some unidentified fish were retained for lab identification. All fishes that were captured were identified to species and measured to the nearest millimeter. If more than 25 of a single species were captured, 25 were randomly chosen to be measured while the remaining fish were enumerated. Fish species were categorized as fluvial dependent and fluvial specialist as identified by Galat et al. (2005). Fluvial dependent or specialist species with modifications made to remove the "tributary stragglers" (Pflieger and Grace 1987) were further classified as big-river species (Tables 2-2, 2-3, & 2-4).

To determine if there was a difference in the fish community upstream and downstream of LD1, species richness, proportion big-river species, and Shannon-Weaver diversity indices were calculated for each combination of gear, season, and position upstream and downstream from LD1. Species richness and the proportion big-river species were calculated using Microsoft Access while Shannon-Weaver was calculated using the vegan package in R (Oksanen et al. 2013). One way analyses of variance (Tomanova et al. 2013) were used to determine if mean species richness, proportion big-river species, and diversity indices differed between upstream and downstream reaches of

LD1 in each season and with all seasons combined. Non-metric multidimensional scaling was used on the CPUE data to determine if there was a pattern in the fish community longitudinally and in particular upstream and downstream of LD1. The ordination analyses were performed in R (version 2.15.0; R Development Core Team 2011) using the vegan package for descriptive community ecology (Oksanen et al. 2013).

Lallaman (2012) found Paddlefish *Polyodon spathula* passage over LD1 when Osage River and Missouri River discharges combined exceeded at 2,975 cms therefore we used discharge data to determine passage during our study time. Osage River discharge was obtained from the U.S. Geological Survey (USGS) monitoring station (06926510) at St. Thomas, Missouri, 35 rkm upstream of LD1 and 54 rkm upstream of the Missouri River confluence. Missouri River discharge was obtained from USGS station (06909000) at Boonville, Missouri, approximately 100 rkm upstream of the Osage River confluence. All discharge data were downloaded from the USGS waterwatch website (http://waterwatch.usgs.gov/).

Results

Sampling was conducted between September 13, 2012, and July 29, 2013 and collected a total of 15,619 fish representing 71 species (Tables 2-2, 2-3, & 2-4). Boat electrofishing and benthic trawls were deployed in every reach in each season. No seining was completed during spring 2013 due to high water and no seining was completed at the reach closest to the Missouri River confluence (reach one) in fall 2012 and summer 2013 due to low water or reaches six and 11 during winter 2012-2013 due to ice.

Fall 2012 was the season with the lowest mean daily discharge in the Osage River for the entire study period (Figure 2-4; Table 2-1). Conversely, the season with the highest mean daily discharge was spring 2013 when the mean daily discharge was 6, 10, and 22 times that in summer, winter, and fall respectively (Figure 2-4; Table 2-1). Mean daily water temperatures differed among all the seasons with the lowest observed in winter and the highest in summer 2013 (Table 2-1).

Of the 71 species collected, 48 species were captured both upstream and downstream of LD1, 13 species were only captured upstream of the structure, and ten species were only captured downstream of the structure. Half of the species only captured downstream of LD1 were big-river species (Skipjack Herring *Alosa chrysochloris*, Speckled Chub *Macrhybopsis aestivalis*, Stonecat *Noturus flavus*, White Bass *Morone chrysops*, and Yellow Bass *Morone mississippiensis*).

Skipjack Herring, one of the eleven big-river species captured, was the only species of conservation concern (SOCC) represented in this study (one American Eel *Anguilla rostrata* was captured during non-standardized sampling immediately downstream of LD1) and seven Skipjack Herring were caught downstream of LD1 with boat electrofishing (Table 2-2). The three smallest (<125 mm) Skipjack Herring were captured in fall, two adults were captured in summer (260 and 290 mm) and two more adults were captured in winter (280 and 336 mm). Two Speckled Chubs (31 and 32 mm total length) were captured by benthic trawl in reaches one and three during winter and spring. The only Stonecat was captured in reach six by benthic trawl in winter 2012-2013. Three White Bass were captured in summer 2013, including an adult (246 mm) in the reach immediately downstream of the LD1 by electrofishing and two juveniles (67 and 91 mm) in reach six by seine. The only Yellow Bass (171 mm) was captured in reach six during summer 2013 by boat electrofishing. No big-river species were only captured upstream of LD1; however, Flathead Catfish *Pylodictis olivaris*, Longnose Gar *Lepisosteus osseus*, and Goldeye *Hiodon alosoides* were only captured upstream during summer 2013. Of the 18 Flathead Catfish captured, only one adult (325 mm) was captured upstream of LD1 (Figure 2-7). A total of 37 Longnose Gar was captured with 32% captured upstream of LD1 in summer 2013. The largest Goldeye (210 mm) was captured six miles upstream of LD1 in summer 2013.

Overall, species richness did not differ upstream and downstream of LD1 for any of the sampling techniques (Table 2-5). There were seasonal differences in species richness for boat electrofishing and benthic trawls, but not seines. Boat electrofishing in winter resulted in more species downstream of the structure (11.7) than upstream (4.3; Table 2-5) but the opposite pattern was true for trawls in fall (downstream = 4.3 and upstream = 8,) and winter (downstream = 3.1 and upstream = 7.3). Of the 687 fish captured with trawls in summer 2013, only 7% of them representing ten species were captured upstream of LD1, none of which were big-river species.

The proportion of big-river species did not differ upstream and downstream of LD1 for fish captured by seine or trawl but was higher in reaches downstream of LD1 for fish collected by boat electrofishing (Table 2-5). Of the species captured with seines and trawls, only 9% and 14%, respectively, were big-river species. Although the proportions of big-river species did not differ upstream and downstream of LD1, the actual species did. For example, Sand Shiners *Notropis stramineus* were consistently captured upstream of LD1 while spring and summer also collected Channel Shiners *Notropis wickliffi*.

The proportion of big-river species captured by boat electrofishing was higher in reaches downstream of LD1 (reaches 1-7) than upstream of the structure (reaches 8-11; Table 2-5). There was about twice the proportion of big-river fishes downstream of LD1 compared to upstream for all seasons combined (downstream=0.14, upstream=0.06), and over four times as many during spring (downstream=0.09, upstream=0.02; Table 2-5) when only Chestnut Lamprey *Ichthyomyzon castaneus* was captured upstream of the structure. In fall 2012, when water levels were the lowest of the study (Figure 2-4), electrofishing did not capture any big-river species upstream of LD1. Conversely, summer 2013 electrofishing resulted in diverse and distributed big-river species with Flathead Catfish, Goldeye, and Longnose Gar detected both upstream and downstream of LD1.

Species diversity indices ranged from 0.4 (benthic trawls in the spring downstream of LD1) to 2.4 (boat electrofishing downstream of LD1, all seasons combined) and were generally consistent upstream and downstream of LD1 for all gear and season combinations (Table 2-5). The one exception is for electrofishing in fall when the downstream Shannon-Weaver diversity index (2.0) was higher than upstream (1.5; Table 2-5). The difference in diversity in the fall was most likely due to reaches upstream of LD1 contained fewer species (mean=9.5, SE=1.19) than downstream reaches (mean=14.0, SE=1.83) and four species (Longear Sunfish *Lepomis megalotis*, Spotted Bass *Micropterus punctulatus*, Bluegill *Lepomis macrochirus*, and Green Sunfish *Lepomis cyanellus*) comprised 90% of all fish captured upstream of the structure.

Sites downstream of LD1 typically had different fish communities than upstream, but this varied by season and sampling gear. Nonmetric multidimensional scaling (NMDS) using species abundance revealed that regardless of season or gear, reaches downstream of LD1 were more similar to each other than to sites upstream of the structure (Figure 2-6). However, there were some exceptions. The boat electrofishing NMDS plots clustered the reach immediately downstream of LD1 (reach 7) with upstream reaches when all seasons were combined and in the fall. This placement is due to high catch rates of Longear Sunfish and Spotted Bass, two species that were more abundant upstream of LD1. Reach 9 was more similar to reaches closer to the Missouri River confluence when electrofishing in summer. This was due to the capture of nine Longnose Gar, a species that was predominately captured downstream of LD1.

The NMDS plot for fall benthic trawls clusters reach eleven, the most upstream reach, with sites six and three downstream of LD1. Eleven species were captured in reach eleven with the benthic trawl in fall 2012 and the most abundant species were Mimic Shiners *Notropis volucellus* and Sand shiners which were also captured in reach three. Gilt Darter *Percina evides*, Logperch *Percina caprodes*, and Spotted Bass catches were similar between reaches six and eleven therefore clustering those reaches together in the fall trawl NMDS plot (Figure 2-6). Reaches seven and nine cluster so closely that they overlap in the fall trawl NMDS plot. Reach seven caught two species, Gilt Darters and Wedgespot Shiners *Notropis greenei*, which were the most abundant species of the five captured in reach nine. Benthic trawls in reach five during fall 2012 only captured six individuals representing two species – one Flathead Catfish and five Gilt Darters.

Gilt Darters were very abundant in trawls during the fall, but only 7% of them were captured downstream of LD1, including the five in reach five.

The winter trawl NMDS plot shows three reaches downstream of LD1 separated from the other downstream reaches. This was likely do to a few rare species collected at these three sites. For example, a Channel Catfish *Ictaluras punctatus* and a Western Mosquitofish *Gambusia affinis* were captured at reach four while Wedgespot Shiners were the only species captured in reach six. These assemblages were different from other downstream reaches which were dominated by Bullhead Minnows *Pimephales vigilax*. Reach seven clustered more closely with reaches upstream of LD1 due to multiple darter species (Percina and Etheostoma) being captured here in winter.

The fish assemblage captured at reach six with beach seines was unique among samples collected as part of this research (Figure 2-6). The only seine habitat in reach six was at the confluence of the Maries and Osage rivers. The fish assemblage captured here consisted of twenty-one species with juvenile Gizzard Shad *Dorosoma cepedianum* dominating the catch. Other species well-represented at reach six that were more common upstream of LD1 included Brook Silverside *Labidesthes sicculus*, Longear Sunfish, Bluntnose Minnow *Pimephales notatus*, and Green Sunfish. Reach six was also of interest for capturing the only juvenile Golden Redhorse *Moxostoma erythrurum*, juvenile Silver Redhorse *Moxostoma anisurum*, and juvenile White Bass and one of two juvenile Quillback *Carpiodes cyprinus* and White Crappie *Pomoxis annularis* captured by seine.

Confluence sites had similar fish communities and thus were clustered together. A total of 37 Longnose Gar was captured during this study and 43% were caught in the three reaches closest to the Missouri River confluence. Sampling during summer detected the most Longnose Gar downstream, too, at 14 fish, all of which were in the four lowest reaches. All but one of the eight Goldeye were captured in the first two reaches. Similarly, 62% of Silver Chub *Macrhybopsis storeriana* were captured in the three reaches closest to the Missouri River (Figure 2-7).

Discussion

Our results suggest that the LD1 on this large river may have affected fish distributions and disrupted the longitudinal pattern of large river fishes, but these differences varied by season and were mainly observed at the species level. Similar findings were observed on the Neosho River in Kansas, where species richness did not differ upstream and downstream of low-head dams but the abundance of some benthic fishes (i.e., Neosho Madtom *Noturus placidus*, Orangethroat Darter *Etheostoma spectabile*, Slenderhead Darter *Percina phoxocephala*, and Suckermouth Minnow *Phenacobius mirabilis*) was greater downstream because the habitat was shallower and swifter downstream of dams while upstream was slower and deeper (Tiemann et al. 2004). Gillette et al. (2005) found temporal variation in assemblages upstream and downstream of low-head dams on the Neosho River was associated with life history events (i.e., spawning and recruitment) as well as seasonal changes in water temperature. Unlike Tiemann et al. (2004) and Gillette et al. (2005) which focused on small-bodied fish, Santucci et al. (2005) looked at the entire fish community in the larger Fox River system, a tributary of the Illinois River in Northern Illinois. Santucci et al. (2005) found truncated distributions of larger riverine species and discontinuous distributions of other warmwater stream fish indicating that multiple dams restrict upstream movement. Chick et al. (2006) found low-head dams on the Upper Mississippi River to restrict certain fish species but little evidence of community-level fragmentation among adjacent pools. Instead, Chick et al. (2006) found longitudinal position and distance between sample sites to be a stronger indicator of changes in fish community. Raabe and Hightower (2014) utilized telemetry to assess the ability of American Shad *Alosa sapidissima*, Gizzard Shad, and Flathead Catfish *Pylodictis olivaris* to traverse low-head dam sites in the Little River, a fourth order tributary of the Neuse River in North Carolina. Passage at a notched dam was most likely to happen at high water, but some individuals remained downstream for more than a day before migrating upstream (Raabe and Hightower 2014). These findings support the serial discontinuity concept predicting shifts in biological phenomena including species abundance patterns in relation to dams (Ward and Stanford 1983).

Overall, Osage LD1 is a semi-permeable barrier with species passing upstream when water levels allow (Lallaman 2012). Our study suggests that even a semi-permeable barrier that may allow fish passage for limited time periods, still may alter the fish assemblage structure by decreasing big-river species upstream of the dam during base flows. Like many other studies investigating the effects of low-head dams, we detected fish species upstream of the structure following a high-water event that were not present during lower water. To assess the effects of semi-permeable barriers such as low-head dams on fish assemblages, Hastings et al. (2016) recommends sampling after base flow has been established.

There were five big-river species – Skipjack Herring, Speckled Chub, Stonecat, White Bass, and Yellow Bass – unique among samples downstream of LD1 and none unique among samples upstream of the structure. This is consistent with other studies that found big-river species distributions truncated by dams (Santucci et al. 2005; Parks et al. 2014). Big-river species captured downstream and upstream of LD1 included Flathead Catfish, Longnose Gar, Chestnut Lamprey, Goldeye, Channel Shiner and Sand Shiners. Aside from the Shiners, the Flathead Catfish, Longnose Gar, Chestnut Lamprey, and Goldeye were captured in spring or summer. Although we hypothesized that spring would show the most homogenous fish community because of spring flows allowing passage over the lock and dam, summer was the most homogeneous. Lallaman (2012) found Paddlefish upstream passage occurred over LD1 when Osage and Missouri rivers discharge combined was greater than 2,975 cms. This discharge combination occurred three days prior to our spring sampling (March 11-14, 2013), 13 days during spring sampling (April 11-14 and April 18-28, 2013) and 31 days before summer sampling (May 5-8 and May 28-June 24, 2013). This overtopping of LD1 potentially contributed to the increased homogenization upstream and downstream of the structure and the increase in big-river fishes captured by electrofishing upstream in summer 2013. Although others have found that fish passage was most likely to occur in spring and fall (Porto et al. 1999) and during high water (Raabe and Hightower 2014; Tripp et al. 2014; Hastings et al. 2016), our results suggest that fish may remain upstream of these barriers after passage occurs.

Silver and Speckled chubs were found downstream of LD1 but only Silver Chub was found upstream in summer. Similarly, Silver Chub were not sampled upstream of the Cedar Rapids Milldam on the Cedar River in Iowa during summer 2010 and 2011 (Parks et al.2014) and Perkin and Gido (2011) found mainstem fragment length influenced persistence of pelagic-spawning cyprinids (i.e. Silver Chub and Speckled Chub) in rivers of the Great Plains. Perkin and Gido (2011) estimated approximately 200 rkm necessary for Silver Chub population persistence and 100 rkm for Speckled Chub. The LD1 is 19 rkm upstream of the Missouri River confluence and only 109 rkm extends upstream of LD1 before encountering Bagnell Dam. These fragment lengths may be one reason for a lack of these species in the Osage River.

In addition to documenting the effect of the low-head dam on the fish community in the lower Osage River, our data shows the influence of the Missouri River on tributary fish assemblage structure. Reaches closest to the Missouri River had similar fish assemblages characterized by Longnose Gar, Goldeye, and Silver Chub. Connected stream networks, and confluences specifically, show higher fish species diversity, proportions of specialized species, and diversity scores than stream networks with cumulative impacts (Benda et al. 2004; Slawski et al. 2008; Thornbrugh and Gido 2009; Cooper et al. 2016). This is most likely due to the possibility of recolonization and recruitment from downstream to upstream segments, lack of dispersal disruptions, and the specific habitat found at confluences (Gorman 1986; Kanehl et al. 1997; Benda et al. 2004; Slawski et al. 2008; Poulos et al. 2014).

Our study focused on the fish assemblages at a small (32 rkm) spatial scale upstream (13 rkm) and downstream (19 rkm) of a lock and dam structure and did not account for habitat differences within a site. Previous large-scale research on fish assemblage structure in Midwestern rivers found local and reach-scale habitat may dictate the presence of specific species of fishes (White et al. 2010; Eitzmann and Paukert 2010; Neebling and Quist 2010; Sindt et al. 2012; Parks et al. 2014). Reach-scale habitat that may have accounted for longitudinal patterns of fish assemblage structure in our study included a tributary confluence, which had a unique assemblage compared to other reaches and is further evidence that tributary confluences may be biological hotspots (Benda et al. 2004; Czegledi et al. 2016)). Previous research also found tributaries to have localized effects downstream of their joining larger streams (Thornbrugh and Gido 2009). In addition, habitat modification such as training structures may also influence the fish community. Although reach 10 was upstream of the LD1, the fish community was unique compared to other upstream reaches, likely because this site was characterized by a large training structure combined with more island and backwater habitat than other reaches (Lobb and Leuckenhoff 2013). The diversity of habitat in this reach resulted in a distinctive assemblage with Flathead Catfish and Goldeye representing the big-river fishes guild and Northern Hogsucker *Hypentelium nigricans* and Shorthead Redhorse *Moxostoma macrolepidotum* representing the riffle or Ozark fishes (Tiemann et al. 2004).

Darters and other species associated with gravel and riffle habitats were more prevalent upstream of LD1 and in reach seven immediately downstream of the structure. Sensitive taxa, such as darters, associate with high-quality riffles and habitat heterogeneity in rivers and streams (Smith et al. 2017). Tiemann et al. (2004) and Gilette et al. (2005) found an increase in abundance of darters at gravel bars downstream of low-head dams on the Neosho River in Kansas when compared to reference gravel bars upstream of structures and further downstream. This pattern was not observed in the Osage River and may be an indication that this habitat is not available downstream of

LD1. Substrate and current velocity likely help structure the fish community at the reach scale (Marsh-Matthews and Matthews 2000; Tiemann et al. 2004; Maloney et al. 2008; Neebling and Quist 2010; Eitzmann and Paukert 2010; Sindt et al. 2012; Parks et al. 2014; Smith et al. 2017). Habitat metrics were not included in this study, but future work may consider adding these measurements to better discern fish community changes in large rivers.

The Lower Osage River had substantial numbers of big-river fishes. Removal or modification of the semi-permeable LD1 could increase distribution of these species in the Osage River and contribute habitat for this group of fishes. Other studies have shown recolonization of upper stream reaches following low-head dam removals or modifications (Kanehl 1997; Catalano et al. 2007; Gardner et al. 2011; Helms et al. 2011; Hogg et al. 2013; Raabe and Hightower 2014) and suggests similar patterns may occur with modifications on the Osage River. Performing studies such as this one before altering habitats can contribute to restoration planning efforts and are important for measuring the effects following modifications.

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Table 2-1. Mean daily water temperature and mean daily discharge for days when sampling occurred and for all days during the four seasonal sampling periods on the Osage River from September 2012- July 2013. Discharge is from the U.S. Geological Survey (USGS) monitoring station (06926510) at St. Thomas, Missouri. Temperature data from temperature logger deployed in the Osage River.

	Fall 2012	Winter 2012-2013	Spring 2013	Summer 2013
Begin date	9/13/2012	12/18/2012	3/27/2013	7/8/2013
End date	10/28/2012	3/7/2013	4/25/2013	7/29/2013
Average Sampling Water Temperature, °C (range)	18.0 (13.1-24.6)	4.2 (2.2-7.3)	8.5 (5.6-11.8)	26.7 (25.0-28.0)
Average Continuous Water Temperature, °C (range)	18.6 (13.9 - 24.4)	6.2 (3.2-9.6)	10.6 (6.7-13.1)	29.2 (27.8-31.4)
Average sampling Discharge, cfs (range)	1,251 (1,034-1,485)	2,701 (1,190-20,551)	28,375 (17,801-36,648)	4,541 (1,538-14,409)
Average continuous Discharge, Cfs (range)	1,290 (1,026-2,627)	2,789 (1,136-20,551)	26,450 (7,668-38,456)	4,798 (1,538-14,409)

Table 2-2. Species, number of fish captured and percent composition (in parentheses) of fish collected by boat electrofishing in the Osage River, September 2012-August 2013. Species codes in bold italic are big-river species. Percent composition calculated by dividing number of individuals of a particular species by total fish captured for each treatment. Proportion big-river species was calculated by dividing number of big-river species by total species richness for each treatment. Species codes are defined in Appendix B.

	Overall		Seasons							
			Fall		Winter		Spring		Summer	
Species	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
BDDR		3 (0.3)		3 (0.8)						
BHCP		2 (0.2)						2 (0.5)		
BMBF	4 (0.2)	2 (0.2)					3 (0.7)		1 (0.2)	2 (1)
BKCP	15 (0.6)	3 (0.3)	1 (0.2)	1 (0.3)	13 (1.5)			2 (0.5)	1 (0.2)	
BLGL	262 (10.3)	256 (24.2)	74 (12.9)	92 (24.9)	86 (9.7)	15 (13.9)	20 (4.6)	80 (21.7)	82 (12.9)	69 (32.9)
BNMW	19 (0.8)	1 (<0.1)	19 (3.3)	1 (0.3)						
BKSS	57 (2.2)	91 (8.6)	4 (0.7)	1 (0.3)	52 (5.8)	55 (50.9)		31 (8.4)	1 (0.2)	4 (1.9)
BHMW	260 (10.2)	5 (0.5)	147 (25.7)		107 (12)	1 (0.9)		4 (1.1)	6 (0.9)	
CNCF	13 (0.5)	7 (0.7)	3 (0.5)	1 (0.3)	2 (0.2)			4 (1.1)	8 (1.3)	2 (1)
CNSN	3 (0.1)						3 (0.7)			
CNLP	1 (<0.1)	1 (<0.1)	1 (0.2)					1 (0.3)		
CARP	19 (0.8)	6 (0.6)	9 (1.6)				2 (0.4)	2 (0.5)	8 (1.3)	4 (1.9)
ERSN	159 (6.3)	3 (0.3)	57 (10)		13 (1.5)		85 (19.3)		4 (0.6)	3 (1.4)
FHCF	14 (0.6)	1 (<0.1)							14 (2.2)	1 (0.5)
FWDM	106 (4.2)	12 (1.1)	26 (4.6)		17 (1.9)	1 (0.9)	7 (1.6)		56 (8.8)	11 (5.2)
GLDR	1 (<0.1)	1 (<0.1)		1 (0.3)					1 (0.2)	
GZSD	745 (29.4)	97 (9.2)	30 (5.2)	4 (1.1)	380 (42.7)		58 (13.2)	69 (18.7)	277 (43.6)	24 (11.4)
GDRH	4 (0.2)	5 (0.5)	2 (0.4)	1 (0.3)					2 (0.3)	4 (1.9)
GDEY	7 (0.3)	1 (<0.1)	3 (0.5)		1 (0.1)				3 (0.5)	1 (0.5)
GSCP	3 (0.1)	5 (0.5)		1 (0.3)			3 (0.7)	3 (0.8)		1 (0.5)
GVCB	1 (<0.1)	4 (0.4)		3 (0.8)	1 (0.1)					1 (0.5)
GNSF	28 (1.1)	16 (1.5)	9 (1.6)	11 (3)	13 (1.5)		6 (1.4)	2 (0.5)		3 (1.4)
GSDR		1 (<0.1)		1 (0.3)						
LMBS	18 (0.7)	9 (0.8)	4 (0.7)	4 (1.1)	6 (0.7)		2 (0.4)	3 (0.8)	6 (0.9)	2 (1)

	Overall		Seasons							
			Fall		Winter		Spring		Summer	
Species	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
LSSR		1 (<0.1)		1 (0.3)						
LGPH	3 (0.1)	5 (0.5)	3 (0.5)	5 (1.4)						
LESF	94 (3.7)	164 (15.5)	28 (4.9)	125 (33.9)	23 (2.6)		7 (1.6)	6 (1.6)	36 (5.7)	33 (15.7)
LNGR	24 (1)	12 (1.1)	2 (0.4)				8 (1.8)		14 (2.2)	12 (5.7)
MMSN	104 (4.1)	1 (<0.1)	6 (1)		63 (7.1)		20 (4.6)	1 (0.3)	15 (2.4)	
OSSF		1 (<0.1)						1 (0.3)		
OTDR		1 (<0.1)		1 (0.3)						
QLBK	1 (<0.1)	2 (0.2)					1 (0.2)			2 (1)
RDSN	54 (2.1)		5 (0.9)		17 (1.9)		17 (3.9)		15 (2.4)	
RESF		3 (0.3)						3 (0.8)		
RVCS	57 (2.2)	15 (1.4)	14 (2.4)	2 (0.5)	14 (1.6)	11 (10.2)	24 (5.4)	1 (0.3)	5 (0.8)	1 (0.5)
RVRH		1 (<0.1)								1 (0.5)
RYSN	31 (1.2)	48 (4.6)	8 (1.4)			8 (7.4)	23 (5.2)	40 (10.8)		
SNSN	9 (0.4)	1 (<0.1)	6 (1)		1 (0.1)	1 (0.9)	2 (0.4)			
SGER	2 (<0.1)		2 (0.4)							
SHRH	3 (0.1)		2 (0.4)						1 (0.2)	
SNGR	26 (1)	11 (1)					8 (1.8)	3 (0.8)	18 (2.8)	8 (3.8)
SVCP	112 (4.4)	13 (1.2)			14 (1.6)	2 (1.8)	98 (22.3)	9 (2.4)		2 (1)
SVCB	5 (0.2)		4 (0.7)		1 (0.1)					
SVRH		1 (<0.1)								1 (0.5)
SJHR	7 (0.3)		3 (0.5)		2 (0.2)				2 (0.3)	
SHDR	4 (0.2)	1 (<0.1)	3 (0.5)	1 (0.3)					1 (0.2)	
SMBS		4 (0.4)		4 (1.1)						
SMBF	12 (0.5)	3 (0.3)	4 (0.7)		3 (0.3)		3 (0.7)	1 (0.3)	2 (0.3)	2 (1)
SFSN	7 (0.3)		7 (1.2)							
STBS	166 (6.6)	159 (15.1)	60 (10.5)	105 (28.5)	34 (3.8)	14 (13)	20 (4.6)	24 (6.5)	52 (8.2)	16 (7.6)
SBWB	2 (<0.1)				1 (0.1)				1 (0.2)	
WRMH		2 (0.2)						2 (0.5)		
WSSN	62 (2.4)	74 (7)	25 (4.4)		17 (1.9)		20 (4.6)	74 (20)		

	Overall		Seasons							
			Fall		Winter		Spring		Summer	
Species	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
MQTF		1 (<0.1)						1 (0.3)		
WTBS	1 (<0.1)								1 (0.2)	
WTCP	10 (0.4)		1 (0.2)		8 (0.9)				1 (0.2)	
YWBS	1 (<0.1)								1 (0.2)	
Fish captured	2,536	1,056	572	369	889	108	440	369	635	210
Species richness	45	46	33	22	25	9	23	25	30	25
Proportion big-river species	0.20	0.11	0.15	0.00	0.12	0.11	0.13	0.04	0.20	0.12
Total species richness	57		41		26		33		37	

Table 2-3. Species, number of fish captured and percent composition (in parentheses) of fish collected by beach seines in the Osage River, September 2012-August 2013. Species codes in bold italic are big-river species. Percent composition calculated by dividing number of individuals of a particular species by total fish captured for each treatment. Proportion big-river species was calculated by dividing number of big-river species by total species richness for each treatment. Species codes are defined in Appendix B.

Species	Overall		Seasons					
			Fall		Winter		Summer	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
BDDR		8 (0.3)		8 (0.4)				
BESN	1 (<0.1)						1 (<0.1)	
BKRH		1 (<0.1)						1 (0.1)
BPTM	3 (<0.1)	18 (0.7)	3 (0.1)	6 (0.3)		2 (2.7)		10 (1.2)
BDSN	793 (13.1)	646 (24)	7 (0.2)				786 (27.7)	646 (76.1)
BLGL	31 (0.5)	21 (0.8)	26 (0.8)	2 (0.1)			5 (0.2)	19 (2.2)
BNMW	29 (0.5)	3 (0.1)		2 (0.1)		1 (1.4)	29 (1)	
BKSS	92 (1.5)	54 (2)	56 (1.8)	35 (2)		10 (13.5)	36 (1.3)	9 (1.1)
BHMW	402 (6.6)	9 (0.3)	377 (12.4)	9 (0.5)	16 (10.4)		9 (0.3)	
CNSN	1 (<0.1)						1 (<0.1)	
ERSN	436 (7.2)	83 (3.1)	361 (11.8)	10 (0.6)	7 (4.6)		68 (2.4)	73 (8.6)
GLDR		3 (0.1)		3 (0.2)				
GZSD	1,415 (23.4)	12 (0.4)					1,415 (49.8)	12 (1.4)
GDRH	2 (<0.1)						2 (<0.1)	
GVCB	66 (1.1)	23 (0.9)	62 (2)	23 (1.3)			4 (0.1)	
GNSF	14 (0.2)	2 (<0.1)	14 (0.5)	2 (0.1)				
LSSR		9 (0.3)		1 (<0.1)				8 (0.9)
LESF	37 (0.6)	9 (0.3)	34 (1.1)	3 (0.2)			3 (0.1)	6 (0.7)
MMSN	921 (15.2)	26 (1)	750 (24.6)	19 (1.1)	100 (64.9)	4 (5.4)	71 (2.5)	3 (0.4)

Species	Overall		Seasons					
			Fall		Winter		Summer	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
MSDR		8 (0.3)		8 (0.4)				
OZMW	3 (<0.1)		1 (<0.1)				2 (<0.1)	
PNSD		1 (<0.1)						1 (0.1)
QLBK	2 (<0.1)						2 (<0.1)	
RDSN	477 (7.9)	13 (0.5)	139 (4.6)		11 (7.1)		327 (11.5)	13 (1.5)
RESF		1 (<0.1)		1 (<0.1)				
RVCS	97 (1.6)	31 (1.2)	96 (3.2)	31 (1.8)	1 (0.6)			
RYSN	181 (3)	233 (8.7)	137 (4.5)	191 (10.8)	7 (4.6)	41 (55.4)	37 (1.3)	1 (0.1)
SNSN	51 (0.8)	71 (2.6)	43 (1.4)	63 (3.6)	1 (0.6)	8 (10.8)	7 (0.2)	
SVRH	1 (<0.1)						1 (<0.1)	
SFSN	133 (2.2)		132 (4.3)				1 (<0.1)	
STBS	18 (0.3)	12 (0.4)	5 (0.2)				13 (0.5)	12 (1.4)
WSSN	459 (7.6)	2 (<0.1)	458 (15)	1 (<0.1)			1 (<0.1)	1 (0.1)
MQTF	377 (6.2)	1,390 (51.7)	349 (11.4)	1,349 (76.3)	11 (7.1)	8 (10.8)	17 (0.6)	33 (3.9)
WTBS	2 (<0.1)						2 (<0.1)	
WTCP	1 (<0.1)	1 (<0.1)					1 (<0.1)	1 (0.1)
Fish captured	6,045	2,690	3,050	1,767	154	74	2,841	849
Species richness	28	27	19	20	8	7	25	17
Proportion big-river species	0.11	0.04	0.05	0.05	0.13	0.14	0.12	0.00
Total species richness	35		25		11		29	

Table 2-4. Species, number of fish captured and percent composition (in parentheses) of fish collected by benthic trawl in the Osage River, September 2012-August 2013. Big-river species codes are in bold italic. Percent composition was calculated by dividing number of individuals of a particular species by total fish captured for each treatment. Proportion big-river species was calculated by dividing number of big-river species by total species richness for each treatment. Species codes are defined in Appendix B.

Species	Overall		Seasons							
			Fall		Winter		Spring		Summer	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
BDDR	1 (<0.1)	52 (3.1)		18 (4.4)	1 (0.6)	30 (8)				4 (7.8)
BESN		127 (7.5)				127 (34)				
BHCP		1 (<0.1)		1 (0.2)						
BLGL	14 (0.9)	8 (0.5)	9 (7.1)		2 (1.2)			6 (0.7)	3 (0.5)	2 (3.9)
BNMW	2 (0.1)	3 (0.2)		3 (0.7)					2 (0.3)	
BHMW	74 (4.6)	45 (2.7)	42 (33.3)	16 (3.9)	24 (13.8)	9 (2.4)	8 (1.2)	16 (1.9)		4 (7.8)
CNCF	17 (1.1)	11 (0.6)	3 (2.4)	3 (0.7)	3 (1.7)	6 (1.6)		1 (0.1)	11 (1.7)	1 (2)
CNSN	16 (1)	175 (10.4)						175 (20.6)	16 (2.5)	
CARP	3 (0.2)		2 (1.6)				1 (0.2)			
FHMW	1 (<0.1)						1 (0.2)			
FHCF	3 (0.2)		2 (1.6)						1 (0.2)	
FWDM	3 (0.2)	1 (<0.1)	2 (1.6)					1 (0.1)	1 (0.2)	
GLDR	61 (3.8)	520 (30.9)	24 (19)	320 (77.7)	6 (3.4)	57 (15.3)	19 (2.8)	142 (16.8)	12 (1.9)	1 (2)
GZSD	41 (2.6)								41 (6.4)	
GDRH		4 (0.2)		1 (0.2)				3 (0.4)		
GVCB	5 (0.3)	73 (4.3)		3 (0.7)	2 (1.2)	32 (8.6)		38 (4.5)	3 (0.5)	
GNSF	1 (<0.1)	3 (0.2)			1 (0.6)			3 (0.4)		
JYDR	1 (<0.1)	1 (<0.1)		1 (0.2)	1 (0.6)					
LGPH	2 (0.1)	4 (0.2)	1 (0.8)	1 (0.2)					1 (0.2)	3 (5.9)

Species	Overall		Seasons							
	Downstream	Upstream	Fall		Winter		Spring		Summer	
			Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
LESF	2 (0.1)	2 (0.1)	2 (1.6)	1 (0.2)						1 (2)
LNGR	1 (<0.1)						1 (0.2)			
MMSN	588 (36.6)	378 (22.4)	3 (2.4)	4 (1)	30 (17.2)	62 (16.6)	239 (35.6)	280 (33)	316 (49.7)	32 (62.8)
MSDR		8 (0.5)		1 (0.2)		4 (1.1)		1 (0.1)		2 (3.9)
NHSK		1 (<0.1)						1 (0.1)		
OTDR		1 (<0.1)				1 (0.3)				
QLBK	1 (<0.1)						1 (0.2)			
RBDR		2 (0.1)						2 (0.2)		
RDSN		6 (0.4)						6 (0.7)		
RVCS	11 (0.7)		2 (1.6)				1 (0.2)		8 (1.3)	
RVRH	1 (<0.1)	1 (<0.1)	1 (0.8)			1 (0.3)				
RYSN		1 (<0.1)		1 (0.2)						
SNSN	4 (0.2)	5 (0.3)	2 (1.6)	4 (1)	2 (1.2)	1 (0.3)				
SHRH	1 (<0.1)	1 (<0.1)						1 (0.1)	1 (0.2)	
SNGR	1 (<0.1)	1 (<0.1)		1 (0.2)					1 (0.2)	
SVCB	19 (1.2)	2 (0.1)	10 (7.9)		1 (0.6)			2 (0.2)	8 (1.3)	
SHDR	1 (<0.1)	8 (0.5)		1 (0.2)		1 (0.3)		5 (0.6)	1 (0.2)	1 (2)
SKCB	2 (0.1)				1 (0.6)		1 (0.2)			
STBS	8 (0.5)	4 (0.2)	7 (5.6)	4 (1)					1 (0.2)	
STCT	1 (<0.1)								1 (0.2)	
WSSN	721 (44.8)	234 (13.9)	14 (11.1)	28 (6.8)	99 (56.9)	42 (11.3)	400 (59.5)	164 (19.3)	208 (32.7)	
MQTF	1 (<0.1)				1 (0.6)					
WTCP		1 (<0.1)						1 (0.1)		

Species	Overall		Seasons							
			Fall		Winter		Spring		Summer	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Fish captured	1,608	1,684	126	412	174	373	672	848	636	51
Species richness	32	32	16	19	14	13	10	19	19	10
Proportion big-river species	0.19	0.06	0.13	0.05	0.14	0.08	0.20	0.05	0.16	0.00
Total species richness	42		26		19		25		23	

Table 2-5. Results from the one-way analysis of variance (ANOVA) for species richness, proportion big-river species and Shannon-Weaver diversity index upstream and downstream of Lock and Dam 1 (LD1) in the Osage River, September 2012-July 2013. Data were log-transformed to better meet the assumptions of normality. Bold italics indicate a significant difference between upstream and downstream of LD1 at the 0.05 level. N=number of reaches sampled; Mean=mean of sample means within a reach; SE=standard error; F=F ratio from ANOVA; P=P value; -- indicates no sampling conducted; # indicates no ANOVA conducted.

	Overall			Fall			Winter			Spring			Summer		
	N	Mean (SE)	F (P)	N	Mean (SE)	F (P)	N	Mean (SE)	F (P)	N	Mean (SE)	F (P)	N	Mean (SE)	F (P)
Species Richness															
Electrofishing															
Downstream	7	26.4 (0.69)	1.49 (0.25)	7	14.0 (1.83)	3.07 (0.11)	***7***	***11.7 (1.25)***	***30.19 (<0.001)***	7	11.9 (1.06)	0.08 (0.79)	7	12.3 (0.64)	0.02 (0.89)
Upstream	4	23.8 (3.33)		4	9.5 (1.19)		***4***	***4.3 (0.63)***		4	11.3 (0.85)		4	13.0 (2.27)	
Seine															
Downstream	6	14.8 (2.04)	0.63 (0.45)	6	10.2 (1.08)	0.003 (0.96)	4	3.3 (1.32)	0.74 (0.43)	0	--	--	6	8.8 (2.83)	0.19 (0.67)
Upstream	4	17.0 (1.96)		4	10.0 (1.08)		3	4.3 (0.88)		0	--		4	8.5 (0.87)	
Trawl															
Downstream	7	11.3 (1.23)	3.87 (0.08)	***7***	***4.3 (0.92)***	***5.49 (0.04)***	***7***	***3.1 (0.96)***	***6.71 (0.03)***	7	2.6 (0.95)	4.65 (0.06)	7	5.7 (1.23)	0.37 (0.56)
Upstream	4	16.5 (2.50)		***4***	***8.0 (1.23)***		***4***	***7.3 (1.11)***		4	6.8 (2.78)		4	4.0 (0.58)	
Proportion Big-River Species															
Electrofishing															
Downstream	***7***	***0.14 (0.01)***	***7.34 (0.02)***	7	0.08 (0.03)	#	7	0.04 (0.02)	0.05 (0.83)	***7***	***0.09 (0.02)***	***5.71 (0.04)***	7	0.16 (0.02)	4.59 (0.06)
Upstream	***4***	***0.06 (0.03)***		4	0 (0)		4	0.04 (0.04)		***4***	***0.02 (0.02)***		4	0.08 (0.03)	
Seine															
Downstream	6	0.05 (0.02)	0.64 (0.45)	6	0.04 (0.02)	4.38 (0.07)	4	0.05 (0.05)	1.06 (0.35)	0	--	--	6	0.05 (0.03)	#
Upstream	4	0.06 (0.01)		4	0.10 (0.01)		3	0.14 (0.07)		0	--		4	0 (0)	
Trawl															
Downstream	7	0.14 (0.03)	2.28 (0.17)	7	0.11 (0.07)	0.68 (0.43)	7	0.10 (0.07)	0.20 (0.66)	7	0.04 (0.04)	0.002 (0.97)	7	0.11 (0.05)	#
Upstream	4	0.05 (0.02)		4	0.02 (0.02)		4	0.03 (0.03)		4	0.02 (0.02)		4	0 (0)	
Shannon-Weaver diversity index															
Electrofishing															
Downstream	7	2.4 (0.12)	1.70 (0.23)	***7***	***2.0 (0.14)***	***6.87 (0.03)***	7	1.7 (0.21)	2.2 (0.17)	7	1.8 (0.20)	1.36 (0.27)	7	1.86 (.21)	0.04 (0.84)
Upstream	4	2.1 (0.21)		***4***	***1.5 (0.11)***		4	1.0 (0.19)		4	1.4 (0.17)		4	1.90 (0.23)	
Seine															
Downstream	6	1.6 (0.16)	0.75 (0.41)	6	1.7 (0.10)	5.18 (0.05)	4	0.5 (0.31)	2.078 (0.21)	0	--	--	6	0.7 (0.16)	1.64 (0.24)
Upstream	4	1.4 (0.39)		4	1.0 (0.27)		3	1.1 (0.19)		0	--		4	1.0 (0.19)	
Trawl															
Downstream	7	1.5 (0.11)	2.14 (0.18)	7	1.1 (0.18)	0.09 (0.77)	7	0.6 (0.19)	3.84 (0.08)	7	0.4 (0.17)	3.39 (0.10)	7	0.9 (0.19)	0.55 (0.48)
Upstream	4	1.8 (0.23)		4	1.1 (0.39)		4	1.4 (0.20)		4	1.0 (0.23)		4	1.2 (0.27)	

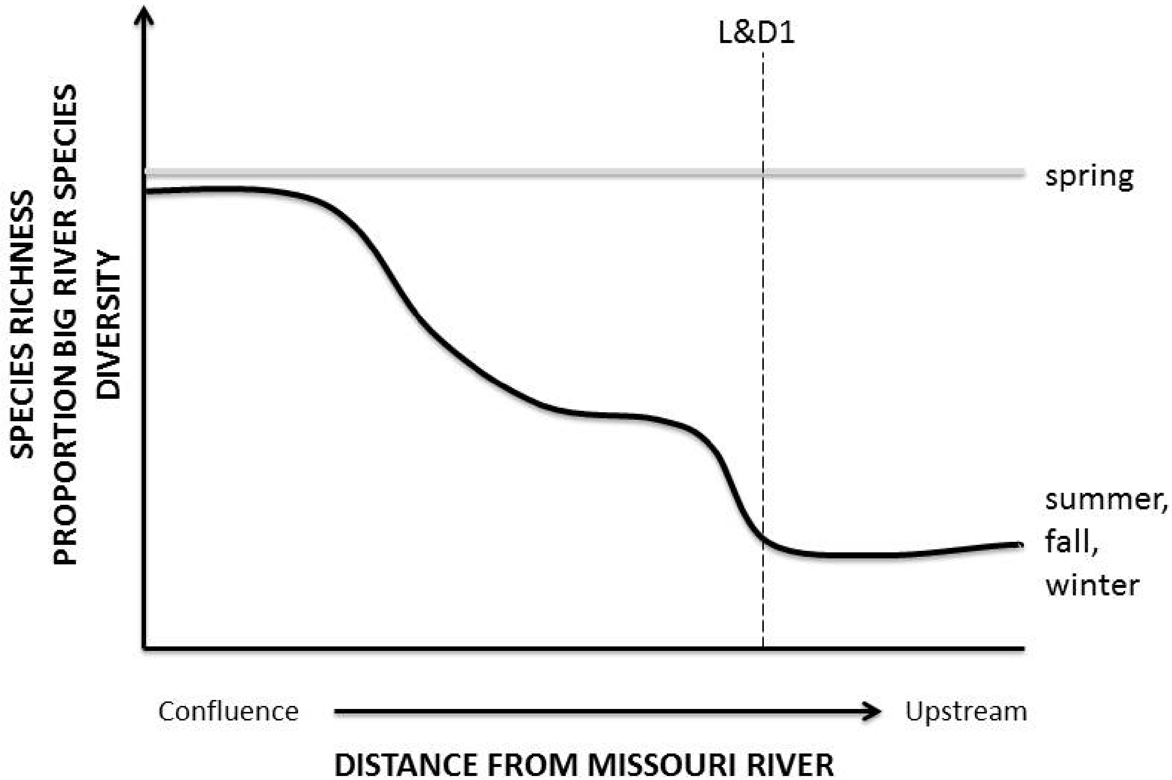

Figure 2-1. Conceptual model of species richness, proportion big-river species, and Shannon-Weaver diversity index in the lower Osage River. The hypothesis is that all metrics will be greatest in study reaches closest to the Missouri River confluence except in spring when the lower Osage River will homogenize and all study reaches will have similar measurements. The Lock and Dam (LD1) on the Osage River will act as a semi-permeable barrier except during spring when high discharge overtopping the dam will allow movement of fish over the barrier.

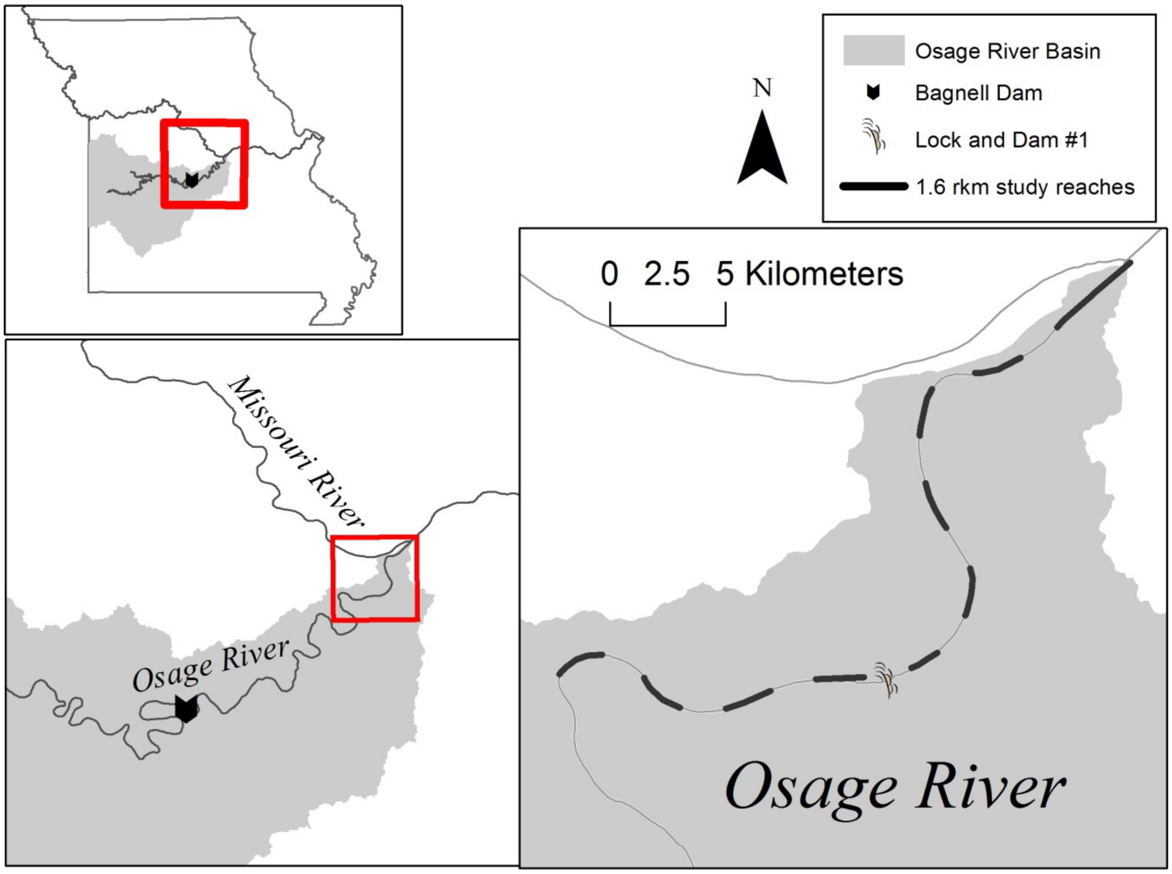

Figure 2-2. Osage River study area in central Missouri, September 2012 - July 2013. Sampling was conducted in the lower 32 rkm of the Osage River, upstream of the Missouri River confluence in central Missouri. Eleven 1.6 rkm reaches were systematically established every 3.2 rkm except at the confluence with the Missouri River where two consecutive reaches were sampled.

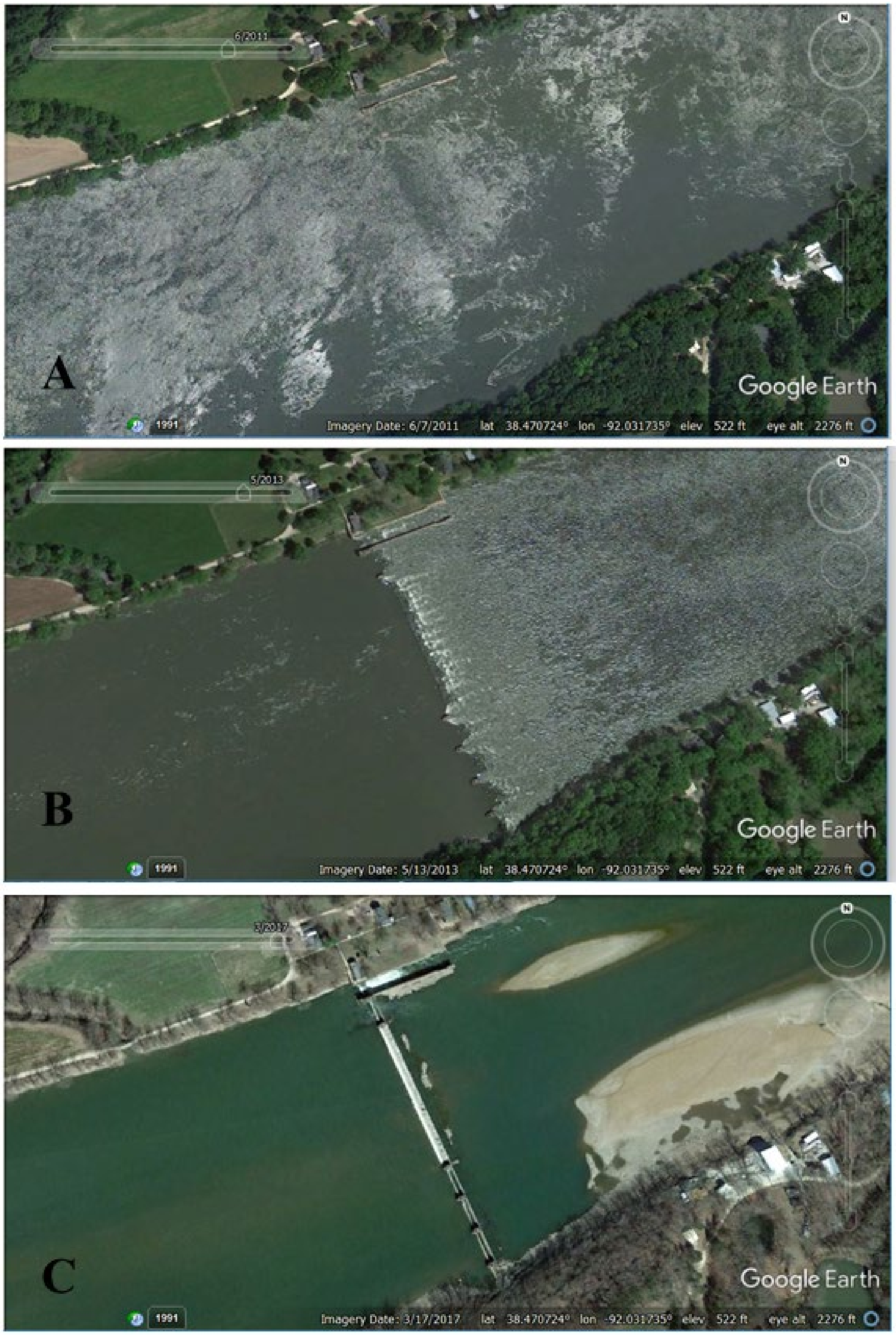

Figure 2-3. Osage Lock and Dam #1 (LD1) is located on the Osage River 19 river kilometers upstream of the Missouri River confluence and 111 river kilometers downstream of Bagnell Dam. These three Google Earth images from (A) June 2011, (B) May 2013, and (C) March 2017 show the range of conditions that contribute to permeability.

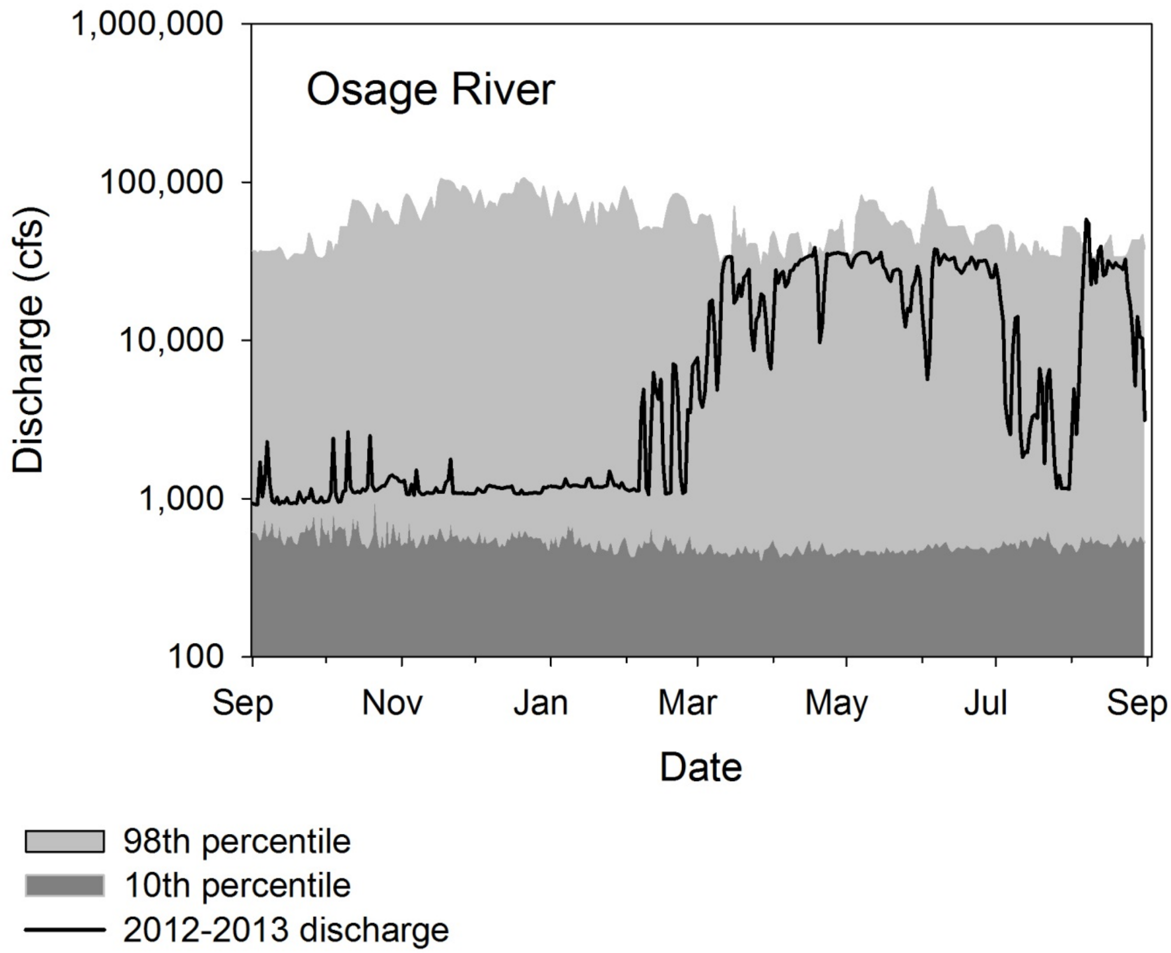

Figure 2-4. Osage River flow duration hydrograph using data from 1925-2013 the 10th (dark grey shaded area) and 98th (light gray shaded area) percentiles were calculated and the mean daily discharge (black line) from September 2012 - August 2013 was overlaid.

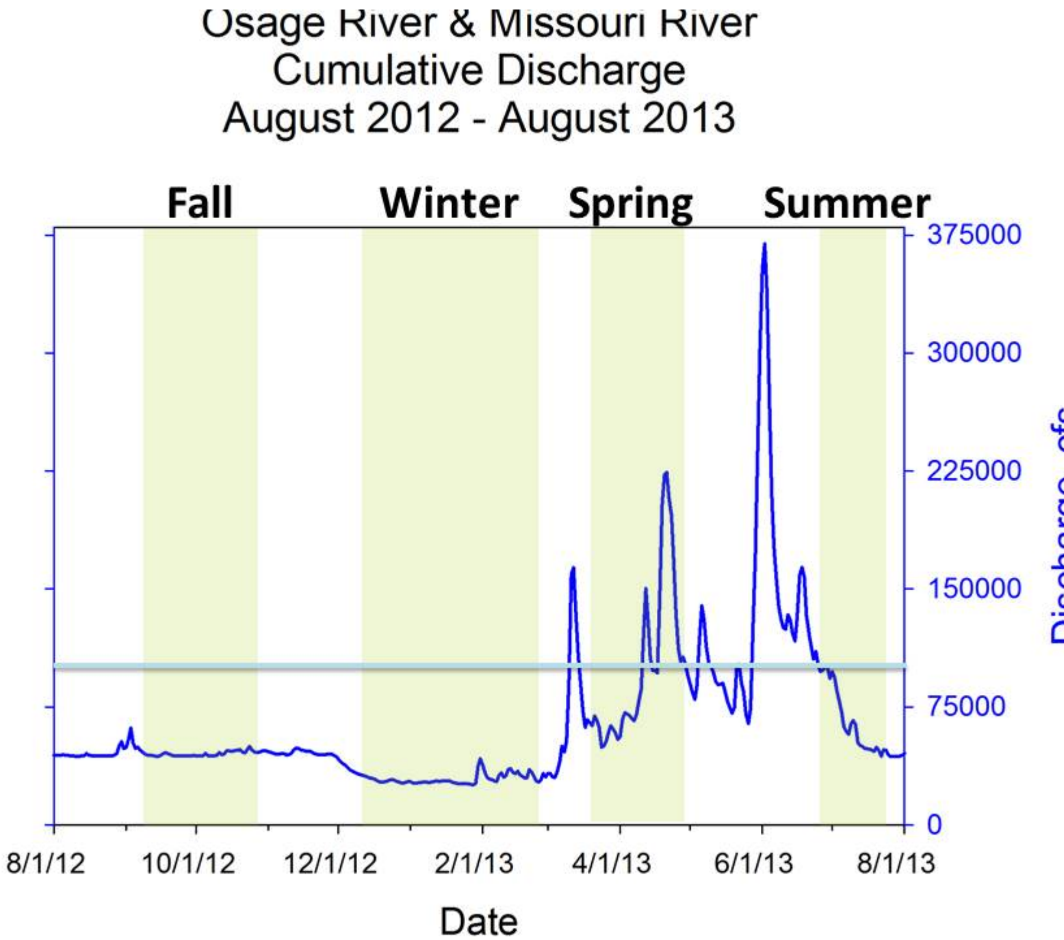

Figure 2-5. Osage River and Missouri River discharge combined with season highlighted and the reference line for 105,000 cfs (2975 cms) which allows passage upstream of Osage Lock and Dam 1 (Lallaman 2012).

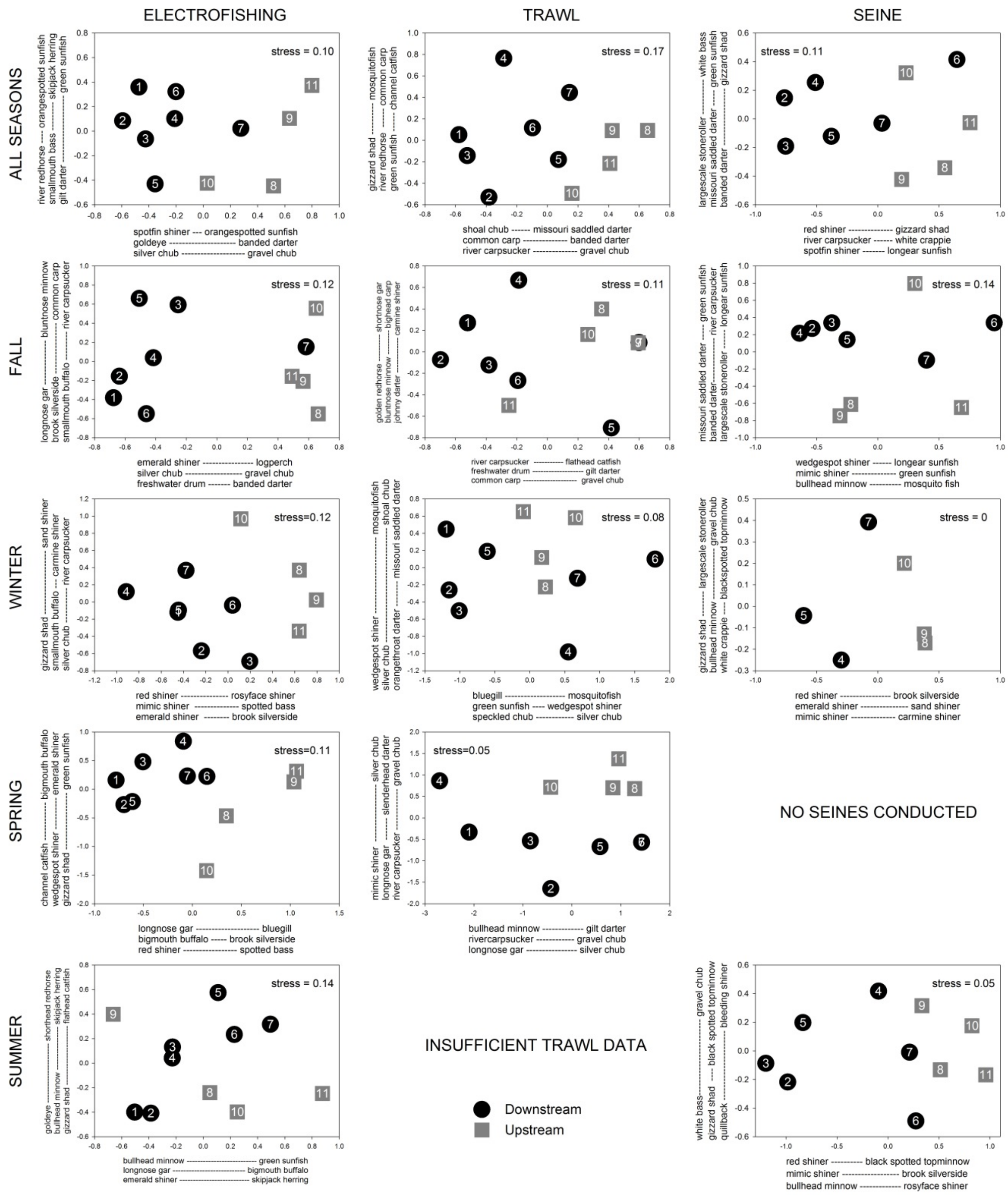

Figure 2-6. Nonmetric multidimensional scaling (NMDS) of species abundances captured in boat electrofishing, benthic trawls, and beach seines in the Osage River, September 2012- July 2013. There was insufficient trawl data to run the analysis for summer 2013 and no seining was conducted in spring 2013 due to a lack of habitat. Reach numbers are given in the symbols. Reaches were numbered consecutively with 1 closest to the Missouri River confluence and 11 furthest upstream.

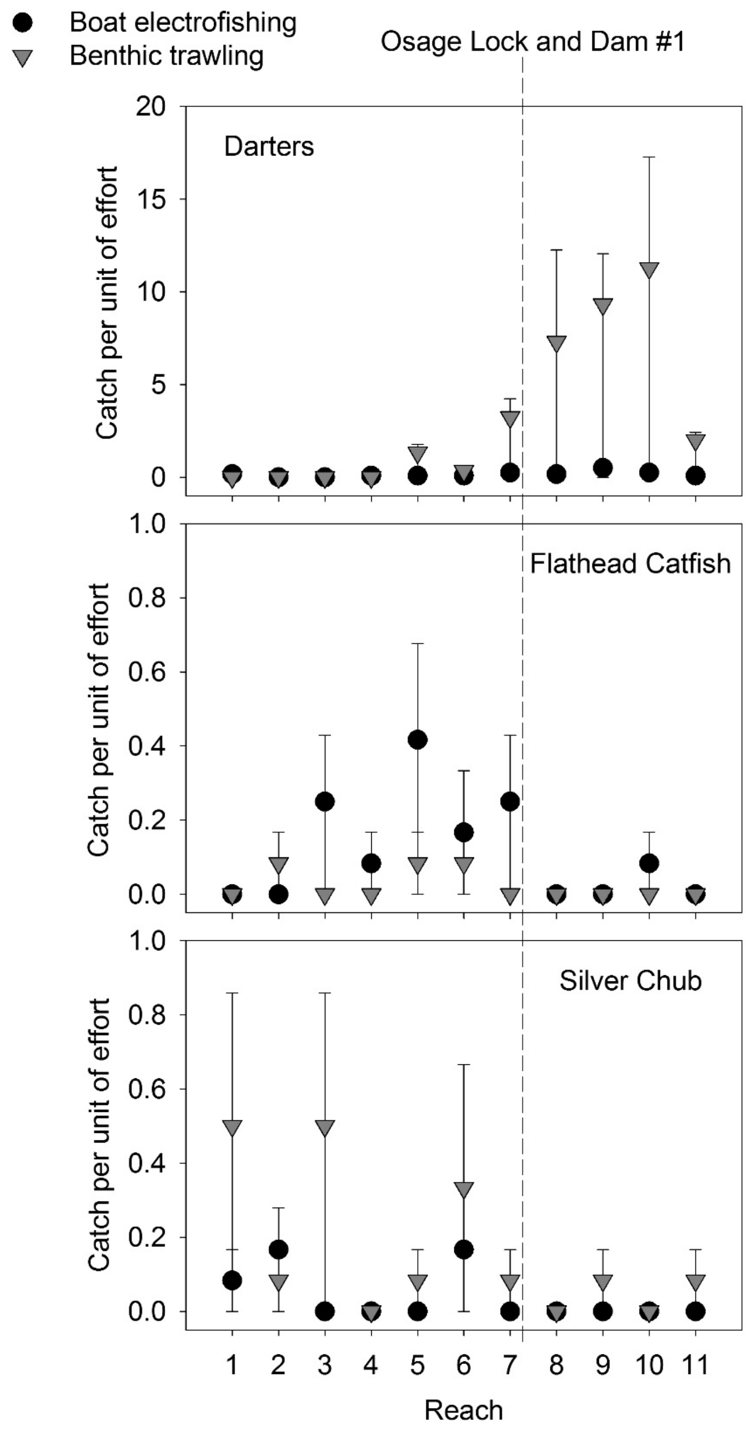

Figure 2-7. Catch per unit of effort (CPUE) of darters (Etheostoma and Percina species), Flathead Catfish, and Silver Chub captured in the Osage River, September 2012 - July 2013 with boat electrofishing (circles) and benthic trawls (triangles). CPUE calculated as fish per 5 minutes electrofishing and per 100 meters trawled. Errors bars represent standard error of mean CPUE. Osage Lock and Dam #1 position indicated by dashed vertical line between reaches 7 and 8. Note Y-axis scales are different.

Appendix B

Species codes, common names and scientific names

Species Code	Common Name	Scientific Name
BDDR	Banded darter	*Etheostoma zonale*
BDSN	Bleeding shiner	*Luxilus zonatus*
BESN	Bigeye shiner	*Notropis boops*
BHCP	Bighead carp	*Hypopthalmichthys nobilis*
BHMW	Bullhead minnow	*Pimephales vigilax*
BKCP	Black crappie	*Pomoxis nigromaculatus*
BKRH	Black redhorse	*Moxostoma duquesnei*
BKSS	Brook silverside	*Labidesthes sicculus*
BLGL	Bluegill	*Lepomis macrochirus*
BMBF	Bigmouth buffalo	*Ictiobus cyprinellus*
BNMW	Bluntnose minnow	*Pimephales notatus*
BPTM	Blackspotted topminnow	*Fundulus olivaceus*
CARP	Common carp	*Cyprinus carpio*
CNCF	Channel catfish	*Ictalurus punctatus*
CNLP	Chestnut lamprey	*Ichthyomyzon castaneus*
CNSN	Channel Shiner	*Notropis subspecies*
ERSN	Emerald shiner	*Notropis atherinoides*
FHCF	Flathead catfish	*Pylodictus olivaris*
FHMW	Fathead minnow	*Pimephales promelas*
FWDM	Freshwater drum	*Aplodinotus grunniens*
GDEY	Goldeye	*Hiodon alosoides*
GDRH	Golden redhorse	*Moxostoma erythrurum*
GLDR	Gilt darter	*Percina evides*
GNSF	Green sunfish	*Lepomis cyanellus*
GSCP	Grass carp	*Ctenopharyngodon idella*
GSDR	Greenside darter	*Etheostoma blennioides*
GVCB	Gravel chub	*Erimystax punctatus*
GZSD	Gizzard shad	*Dorosoma cepedianum*
JYDR	Johnny darter	*Etheostoma nigrum*
LESF	Longear sunfish	*Lepomis megalotis*
LGPH	Logperch	*Percina caprodes*
LMBS	Largemouth bass	*Micropterus salmoides*
LNGR	Longnose gar	*Lepisosteus osseus*
LSSR	Largescale stoneroller	*Campostoma oligolepis*
MMSN	Mimic shiner	*Notropis volucellus*
MQTF	Western Mosquitofish	*Gambusia affinis*

Species Code	Common Name	Scientific Name
MSDR	Missouri saddled darter	*Etheostoma tetrazonum*
NHSK	Northern hog sucker	*Hypentelium nigricans*
OSSF	Orangespotted sunfish	*Lepomis humilis*
OTDR	Orangethroat darter	*Etheostoma spectabile*
OZMW	Ozark minnow	*Notropis nubilus*
PNSD	Pumpkinseed	*Lepomis gibbosus*
QLBK	Quillback	*Carpiodes cyprinus*
RBDR	Rainbow darter	*Etheostoma caeruleum*
RDSN	Red shiner	*Cyprinella lutrensis*
RESF	Redear Sunfish	*Lepomis microlophus*
RVCS	River carpsucker	*Carpiodes carpio*
RVRH	River redhorse	*Moxostoma carinatum*
RYSN	Rosyface shiner	*Notropis rubellus*
SBWB	Striped bass x White bass	*Morone saxatilis x Morone chrysops*
SFSN	Spotfin shiner	*Cyprinella spiloptera*
SGER	Sauger	*Sander canadense*
SHDR	Slenderhead darter	*Percina phoxocephala*
SHRH	Shorthead redhorse	*Moxostoma macrolepidotum*
SJHR	Skipjack herring	*Alosa chrysochloris*
SKCB	Speckled chub	*Macrhybopsis aestivalis*
SMBF	Smallmouth buffalo	*Ictiobus bubalus*
SMBS	Smallmouth bass	*Micropterus dolomieu*
SNGR	Shortnose gar	*Lepisosteus platostomus*
SNSN	Sand shiner	*Notropis stramineus*
STBS	Spotted bass	*Micropterus punctulatus*
STCT	Stonecat	*Noturus flavus*
SVCB	Silver chub	*Macrhybopsis storeriana*
SVCP	Silver carp	*Hypopthalmichthys molitrix*
SVRH	Silver redhorse	*Moxostoma anisurum*
WRMH	Warmouth	*Lepomis gulosus*
WSSN	Wedgespot shiner	*Notropis greenei*
WTBS	White bass	*Morone chrysops*
WTCP	White crappie	*Pomoxis annularis*
YWBS	Yellow bass	*Morone mississippiensis*

CHAPTER 3 REPRODUCTION IN THE OSAGE AND GASCONADE RIVER BASINS

Abstract

Environmental variables such as water temperature and discharge often trigger reproduction in fish, but river regulation may disrupt these cues. This study investigated the influence of river regulation in the Osage River on reproductive biology of fishes by comparing sex and reproductive readiness of Golden Redhorse and Spotted Bass in the regulated Osage River and the neighboring Gasconade River, a free-flowing tributary of the Missouri River. Gonadosomatic index (GSI) and histological observation of gonads were collected from February 2013 through July 2013 and were used as indicators of reproductive readiness. Mean GSIs did not differ between rivers for female Golden Redhorse (t=1.487, df=62, P = 0.142), male Golden Redhorse (t = 0.141, df=10, P = 0.890), female Spotted Bass (t = -0.365, df=48, P = 0.717), or male Spotted Bass (t = 1.102, df=47, P = 0.276). For all species and sex combinations except male Spotted Bass, GSI was significantly higher at the spawning capable phase (phase III) as identified through histology. Linear regression models exploring patterns of female Golden Redhorse GSI suggested that cooler water temperatures and discharge slightly higher than average best predicted reproductive readiness regardless of river. The top-ranked model for predicting female Spotted Bass GSI indicated that average spring discharge occurring in April and May best predicted reproductive readiness in the regulated Osage River. One intersex Spotted Bass caught in the Gasconade River was identified by histology. Histology of gonads also enabled the identification of Golden Redhorse sex that were unidentifiable during visual observation. Our results suggest that the cues for reproductive readiness in the regulated Osage River and the free-flowing Gasconade

River do not differ for Golden Redhorse yet the regulated Osage River may favor Spotted Bass.

Introduction

Temperature and flow are often cues triggering distribution, movement, and spawning of fish. Impounding of rivers can modify discharge and moderate water temperatures, altering the presence and timing of fish reproduction (Agostinho 2004; Dallas 2008; Craven et al. 2010; Olden and Naimen 2010; Weber 2013). Discharge, water temperature, and photoperiod, alone or in combination, are thought to cue reproductive behaviors in fishes (Okuzawa et al. 1989; Pankhurst and Porter 2003; Shimizu 2003; Delonay et al. 2009; Miller et al. 2011). Pankhurst and Porter (2003) found photoperiod to be the environmental cue initiating reproductive activity with water temperature synchronizing the final stages of reproductive development and signaling the end of the reproductive episode. In the Missouri River, Montana, Paddlefish *Polyodon spathula* spawn in the spring during peaking discharge and seasonally warming water temperatures (Miller et al. 2011) while Redhorse (*Moxostoma* spp.) spawning in Michigan rivers was correlated with the timing of suitable water temperatures and flow levels, respectively (Reid 2006). Similarly, high water levels in the beginning of summer were important for the successful spawning of migratory species in neotropical rivers (Agostinho 2004) while regulated rivers show decreased successful spawning (Weber 2013).

Despite alterations in rivers and their tributaries, fish spawning continues to occur. Reproductive female Paddlefish were documented on the Osage River downstream of Bagnell Dam (Lallaman 2012). Another migratory big-river fish, the Blue Sucker

Cycleptus elongatus, was observed spawning in the Grand River, Missouri, a larger tributary to the channelized lower Missouri River (Vokoun et al. 2003). Although adult reproductive Paddlefish and Blue Sucker were observed in these Missouri River tributaries, no larvae were recovered. In contrast, Brown and Coon (1994) captured Blue Sucker and Paddlefish larvae at the confluence of the Lamine and Missouri rivers, but no effort was made to detect the source of these larvae. However, these studies suggest that some big-river fish species are utilizing the larger tributaries of the Missouri River during one or more portions of their life cycles.

This study investigated the influence of river regulation in the Osage River on reproductive biology of fishes by comparing sex and reproductive readiness of Golden Redhorse *Moxostoma erythrurum* and Spotted Bass *Micropterus punctulatus* in the Osage River as well as the neighboring Gasconade River, a free-flowing tributary of the Missouri River. The Golden Redhorse is an abundant native riverine species that is found in slightly turbid, warmer rivers (Pflieger 1997). They migrate into tributaries to spawn on sand/gravel substrates between 15-21°C and then move downstream after spawning is complete, potentially influenced by increasing discharge (Curry and Spacie 1984; Kwak and Skelly 1992; Pflieger 1997; Grabowski and Isely 2007). Spotted Bass are the most abundant black bass in larger Missouri streams inhabiting warmer, slightly turbid, permanent-flowing waters and reservoirs (Pflieger 1997; Johnson et al. 2009). Spotted Bass nesting activity is most intense from 14-23°C in stream pools of various substrates (Pflieger 1997; Warren 2009). Spotted bass species are not migratory fish and have small home ranges (Todd and Rabeni 1989) making them a good reference species to compare the spawning timeframe compared to a migratory species like the Golden Redhorse.

Physiology data regarding sex and reproductive condition of individual fish contributes valuable information when interpreting the behavior of a population and the importance of habitat and environmental cues. Reproductive readiness of fish has been investigated by several techniques: macroscopic observation of gonads, gonadosomatic indices (GSI), and histology (Guiguen et al. 1993; Okuzawa et al. 1989; Wildhaber et al. 2007; Hinck et al. 2009; Rehulka 2013). Gonadosomatic index, GSI, is the proportion of body weight that is gonadal tissue and is often used in combination with other methods to determine reproductive readiness of a population. Gonad histology, a microscopic examination of gonad cells and tissue used to both identify phenotypic sex and classify individuals into specific reproductive phases (Leino and McCormick 1997; Wildhaber et al. 2007; Fox 2010; Brown-Peterson et al. 2011; Lowerre-Barbieri et al. 2011), is one method to determine reproductive condition of fishes. Histological examination of the ovaries has been used to identify repeat spawning events of the Eurasion ruffe *Gymnocephalus cernuus* in Lake Superior (Leino and McCormick 1997), the timing of the spawning season of Yellow Bass *Morone mississippiensis* in the Barataria Estuary, Louisiana (Fox 2010), the variability in reproductive timing of marine fishes (Lowerre-Barbieri et al. 2011), and the spawning chronologies of river-dwelling fishes in Missouri (Brewer et al. 2006; Papoulias et al. 2006).

This study will investigate the influence of river regulation in the Osage River on reproductive biology of fishes by comparing sex and reproductive readiness of Golden Redhorse and Spotted Bass in the Osage River as well as the neighboring Gasconade

River, a free-flowing tributary of the Missouri River. I hypothesize that Golden Redhorse and Spotted Bass will be collected in spawning capable reproductive condition (as indicated by increased GSI and histological examination of the gametes) in the Osage and Gasconade Rivers and that spawning capable fish from their respective tributaries will be synchronized. These hypotheses are generated by the theories that photoperiod and water temperature initiate spawning cycles and discharge provides final cues for release of gametes (Okuzawa et al. 1989; Pankhurst and Porter 2003; Shimizu 2003; Miller et al. 2011). Furthermore, I hypothesize that Golden Redhorse and Spotted Bass in the Gasconade River will appear in reproductive condition before the Osage River because the Gasconade River water temperatures warm up earlier in the spring than the Osage River (Figure 3-1). Moreover, I hypothesize that high GSI will be associated with the spawning capable phase defined as the fish being capable of spawning due to advanced gamete development, measured by a majority of eggs in the tertiary vitellogenesis stage in females (Brown-Peterson et al. 2011). I hypothesize that water temperature and discharge will influence reproductive readiness and spawning of Golden Redhorse and Spotted Bass. Quist and Speigel (2011) did not find discharge and temperature to have an effect on recruitment of Golden Redhorse, but they encouraged others to investigate this pattern in other river systems since none of their study sites were influenced by large dams.

Methods

Study area and reaches

The Osage and Gasconade rivers, an eighth-order stream and a sixth-order stream at their respective confluences with the Lower Missouri River, enter the mainstem

Missouri River approximately 40 river kilometers (rkm) apart in central Missouri, with the Osage River confluence upstream of the Gasconade (Figure 3-3). Study reaches encompassed the lower 19 rkm of the Gasconade River and 32 rkm of the Osage River, upstream of their confluences with the Missouri River, in central Missouri (Figure 3-3).

The Osage River is impounded by Bagnell Dam at rkm 130 leaving 130 river km of regulated river between the dam and the confluence of the Missouri River. The current Federal Energy Regulatory Commission license dictates Bagnell Dam will have a regulated minimum discharge of 25.5 cubic meters per second (cms), but also includes seasonally varying caps limiting the prescribed minimum flow and rules for post-flood ramp down and re-aeration flows following power generation. This regulation has altered the downstream water temperature so the Osage River warms up slower in the spring, is cooler in summer, warmer in winter, and less variable throughout the day than the unregulated Gasconade River (Figure 3-1 and Figure 3-2).

In contrast to the Osage River, the Gasconade River is free-flowing for nearly 500 rkm and water temperatures approach the optimum temperatures to cue migration and spawning of Catostomids (i.e., 16-27°C; Catalano and Bozek 2015; Straight et al. 2015) and Spotted Bass (14-23°C; Pflieger 1997; Warren 2009) approximately two weeks before the Osage River (Figure 3-1). In addition, the Gasconade River exhibits a natural flow regime with high water events more frequent in the spring tapering off to seasonally low flows whereas the Osage River exhibits highly fluctuating flows of up to 2 m per day (Figure 3-2).

Environmental data

Water temperature was collected every 15 minutes during the study period by temperature loggers deployed by U.S. Geological Survey, Columbia Environmental Research Center in the Gasconade and Osage rivers. River discharge data was obtained from waterwatch.usgs.gov for the following stream gages: 06926510 at St. Thomas, Missouri for the Osage River; 06934000 at Rich Fountain, Missouri for the Gasconade River; and 06909000 at Boonville, Missouri for the Missouri River. Mean water temperatures on the days of sampling and mean daily discharge as a proportion of the previous six-year average discharge between February and August 2013 were calculated in Microsoft Access.

Fish collections

Fish were collected twice per month from February 2013 through July 2013 in each tributary generally with two weeks between samples and additional days spent in the Osage River each month to sample the entire 32 rkm reach. Collections were made by boat electrofishing conducted during daylight hours by a crew of one boat operator and two netters outfitted with 3 mm mesh, long-handled dip nets. A Midwest Lake Electrofishing Systems (Polo, MO) Infinity electrofishing box with pulsed direct current at 60 Hz and 40% duty cycle was used to target the power (watts) and amps to the recommended levels by Miranda (2009) for the ambient conductivity of the water at sampling time. Downstream longitudinal transects targeted bankline, bar, and channel border habitats less than three meters deep.

Gonad collection and histology

Spotted Bass and Golden Redhorse length at maturity is 250 mm and 218 mm, respectively (Pflieger 1997). To obtain a wide range of maturity levels, Spotted Bass and Golden Redhorse greater than 200 mm were weighed, measured, and necropsied to obtain gonads. Sex was determined by gross observation of the gonads. Removed gonads were weighed wet to the nearest hundredth of a gram and their size was specified as a percentage of total body weight. This gonadosomatic index (GSI) was calculated as [gonad weight]/[total weight-gonad weight] X 100.

Histology of the gonads was used to confirm sex determined by gross observation, determine the sex of individuals whose sex was indeterminable by gross observation, and determine the reproductive phase defined by Brown-Peterson et al. (2011; Table 3-1). Brown-Peterson et al. (2011) used macroscopic and histological features to identify five phases in the reproductive cycle that can be applied to all male and female teleost fishes. Following the removal and weighing of gonads, one section 3-5 mm^2 was removed from the anterior, middle, and posterior sections of one gonad lobe. The three sections were stored in labeled histology cassettes and preserved in 10% neutral buffered formalin. Preparation of tissues followed standard histological techniques described in Papoulias et al. (2006). Following processing, tissues were embedded in paraffin wax, sliced in 5–6 micron sections, placed on slides, and stained. A minimum of three samples was obtained from each embedded gonad. Slide-mounted sections were stained with hemotoxylin and counter-stained with eosin. Mounted and stained tissues were observed under a microscope to confirm or determine sex and reproductive phase.

Determining reproductive phase

The reproductive phase was determined per the definitions outlined by Brown-Peterson et al. (2011; Table 3-1). Individuals identified as “immature” (phase I) have macroscopically indiscernible gonads, have never spawned, and are not yet capable of spawning. The “developing” phase II is characterized by identifiable and vascularized gonads with growing and developing gametes. “Spawning capable” (phase III) are fishes whose gonads are large with gametes of various mature stages. The “regressing” phase IV is the cessation of spawning and is characterized by flaccid gonads containing residual gametes. A fish in the “regenerating” phase V is sexually mature, as indicated by the presence of a combination of immature and residual gametes, but reproductively inactive.

Data analysis

Sex ratios for each river and species were calculated as the number of fish of each sex divided by the total number of fish. The mean differences in GSI between tributaries of each species and sex combination were compared using a *t*-test. A one-way Analysis of Variance (ANOVA) was used to compare mean GSI among phases of a given sex by species. For statistically significant mean GSIs, pairwise comparisons were tested using a Bonferroni *t*-test. All of these analyses were completed in SigmaPlot 11.

Utilizing an information-theoretic approach, seven linear regression models were developed *a priori* to evaluate environmental variables including date, water temperature, and discharge as predictors of GSI for females of each species in the regulated Osage River and the unregulated Gasconade River (Table 3-2). GSI data were log-transformed to better meet the assumptions of normality prior to running linear models. The water temperature variable was the mean water temperature at day of capture while the discharge variable was the mean daily discharge as a proportion of the previous six-year average discharge between February and August. To account for the bell curve shape of the raw GSI data in relation to mean daily water temperature and mean daily discharge data over the study period, a parabolic form of the discharge and water temperature measurements were included in select models (Figure 3-4). River was used as a covariate in all models to determine if these patterns differ by river. Linear models were run in R using the R Stats Package (version 2.15.0; R Development Core Team 2011) and compared using Akaike's Information Criterion for small sample sizes (AICc) with the aictab function in the AICcmodavg package (Mazerolle 2013) and the model select function (mod.sel) in the multi-model inference (MuMIn) package (Barton 2013). The model with the lowest AICc value was considered the best-fit model from the candidate set. However, those with ΔAICc less than or equal to two were considered "equal" (Burnham & Anderson 2002).

Results

In 34 days of sampling (21 in the Osage River and 13 in the Gasconade), 77 Golden Redhorse (238 to 525 mm total length) and 100 Spotted Bass (201 to 417 mm total length) were captured between February 6 and July 25, 2013 in the Gasconade and Osage rivers. The two rivers had similar male to female ratios for both species (Table 3-3). Overall sex ratios between the two rivers were 84% female and 16% male for Golden Redhorse and 50% female, 49% male, and 1% intersex for Spotted Bass. In the Gasconade River, 35 Golden Redhorse were captured, of which 83% were female (n=29) and 17% were male (n=6). In the Osage River, 42 Golden Redhorse were captured, of which 86% were female (n=36) and 14% were male (n=6). Forty-one Spotted Bass were captured in the Gasconade River, of which 51% were female (n=21) and 46% were male (n=19). Fifty-nine Spotted Bass were captured in the Osage River, of which 49% (n=29) were female and 51% (n=30) were male. One intersex Spotted Bass caught in the Gasconade was identified by histology but not by gross observation of gonads (Figure 3-5).

Histology identified 100% of the six Golden Redhorse identified as "unknown" sex during visual observation of the gonads. Half were identified as female with one each of the immature phase I (238 mm), phase II (488 mm) and phase V (322 mm). Similarly, three males were identified with one each of phase I (321 mm), phase II (270 mm) and phase V (298 mm).

Mean GSI did not differ between rivers for female Golden Redhorse (t=1.487, df=62, P = 0.142), male Golden Redhorse (t = 0.141, df=10, P = 0.890), female Spotted Bass (t = -0.365, df=48, P = 0.717), or male Spotted Bass (t = 1.102, df=47, P = 0.276). For all species and sex combinations except male Spotted Bass, GSI was significantly higher at phase III (Table 3-4) and was typically 2.5 to 47 times higher than Phase II fish. Male GSI of either species was not analyzed further due to insignificance between reproductive phases and small sample sizes.

Linear regression models explaining patterns of female Golden Redhorse GSI suggested that the model including water temperature, mean daily discharge, and river (the "Temp + Flow" model) was the best fit with an Akaike weight of 0.82, which is nearly 5 times that of the second ranked Global model. Temperature was a substantial predictor in the top model (Table 3-5) with Golden Redhorse GSI decreased to near zero indicating fish were no longer reproductive after water temperatures reached 15°C (Figure 3-4 B), regardless of river. Although temperature was correlated with date (r=0.96; Figure 3-2), date was not a substantial predictor in the top models, likely because female Golden Redhorse maximum GSI in the Osage was nearly 2 months earlier than the Gasconade River. Although not a substantial predictor, discharge was correlated with high female Golden Redhorse GSI, including the maximum GSI in the Gasconade River captured during a high water event (Figure 3-4 C).

The top-ranked model for predicting female Spotted Bass GSI included Julian day, discharge, and river (the "Day + Flow" model) with an Akaike weight of 0.6, which is 4 times that of the second ranked "Day" model. In the "Day + Flow" model, all the variable coefficients were important (Table 3-5). Female Spotted Bass were found in reproductive condition (phase III) from February until June with the highest GSIs (>8%) observed between April 25 – May 23, 2013 (Figure 3-4 D). Although both rivers produced female Spotted Bass with high GSIs, four of the six maximum GSIs observed during that time were captured in the Osage River (Figure 3-4). Unlike female Golden Redhorse, female Spotted Bass GSI was not correlated with the highest discharges but those closer to average when the proportion of average spring discharge was approaching 1 (Figure 3-4 F). Temperature was not a component in the top model most likely because of the differences in water temperature between the two systems and the temperatures did not correlate with date and discharge for the highest GSI values in these additive linear regression models.

Discussion

Our results suggest that the cues for reproductive readiness in the regulated Osage River and the free-flowing Gasconade River do not differ for Golden Redhorse yet conditions for Spotted Bass spawning – average discharge and day – were more closely synchronized in the regulated Osage River in spring 2013. As hypothesized, our study found that temperature and discharge were correlated with reproductive condition of female Golden Redhorse; however, river regulation did not diminish these reproductive cues as was hypothesized. The Golden Redhorse is a migratory species that uses warming spring temperatures to move into smaller streams and then disappear following the first spring rise when spawning is complete (Pflieger 1997). As we hypothesized based on this spawning strategy, water temperature was a strong predictor of GSI. Golden Redhorse had completed spawning by time water temperatures were 15°C and water temperature was our top predictor of female Golden Redhorse GSI. These results are similar to research on Robust Redhorse *Moxostoma robustum* in Georgia where spawning rates declined with increasing water temperatures in both regulated and unregulated rivers (Straight et al. 2015). On the Baraboo River in Wisconsin, temporal variation in Catostomid reproductive condition appeared to be driven by complex interactions among species and environmental cues, including short-term variation in water temperature and discharge (Catalano and Bozek 2015). Although proportion of spring discharge was a component of the top model predicting female Golden Redhorse GSI, it was not a substantial predictor. It is difficult to interpret what aspect of the flow regime – magnitude, timing, duration, variability, or frequency – influences spawning timeframes (Mims and Olden 2012). Peterson et al. (2013) modeled successful recruitment of Robust Redhorse and Notchlip Redhorse *Moxostoma collapsum* in Oconee

River, Georgia, and found that low-stable flows for at least a 2-week period during spawning and rearing may increase reproductive success as measured by the abundance of age 0 fish of these two redhorse species. In this study, there were low-stable flows between the end of March and mid-April which synchronized with water temperatures between 10 and 15°C in the Gasconade River, however, discharge in the Osage River during this time was high (Figure 3-2). To tease out what element of discharge is influencing Golden Redhorse reproductive readiness, future model selections may need to incorporate additional flow metrics and/or sampling conducted when discharge conditions hypothesized to trigger spawning are occurring.

In this study, we captured female Golden Redhorse in spawning capable phase III (mean GSI = 6.5; SD = 3.3; Table 3-4 and Figure 3-4) from February to May but there was a paucity of specimens from the Osage River between early March and May. The lack of reproductive Golden Redhorse captured in the Osage River when water temperatures were ideal for spawning (warming to 15°C) followed by the subsequent capture of post-spawn adults leads us to speculate that their spawning migration was earlier in the Osage River than the Gasconade and that they migrated upstream of our study reach in the Osage River to suitable spawning habitats. We targeted a variety of habitats in our study reaches but encountered shallow riffles and gravel bars indicative of suitable spawning habitat (Pflieger 1997) more frequently in the Gasconade River study reach. Grabowski and Isely (2007) found telemetered Robust Redhorses *Moxostoma robustum* began to make upstream migrations to suitable spawning habitat in early to mid-March when water temperatures were approximately 10-12°C although spawning water temperatures are believed to be between 17 and 27°C (Kwak and Skelly 1992;

Peterson et al. 2000; Freeman and Freeman 2001). Considering that we detected Golden Redhorse in early spring 2013 with high GSIs when water temperatures were 5°C in the Osage River and then not again until after May 1, 2013, with reduced GSI indicates that we caught these fish migrating upstream and then post-spawn as they were resting or migrating downstream. In the Gasconade River, we detected the species throughout the spawning season as indicated by increasing GSIs followed by a drastic decrease. Regardless, fish in both systems were found with reduced GSIs indicating that spawning was complete when water temperatures exceeded 15°C.

Considering that nearly 70% of the female Golden Redhorses captured in our study were in post-spawn reproductive stages IV and V indicates we may not have sampled active spawning sites but were capturing fish resting after spawning was complete. These results may be linked to the behavior of redhorse species. Greater Redhorse *Moxostoma valenciennesi* in the Grand River, Ontario, were found to move as much as 15 km downstream of spawning areas and remained in low velocity runs for the summer (Bunt and Cooke 2001). Although Bunt and Cooke (2001) did not see differences in the movement of male and female Greater Redhorse post-spawn, the sex ratios we observed and the majority of females found in post-spawn reproductive phases may indicate that male Golden Redhorse leave the system after spawning while females remain in the tributaries to rest and take advantage of the resources available.

We hypothesized that increased temperatures and low flows would correlate with an increase in the reproductive readiness of the sedentary, nest-guarding Spotted Bass and our results supported part of these predictions. We observed that female Spotted Bass exhibited a protracted spawning period over a wide range of days, temperatures, and discharges. Unlike Golden Redhorse, the Osage River was a substantial predictor in the top model in addition to the Julian date and discharge as important predictors for Spotted Bass GSI. Maximum GSI in the Osage River peaked around May 1, 2013 during average spring flows when water temperatures were 15°C. As discharge dropped below average spring flows and water temperatures warmed, so did GSI. This corroborates published literature on reproduction of Spotted Bass describing spawning occurring over a 1- to 2-month period from March to early June with temperatures between 14°C and 23°C (Sammons et al. 1999; Warren 2009). Studies have related the reproductive strategy of sedentary nest builders to low flow variability and successful recruitment of centrarchids (Sammons 1999; Clark et al. 2008; Mims and Olden 2012; Taylor and Peterson 2014). In our study, Spotted Bass were reproductively ready during high spring discharge and GSI indicated that spawning occurred when flows and habitat stabilized. Although the Spotted Bass is associated with flowing rivers, they are also popular reservoir fish and do well in regulated lotic waters (Sammons et al. 1999).

Histology was a useful tool in this study to accurately verify sex, determine the reproductive phase of individual fish, and detect abnormalities in gonad development. Golden Redhorse are complete spawners and histology helped discern between males and females as well as between immature and post-spawn individuals. The finding of an intersex Spotted Bass is important in light of the high incidence of intersex Missouri River sturgeon (Delonay et al 2016). Hinck et al. (2009) found 3% of freshwater fishes in nine basins of the United States were intersex, with 18% of male Largemouth Bass *Micropterus salmoides* and 33% of male Smallmouth Bass *Micropterus dolomieu* containing testicular oocytes. However, no Spotted Bass were found to be intersex by

Hinck et al. (2009). Although histology is an invasive technique often requiring sacrifice of the individual, much can be gathered including baseline information about common species that can be used to evaluate future modifications or extrapolated to other similar species.

Our study suggests that spawning is associated with a combination of discharge, temperature, and day; however, the specific combination of these variables is indicative of the target species life history and spawning strategy. In regulated rivers, the disruption in seasonality, magnitude, and duration of hydrologic events is common. Our models indicate that increased spring discharges were associated with Golden Redhorse and Spotted Bass reproductive readiness. We did not collect larvae and thus cannot discern the success of spawning events. However, previous studies indicate that stable flows provide opportunity for young-of-year to hatch and rear and that the timing for these stable flows varies depending on the species and spawning strategy (Craven et al. 2010). Future research documenting spawning success in relation to reproductive readiness of select species will help evaluate the regulated Osage River as spawning and rearing habitat in comparison to other Missouri River tributaries in this connected riverine system.

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Table 3-1. Macroscopic and microscopic descriptions of the reproductive phases of female and male fishes from Brown-Peterson et al. (2011); A Standardized Terminology for Describing Reproductive Development in Fishes. Criteria listed for phases may vary. (PG = primary growth; Sg1 = primary spermatogonia; CA = cortical alveolar; Vtg1 = primary vitellogenic; Vtg2 = secondary vitellogenic; POF = postovulatory follicle complex; Vtg3 = tertiary vitellogenic; Sg2 = secondary spermatogonia; Sc1 = primary spermatocyte; Sc2 = secondary spermatocyte; St = spermatid; Sz = spermatozoa; GE = germinal epithelium; OM = oocyte maturation)

Phase	Macroscopic and histological features	
	Female	Male
I - Immature (never spawned)	Small ovaries, often clear, blood vessels indistinct. Only oogonia and PG oocytes present. No atresia or muscle bundles. Thin ovarian wall and little space between oocytes.	Small testes, often clear and threadlike. Only Sg1 present; no lumen in lobules.
II - Developing (gonads beginning to grow and develop but not ready to spawn)	Enlarging ovaries, blood vessels becoming more distinct. PG, CA, Vtg1, and Vtg2 oocytes present. No evidence of POFs or Vtg3 oocytes. Some atresia can be present.	Small testes but easily identified. Spermatocysts evident along lobules. Sg2, Sc1, Sc2, St, and Sz can be present in spermatocysts. Sz not present in lumen of lobules or in sperm ducts. GE continuous throughout.
III - Spawning capable (fish are developmentally and physiologcally able to spawn in this cycle)	Large ovaries, blood vessels prominent. Individual oocytes visible macroscopically. Vtg3 oocytes present or POFs present in batch spawners. Atresia of vitellogenic and/or hydrated oocytes may be present. Early stages of OM can be present.	Large and firm testes. Sz in lumen of lobules and/or sperm ducts. All stages of spermatogenesis (Sg2, Sc, St, Sz) can be present. Spermatocysts throughout testis, active spermatogenesis. GE can be continuous or discontinous.
IV - Regressing (cessation of spawning)	Flaccid ovaries, blood vessels prominent. Atresia (any stage) and POFs present. Some CA and/or vitellogenic (Vtg1, Vtg2) oocytes present.	Small and flaccid testes, no milt release with pressure. Residual Sz present in lumen of lobules and in sperm ducts. Widely scatttered spermatocysts near periphery containing Sc2, St, Sz. Little to no active spermatogenesis. Spermatogonial proliferation and regeneration of GE common in periphery of testes.
V - Regenerating (sexually mature, reproductively inactive)	Small ovaries, blood vessels reduced but present. Only oogonia and PG oocytes present. Muscle bundles, enlarged blood vessels, thick ovarian wall and/or gamma/delta atresia or old, degenerating POFs may be present.	Small testes, often threadlike. No spermatocysts. Lumen of lobule often nonexistent. Proliferation of spermatogonia throughout testes. GE continuous throughout. Small amount of residual Sz occasionally present in lumen of lobules and in sperm duct.

Table 3-2. A priori models tested to predict GSI of female Golden Redhorse and Spotted Bass in the Gasconade and Osage rivers in spring 2013. (DAY = Julian day of 2013, RIV = River, TEM = mean water temperature at day of capture, FLO = mean daily discharge as a proportion of the previous six year average discharge between February and August).

Model Name	Parameters
Day	$= \beta1(DAY) + \beta2(DAY^2) + \beta3(RIV)$
Temp	$= \beta1(TEM) + \beta2(TEM^2) + \beta3(RIV)$
Flow	$= \beta1(FLO) + \beta2(FLO^2) + \beta3(RIV)$
Day + Temp	$= \beta1(DAY) + \beta2(DAY^2) + \beta3(TEM) + \beta4(TEM^2) + \beta5(RIV)$
Day + Flow	$= \beta1(DAY) + \beta2(DAY^2) + \beta3(FLO) + \beta4(FLO^2) + \beta5(RIV)$
Temp + Flow	$= \beta1(TEM) + \beta2(TEM^2) + \beta3(FLO) + \beta4(FLO^2) + \beta5(RIV)$
Global	$= \beta1(DAY) + \beta2(DAY^2) + \beta3(TEM) + \beta4(TEM^2) + \beta5(FLO)+\beta6(FLO^2) +\beta7(RIV)$

Table 3-3. Sex ratios of Golden Redhorse and Spotted Bass determined by visual observation and histology in the Osage and Gasconade rivers, February through July 2013.

	Number of fish	% Female	% Male	% Intersex
Spotted Bass	100	50	49	1
Osage River	59	49	51	--
Gasconade River	41	51	46	2
Golden Redhorse	77	84	16	--
Osage River	42	86	14	--
Gasconade River	35	83	17	--

Table 3-4. Reproductive stage and mean gonadosomatic index (GSI) for female and male Golden Redhorse and Spotted Bass in the Osage and Gasconade rivers, February-July 2013. Mean GSI did not differ between the rivers, so the rivers were combined for future analysis. Number of fish observed is in parentheses. Superscript letters indicate significant difference between GSI of the different phases for each sex and species combination ($P \leq 0.05$). ND = none detected. n is number of fish.

Reproductive phase	Golden Redhorse GSI		Spotted Bass GSI	
	Female	Male	Female	Male
	Mean +/- SD (n)	Mean +/- SD (n)	Mean +/- SD (n)	Mean +/- SD (n)
I	0.2 +/-0.06 (5)^{a}	0.1 (1)^{a}	ND	ND
II	0.3 (1)^{a}	0.1 (1)^{a}	1.9 +/-1.1 (9)^{a}	0.4 +/-0.2 (17)^{a}
III	6.5 +/-3.3 (14)^{b}	4.7 +/-0.4 (2)^{b}	4.9 +/-3.2 (30)^{b}	0.4 +/-0.2 (25)^{a}
IV	0.7 +/-0.2 (14)^{a}	ND	0.8 +/-0.4 (11)^{a}	0.2 +/-0 (3)^{a}
V	0.4 +/-0.1 (30)^{a}	0.2 +/-0.1 (8)^{a}	ND	0.2 +/-0.1 (3)^{a}

Table 3-5. Model results predicting GSI of female Golden Redhorse and Spotted Bass in the Gasconade and Osage rivers, spring 2013. Coefficient estimates are given for each variable with standard errors in parenthesis. Numbers in bold & italics indicate coefficient estimates that did not include zero. Coefficients estimates approaching 1 for the River variable indicate higher probability in the Osage River.

Model	K	AICc	Δ AICc	AICcWt	River	Day	Day^2	Temp	$Temp^2$	Flow	$Flow^2$
Golden Redhorse											
Temp + Flow	7	-347.38	0.00	0.82	-0.011			***-0.008***	***0.000***	0.004	0.004
					(0.006)			***(0.002)***	***(0.000)***	(0.012)	(0.002)
Global	9	-344.28	3.10	0.17	-0.010	0.001	0.000	***-0.012***	***0.000***	0.002	0.004
					(0.006)	(0.001)	(0.000)	***(0.003)***	***(0.000)***	(0.012)	(0.002)
Spotted Bass											
Day + Flow	7	-223.73	0.00	0.60	***0.026***	***0.004***	***0.000***			***-0.050***	***0.010***
					(0.013)	***(0.001)***	***(0.000)***			***(0.023)***	***(0.004)***
Day	5	-221.00	2.72	0.15	0.002	***0.002***	***0.000***				
					(0.007)	***(0.001)***	***(0.000)***				
Temp	5	-220.23	3.50	0.10	-0.003			***0.011***	***0.000***		
					(0.008)			***(0.003)***	***(0.000)***		
Global	9	-219.53	4.20	0.07	0.024	***0.003***	***0.000***	0.005	0.000	***-0.047***	***0.010***
					(0.013)	***(0.001)***	***(0.000)***	(0.004)	(0.000)	***(0.024)***	***(0.004)***

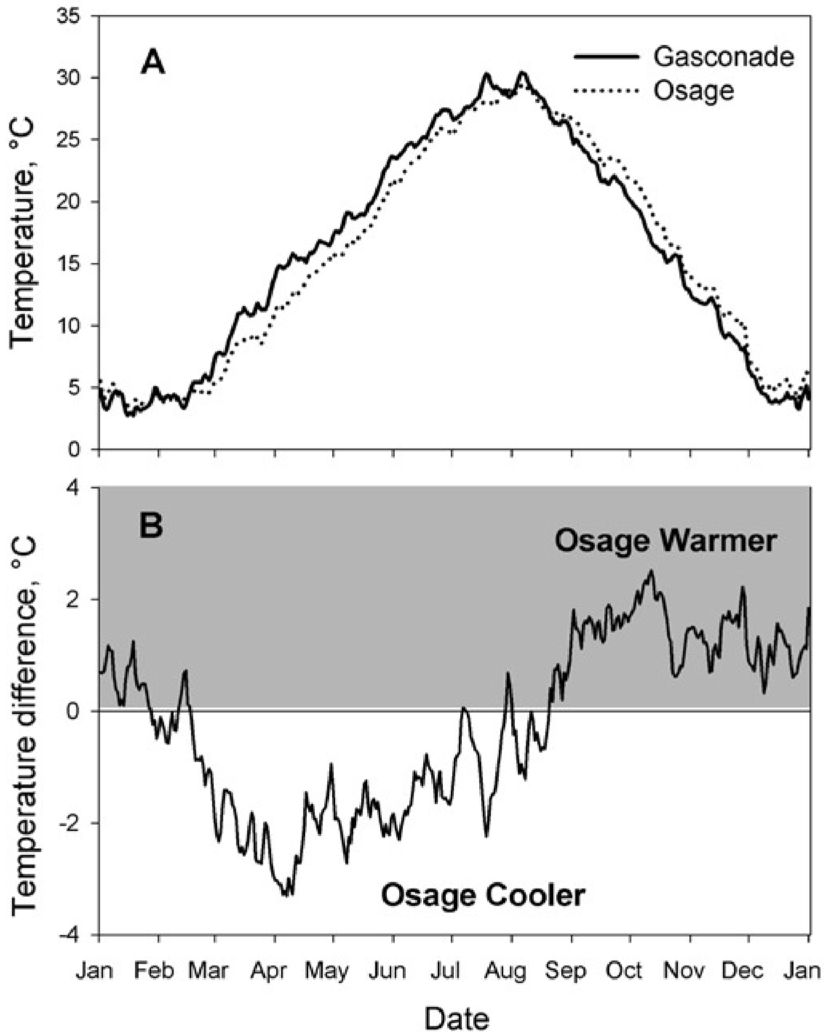

Figure 3-1. (A) Mean water temperature in the Gasconade and Osage rivers, 2006-2013. (B) Difference between Gasconade River and Osage River mean daily water temperatures, 2006-2013. Temperature data collected every 15 minutes from USGS-CERC deployed temperature loggers.

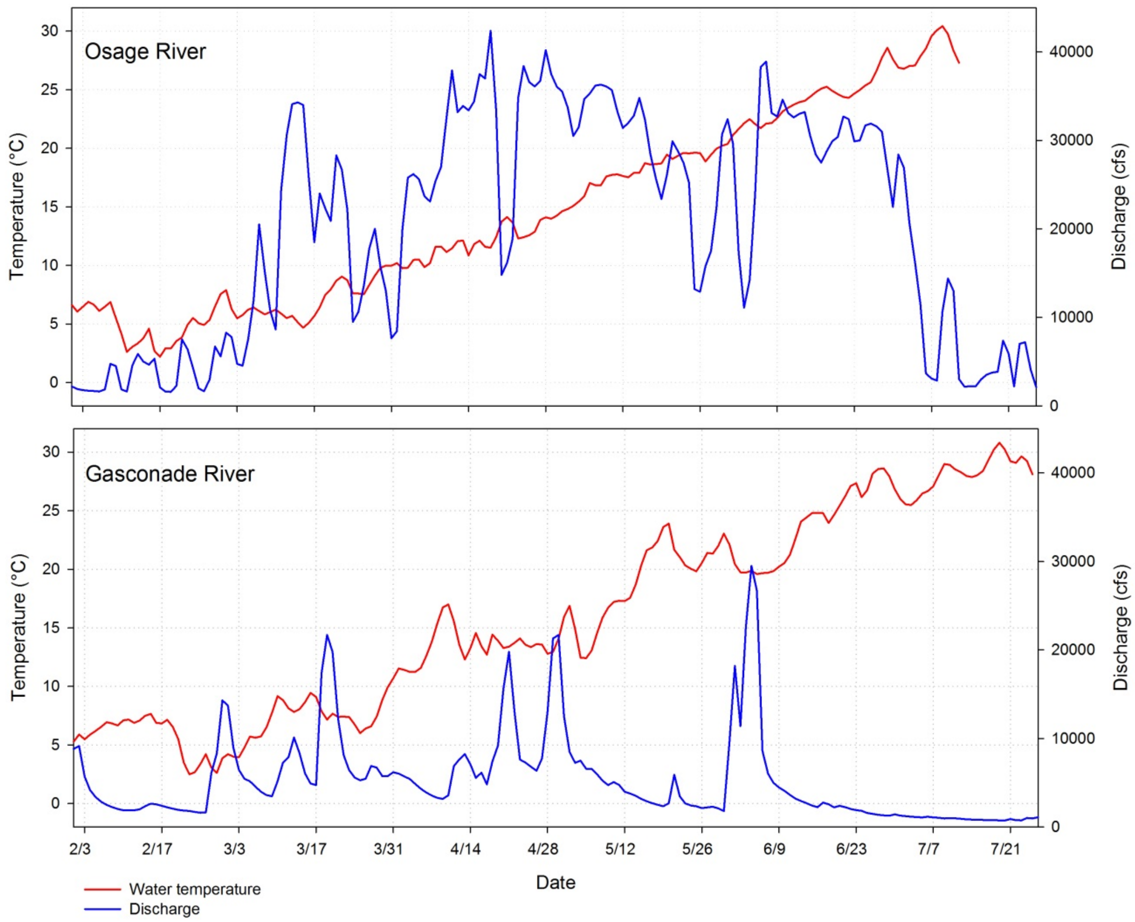

Figure 3-2. Discharge and water temperature of the Gasconade and Osage rivers, February - July 2013. Water temperatures were typically 2°C cooler and discharge was 14,400 cfs higher in the Osage River.

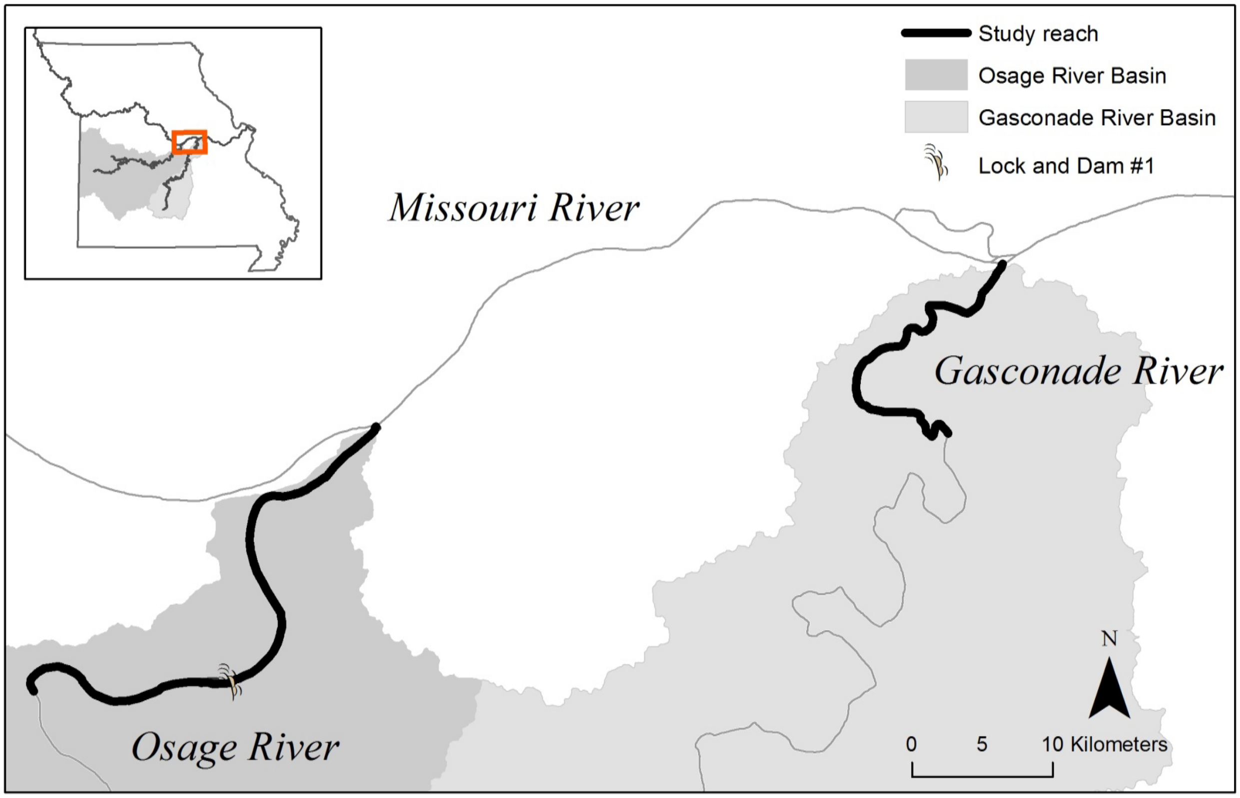

Figure 3-3. Osage and Gasconade rivers study are in central Missouri, February-July 2013.

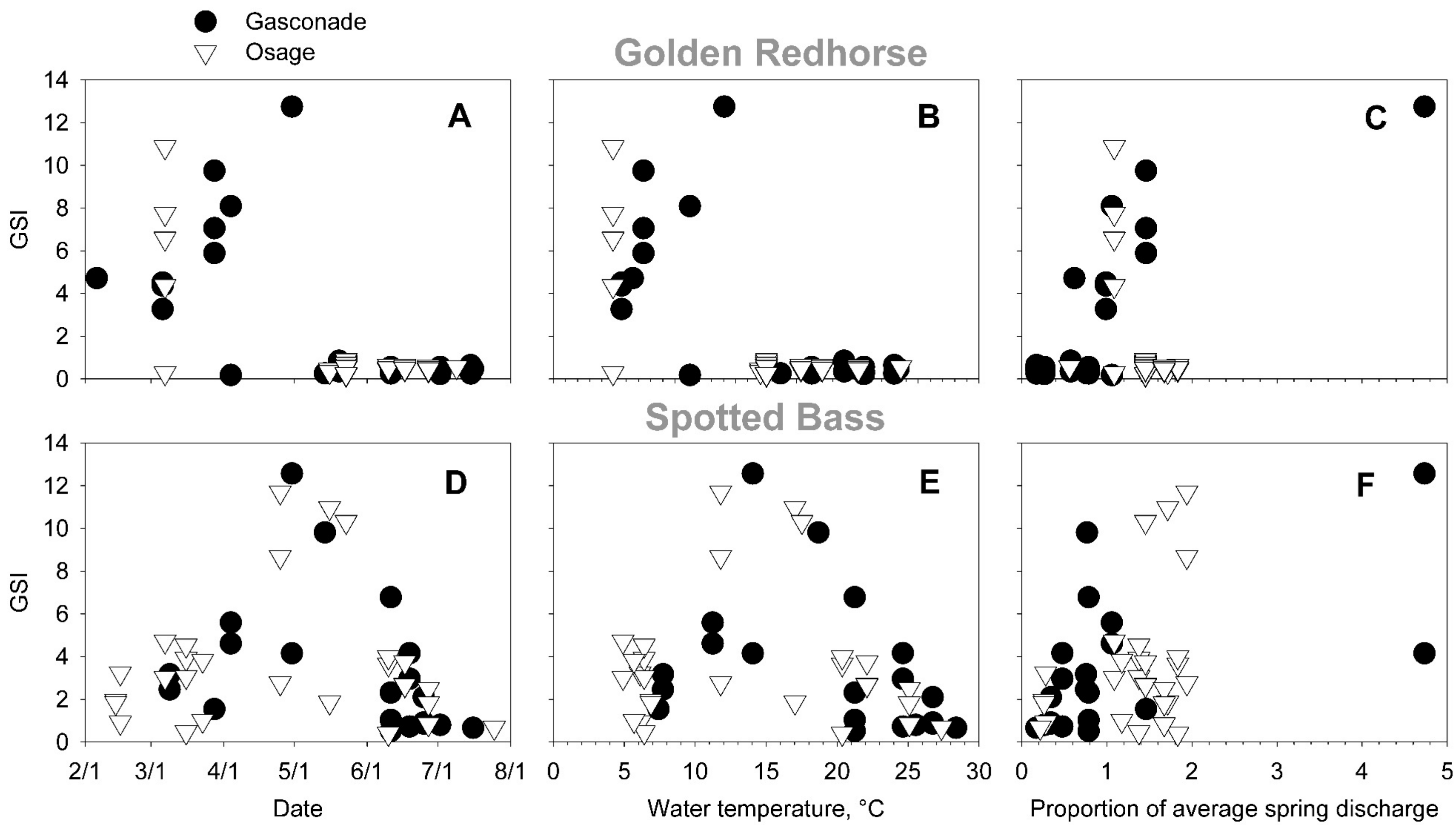

Figure 3-4. GSI of female Golden Redhorse & Spotted Bass associated with date (A&D), water temperature (B & E), and the mean daily discharge as a proportion of the previous 6 year mean spring discharge (C & F) in the Osage and Gasconade rivers, February to August 2013.

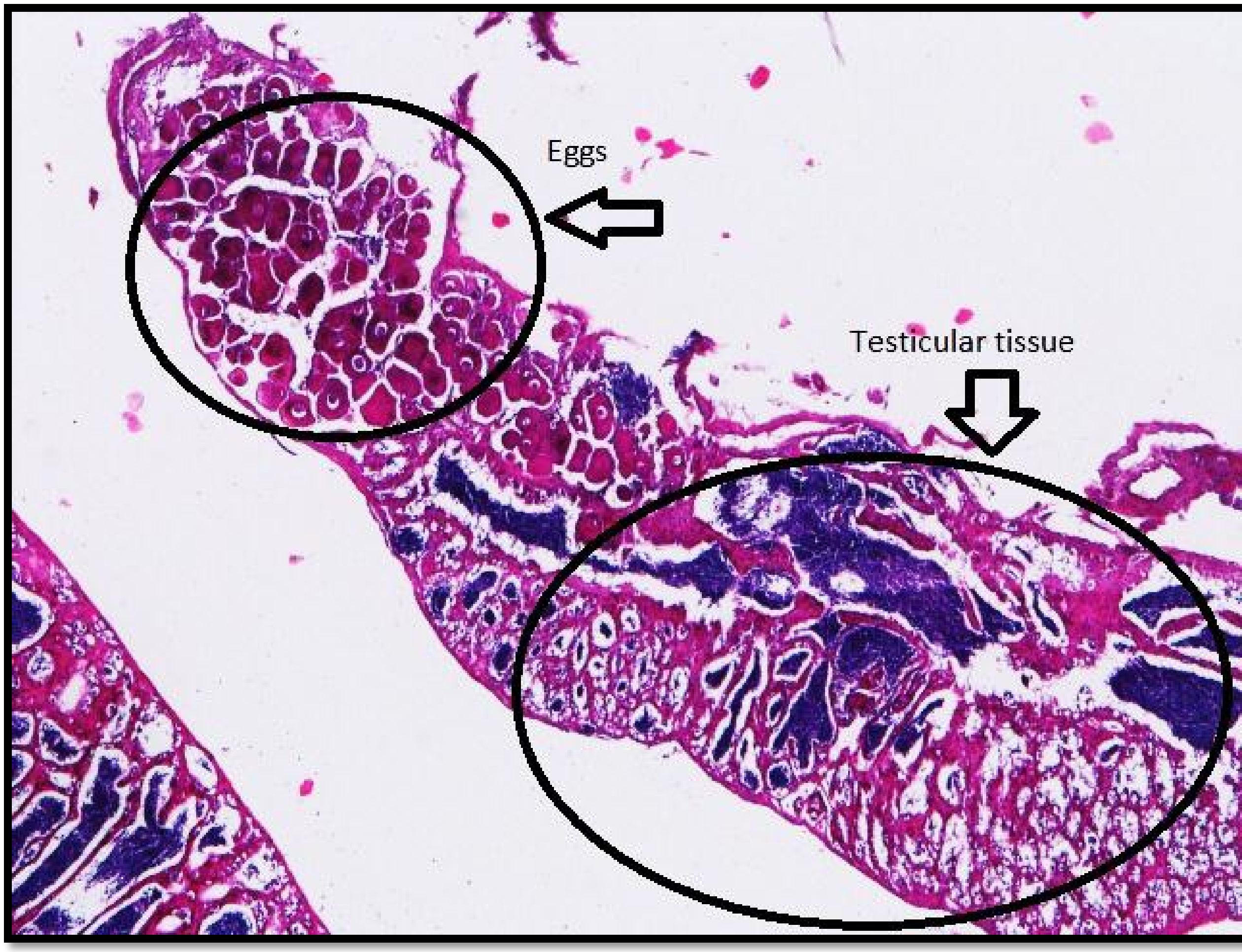

Figure 3-5. Histology revealed ova (eggs) on the testes of one male spotted bass indicating an intersex fish.