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## **Fish Assemblage Response to Environmental Gradients and Altered Dendritic Connectivity in the Red River Basin, Central Louisiana**

Catherine Nell Reuter

*Louisiana State University and Agricultural and Mechanical College*

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FISH ASSEMBLAGE RESPONSE TO ENVIRONMENTAL GRADIENTS AND ALTERED  
DENDRITIC CONNECTIVITY IN THE RED RIVER BASIN, CENTRAL LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
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by  
Catherine N. Reuter  
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## **ABSTRACT**

Louisiana's small streams provide critical habitat for diverse ecologically and economically important fish species. However, the relationship between these fish assemblages and habitat variables remains poorly understood. The role of anthropogenic alteration of dendritic stream connectivity is of specific interest and has been shown to significantly influence stream ecology. This study explored the interaction among watershed characteristics, stream connectivity, stream physico-chemistry, and fish assemblages in little-studied Red River basin of central Louisiana as well as how reservoir littoral zones compared to streams, both in terms of fish assemblage and habitat.

Fish and habitat were sampled in 21 headwater streams, half of which flowed directly into a reservoir, and in four reservoir littoral zone sites. Multivariate analyses indicated that level of dendritic connectivity did not explain a significant amount variation in stream fish assemblages. Fish assemblage composition and its relationship to common environmental gradients were similar in in all streams regardless of connectivity. Additionally, the assemblage and habitat of the reservoir littoral zone was comparable to that found in streams indicating that reservoirs were not serving as deleterious barriers to stream fish assemblages. However, individual species modeling revealed greater abundance of three species in streams with unaltered connectivity. These results do not parallel trends observed in other examinations of altered dendritic connectivity, however, they are concurrent with studies of coastal plain fishes' response to other disturbances. Understanding the magnitude and structure of response to disturbance is critical for preserving aquatic ecosystems and focusing conservation efforts. Even systems such as the Red River Basin, which evidence strong resilience to human disturbance, warrant closer inspection before heedless system alteration continues.

## 1. INTRODUCTION

Freshwater systems comprise some of the most diverse and productive habitats in the world (Taylor et al. 2007; Bogan 2008; Carrizo et al. 2013), but unfortunately are also among the most threatened by anthropogenic disturbance (MEA 2005; Dudgeon et al. 2006; Jelks et al. 2008; Baillie 2010; Carrizo et al. 2013). This concern is particularly relevant in the southeastern United States, which has been repeatedly recognized as a hotspot for aquatic biodiversity (Williams et al. 1993; Abell et al. 2000; Smith et al. 2002; Taylor et al. 2007; Jelks et al. 2008). Louisiana contributes significantly to the wealth of freshwater fish richness, with the greatest amount of surface water in the region supporting 148 fish species. Although heavily exploited and manipulated historically (Felley 1992; Lydeard and Mayden 1995; Warren et al. 2000), Louisiana's freshwater systems have received limited scientific scrutiny, and the ecology of their fish assemblages remains poorly understood. As effective management and conservation decisions rely on understanding the factors responsible for species' distribution and abundance patterns, filling this data gap is a priority for state regulatory agencies (Lester et al. 2005).

Fish assemblage distribution, composition, and structure have been correlated with many physicochemical gradients at both local (i.e. flow, temperature, substrate type, elevation, dissolved oxygen, pH) and watershed scales (i.e., catchment size, land use; Wang et al. 2003; Diana et al. 2006; Helms et al. 2009; Albanese et al. 2013). Several studies have illustrated the ability of land-cover types such as forest cover (Anderson et al. 2012), impervious/urban cover (Meador et al. 2005; Roy et al. 2005; Wenger et al. 2008) and agricultural lands (Harding et al. 1998; Walser and Bart 1999; Vondracek et al. 2005; Infante and Allan 2010) to predict fish assemblage (Weijters et al. 2009). However, the relative predictive power of watershed- and local-scale variables is still widely debated and may be influenced by factors such as level of



disturbance (Diana et al. 2006; Wang et al. 2006) or dominance of a specific land-cover type (Heitke et al. 2006).

Increasingly, longitudinal and dendritic connectivity is being considered as another crucial factor shaping fish population distribution and abundance (Pringle et al. 2000; Swan and Brown 2011). Construction of large and small impoundments since 1800 has fragmented aquatic habitats around the world (Beaumont 1978; Benke 1990). The 2013 National Inventory of Dams estimated 86,000 dams in the U.S. (U.S. Army Corps of Engineers 2013), but the actual number may be much higher when smaller dams are also considered (Graf 1999). Shifts in vertebrate and invertebrate species composition and abundance due to river main-stem impoundments have been well documented, often associated with replacement of riverine/stream specialists and native species with lentic, introduced, and generalist species, particularly piscivorous sportfishes (Schlosser et al. 2000; Gido et al. 2002; Freeman and Marcinek 2006; Freedman et al. 2014). Shifts in community structure typically continue upstream of the actual impoundment into the free-flowing section of the stream, with decline of native stream-specialists paired with increase of generalist and introduced species (Franssen and Tobler 2013). Physical downstream effects of dams include alteration of the sediment regime, flow volume and seasonality, and altered channel planform (Kondolf 1997; Vörösmarty et al. 2003; Petts and Gurnell 2005; Graf 2006; Poff et al. 2007). A multitude of associated negative ecological effects range from spawning habitat degradation to reduction of riparian plant recruitment (Kondolf 1997; Poff et al. 2007). Finally, dams often serve as physical barriers to upstream movement, isolating migratory fishes from historic breeding areas as well as altering gene flow between formerly connected populations (Neraas and Spruell 2001; Limburg and Waldman 2009).

Although the effects of impoundments on tributary streams have been less thoroughly described (Pringle 1997), reservoir tributaries also experience important alterations in structure and function. The most obvious result of impoundment is the modified longitudinal connectivity of streams, which changes from a continuous lotic system to a truncated stream system that flows into a lentic habitat. This new pattern results in some degree of isolation of a tributary stream that may have deleterious effects on the fish assemblage, depending on movement patterns of resident species. Inability of some lotic species to span the unsuitable habitat of the reservoir reduces connectivity of adjacent impounded tributaries. Increased predation risk associated with passing through the reservoir can also constrain stream fish mobility (Fraser et al. 1995; Schlosser et al. 2000). Reservoir-induced habitat fragmentation reduces gene flow between populations of some stream fishes, with potential negative impacts on persistence (Franssen 2012; Fluker et al. 2014). Disjunction from source populations can also limit influx of new individuals to repopulate a stream after disturbance. Importantly, reductions in gene flow and recolonization potential can both serve as the drivers of documented changes in native lotic fish assemblages in impounded reaches (Winston et al. 1991; Reyes-Gavilan et al. 1996; Falke and Guido 2006; Guenther and Spacie 2006; Matthews and Marsh-Mathews 2007). Further, proximity of the reservoir can threaten stream fishes regardless of their mobility. As noted for the river main-stem, reservoir habitat can serve as a source of predatory and competitive species normally far-removed from upstream habitats (Werner et al. 1983; He and Kitchell 1990; Schlosser 1995; Matthews and Marsh-Mathews 2007). As a result, numerous reservoir tributary streams have exhibited greater diversity and abundance of lentic and generalist species compared to similar stream tributaries (Herbert and Gelwick 2003; Falke and Guido 2006; Guenther and Spacie 2006).

Louisiana boasts a wealth of freshwater fish species, the management and conservation of which is the responsibility of the Louisiana Department of Wildlife and Fisheries (LDWF). To build knowledge of this resource, LDWF has provided funds through the State Wildlife Grant program to research freshwater fish assemblages in the little-studied Red, Sabine, and Calcasieu River basins. Of these basins, the Red River basin contains the greatest number of impoundments. Between 1950s and 1975, over ten streams were dammed creating sizable impoundments ranging in surface area from about 800 to over 2823 hectares. These lakes altered the dendritic connectivity of numerous small, wadeable tributaries as described above, while other streams remained outside the reservoirs' influence. The Red River basin, therefore, serves as an excellent system for exploring the relative importance of in-stream, watershed, and connectivity characteristics in structuring the fish assemblages in connected and truncated tributary systems, while also providing valuable baseline information for local resource managers. Specifically, I was interested in the following questions:

1. What is the relative importance of local in-stream and watershed scale variables in structuring the fish communities (diversity, composition, abundance) of wadeable tributaries of the Red River, specifically does level of dendritic connectivity play a significant role?
2. How does the reservoir littoral zone compare to the stream sites both in terms of fish assemblage and habitat?

Answering these questions helped determine the validity of the following hypotheses concerning the upstream effects of impoundments on wadeable streams in the Red River Basin:

1. River tributaries and lake tributaries differ in their resident fish assemblages. Specifically, compared to river tributaries, lake tributaries will exhibit lower richness and abundance of stream-specialist fish species, and a greater richness and abundance of generalist/reservoir species.
2. The reservoir littoral zone fosters a different fish assemblage from adjacent tributary streams. Specifically, the littoral zone will exhibit greater proportions of lentic, generalist, and non-native species that are potential predators and competitors for native stream fishes.
3. Incongruous habitat and greater predation risk deter stream specialists from moving through the reservoir littoral zone to adjacent streams.

## 2. METHODS

### 2.1 Site selection

I selected 21 wadeable 1<sup>st</sup> and 2<sup>nd</sup> order streams in the central portion of the Red River basin for study (Figure 1). Ten streams fed into free-flowing dendritic systems upstream of any reservoir influence. These streams were considered ‘river’ tributaries, and represented the extant natural stream communities of the watershed. In contrast, the eleven remaining ‘lake’ tributaries flowed directly into impoundments, representing streams in a truncated watershed. Figure 2 illustrates the difference between lake and river tributaries. All streams were located within the Southern Coastal Plain Ecoregion (USEPA Level III, Daigle et al. 2006) and were selected for comparable size and surrounding land-use. Many candidate streams were inaccessible on privately held lands or were too deep for wading. Nearby streams outside the Red River basin were not considered as study sites, as previous studies indicated that fishes in this region differ meaningfully across watershed boundaries (Williams et al. 2005; Hoeinghuas et al. 2007; Kaller et al. 2013). Therefore, spatial distribution of the sites was not random, and all streams included public bridges as access points

I also selected four reservoir littoral zone sites adjacent to reservoir tributaries, with site selection based on accessibility by small boat via reservoir public boat launches.

### 2.2 Stream fish sampling and habitat characterization

A 150-m sampling reach (minimum 130 m) was established in each stream beginning at the tree line upstream of the bridge crossing access point. Upstream and downstream block-nets were set to isolate the reach and allow for quantitative 2-pass removal electrofishing. Prior to electrofishing, within each reach, we seined (3m seine with 6.35 mm bar mesh) all possible habitats (usually 2-3 seine hauls) for cyprinids and fundulids that were less vulnerable to

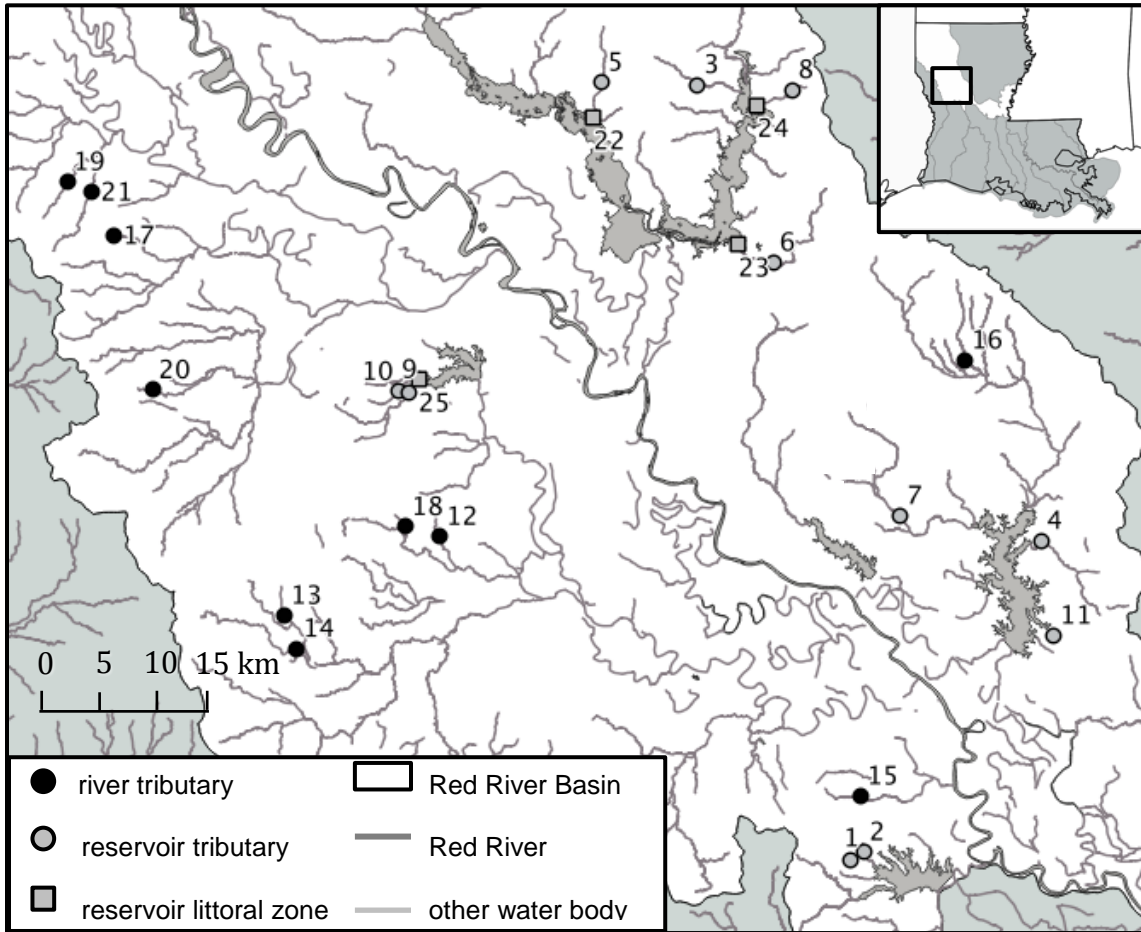


Figure 1. Stream and reservoir sample sites in the Red River Basin that were sampled for fish assemblage composition in 2014 and 2015. Numbers correspond to sites listed in Appendix A.

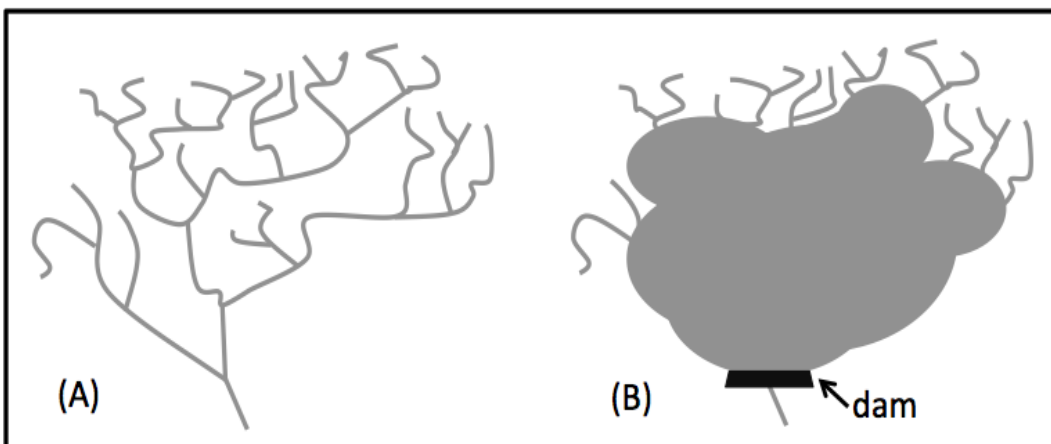


Figure 2. Unaltered versus altered stream connectivity. (A) River tributaries that are part of a free-flowing dendritic stream system and (B) lake tributaries that flow directly into an impoundment exhibiting truncated dendritic connectivity.

electrofishing. We followed seining with two electrofishing passes using one or two backpack DC electrofishers (Halltech HT-2000, Halltech Aquatic Research, Inc.) set to 150-200 volts outputting ~1.8 amps of current, each paired with a dip-netter (number of units determined by stream width and general habitat complexity, typically two used if average width >4 m). We recorded electrofishing time of each pass to allow calculation of catch per unit effort (CPUE). Fish were removed as sampled and kept in an aerated bucket until the end of the sampling pass. After completing all sampling fish were identified to species, counted, and released in the sample reach, with the exception of voucher specimens or unidentifiable individuals. These were anesthetized in an ice slurry following LSU IACUC A2011-16, with moribund individuals fixed in 10% formalin and returned to the lab for subsequent identification/preservation. Each site was sampled between May and August in both 2014 and 2015.

The field team performed same day in-stream characterization of both physical and chemical characteristics at each sample site during both years of sampling. The field team used a multi-probe meter (YSI 650, YSI, Inc.) to determine temperature (°C), specific conductance (mS/cm), dissolved oxygen (DO:mg/L), pH, and turbidity (NTU). Ten cross-sectional transects, 15 meters apart, were spaced along each sample reach. Along each transect, wetted width, stream bank stability, riparian cover, and % canopy cover were recorded. Additionally, the team recorded depth (m), flow velocity (m/s; SONTEK, YSI, Inc.), and the abundance of woody debris (recorded as...) at 25%, 50%, and 75% of stream width. Substrate was characterized via a pebble count along each transect (Kaufmann 1999).

Within GIS (ArcMap 10.2, ESRI, Inc.), I used a digital elevation model and the National Hydrography Dataset (NHD) (Homer et al. 2007), 1:24,000 resolution, to calculate upstream watershed catchment area for each stream site. . I then used the 2001 USGS National Land

Cover Dataset for Louisiana to determine the percent land cover of open water, developed infrastructure (high, medium, low, bare), forest (mixed, evergreen, deciduous), shrub, herbaceous, agriculture (crop, pasture), and wetlands (woody, herbaceous). These land cover classifications were consistent with our onsite observations.

### 2.3 Reservoir littoral zone fish sampling and habitat characterization

Fish sampling in the reservoir littoral zone mirrored the protocol employed in the streams. The stream outlet was located and a 150-meter reach established starting where the defined stream channel first allowed access to open reservoir water. The reach extended in the direction of flow from this transition point. Reservoir-riparian margins were not distinct and were characterized by a gentle, gradual transition; therefore, a firm bank could not define the margin of the sampling reach. Thus, a standard width of 4 meters defined each sample reach. Seining, electrofishing, and identification protocols proceeded as described above. Additionally, to compensate for the lack of banks that might make electrofishing less effective, minnow traps were set overnight at each site. Five traps, baited with wet cat food (Purina Friskies® Wet Cat Food), were set at 30 m intervals along the reach. Sampling of the reservoir littoral zone took place in April 2015 in an effort to capture seasonal movement of many species for spawning purposes (Schlosser et al. 2000; Albanese et al. 2004).

Reservoir littoral zone habitat characterization paralleled methodology used for in-stream sampling, with measurement of both physical and chemical characteristics as described above. Additionally, number and diameter of tree and shrub stems was recorded at each transect. For littoral zone sites, values from the corresponding reservoir tributary were used for the landscape variables.

## 2.4 Habitat Analyses

I examined interrelationships among habitats and site types with partial canonical correspondence analysis, detrended correspondence analysis, and non-metric multi-dimensional scaling. I examined axis length and STRESS2 to decide which method was most appropriate for interpretation following the criteria of ter Braak and Verdonschot (1995) and Hirst and Jackson (2007). The goal was to determine whether site type (river tributary, reservoir tributary, or reservoir littoral zone site) influenced the distribution of habitat characteristics. All ordinations were performed in Program R (vers. 3.3, R Core Team 2015; Oksanen et al. 2015).

## 2.5 Fish assemblage analyses

After all specimens were identified to species or lowest taxonomic group possible, taxa were assigned to spawning, feeding, and feeding location functional groups as well as either habitat generalists or fluvial/stream habitat specialists based on examination of habitat requirements [referencing Hendrickson and Cohen (2015) and Ross (2001); Table 1].

Table 1. Functional group categories for fishes collected in the Red River Basin in 2014 and 2015 based on Ross (2001) and Hendrickson and Cohen (2015).

Feeding mode	Feeding location	Spawning mode	Habitat preference
D - Detritivore	B - Benthic	A – Nest associate	G - Habitat generalist
I - Invertivore	E - Everywhere	B - Broadcast	S – Stream habitat
O - Omnivore	G - Grazer	C - Cavity	specialist
P - Piscivore	S - Surface	L - Livebearer	
	W - Water column	N - Nest	
		P - Plant	
		S - Substrate	

Assemblage data from seining and electrofishing collections were kept distinct, as seining effort was not comparable between sites; fish metrics were calculated separately for each gear type. Relative abundance was calculated for each taxon, and relative abundance and



species richness were calculated for each functional group and habitat specialist/generalist group. Electrofishing passes were pooled when calculating relative abundance. Relative abundance was used for all assemblage-wide analyses as few species met the assumptions for calculating true abundance estimates. The following analyses for the seine and electrofishing datasets were performed independently. I used a constrained ordination to investigate relationships between fish species with habitat variables and site types. The type of constrained ordination (e.g., canonical correspondence analysis, detrended correspondence analysis, or non-metric multi-dimensional scaling) was determined by the same criteria employed in selecting the habitat ordination. This interpretation led to further investigation of relationships between fish species' distributions and environmental variables with a step-forward selection canonical correspondence analysis (CCA). Significance of the retained variables was determined by fitting environmental factors to the ordination based on the permutation-based linear modeling procedure (Oksanen et al. 2015). Habitat variables included in the final model were then used as partial variables in an additional CCA that evaluated fish assemblages as explained by sample site type (river tributary, reservoir tributary, or reservoir littoral zone site). All ordinations were performed in Program R (vers. 3.3, R Core Team 2015; Oksanen et al. 2015).

I employed separate generalized linear mixed models to examine the relationship between sample site type and several different response variables: overall species richness, species richness of habitat generalist and stream specialists, relative abundance of stream specialists, and relative abundance of the different functional groups. Model structures are described in Table 2. For these models, I initially included the habitat variables retained by the earlier step-forward constrained ordination. However, inclusion of these variables did not improve model fit (based on general  $\chi^2$ /degrees of freedom and proximity of y-intercept to 0),

so following traditions of parsimony, conclusions are based on a simple model structure with site type as the only explanatory variable. All models were performed in SAS (vers. 9.4, SAS Institute, Inc., Cary, NC).

Table 2. Model structures for species assemblage analysis. Modeling was repeated for electrofishing and seine datasets separately.

Response variable	Response variable distribution	Fixed variable	Random variables	Link function
Total species richness	Poisson	site type	month, year	log
Habitat generalist richness	Poisson	site type	month, year	log
Stream habitat specialist richness	Poisson	site type	month, year	log
Relative abundance stream specialists	binomial	site type	month, year	logit
Relative abundance of functional trait groups	binomial	site type	month, year	logit

## 2.6 Individual species models

Further analysis of were performed for select species that were found in only one connectivity type, with much greater abundance in a specific connectivity type, or that showed some resolution in the ordination analyses. Responses of these species' abundances to level of dendritic connectivity was modeled with generalized linear mixed models based on the log link function, with month and year included as random variables, and either a negative binomial or Poisson distribution for the response variables. I used the Zippin (1958) estimator to calculate abundance estimates for each species from the 2 pass-removal data. Zippin-based abundance estimates were used instead of relative abundance, as it is more difficult for models to detect differences between the smaller proportion-based values inherent to relative abundance data (Zuur et al. 2009; Agresti 2015). All models were performed in SAS (vers. 9.4, SAS Institute, Inc., Cary, NC).

### 3. RESULTS

#### 3.1 Habitat

Study sites were all located in relatively small, shallow first or second order streams (mean width  $3.5 \pm 0.2$  m SE, mean depth  $29 \pm 2$  cm SE). Habitat did not vary widely among streams and was characteristic of coastal plain warm-water systems (Cross et al. 1986; Ross 2001; Felley 2002;). Under non-flood conditions, I observed very low flow velocities (mean  $0.057 \text{ m/s} \pm 0.009$  SE). Streams exhibited variety of substrates but most streams were dominated by sand and silt/clay (mean sand coverage  $40 \pm 4\%$  SE, mean silt/clay coverage  $23 \pm 4\%$  SE). In most streams, woody debris was also provided abundant substrate (mean total coverage  $15 \pm 2\%$  SE), likely input during storm events and retained due to otherwise low flows. Canopy cover was extensive in all streams (mean coverage  $90 \pm 1\%$  SE). Values for other basic physicochemical characteristics are given in Table 3.

Despite the similarity in stream size, there was a wide range in watershed area among sites (range  $0.58\text{--}92.6 \text{ km}^2$ ), although this was not correlated with average width or depth (Figure 3). All watersheds were extremely rural, primarily forested, with less than 2% developed area, less 2% row agriculture, and all but two sites less than 2% pasture.

Reservoir littoral zone sites were open water with no banks; however, this land water interface was gentle and in flux throughout the year as water levels within the reservoir rose and fell. Littoral zones exhibited physicochemical characters similar to the streams sites, although littoral zone sites exhibited only three kinds of substrate, silt/clay (again dominant), leaf litter and wood. Additionally, these had numerous trees and woody stems within each transect. Occurrence of trees in the middle of a stream was so rare that this metric was not recorded, which unfortunately prevents direct numerical comparisons with reservoir littoral zones. Mean

canopy cover was lower at littoral zone sites (mean  $\pm$  standard error,  $23 \pm 11$  % coverage) but this was an artifact of sampling season (spring before full leafing out of all species), based on the abundance of trees I infer that summer values would have been comparable to streams.

Table 3. Selected physicochemical conditions at sample sites averaged between sample years, showing means  $\pm$  standard error (range). Certain variables are included as they were significant in subsequent ordinations.

	Reservoir tributary	River tributary	Reservoir littoral zone site
Dissolved Oxygen (DO:mg/L)	$6.17 \pm 0.56$ (1.70-9.88)	$5.32 \pm 0.58$ (0.30-8.84)	$6.69 \pm 1.58$ (2.50-10.09)
Temperature ( C)	$22.24 \pm 0.041$ (19.22-25.32)	$22.94 \pm 0.90$ (18.79-26.08)	$20.88 \pm 2.07$ (16.16-24.68)
Turbidity (NTU)	$36.1 \pm 3.3$ (13.3-68.0)	$23.2 \pm 3.0$ (6.0-68.6)	$38.5 \pm 6.3$ (25.5-55.7)
Boulders (% coverage)	$0.26 \pm 0.22$ (0-4.76)	$0.14 \pm 0.14$ (0-2.86)	0 0
Fine gravel (% coverage)	$1.31 \pm 0.61$ (0-10.74)	$10.05 \pm 4.18$ (0-76.19)	0 0
Leaf litter (% coverage)	$9.24 \pm 1.71$ (0-25.00)	$4.72 \pm 1.21$ (0-16.19)	$63 \pm 10.97$ (39.28-83.81)
Root (% coverage)	$0.81 \pm 0.54$ (0-10.61)	$2.15 \pm 1.48$ (0-32-07)	$1.52 \pm 1.16$ (0-4.90)
Woody debris (% coverage)	$8.44 \pm 1.06$ (0.40-18.93)	$7.02 \pm 1.22$ (0.62-20.36)	$14.24 \pm 2.45$ (8.33-20.06)

Despite these observed differences, ordination of both in-stream physicochemical variables and watershed scale variables illuminated no distinct patterns between sites types; no variables correlated uniquely with reservoir tributaries, river tributaries, or the reservoir littoral zone sites (Figure 3). Though visual inspection showed the reservoir littoral zone sample sites to cluster, further analysis did not support this grouping. Thus, though I observed some diversity in habitat among sites, this variability was equally shared between both stream types and the reservoir littoral zone.

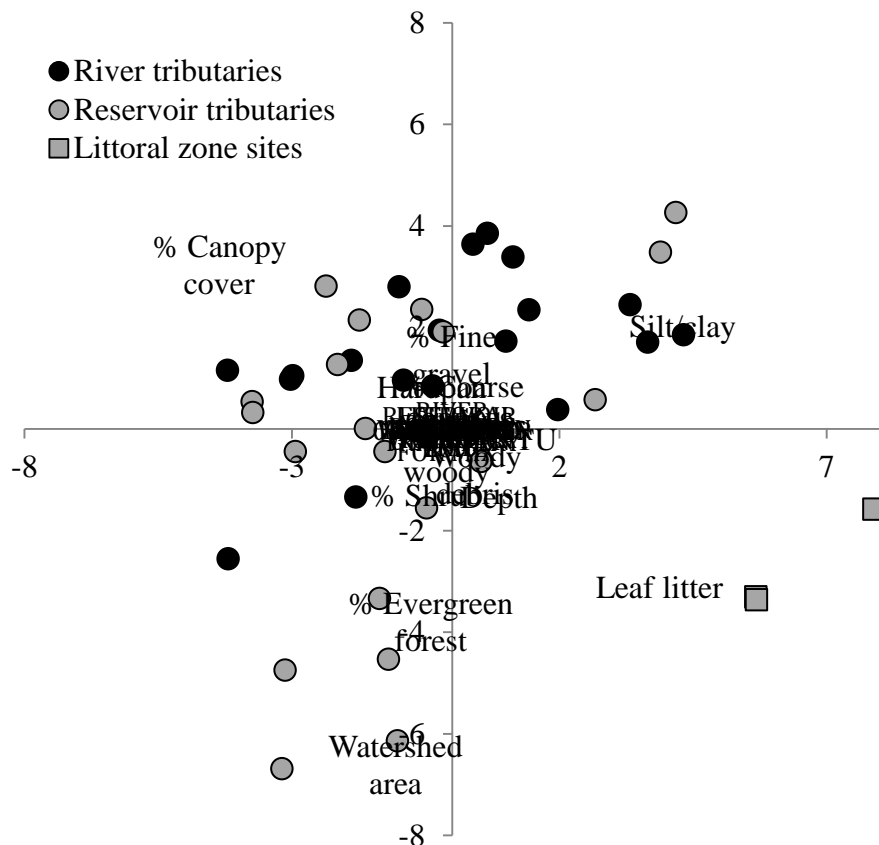


Figure 3. Partial canonical correspondence analysis of landscape and physicochemical habitat variables recorded at river tributary, reservoir tributary, and reservoir littoral zone sample sites in the Red River Basin during 2014 and 2015.

### 3.2 Fish sampling

Electrofishing and seining yielded 46 species of fish, ranging from 1-28 species at a given site. The Centrarchidae yielded the greatest richness with 12 species, followed by the Cyprinidae (9 species) and Percidae (5 species). Fish samples included 25 to 489 individuals, both of which were collected from river tributaries. Cyprinids were most abundant in the samples, particularly Redfin Shiners *Lythrurus umbratilis* and Striped Shiners *Luxilus chrysocephalus*. Centrarchids were also abundant at the sample sites, although evenness among the sunfish species was much higher than for the minnows. I collected 27 species of habitat generalists and 20 species of stream habitat specialists. 35 species were found in both stream

sites. Species unique to river tributaries include the Bantam Sunfish *Lepomis symmetricus*, Pugnose Minnow *Opsopoeodus emiliae*, and Bullhead Minnow *Pimephales vigilax* while Harlequin Darters *Etheostoma histrio*, Gizzard Shad *Dorosoma cepedianum*, Brook Silversides *Labidesthes sicculus*, Spotted gar *Lepisosteus oculatus*, Spotted suckers *Minytrema melanops*, and White crappie *Pomoxis annularis* were captured only in reservoir tributaries. Bowfin *Amia calva* and Golden Topminnows *Fundulus chrysotus* were captured only in the reservoir littoral zone. Functional group categorizations for each species are in Appendix B.

As expected, electrofishing typically yielded greater abundance and richness of fishes. However, Brook Silversides were only collected with seines, and only seining yielded >10 individuals of pelagic Redfin Shiners, Ribbon Shiner *Lythrurus fumeus*, Striped Shiner, and Golden Shiner *Notemigonus crysoleucas* at any site.

Sampling difficulty in the reservoir littoral zone was comparable to streams. Though a lack of banks and block nets may have allowed some individuals to avoid capture, extensive structure in the form of trees, shrubs and woody debris provided shelter and barriers to retain individuals in the transect. Further evidence to support our efficient sampling in this habitat included the lack of significant supplemental catch in baited minnow traps (only juvenile Bowfin, n=2) and visual confirmation of the absence of highly observable species, such as the Black-spotted Topminnow *Fundulus olivaceus*, remaining within the reach after sampling.

### 3.3 Assemblage analyses

Assemblage level analyses identified limited patterns in fish distribution based on both electrofishing and seining data. Detrended correspondence analysis (DCA) was the most appropriate ordination for both data sets but provided little resolution of relative abundance distribution patterns (Figure 4).

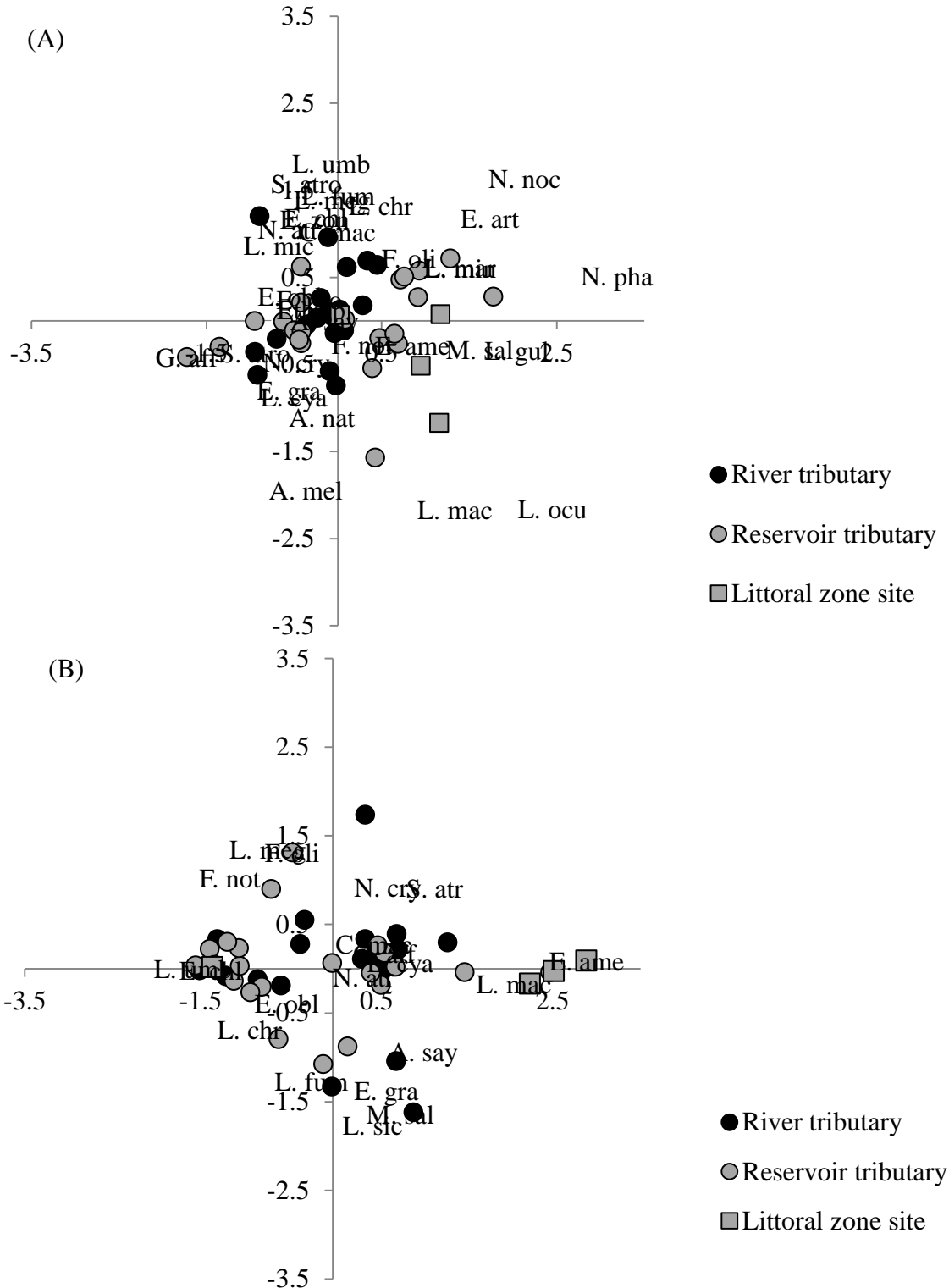


Figure 4. Detrended correspondence analysis of fish relative abundance values for all Red River Basin sites based on (A) electrofishing data and (B) seine data. Fish are labeled with first letter of genus and first three letters of species name; see Appendix B for species codes.

The forward stepwise CCA investigating fish assemblage as distributed by habitat variables (including connectivity type) identified several habitat variables as influencing fish distribution (Table 4). For the electrofishing data, these included: year of sample, average depth, average flow velocity, % root substrate, % fine gravel substrate, and canopy cover. Overall, this ordination explained 26% of the variation in fish assemblage composition, with the first two axes (Figure 5, A) accounting for 14%. For the seine data, this procedure retained % leaf litter substrate, dissolved oxygen concentration, woody debris coverage, % boulder substrate, and whether a site was a river tributary as influential variables. Overall, this ordination explained 22% of the variation in fish assemblage, with the first two axes (Figure 5, B) accounting for 13%.

Table 4. Habitat variables retained by step-forward Canonical Correspondence Analysis investigating Red River Basin fish assemblage composition.

Electrofishing data	$r^2$	Pr(>r)	Seine data	$r^2$	Pr(>r)
Canopy cover	0.2710	0.021	Boulders	0.1115	0.081
Depth	0.4411	0.001	Dissolved Oxygen	0.1196	0.063
Fine gravel	0.0522	0.200	Leaf litter	0.5114	0.001
Flow	0.2341	0.005	River tributary	0.1529	0.024
Root	0.7899	0.003	Woody debris	0.0059	0.896
Year	0.2233	0.004			



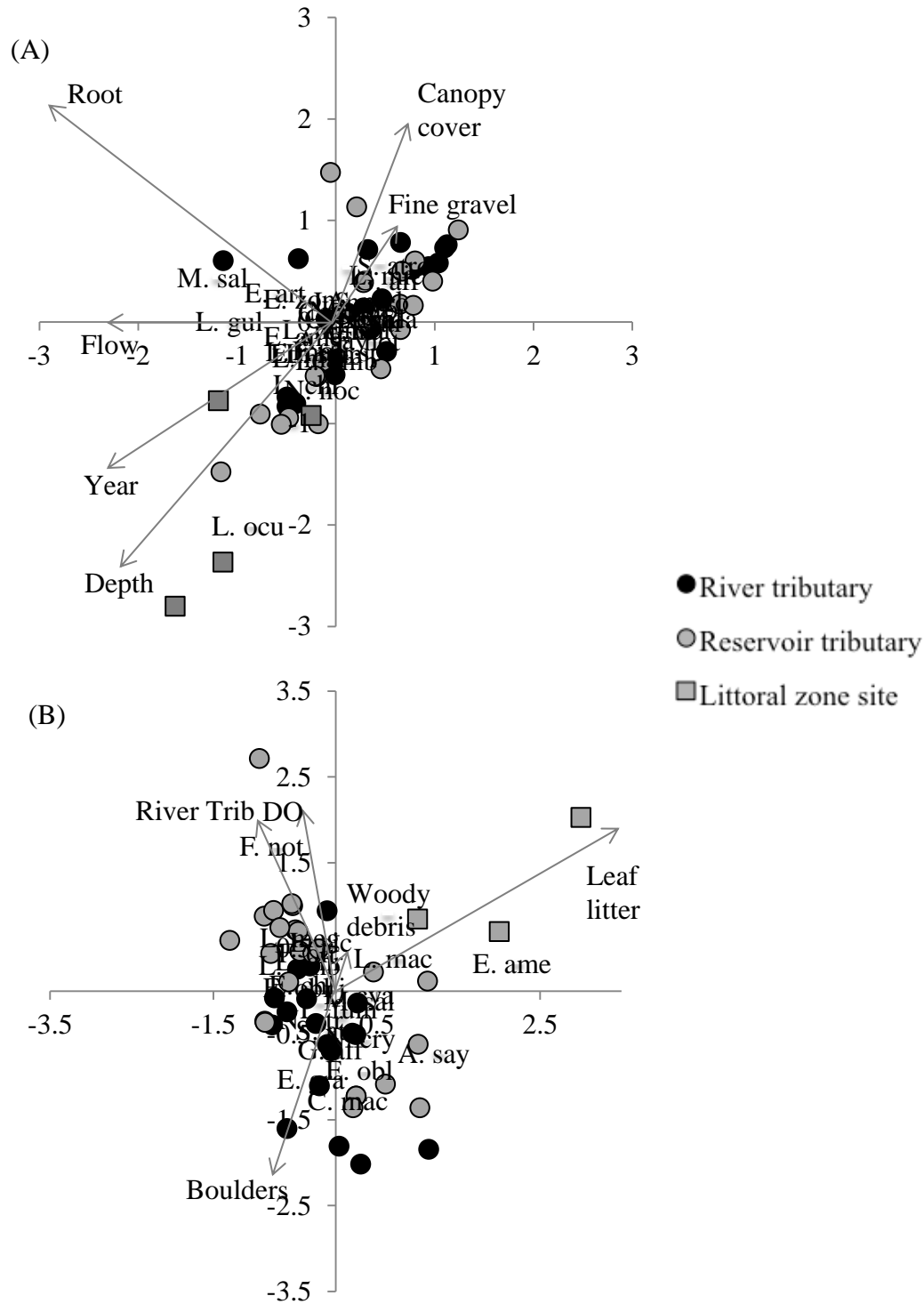


Figure 5. Results for step-forward Canonical Correspondence Analysis investigating Red River Basin fish distribution and relative abundance by landscape-scale and physico-chemical habitat variables for (A) electrofishing and (B) seine data. Arrows indicate direction and strength of relationships. Fish are labeled with first letter of genus and first three letters of species name; see Appendix B for species codes.

To determine whether effects of these influential habitat variables were masking effects of sample site type, I performed another round of CCAs with both the electrofishing and seine data with the habitat variables as conditional variables. Neither model provided strong evidence for a difference between site types (Figure 6).

Results of total species richness, relative abundance of specialist species, and richness of generalist and specialist species analyses did little to differentiate river from reservoir tributaries and the littoral zone sample sites (Table 5). Based on the electrofishing data, river and reservoir tributaries were similar in total species richness, relative abundance of specialist species, and richness of habitat generalist and specialist species. The seine data presents a slightly different picture, indicating that river tributaries had greater total richness and greater generalist species richness. The reservoir tributaries were indistinguishable from the littoral zone based on these variables but the river tributaries had greater total richness and greater specialist richness than the reservoir littoral zone sites (Figure 7, A-C). Analysis of species functional groups yielded no evidence of differences between sample site types. The different feeding modes, feeding locations, and spawning modes seem to be equally distributed among sample site types.

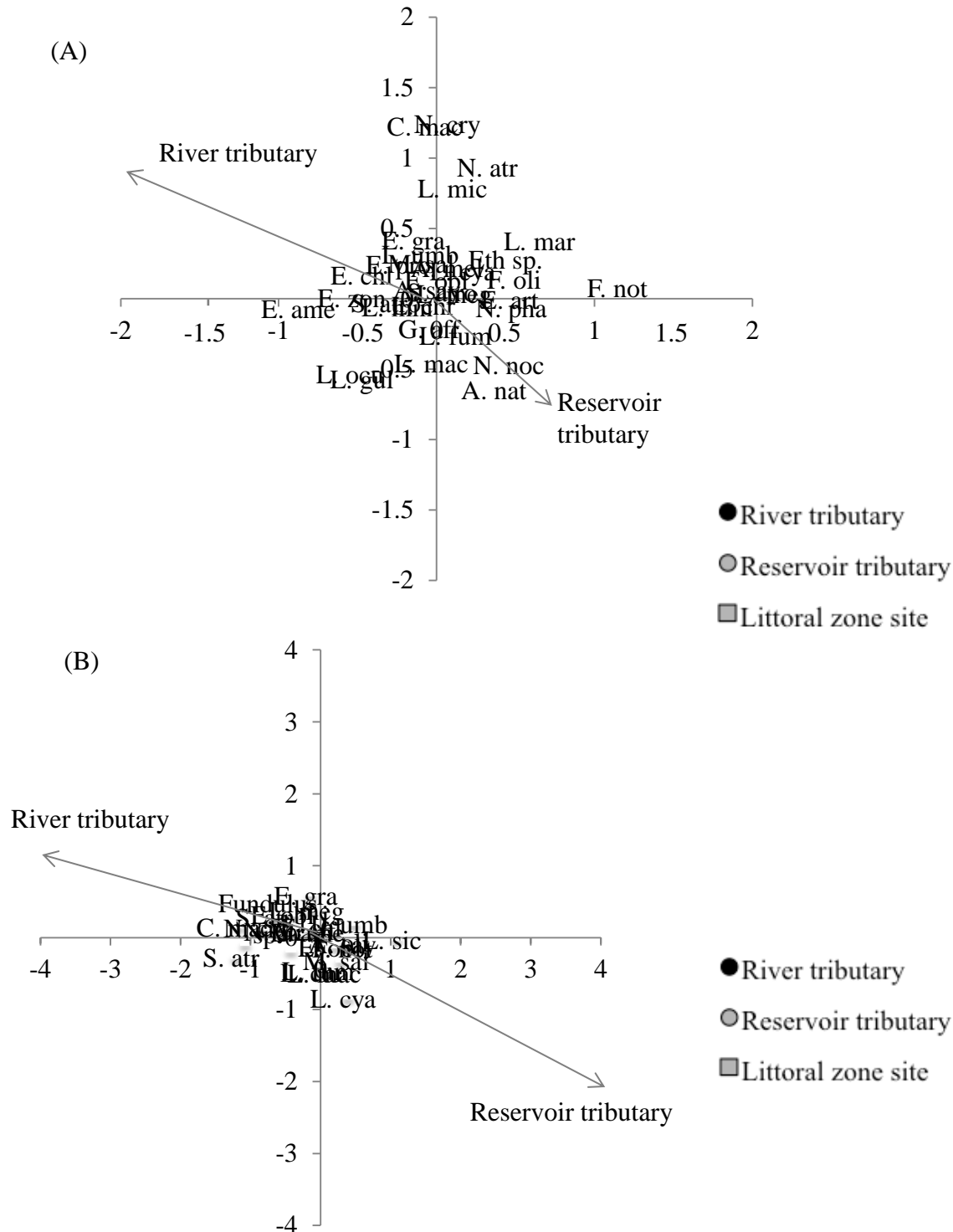


Figure 6. Results of Canonical Correspondence Analysis investigating influence of site type on Red River Basin fish distribution and abundance variables for (A) electrofishing and (B) seine data. Influential habitat variables were included as partial variables. Arrows indicate direction and strength of relationships. Fish are labeled with first letter of genus and first three letters of species name; see Appendix B for species codes.

Table 5. Results from generalized linear mixed models examining the relationship between sample site type and various assemblage metrics for Red River Basin fishes sampled in 2014 and 2015. Significant differences in bold. Dataset indicated by ‘ef’ for electrofishing and ‘seine’ for seining. “litt. zone” indicates littoral zone sampling site.

	Dataset	Model-wide		Adj. P-value		
		F-value	Pr > F	river tribs	river tribs	lake tribs
				vs. lake tribs	vs. litt. zone	vs. litt. zone
Total richness	ef	3.96	<b>0.0276</b>	0.5034	<b>0.0250</b>	0.0626
	seine	9.92	<b>0.0004</b>	<b>0.0006</b>	0.0755	0.6843
Stream habitat specialist	ef	0.36	0.6988	0.9729	0.7320	0.6760
relative abundance	seine	1.04	0.3629	0.7885	0.5361	0.3472
Stream habitat	ef	4.79	<b>0.0600</b>	0.1316	<b>0.0347</b>	0.1155
specialist richness	seine	3.04	0.0600	0.7956	0.0751	<b>0.0499</b>
Habitat generalist	ef	8.43	<b>0.0010</b>	<b>0.0008</b>	0.2744	0.7965
species richness	seine	2.93	0.0658	0.2003	0.1187	0.4712

(A) Total species richness

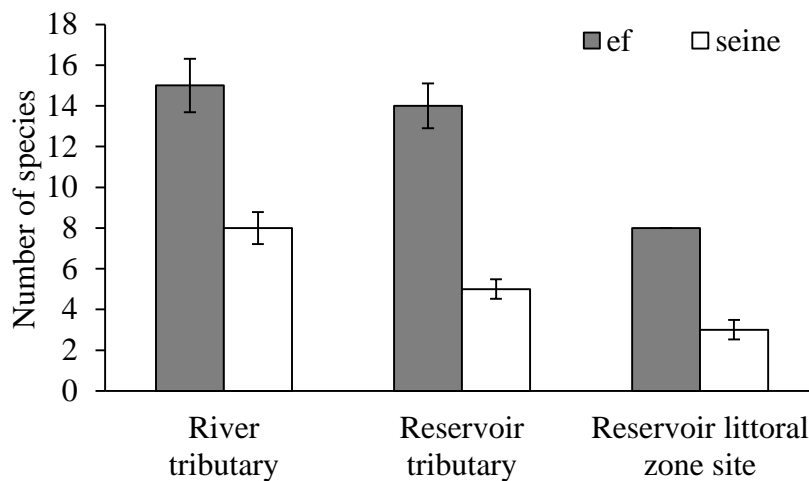
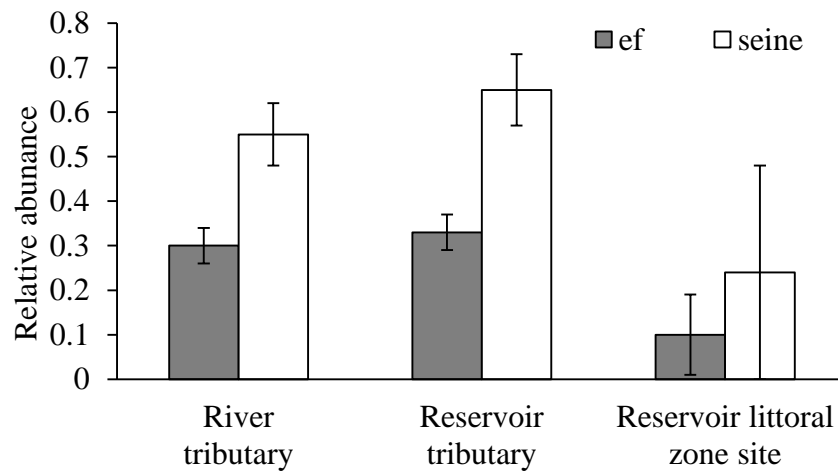


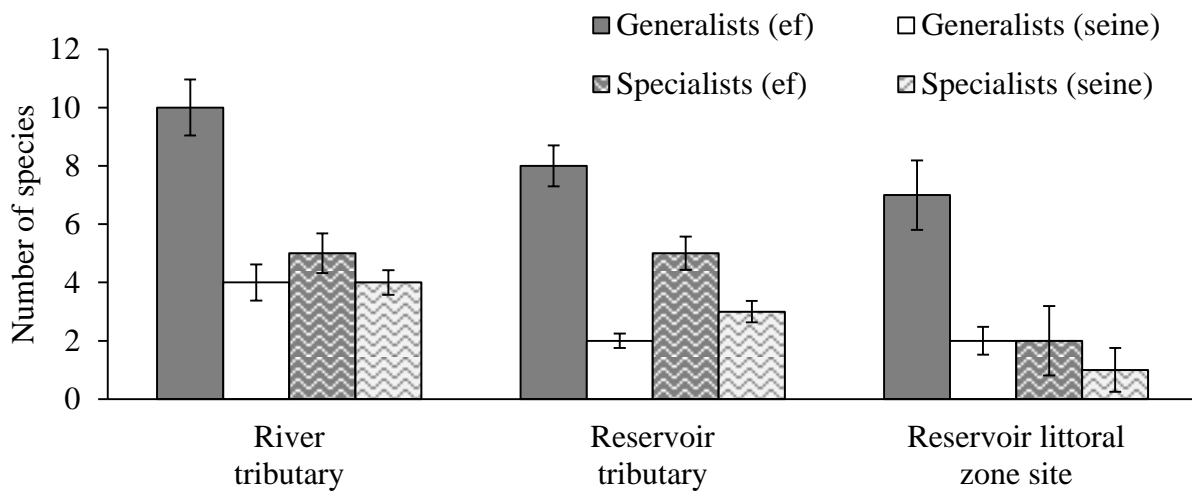
Figure 7. Average of assorted assemblage metrics in Red River Basin fish assemblages sampled in 2014 and 2015. Total species richness (A), relative abundance of stream specialist species (B), and species richness of habitat generalist and stream specialists (C). Dataset indicated by ‘ef’ for electrofishing and ‘seine’ for seining.

(Figure 7 continued)

(B) Stream specialist abundance



(C) Generalists and specialists richness



### 3.4 Individual species models

I performed independent species-specific analysis for ten species of interest that had abundance estimates suitable for modeling, and sample site type explained a significant amount of the variation in the distribution of Bluntnose Darter *Etheostoma cholorsoma*, Redfin Pickerel *Esox americanus*, and Bluegill *Lepomis macrochirus*, all of which were significantly more abundant in river tributaries (Table 6). Additionally, Redfin Pickerel was significantly more

abundant in streams than in the reservoir littoral zone. The strength of this effect was much larger than the difference between streams, indicating a much greater abundance in the streams than in the reservoir.

Table 6. Results from generalized linear mixed models examining the relationship between sample site type and the estimated abundance of Red River Basin fishes sampled in 2014 and 2015. Significant differences are in bold.

Species	Model-wide		Adj. P-value		
	F-value	Pr > F	river tribs	river tribs	lake tribs
			vs. lake tribs	vs. littoral zone	vs. littoral zone
<i>Etheostoma chlorosoma</i>	19.21	<b>&lt;.0001</b>	<b>&lt;.0001</b>	0.9807	0.9027
<i>Esox americanus</i>	41.25	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>0.0004</b>
<i>Elassoma zonatum</i>	3.06	0.0610	---	---	---
<i>Fundulus notatus</i>	1.66	0.2040	---	---	---
<i>Lepomis gulosus</i>	2.05	0.1459	---	---	---
<i>Lepomis macrochirus</i>	8.90	<b>0.0008</b>	<b>0.0008</b>	0.3948	0.6176
<i>Lepomis microlophus</i>	1.50	0.2372	---	---	---
<i>Lepomis symmetricus</i>	0.88	0.4243	---	---	---
<i>Notemigonus chrysoleucas</i>	0.64	0.5351	---	---	---
<i>Semotilus atromaculatus juv.</i>	0.96	0.3932	---	---	---

#### **4. DISCUSSION**

This study focused on two central questions related to fish assemblage dynamics in Red River headwater tributaries. First, I sought to establish baseline relationships between standard habitat variables and fish assemblages and to probe the previously unexamined role of altered dendritic connectivity. I hypothesized that generalist species would be more abundant and diverse than stream specialists in reservoir tributaries, similar to other disturbed systems (Herbert and Gelwick 2003; Falke and Guido 2006; Guenther and Spacie 2006). I found very limited support for this hypothesis; very few assemblage metrics demonstrated any difference between tributary types, and those patterns that were significant did not parallel the expected alteration-induced species shifts. In other study systems where connectivity influenced fish assemblage distribution (Winston et al. 1991; Reyes-Gavilan et al. 1996; Falke and Guido 2006; Guenther and Spacie 2006; Matthews and Marsh-Mathews 2007), connection to the reservoir has been implicated in the mechanisms behind this influence. I therefore compared habitat and fish assemblages between tributaries and associated impoundments to illuminate the potential for such mechanisms to exist. My first broad hypothesis was supported related to reservoirs; the impoundment littoral zone did contain fish assemblages different from streams in some respects. However, these differences did not support my more specific hypothesis, as I did not find a unique collection of predators and competitors that could influence the abundance and distribution of transient stream specialists or upstream assemblage dynamics. Additionally, based on the habitat variables I examined, the reservoir littoral zone was similar to streams. Combined, these facts provide little support for my final hypothesis, and I could substantiate no means for the reservoir to serve as a barrier to movement for stream specialists. Thus, the

upstream effects of impoundment on the headwater streams of the Red River Basin appear very nuanced and do not mirror those seen in other systems.

#### 4.1 Similarity of reservoir and river tributary streams: habitat

Although I was most interested in the potential influence of dendritic connectivity on fish assemblages, I anticipated that it would be one of many influential habitat variables.

Although habitat analysis indicated stream type could not be distinguished by habitat, other habitat variables, including flow, depth, canopy cover and an assortment of substrate categories were related to variation in fish assemblages (Figure 3). These habitat variables, though statistically significant, left much unexplained variation in fish assemblages.

This result is very similar to the findings of a similar study of fish assemblages in the Red, Sabine, and Calcasieu Rivers. Williams et al. (2005) investigated relationships between fish assemblages and habitat variables, including depth, flow velocity, substrate gradient, and military training, summarized as a landscape disturbance variable. In their study, habitat variables explained similar amounts of assemblage variation as my result (25%), however, they found that the variation uniquely attributable these effects was non-significant. The authors attribute lack of significance to in-stream habitat variation and a lack of strong habitat associations for many species (Williams et al. 2005). In addition to Williams et al. (2005) finding that the Red River basin shared more than half its species with one of the more southern drainages, others have remarked on the cosmopolitan nature of coastal plain fish fauna generally (Felley 1992), especially among adjacent river basins (Hoeinghaus et al. 2007; Kaller et al. 2013). Indeed, even more distant basins are faunally similar to the Red River basin. For example 26 out of 36 species in Mississippi headwater streams were also present in Red River study sites (Smiley et al. 2005). This could explain the lack of strong relationships between



habitat conditions and assemblage variation in the results as well, i.e., Red River Basin fish assemblages are composed mostly of generalist, cosmopolitan species that are able to successfully exploit a wide range of habitat conditions.

Regardless, other studies in coastal plain streams have successfully resolved habitat species relationships. For example several studies of Mississippi streams (orders 1-5) observed correlations of fish with wetted width, canopy cover, flow velocity, and depth, sand, detritus, clay, canopy cover and channel cross-section area among others (Shields et al. 1995; Smiley et al. 2005; Warren et al. 2002). Streams in the central Oklahoma/Texas plains, more similar to the Red River biogeographically (west of the Mississippi River biogeographic interruption; Robinson 1986) though in a different ecoregion, found similar influential habitat variables, in particular depth, water velocity, width, specific conductance, presence of deep pools, and percent sand coverage (Lienesch et al. 2000; Herbert and Gelwick 2003). These important parameters are similar to the variables retained by my CCA and the Williams et al. (2005) study, supporting the biological reality of these relationships, despite their lack of importance relative to other variables. Although these studies examined headwater streams similar in biogeography to the Red River study sites and therefore can contextualize the observed habitat relationships, few incorporated sample sites that could qualify as reservoir tributaries and do little to illuminate the dichotomy of interest in this study. Only Lienesch et al. (2000) identified the presence of a reservoir as a correlate of fish assemblage structure.

#### 4.2 Similarity of reservoir and river tributary streams: fish assemblage

The small portion of fish assemblage variation explained by habitat (i.e., habitat analysis indicated stream type could not be distinguished by habitat), suggested that observed fish assemblage differences might have been explained by stream-type differences in dendritic

connectivity. However, even with this variation held constant, dendritic connectivity was not a significant predictor of broad assemblage structure (Figure 6). Though none of the metrics of fish assemblage structure supported my specific hypothesis, I found one indication that assemblages are not completely equivalent between stream types. Examination of the richness data from the seine dataset indicated that more species were sampled in river tributaries than in reservoir tributaries, though this trend was not supported by the electrofishing dataset. Pelagic species that inhabit the water column or stream surface are often more susceptible to seining than other sampling methods (Rabeni et al. 2009). Many species within this species group are habitat specialists (e.g., topminnows *Fundulus* spp., Striped Shiner, finescale shiners *Lythrurus* spp., Pugnose Minnow *Opsopoeodus emiliae*, and Creek Chub *Semotilus atromaculatus*). If the increase in richness were attributable to these species, it would provide evidence for my first hypothesis that river tributaries possess stream specialist diversity that is lost in reservoir tributaries and would have substantiated a reservoir effect. However, analysis of generalist vs. stream specialist richness in the seine data indicated significantly greater generalist species richness in river tributaries but not significantly different specialist richness. Thus, I infer that the higher total richness is due to more habitat generalists. The stark habitat generalist/specialist categorizations used in these analyses simplify a continuum of fish/habitat preferences, and it is possible these delineations masked subtle habitat associations affecting species' responses to the impoundment (Schlosser 1987). I attempted to elucidate microhabitat preferences through examination of feeding and reproductive functional groups, but detected no differences in the proportion of these groups between stream types. Traits that I did not consider, such as differential swimming ability, differences in escape behaviors, and differences in habitat use that effect predation risk can all influence relative survival of stream fishes (Wahl and Stein

1988; Godinho and Ferreira 2006; Albanese et al. 2009; Santos et al. 2009; Marsh-Matthews et al. 2013) and could be at the root of the differences observed in the seine captures.

Nevertheless, the differences observed provide little support for reservoir-mediated variation in fish assemblages in the study streams and in general it appears river and reservoir tributaries are as alike in fish as they are in habitat.

These results contrast with the few other studies of impoundment of headwater streams, which found significant differences between river and reservoir type tributaries. No comparable research has been performed in Louisiana or elsewhere in the Southern Coastal Plain ecoregion, but studies in Indiana, Oklahoma, and Kansas all quantified declines for stream specialists and increases in generalist abundance (Winston 1991; Herbert and Gelwick 2003; Falke and Guido 2006; Guenther and Spacie 2006; Matthews and Marsh-Matthews 2007). These study systems shared at least a 30% of their diversity with Red River headwater streams, primarily habitat generalist species. Some of the observed connectivity-driven differences involved these shared taxa; for example, the Largemouth Bass *Micropterus salmoides*, Gizzard Shad and Western Mosquitofish *Gambusia affinis* were all generalist reservoir invasives that distinguished reservoir tributaries from unimpounded streams. As sampling methodology and number of sample sites were comparable between my study and other investigations, it is difficult to illuminate why these coastal plain streams not replicate such trends. One reason may be that some of these studies (Winston 1991; Falke and Guido 2006; Guenther and Spacie 2006) investigated slightly larger 3<sup>rd</sup> order streams, which perhaps were more inviting to the larger species than 1<sup>st</sup> and 2<sup>nd</sup> order sites examined in the Red River.

Grass Pickerel *Esox americanus* demonstrated a greater affinity to unfragmented streams than other species in this study and may be responding to reservoirs differently than other

fishes. In two other studies, Grass pickerel, a common stream predator in the coastal plain, was found in greater abundance (and size) in unfragmented tributaries (Herbert and Gelwick 2003; Guenther and Spacie 2006), a trend I also observed in the Red River streams. Authors of these studies attributed the difference to competition from other predators such as Largemouth Bass in reservoir tributaries; however, other predators were rarely observed in Red River streams. Perhaps the greater number of Grass Pickerel in unfragmented streams may be a more of a signal of an existing connection to a river than loss of connection because of a reservoir (see Meffe 1991). Grass Pickerel are common seasonal users of adjacent and upland floodplain habitats of medium sized rivers (e.g., Kwak 1988; Bright et al. 2010) and headwaters in the coastal plain (Smiley et al. 2005). Floodplains serve many of the same habitat roles during life histories of many fishes as headwaters serve (Smock and Gilinsky 1992). In the Red River basin, many floodplains have been disconnected by levees, possibly increasing the importance of headwater habitats. It is possible that Grass Pickerel in unfragmented streams are populations associated with larger downstream rivers that are using these headwaters as off-channel habitats, suggesting that connection to the river is important to this species.

Unlike common generalist species, there was little overlap in stream specialist species in this study and other studies of dendritic connectivity (Winston 1991; Herbert and Gelwick 2003; Falke and Guido 2006; Guenther and Spacie 2006; Matthews and Marsh-Matthews 2007). Only Redfin Shiner, Bullhead Minnow, and Creek Chub were also present in these studies and trends for specialists did not involve these shared species. For example, changes in stream specialists populations were mainly driven by declines of Rainbow Darter *Etheostoma caeruleum*, Greenside Darter *Etheostoma blenniodes*, and Johnny Darter *Etheostoma nigrum* in Indiana streams (Guenther and Spacie 2006), by Sand Shiners *Notropis stramineus* and Fathead

Minnows *Pimephales promelas* in Oklahoma tributaries (Matthews and Marsh-Matthews 2007), and by the extirpation of the Topeka Shiner *Notropis topeka* and Carmine Shiner *Notropis percobromus* as well as great reductions in Sand Shiners at reservoir sites in Kansas (Falke and Guido 2006). Although Red River streams possessed some functionally comparable species, e.g., Redspot Darter *Etheostoma artesiae*, and Bluntnose Darters *Etheostoma chlorosoma*, Striped Shiners and Blackspot Shiners *Notropis atrocaudilis*, only the Bluntnose Darter exhibited a significant trend of greater abundance in river tributaries. As stochastic processes can easily result in dissimilarity between sites (Resh et al. 1988; Lake 2000) and with no other similar trends observed, I do not find this observation to be compelling evidence for a widespread decline of specialist species in Red River Basin lake tributary streams.

#### 4.3 Cosmopolitan coastal plain fishes

There are several reasons why Louisiana's Red River Basin streams remain similar in fish assemblage composition in face of altered dendritic connectivity. Firstly, headwater streams of this basin are home to a large number of cosmopolitan, tolerant fish with the overall assemblage dominated by widely distributed habitat generalists that can inhabit streams, swamps, ponds, and reservoirs (Appendix 2, Felley 1992; Ross 2001; Warren et al. 2002). Indeed, species that are often considered indicators of stream impairment such as pollution-tolerant centrachids are common, natural features of the assemblage (Helms et al. 2009). In this study's collections, less than half the species captured qualify as stream habitat specialists and for many, their requirements are not stringent (e.g., Bluntnose Darters are found in lentic-like slack waters; Ross 2001). Moreover, five stream specialist species were also captured in the reservoir littoral zone sites.

Current fish distributions within the Gulf of Mexico coastal plain was determined largely by the combined legacies of geologic change (Robinson 1986; Felley 1992; Isphording and Fitzpatrick 1992; Adams et al. 2004; Brown and Matthews 2006), climatic events (Perret et al. 2010, van Vrancken and O'Connell 2010), and anthropogenic disturbance (Harding et al. 1998; Lopez 2009; Piller and Geheber 2015). From the potential regional taxonomic pool, these factors acted as ecological filters (Schlosser 1987; Resh et al. 1988; Winemiller and Rose 1992; Poff et al. 1997; McManamay and Frimpong 2015). Resulting fish assemblages had barriers to colonization/recolonization (e.g., the Mississippi River; Douglas 1974; Kaller et al. 2013), and were resilient to upland and riparian fire (Glitzenstein et al. 1995; Dunham et al. 2007), seasonal and multi-year dry conditions with low water quantity and depressed dissolved oxygen (Felley 1992; Justus et al. 2014), and dynamic in-stream habitats (Geheber and Pillar 2012). More specifically, headwaters generally experience frequent disturbance, potentially exacerbating selective pressures (Horwitz 1978; Schlosser 1987; Poff and Allan 1995; Griffiths 2010). In total, the fishes inhabiting Red River headwater streams may have faced severe selection processes that would have favored tolerant, generalist species. Evidence of these legacies is clear in coastal plain fishes' rapid recolonization abilities (Sheldon and Meffe 1994) and their resiliency to land cover changes and timber harvest (Williams et al. 2002; Williams et al. 2007; Fitzgerald 2012, but see Daniel et al. 2014). Therefore, for the fishes of the Red River Basin, altered dendritic connectivity may not be an insuperable disturbance.

The lack of influence of altered connectivity may also originate from the nature of the disturbance rather than the fish assemblage facing it. Natural dams formed by log jams are a common feature of many river systems, the Red River being the site of the largest recorded in American history (Watson 1967, Slingerland and Smith 2004) such that naturally altered

connectivity may also have shaped fish assemblages as described. Furthermore, it may be that in the context of the wider Red River habitat, a reservoir does not qualify as significant disturbance.

#### 4.4 Streams versus Reservoir: Similarity in habitat and assemblage

Studies that have identified upstream effects of impoundment have been unable to identify the exact mechanism behind resultant species assemblage shifts though most suggest two suites of hypotheses: one based on the isolation of streams caused by the reservoir, the second based on the proximity of novel assemblages living in the reservoir (Fraser et al. 1995; Schlosser et al. 2000; Gido et al. 2002; Freeman and Marcinek 2006). Thus, concurrent with the comparison of river and reservoir tributaries, I investigated the assemblage and habitat present in the reservoir littoral zone. Contrary to my hypotheses, I found no evidence that the reservoirs act as barriers to movement or as a source of predator/competitor species. Habitat along the edge of the reservoir was comparable to that found in headwater streams (Figure 3) and, therefore, unlikely to deter fish movement. Additionally, the predation risk did not appear higher in the littoral zone compared to streams, based on sampled predator fishes. Though river tributaries had total greater species richness, presumably augmented by greater richness in stream specialists (Figure 7), all other assemblage metrics found both stream types and the reservoir littoral zone to have comparable fish assemblages (Figure 6 and functional group analyses). I encountered only one novel predator in the littoral zone, adult Bowfin *Amia calva*, and no other large predators, such as Largemouth Bass *Micropterus salmoides* or Channel Catfish *Ictalurus punctatus*, which have been implicated in creating ‘predation barriers’ in other studies (Winston et al. 1991; Herbert and Gelwick 2003; Guenther and Spacie 2006). Moreover, I did not document the incursion of these species or competitor species into tributary streams.

However, the observed reduction of the predatory Grass Pickerel in the reservoir littoral zone could suggest exclusion by other ecologically-similar fishes (Herbert and Gelwick 2003; Guenther and Spacie 2006).

More complex littoral zone habitats with submerged vegetation and woody debris can support a greater diversity of fish, particularly cyprinids, whereas in reservoirs with simplified, unshaded, wave-washed littoral zones, perciform and predatory fishes dominate (Duncan and Kubečka 1995). Thus, it is not surprising that the littoral zones examined, so similar in habitat to our streams, did not foster a strong reservoir effect upstream. The apparent innocuity of the littoral zone supports the observed lack of differences between river and reservoir tributary fish assemblages.



## 5. CONCLUSION

Results of the investigation of fish assemblage response to altered connectivity provide an interesting contrast to other studies of upstream effects of impoundments on small dendritic headwater systems. Multi-region analyses of the impacts of disturbance, such as pesticide use, land conversion to agriculture, and urbanization, have indicated that responses are mediated by local rates of physicochemical change, land use history, and species' inherent vulnerability and resilience (Jordan et al. 1997; Poff et al. 2006; Sprague and Nowell 2008). Thus, disturbance that has stark negative effects in one system may induce milder, more nuanced impacts in other areas. Indeed, some comparative studies indicate that coastal plain fishes may be less vulnerable to increased urbanization and agriculture than other ecoregions (Morgan and Cushman 2005; Utz et al. 2010). Other studies in the influence of timber harvest and military activities also showed limited effects in coastal plain systems (Williams et al. 2002; Williams et al. 2005). Considering these divergences, our conclusion that altered dendritic connectivity has little influence on fish assemblage structure in Red River basin headwater streams is not improbable.

Freshwater fishes and the environments they inhabit are under serious threat from innumerable directions. Understanding the magnitude and structure of response to these threats is critical for preserving aquatic ecosystems and focusing conservation efforts. Thus, the subtle differences I documented in the Red River basin merit more exploration. The grosser metrics of readily apparent species shifts or diversity loss examined in this study and many others may fail to document more understated impacts such as altered predator-prey relationships or size distributions, which could potentially inhibit species' persistence over time. Even systems such as the Red River Basin that evidence strong resilience to human disturbance warrant closer inspection before heedless system disturbance and alteration continue.

## LITERATURE CITED

- Abell R. A., D. M. Olson, E. Dinerstein, P. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C. J. Loucks, et al. 2000. *Freshwater Ecoregions of North America: A Conservation Assessment*. Island Press, Washington, DC.
- Adams, S. B., M. L. Warren, and W. R. Haag. 2004. Spatial and temporal patterns in fish assemblages of upper coastal plain streams, Mississippi, USA. *Hydrobiologia* 528:45-61.
- Agresti, A. 2015. *Foundations of Linear and Generalized Linear Models*. John Wiley, New York, NY.
- Albanese, B., P. L. Angermeier, and S. Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 61:857-869.
- Albanese, B., P. L. Angermeier, and J. T. Peterson. 2009. Does mobility explain variation in colonization and population recovery among stream fishes? *Freshwater Biology*. 54:1444-1460.
- Albanese, B. T. Litts, M. Camp and D. A. Weiler. 2013. Using occupancy and species distribution models to assess the conservation status and habitat use of the goldline darter (*Percina aurolineata*) in Georgia, USA. *Ecology of Freshwater Fish*. 23: 347-359.
- Anderson, G. B., M. C. Freeman, M. M. Hagler, and B. J. Freeman. 2012. Occupancy modeling and estimation of the Holiday Darter species complex within the Etowah River System. *Transactions of the American Fisheries Society*. 141:34-45.
- Baillie, J. E., J. Griffiths, S. T. Turvey, J. Loh, and B. Collen, editors. 2010. *Evolution Lost: Status and Trends of the World's vertebrates*. Zoological Society of London, London, UK.
- Beaumont, P. 1978. Man's impact on river systems: a worldwide view. *Area*. 10:38-41.
- Benke, A. C. 1990. A perspective on America's vanishing streams. *Journal of the North American Benthological Society*. 9:77-88.
- Bogan A. E. 2008. Global diversity of freshwater mussels (Mollusca, Bivalvia) in freshwater. *Hydrobiologia*. 595:139-147.
- Bright, E. G., D. P. Batzer, and J. A. Garnett. 2010. Variation in invertebrate and fish communities across floodplain ecotones of the Altamaha and Savannah Rivers. *Wetlands*. 30:1117-1128.
- Brown, A. V. and W. J. Matthews. 2006. Stream ecosystems of the central United States. Pages 89-116 in C.E. Cushing, K. W. Cummins, and G. W. Minshall, editors. *River and Stream Ecosystems of the World*. University of California Press, Berkeley, CA.

- Carrizo, S. F., K. G. Smith, and W. R. T. Darwall. 2013. Progress towards a global assessment of the status of freshwater fishes (Pisces) for the IUCN Red List: application to conservation programmes in zoos and aquariums. *International Zoo Yearbook*. 47:46-64.
- Cross, F. B., Mayden, R. L., and J. D. Stewart. 1986. Fishes in the western Mississippi basin (Missouri, Arkansas and Red Rivers). Pages 363-412 in C. H. Holcutt and E. O. Wiley, editors. *The Zoogeography of North American Freshwater Fishes*. John Wiley , New York, NY.
- Daigle, J. J., G. E. Griffith, J. M. Omernik, P. L. Faulkner, R. P. McCulloh, L. R. Handley, L.M. Smith, and S.S. Chapman. 2006. *Ecoregions of Louisiana*. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, VA. Scale 1:1,000,000.
- Daniel, W. M., K. M. Brown, and M. D. Kaller. 2014. A tiered aquatic life unit bioassessment model for Gulf of Mexico coastal streams. *Fisheries Management and Ecology*. 21:491-502.
- Diana, M., J. D. Allan, and D. Infante. 2006. The influence of physical habitat and land use on stream fish assemblages in southeastern Michigan. Pages 359-374 in R. M Hughes,, L. Wang, and P. Seelbach, editors. *Landscape Influences on Stream Habitats and Biological Assemblages*. American Fisheries Society Symposium 48. American Fisheries Society, Bethesda, MD.
- Douglas, N. H. 1974. Freshwater Fishes of Louisiana. Claitor's Publishing Division, Baton Rouge, LA.
- Dudgeon D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Leveque, R. J. Naiman, A. H. Prieur-Richard, D. Soto, L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Review*. 81:163-182.
- Duncan, A. and J. Kubečka. 1995. Land/water ecotone effects in reservoirs on the fish fauna. Pages 11-30 in F. Schiemer, M. Zalewski, and J. E. Thorpe, editors. *The importance of aquatic-terrestrial ecotones for freshwater fish* (Vol. 105). Springer Science and Business Media. Netherlands.
- Dunham, J. B., A. E. Rosenberger, C. H. Luce, and B. E. Rieman. 2007. Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. *Ecosystems*. 10:335-346.
- Falke, J. A. and K. S. Gido. 2006. Effects of reservoir connectivity on stream fish assemblages in the Great Plains. *Canadian Journal of Fisheries and Aquatic Sciences*. 63:480-493.
- Felley, J. D. 1992. Medium-low gradient streams of the Gulf Coastal Plain. Pages 233-269 in C. T. Hackney, S. M. Adams, and W. H. Martin, editors. *Biodiversity of the Southeaster United States: Aquatic Communities*. John Wiley , New York, NY.

- Fitzgerald, A. M. 2012. Effects of varying land use on headwater stream fish assemblages and in-stream habitats in southwestern Louisiana. Master's thesis. Louisiana State University, Baton Rouge, LA.
- Fluker, B. L., Kuhajda B. R., and Harris P. M. 2014. The effects of riverine impoundment on genetic structure and gene flow in two stream fishes in the Mobile River basin. *Freshwater Biology*. 59:526-543.
- Franssen, N. R. 2012. Genetic structure of a native cyprinid in a reservoir-altered stream network. *Freshwater Biology*. 57:155-165.
- Franssen, N. R., and M. Tobler. 2013. Upstream effects of a reservoir on fish assemblages 45-years following impoundment. *Journal of Fish Biology*. 82:1659-1670.
- Fraser, D. F., J. F. Gilliam, and T. Yiphoi. 1995. Predation as an agent of population fragmentation in a tropical watershed. *Ecology*. 76:1461-1472.
- Freedman, J. A., B. D. Lorson, R. B. Taylor, R. F. Carline, and J. R. Stauffer, Jr. 2014. River of the dammed: longitudinal changes in fish assemblages in response to dams. *Hydrobiologia* 727:19-33.
- Freeman, M. C. and P. A. Marcinek. 2006. Fish assemblage responses to water withdrawals and water supply reservoirs in piedmont streams. *Environmental Management*. 38:435-450.
- Geheber, A. D., and K. R. Piller. 2012. Spatio-temporal patterns of fish assemblage structure in a coastal plain stream: appropriate scales reveal historic tales. *Ecology of Freshwater Fish*. 21:627-639.
- Gido, K. B., C. W. Hargrave, W. J. Matthews, G. D. Schnell, D. W. Pogue, and G. W. Sewell. 2002. Structure of littoral-zone fish communities in relation to habitat, physical, and chemical gradients in a southern reservoir. *Environmental Biology of Fishes*. 63:253-263.
- Glitzenstein, J. S., W. J. Platt, and D. R. Streng. 1995. Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. *Ecological Monographs*. 65:441-476.
- Godinho, F. N. and M. T. Ferreira. 2006. Influence of habitat structure on the fish prey consumption by largemouth bass, *Micropterus salmoides*, in experimental tanks. *Limnetica*. 25: 657-664.
- Graf, W. L. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research*. 35:1305-1311.
- Graf, W. L. 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology*. 79:336-360.
- Griffiths, D. 2010. Pattern and process in the distribution of North American freshwater fish. *Biological Journal of the Linnean Society*. 100:46-61.

- Guenther, C. B., and A. Spacie. 2006. Changes in fish assemblage structure upstream of impoundments within the Upper Wabash River basin, Indiana. *Transactions of the American Fisheries Society*. 135:570-583.
- Harding, J. S., E. F. Benfield, P. V. Bolstad, G. S. Helfman, and E. B. D. Jones. 1998. Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences of the United States of America*. 95:14843-14847.
- He, X., and J. F. Kitchell. 1990. Direct and indirect effects of predation on a lake fish community. *Transactions of the American Fisheries Society*. 119:825–835.
- Heitke, J. D., C. L. Pierce, G. T. Gelwicks, G. A. Simmons, and G. L. Segworth. 2006. Habitat, land use, and fish assemblage relationships in Iowa streams: Preliminary assessment in an agricultural landscape. Pages 281-303 in R. M. Hughes, L. Wang, and P. Seelbach, editors. *Landscape Influences on Stream Habitats and Biological Assemblages*. American Fisheries Society Symposium 48. American Fisheries Society, Bethesda, MD.
- Helms B. S., J. E. Schoonover, and J. W. Feminella. 2009. Assessing influences of Hydrology, Physicochemistry, and Habitat on Stream Fish Assemblages across a changing Landscape. *Journal of the American Water Resources Association*. 45:157-169.
- Hendrickson, D. A. and A. E. Cohen. 2015. Fishes of Texas Project and Online Database (version 2.0) (<http://fishesoftexas.org>). Published by the Ichthyology Collection of The University of Texas at Austin. Accessed September 2015.
- Herbert, M. E. and F. P. Gelwick. 2003. Spatial variation of headwater fish assemblages explained by hydrologic variability and upstream effects of impoundment. *Copeia*. 273-284.
- Hirst, C. N., and D. A. Jackson. 2007. Reconstructing community relationships: the impact of sampling error, ordination approach, and gradient length. *Diversity and Distributions* 13:361-371.
- Hoeinghaus, D. J., K. O. Winemiller, and J. S. Birnbaum. 2007. Local and regional determinants of stream fish assemblage structure: inferences based on taxonomic vs. functional groups. *Journal of Biogeography*. 34: 324-338.
- Homer, C., J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J. N. VanDriel, and J. Wickham. 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States. *Photogrammetric Engineering and Remote Sensing*. 73:337-341.
- Horwitz, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecological Monographs*. 48:307-321.
- Infante, D. M. and J. D. Allan. 2010. Response of stream fish assemblages to local-scale habitat as influenced by landscape: a mechanistic investigation of stream fish assemblages. Pages 371-397 in K. B. Gido, and D. A. Jackson, editors. *Community ecology of stream*

- fishes: concepts, approaches, and techniques*. American Fisheries Society, Symposium 73, Bethesda, MD.
- Isphording, W. C. and J. F. Fitzpatrick, Jr. 1992. Geologic and evolutionary history of drainage systems in the southeastern United States. Pages 19-56 in C.T. Hackney, S. M. Adams, and W. H. Martin, editors. *Biodiversity of the southeastern United States. Aquatic communities*. John Wiley , New York, NY.
- Jelks H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, et al. 2008. Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. *Fisheries*. 33:372-407.
- Jordan, T. E., D. L. Correll, and D. E. Weller. 1997. Relating nutrient discharges from watersheds to land use and streamflow variability. *Water Resources Research*. 33:2579-2590.
- Justus, B. G., S. V. Mize, J. Wallace, and D. Kroes. 2014. Invertebrate and fish assemblage relations to dissolved oxygen minima in lowland streams of southwestern Louisiana. *River Research and Applications*. 30:11-28.
- Kaller, M. D., C. E. Murphy, W. E. Kelso, and M. R. Stead. 2013. Basins for fish and ecoregions for macroinvertebrates: different spatial scales are needed to assess Louisiana wadeable streams. *Transactions of the American Fisheries Society*. 142:767-782.
- Kaufmann, P. R, P. Levine, E. G. Robison, C. Seeliger, and D. V. Peck. 1999. Quantifying Physical Habitat in Wadeable Streams. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington, DC.
- Kondolf, G. M. 1997. Hungry water: Effects of dams and gravel mining on river channels. *Environmental Management*. 21:533-551.
- Kwak, T. J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. *American Midland Naturalist*. 120:241-249.
- Lake, P. S. 2000. Disturbance, patchiness, and diversity in streams. *Journal of the North American Benthological Society*. 19:573-592.
- Lester, G. D., S. G. Sorenson, P. L. Faulkner, C. S. Reid, and I. E. Maxit. 2005. Louisiana Comprehensive Wildlife Conservation Strategy. Baton Rouge, LA: Louisiana Department of Wildlife and Fisheries.
- Lienesch, P. W., W. I. Lutterschmidt, and J. F. Schaefer. 2000. Seasonal and long-term changes in the fish assemblage of a small stream isolated by a reservoir. *Southwestern Naturalist*. 45:274-288.
- Limburg, K. E. and J. R. Waldman. 2009. Dramatic declines in North Atlantic diadromous fishes. *Bioscience*. 59:955-965.

- Lopez, J. A. 2009. The environmental history of human-induced impacts to the Lake Pontchartrain basin in southeastern Louisiana since European settlement-1718 to 2002. *Journal of Coastal Research*. Special Issue 54:1-11.
- Lydeard, C. and R. L. Mayden. 1995. A diverse and endangered aquatic ecosystem of the southeast United States. *Conservation Biology*. 9:800-805.
- Marsh-Matthews E., J. Thompson, W. J. Matthews, A. Geheber, N. R. Franssen, and J. Barkstedt . 2013. Differential survival of two minnow species under experimental sunfish predation: implications for re-invasion of a species into its native range. *Freshwater Biology*. 58:1745–1754.
- Matthews, W. J. and E. Marsh-Matthews. 2007. Extirpation of red shiner in direct tributaries of Lake Texoma (Oklahoma-Texas): a cautionary case history from a fragmented river-reservoir system. *Transactions of the American Fisheries Society*. 136:1041-1062.
- McManamay, R. A., and E. A. Frimpong. 2015. Hydrologic filtering of fish life history strategies across the United States: implications for stream flow alteration. *Ecological Applications*. 25:243-263.
- (MEA) Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, D.C.
- Meador, M. R., J. F. Coles, and H. Zappia. 2005. Fish assemblage responses to urban intensity gradients in contrasting metropolitan areas: Birmingham, Alabama and Boston, Massachusetts. Pages 409–423 in L. R. Brown, R. Gray, R. M. Hughes, and M. R. Meador, editors. *Effects of urbanization on stream ecosystems*. AFS Symposium 47. American Fisheries Society, Bethesda, MD.
- Meffe, G. K. 1991. Failed invasion of a southeastern blackwater stream by bluegills: implications for conservation of native communities. *Transactions of the American Fisheries Society*. 120:333-338.
- Morgan, R. P. and S. F. Cushman. 2005. Urbanization effects on stream fish assemblages in Maryland, USA. *Journal of the North American Benthological Society*. 24:643-655.
- Neraas, L. P. and P. Spruell. 2001. Fragmentation of riverine systems: the genetic effects of dams on bull trout (*Salvelinus confluentus*) in the Clark Fork River system. *Molecular Ecology*. 10:1153-1164.
- Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. Henry, H. Stevens, and H. Wagner. 2015. vegan: Community Ecology Package. R package version 2.3-1. <http://CRAN.R-project.org/package=vegan>.
- Perret, A. J., M. D. Kaller, W. E. Kelso, and D. A. Rutherford. 2010. Effects of Hurricanes Katrina and Rita on sport fish community abundance in the eastern Atchafalaya River basin, Louisiana. *North American Journal of Fisheries Management*. 30:511-517.

- Petts, G. E., and A. M. Gurnell. 2005. Dams and geomorphology: Research progress and future directions. *Geomorphology*. 71:27-47.
- Piller, K. R., and A. D. Geheber. 2015. Black liquor and the hangover effect: fish assemblage recovery dynamics following a pulse disturbance. *Ecology and Evolution*. 5:2433-2444.
- Poff, N. L. 1997. Landscape filters and species traits: Towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society*. 16:391-409.
- Poff, N. L., and J. D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology*. 76:606-627.
- Poff, N. L., B. P. Bledsoe, and C. O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: Geomorphic and ecological consequences for stream ecosystems. *Geomorphology*. 79:264-285.
- Poff, N. L., J. D. Olden, D. M. Merritt, and D. M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences of the United States of America*. 104:5732-5737.
- Pringle, C. M. 1997. Exploring how disturbance is transmitted upstream: Going against the flow. *Journal of the North American Benthological Society*. 16:425-438.
- Pringle, C., M. C. Freeman, and B. J. Freeman. 2000. Regional effects of hydrological modification on riverine macrobiota in the new world: tropical-temperate comparisons. *Bioscience*. 50:807-823.
- R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. URL <https://www.R-project.org/>.
- Rabeni, C. F., J. Lyons, N. Mercado-Silva, and J. T. Peterson. 2009. Warmwater fish in wadeable streams. Pages 42-58 in S. A. Bonar, W. A. Hubert, and D. W. Willis, editors. *Standard Methods for Sampling North American Freshwater Fishes*. American Fisheries Society, Bethesda, MD.
- Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. C. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society*. 7:433-455.
- Reyes-Gavilan, F. G., R. Garrido, A. G. Nicieza, M. M. Toledo, and F. Brana. 1996. Fish community variation along physical gradients in short streams of northern Spain and the disruptive effect of dams. *Hydrobiologia*. 321:155-163.
- Robinson, H. W. 1986. Zoogeographic implications of the Mississippi River basin. Pages 267-285 in C. H. Holcutt and E. O. Wiley, editors. *The Zoogeography of North American Freshwater Fishes*. John Wiley, New York, NY.



- Ross, S.T. 2001. Inland Fishes of Mississippi. University Press of Mississippi. Oxford, MS.
- Roy, A. H., M. C. Freeman, B. J. Freeman, S. J. Wenger, W. E. Ensign, and J. L. Meyer. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. *Journal of the North American Benthological Society*. 24:656–678.
- Santos A F. G. N., L. N., Santos, E. Garcia-Berthou, and C. Hayashi. 2009. Could native predators help to control invasive fishes? Microcosm experiments with the Neotropical characid, *Brycon orbignyanus*. *Ecology of Freshwater Fish*. 18:491–499.
- Schlosser, I. J. 1987. A conceptual framework for fish communities in small warmwater streams. Pages 17-24 in W. J. Matthews and D. C. Heins, editors. *The ecology and evolution of North American stream fish communities*. University of Oklahoma Press, Norman, OK.
- Schlosser, I. J. 1995. Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. *Ecology*. 76:908-925.
- Schlosser, I. J., J. D. Johnson, W. L. Knotek, and M. Lapinska. 2000. Climate variability and size-structured interactions among juvenile fish along a lake-stream gradient. *Ecology*. 81:1046-1057.
- Sheldon, A. L. and G. K. Meffe. 1995. Short-term recolonization by fishes of experimentally defaunated pools of a coastal plain stream. *Copeia*. 1995:828-837.
- Shields, Jr., F. D. S. S. Knight, and C. M. Cooper. 1995. Use of the index of biotic integrity to assess physical habitat degradation in warmwater streams. *Hydrobiologia*. 312:191-208.
- Slingerland, R. and N. D. Smith. 2004. River avulsions and their deposits. *Annual Review Earth Planet. Science*. 32:257-285.
- Smiley, P. C., E. D. Dibble, and S. H. Schoenholtz. 2005. Fishes of first-order streams in north-central Mississippi. *Southeastern Naturalist*. 4:219-236.
- Smith, R. K., P. L. Freeman, J. V. Higgins, K. S. Wheaton, T. W. FitzHugh, K.J. Ernststrom, and A. A. Das. 2002. Priority Areas for Freshwater Conservation Action: A Biodiversity Assessment of the Southeastern United States. The Nature Conservancy.
- Smock, L. A. and E. Gilinsky. 1992. Coastal Plain Blackwater Streams. Pages 271-311 in C.T. Hackney, S. M. Adams, and W. H. Martin, editors. *Biodiversity of the Southeastern United States: Aquatic Communities*. John Wiley. New York, NY.
- Sprague, L. A., and L. H. Nowell. 2008. Comparison of pesticide concentrations in streams at low flow in six metropolitan areas of the United States. *Environmental Toxicology and Chemistry*. 27:288-298.
- Swan, C. M. and B. L. Brown. 2011. Advancing theory of community assembly in spatially structured environments: local versus regional processes in river networks. *Journal of the North American Benthological Society*. 30:232-234.

- Taylor C. A., G. A. Schuster, J. E. Cooper, R. J. DiStefano, A. G. Eversole, P. Hamr, H. H. Hobbs, H. W. Robison, C. E. Skelton, and R. F. Thoma. 2007. A reassessment of the conservation status of crayfishes of the United States and Canada after 10+ years of increased awareness. *Fisheries*. 32:372-389.
- ter Braak, C. J. F. and P. F. M. Verdonschot. 1995. Canonical correspondence-analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences*. 57:255-289.
- U.S. Army Corps of Engineers. 2013. National Inventory of Dams. Available: <http://geo.usace.army.mil/pgis/f?p=397:1:0::NO>. Accessed May 2014.
- Utz, R. M., R. H. Hilderbrand, and R. L. Raesly. 2010. Regional differences in patterns of fish species loss with changing land use. *Biological Conservation*. 143:688-699.
- van Vrancken, J. and M. O'Connell. 2010. Effects of Hurricane Katrina on Freshwater Fish Assemblages in a Small Coastal Tributary of Lake Pontchartrain, Louisiana. *Transactions of the American Fisheries Society*. 139:1723-1732.
- Vondracek, B., K. L. Blann, C. B. Cox, J. F. Nerbonne, L. A. Sovell, and J. K. H. Zimmerman. 2005. Land use, spatial scale, and stream systems: Lessons from an agricultural region. *Environmental Management*. 36:775-791.
- Vörösmarty, C. J., M. Meybeck, B. Feketea, K. Sharmad, P. Greena, and J. P. M. Syvitskie. 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change*. 39:169-190.
- Wahl D. H. and R. A. Stein. 1988. Selective predation by three esocids: the role of prey behavior and morphology. *Transactions of the American Fisheries Society*. 117:142–151.
- Walser, C. A. and H. L. Bart. 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. *Ecology of Freshwater Fish*. 8:237–46.
- Wang, L., J. Lyons, P. Rasmussen, P. Seelbach, T. Simon, M. Wiley, P. Kanehl, E. Baker, S. Niemela, and P. M. Stewart. 2003. Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences*. 60:491-505.
- Wang, L. P., W. Seelbach, and J. Lyons. 2006. Effects of levels of human disturbance on the influence of catchment, riparian, and reach-scale factors on fish assemblages. Pages 199–220 in R. M. Hughes, L. Wang, and P. W. Seelbach, editors. *Influences of Landscapes on Stream Habitats and Biological Assemblages*. American Fisheries Society, Symposium 48, Bethesda, MD.
- Warren, M. L., B. M. Burr, S. J. Walsh, H. L. Bart, R. C. Cashner, D. A. Etnier, B. J. Freeman, B. R. Kuhajda, R. L. Mayden, H. W. Robison, S. T. Ross, and W. C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries*. 25:7-31.

- Warren M. L., W. R. Haag, and S. B. Adams. 2002. Forest linkages to diversity and abundance in lowland stream fish communities. Pages 168–182 in M. M. Holland, J. A. Stanturf, and M. L. Warren, Jr., editors. *Proceedings of a Conference on Sustainability of Wetland and Water Resources*, May 23–25, 2000, University of Mississippi: Oxford; USDA Forest Service, General Technical Report SRS-50.
- Watson, J. 1967. The Red River Raft. *East Texas Historical Journal*, 5:8.
- Weijters, M. J., J. H. Janse, R. Alkemade, and J. T. A. Verhoeven. 2009. Quantifying the effect of catchment land use and water nutrient concentrations on freshwater river and stream biodiversity. *Aquatic Conservation*. 19:104-112.
- Wenger, S. J., J. T. Peterson, M. C. Freeman, B. J. Freeman, and D. D. Homans. 2008. Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors. *Canadian Journal of Fisheries and Aquatic Sciences*. 65:1250-1264.
- Werner, E. E., J. F. Gilliam, D. J. Hall, and G. G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. *Ecology*. 64:1540-1548.
- Williams, L. R., T. H. Bonner, J. D. Hudson, M. G. Williams, T. R. Leavy, and C. S. Williams. 2005. Interactive effects of environmental variability and military training on stream biota of three headwater drainages in western Louisiana. *Transactions of the American Fisheries Society*. 134:192-206.
- Williams, L. R., J. D. Hudson, III, M. G. Williams, V. Campbell-Arvai, and T. H. Bonner. 2007. Evaluation of a stream system after clearcut logging disturbance in the gulf coastal plain. *Journal of Freshwater Ecology*. 22:119-133.
- Williams, J. D., J. Melvin, L. Warren, K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. *Fisheries*. 18: 6–22.
- Williams, L. R., C. M. Taylor, M. L. Warren Jr, and J. A. Clingenpeel. 2002. Large-scale effects of timber harvesting on stream systems in the Ouachita Mountains, Arkansas, USA. *Environmental Management*. 29:76-87.
- Winemiller, K. O. and K. A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences*. 49:2196-2218.
- Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. *Transactions of the American Fisheries Society*. 120:98-105.
- Zippin, C. 1958. The removal method of population estimation. *Journal of Wildlife Management*. 22:82-90.

Zuur, A., E. N Ieno, N.Walker, A. A. Saveliev, and G. M. Smith, 2009. Mixed effects models and extensions in ecology with R. Springer Science and Business Media. Netherlands.

## APPENDIX A. SITE INFORMATION

Site number	Stream	Site type	Sample date		Road crossing	X	Y
			Year 1	Year 2			
1	Bacon Branch	lake trib	2014-07-09	2015-06-05	Campbell Creek Rd.	519461.5655	3473733.765
2	Bayou Castor	lake trib	2014-07-09	2015-07-06	Highway 8	520438.9903	3474430.844
3	Big Fordoche Creek	lake trib	2014-07-08	2015-06-03	Goldonna Rd.	507080.791	3536946.084
4	Black Creek	lake trib	2014-06-19	2015-07-10	LA 122	534740.3893	3499788.861
5	Bryant Creek	lake trib	2014-07-08	2015-05-13	State Route 156	499324.4622	3537140.247
6	Couley Creek	lake trib	2014-08-19	2015-07-09	Double Church Rd.	513202.1738	3522457.474
7	Dartigo Creek	lake trib	2014-07-23	2015-07-08	French Cemetery Rd.	523429.1937	3501834.826
8	Mill Creek	lake trib	2014-08-20	2015-05-13	State Route 156	514663.3944	3536527.099
9	Sibley 1	lake trib	2014-07-10	2015-05-12	Eight Mile Rd.	483816.438	3511921.773
10	Sibley 2	lake trib	2014-07-23	2015-06-04	Eight Mile Rd.	483024.9363	3511938.856
11	Unknown Iatt	lake trib	2014-06-19	2015-06-04	Eastern turn off of Lake Rd	535788.5551	3492070.247
12	Bayou Blue	river trib	2014-07-22	2015-05-15	LA 120	486299.8394	3500128.839
13	Bayou Chiori Trib	river trib	2014-07-29	2015-06-02	Provencal, Vowell's Mill Rd.	473753.0641	3493697.845
14	Bayou Santabarb	river trib	2014-05-22	2015-07-07	Cox Lane	474750.9349	3491001.897
15	Carnahan Creek	river trib	2014-07-21	2015-06-05	Lena Flats Rd.	520222.319	3478993.651
16	Cruie Creek	river trib	2014-06-18	2015-07-08	LA 1228	527943.6448	3516355.107

(Appendix A continued)

Site number	Stream	Site type	Sample date		Road crossing	X	Y
			Year 1	Year 2			
17	D. Anderson 1	river trib	2014-07-30	2015-05-14	Dick Anderson Rd., Parish Rd.457	460032.6495	3524688.886
18	Edmund Bayou	river trib	2014-07-22	2015-07-07	LA 120	483497.4635	3500928.9
19	Little Wallace Creek	river trib	2014-07-24	2015-05-14	LA 177	456222.5036	3529028.798
20	Mayous Bayou	river trib	2014-08-21	2015-06-02	LA 487	463121.1467	3512066.603
21	Wallace Bayou	river trib	2014-07-24	2015-06-01	Carol Baxter Rd., Paris Rd.361	458261.0867	3528224.459
22	Bryant Creek @ Clear Lake	littoral zone	n/a	2015-04-08		484546.4676	3512924.944
23	Couley Creek @ Saline Lake	littoral zone	n/a	2015-04-07	Boat launch at the end of Mulligan End Rd.	498651.6152	3534273.276
24	Mill Creek @ Saline Lake	littoral zone	n/a	2015-04-06	Sand Point boat landing off Hwy 156	510336.303	3523929.582
25	Sibley 1 @ Sibley Lake	littoral zone	n/a	2015-04-09	boat landing off Hwy 504	511867.249	3535289.863

## APPENDIX B: FUNCTIONAL GROUP CATEGORIZATIONS AND SPECIES FIGURE CODES

Scientific Name (Figure code)	Common name	Feeding mode	Feeding location	Spawning location	Habitat preference
<i>Ameiurus melas</i> (A. mel)	Black bullhead	O	B	N	G
<i>Ameiurus natalis</i> (A. nat)	Yellow bullhead	O	B	C	G
<i>Amia calva</i> (A. cal)	Bowfin	P	W	n	G
<i>Aphredoderus sayanus</i> (A. say)	Pirate perch	I	B	P	G
<i>Centrarchus macropterus</i> (C. mac)	Flier	I	W	N	G
<i>Dorosoma cepedianum</i> (D. cep)	Gizzard shad	D	B	B	G
<i>Elassoma zonatum</i> (E. zon)	Banded pygmy sunfish	I	W	P	G
<i>Erimyzon oblongus</i> (E. obl)	Creek chubsucker	O	B	N	S
<i>Erimyzon sucetta</i> (E. suc)	Lake chubsucker	O	B	P	G
<i>Esox americanus</i> (E. ame)	Redfin pickerel	P	W	P	G
<i>Etheostoma artesiae</i> (E. art)	Redspot darter	I	B	S	S
<i>Etheostoma chlorosoma</i> (E. chl)	Bluntnose darter	I	B	P	S
<i>Etheostoma gracile</i> (E. gra)	Slough darter	I	B	P	G
<i>Etheostoma histrio</i> (E. his)	Harlequin darter	I	B	P	S
<i>Etheostoma proeliare</i> (E. pro)	Cypress darter	I	B	S	G
<i>Fundulus chrysotus</i> (F. chr)	Golden topminnow	I	S	P	G
<i>Fundulus notatus</i> (F. not)	Blackstripe topminnow	I	S	P	S
<i>Fundulus olivaceus</i> (F. oli)	Blackspotted topminnow	I	S	S	S
<i>Gambusia affinis</i> (G. aff)	Western mosquitofish	I	S	L	G
<i>Ichthyomyzon castaneus</i> (I. cas)	Chestnut lamprey	D	W	N	S

## (Appendix B continued)

Scientific Name	Common name	Feeding mode	Feeding location	Spawning location	Habitat preference
<i>Labidesthes sicculus</i> ( <i>L. sic</i> )	Brook silverside	I	W	P	G
<i>Lepisosteus oculatus</i> ( <i>L. ocu</i> )	Spotted gar	P	W	P	G
<i>Lepomis cyanellus</i> ( <i>L. cya</i> )	Green sunfish	P	W	N	G
<i>Lepomis gulosus</i> ( <i>L. gul</i> )	Warmouth	P	W	N	G
<i>Lepomis humilis</i> ( <i>L. hum</i> )	Orange-spotted sunfish	I	W	N	G
<i>Lepomis macrochirus</i> ( <i>L. mac</i> )	Bluegill	I	W	N	G
<i>Lepomis marginatus</i> ( <i>L. mar</i> )	Dollar sunfish	I	W	N	G
<i>Lepomis megalotis</i> ( <i>L. meg</i> )	Longear sunfish	I	W	N	G
<i>Lepomis microlophus</i> ( <i>L. micro</i> )	Redear sunfish	I	B	N	G
<i>Lepomis miniatus</i> ( <i>L. min</i> )	Redspotted sunfish	I	B	N	G
<i>Lepomis symmetricus</i> ( <i>L. sym</i> )	Bantam sunfish	I	W	N	G
<i>Luxilus chrysocephalus</i> ( <i>L. chr</i> )	Golden shiner	O	W	N	S
<i>Lythrurus fumeus</i> ( <i>L. fum</i> )	Ribbon shiner	I	E	B	S
<i>Lythrurus umbratilis</i> ( <i>L. umb</i> )	Redfin shiner	I	S	B	S
<i>Micropterus salmoides</i> ( <i>M. sal</i> )	Largemouth bass	P	W	N	G
<i>Minytrema melanops</i> ( <i>M. mel</i> )	Spotted sucker	I	B	B	S
<i>Moxostoma poecilurum</i> ( <i>M. poe</i> )	Blacktail redhorse	I	B	N	S
<i>Notemigonus crysoleucas</i> ( <i>N. cry</i> )	Golden shiner	I	W	P	G
<i>Notropis atrocaudalis</i> ( <i>N. atr</i> )	Blackspot shiner	I	B	B	S
<i>Noturus gyrinus</i> ( <i>N. gyr</i> )	Tadpole madtom	I	B	C	S
<i>Noturus nocturnus</i> ( <i>N. noc</i> )	Freckled madtom	I	B	C	S



(Appendix B continued)

Scientific Name	Common name	Feeding mode	Feeding location	Spawning location	Habitat preference
<i>Noturus phaeus</i> ( <i>N. pha</i> )	Brown madtom	I	B	C	S
<i>Opsopoeodus emiliae</i> ( <i>O. emi</i> )	Pugnose minnow	I	W	C	S
<i>Pimephales vigilax</i> ( <i>P. vig</i> )	Bullhead minnow	I	B	C	S
<i>Pomoxis annularis</i> ( <i>P. ann</i> )	White Crappie	P	W	N	G
<i>Semotilus atromaculatus</i> ( <i>S. atr</i> )	Creek chub	O	E	N	S

## **VITA**

Catherine Nell Reuter, a native of Farmington, Georgia, received her bachelor's degree from Macalester College in 2010. After graduation diverse experiences, ranging from seasonal wildlife work with the Bureau of Land Management in Utah and Montana and the Georgia Department of Natural Resources to teaching English and volunteering on small farms in northern France, honed her interests in natural resource management. She expects to receive her master's degree in December 2015 and will directly begin work on an organic farm and as project director for a private environmental education non-profit foundation.