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Fish Community Assembly At Multiple Spatial Scales In East Texas Streams

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FISH COMMUNITY ASSEMBLY AT MULTIPLE SPATIAL SCALES IN EAST
TEXAS STREAMS

By

JAKE R. SWANSON, Bachelor of Science

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
Of the Requirements

For the Degree of
Master of Science in Environmental Science

STEPHEN F. AUSTIN STATE UNIVERSITY

May, 2022

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ABSTRACT

Stream communities are structured by environmental processes that vary in strength across different spatiotemporal scales. Therefore, revealing how stream fish communities are influenced by environmental gradients may clarify how communities respond to disturbance associated with anthropogenic change. I investigated the relative role environmental variables play in the processes that structure the taxonomic and functional diversity of stream fish communities, as well as historical trends in occurrence and local habitat associated with a species of greatest conservation need within east Texas. The results of this study indicate that stream sites with more habitat complexity and stability support a more taxonomically and functionally diverse fish assemblage, while alterations in local habitat may be limiting the occurrence of rare minnow species within edges of its native Texas range. My research highlights the importance of environmental variables in the stream fish assembly process, and increases the ability to predict species distributional responses associated with environmental change.

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Taxonomic and Functional Organization of Stream Fish Communities Across Landscape and Local Environmental Gradients in East Texas

INTRODUCTION

Patterns of species diversity and the underlying mechanisms of community assembly are the result of integrative processes occurring across multiple spatial and temporal scales (Whittaker 1972; Ricklefs 1987; Winemiller 1990, 1991; Montaña et al. 2014). While the majority of studies investigating the organism-environment relationship have focused on small spatiotemporal extents (Ricklefs, 2008), the ability to identify whether landscape factors may have explanatory power in the variation of community patterns may be limited, particularly in human dominated landscapes (Snyder et al., 2003; Tóth et al., 2019). Large scale factors such as dispersal, extinction, and speciation appear to determine the organization of species at local scales (Vellend, 2016), while habitat characteristics and environmental (i.e. abiotic factors) factors mediate biotic interactions and the likelihood of species persistence at local scales (Levin, 1992; Jackson et al., 2001). Characterizing the variation in a community across multiple spatial scales can advance the understanding of how ecosystems, its biota, and their surrounding landscape can be an important criterion for enhancing biodiversity conservation, as well as habitat management and restoration.

Landscape-level environmental factors play an important role in structuring aquatic communities (Roth et al. 1996; Allan et al. 1997; Poff 1997; Snyder et al. 2003; Wang et al. 2006). Ecoregional differences in geomorphology and climate characteristics shape stream order connectivity and types of land cover (Frissell et al. 1986; Marsh-Matthews and Matthews 2000; Wang et al. 2013). Within basins, stability in regional characteristics create gradients that establish variability in land cover, that in turn, determine the vegetation, hydrology, and amount and quality of inorganic and organic material input into streams (Richards et al. 1996; Diana et al. 2006; D'Ambrosio et al. 2009; Montaña and Schalk 2018). Land use practices (e.g., agriculture, forestry, urbanization) are a major contributor to the alteration of stream fish communities and can result in the loss of aquatic biodiversity (Roth et al. 1996; Snyder et al. 2003; Rowe et al. 2009). For example, increases in total dissolved solids, instantaneous flow velocity, water temperature, and homogenized flow regime dynamics are products from land cover change that can negatively affect diversity downstream (Allan, 2004). These properties associated with land cover change influence downstream habitat quality, altering the trajectories of community assembly.

Although relationships between local and regional species diversity suggests that regional processes (e.g., land cover) mediate local fish diversity (Argent and Carline 2004; Hoeinghaus et al. 2007; Gido et al. 2010), local stream characteristics and species interactions are important in determining species abundance and community organization (Montaña and Winemiller 2010; Pease et al. 2011; Wang et al. 2013). More complex

habitats increase micro-habitat diversity that can be exploited by species, thus increasing the available niches within a community (Willis et al. 2005; Montaña et al. 2014). For example, heterogeneous instream habitat supports a greater diversity of aquatic insects, that are in turn, food for carnivorous fish, which underlies these foundational consumer-resource relationships in aquatic food webs (Schneider and Winemiller 2008; Ceneviva-Bastos et al. 2017; Montag et al. 2019). Within local habitats, biotic interactions such as competition and predation, shape species distributions within and among stream habitats as well as resource use (Schlosser 1988; Hart 1992; Peres-Neto 2004; Hoeinghaus et al. 2007). For example, increased predation risk can alter the life history traits of an organism and increase movements between habitat patches (Schlosser, 1988; Schneider & Winemiller, 2008). Habitat generalists may outcompete specialist species, when resources are limited, resulting in shifts of community structure (Hart 1992; Jackson et al. 2001; Gido et al. 2016).

Studies addressing fish assemblage-environmental relationships have been conducted across multiple biogeographic regions (Angermeier and Winston 1998; Pease et al. 2011; Montag et al. 2019). However, the relative importance of catchment versus local scale factors underlying community structure for stream biota remain relatively indistinct. Environmental characteristics that occur within river basins can affect the diversity of the regional species pool, but river basins, can occur across multiple ecoregions and can be influenced by multiple land cover types (Allan et al. 1997; Troia and Gido 2013). Thus, to fully understand the processes underlying community structure

of stream fish, surveys must be conducted across multiple ecoregions and river basins. In all major Texas river basins, the modification of natural systems associated with anthropogenic alterations has caused declines of some fish families (i.e., Percidae and Cyprinidae) (Hubbs et al. 1991; Anderson et al. 1995). Within the upper Trinity River basin, nonpoint source pollution produced from the Dallas-Fort Worth metropolitan area has resulted in declines in fish species richness (Perkin & Bonner, 2016). Alteration in flow regime from the formation of low head dams and periods of prolonged drought in the upstream network of the San Marcos and Guadalupe Rivers have isolated the reproductive capabilities of Burrhead Chub *Machrybopsis marconis* (Perkin et al., 2013). Additionally, long-term monitoring (1998-2006) in the Guadalupe and San Marcos Rivers of central Texas suggests that flow regime fragmentation has shifted stream fish communities, from fluvial specialists to more tolerant, generalized species, homogenizing the stream fish assemblage (Perkin & Bonner, 2011a).

Although the taxonomic structure of fish assemblages changes along environmental gradients (Lamouroux et al., 2002; McGill et al., 2006; Dolédec & Statzner, 2010), generalizations developed from species richness cannot be applied directly to assemblage structure and function (Marsh-Matthews and Matthews 2000). Ecologists have used species functional traits to make inferences in those processes that structure communities across scales and environmental gradients (Culp et al. 2011; Montaña et al. 2014; Teresa and Casatti 2017; Kirk et al. 2021). A species' functional trait is any feature that affects its performance or fitness, such as those related to food

acquisition (e.g., body size, mouth size and position), mobility and habitat use (e.g., body size and shape, fin size and position) and reproduction (e.g., reproductive effort, parental investment) (McGill et al., 2006). Ichthyofauna inhabiting small lotic streams tend to have smaller, more streamlined bodies, while streams with deeper channels with more pool microhabitats contained species with deeper bodies, larger eyes, and longer fins (Pease et al., 2015; Ribeiro et al., 2016; Kern & Langerhans, 2019). The relationships between functional traits and habitat variables provide an opportunity to analyze the associations between species abundance and habitat, while enabling ecologists to develop predictions of species' responses to anthropogenic alterations to habitat.

In this study, I used a multiscale approach to examine the relative contributions of landscape and local environmental gradients on the taxonomic and functional organization of stream fish communities in east Texas. I hypothesized that both local and landscape (i.e., regional) environmental variables will influence stream assembly since landscape variables have indirect influences on the stream fauna through their direct effects on local factors (Hoeinghaus et al. 2007; Montaña and Winemiller 2010; Pease et al. 2015). The study was designed to distinguish environmental variables that influence fish assemblages, and construct links of functional trait structure of fish to habitat types. Specifically, the objectives were (1) to characterize fish assemblages at regional (e.g., basin) and local (e.g., reach) scales at selected streams across five major river basins across east Texas, (2) to characterize relationships between fish composition and environmental variable at landscape and local-reach scales across river basins, and (3) to

quantify the relationship between functional diversity and environmental variables across river basins. I predicted that fish assemblage composition will respond to environmental variables acting at both the basin and local scale. Because morphology links to the autecology of feeding and microhabitat selection by fish (Gatz 1979; Frimpong and Angermeier 2010), I further predicted that aspects of locomotion, habitat use, and feeding ecology traits of the fish assemblage will be correlated with habitat descriptors such as flow regime characteristics and in-stream habitat. These results will allow the measurement of biodiversity of streams across spatial gradients in east Texas, a region that contains exceptionally diverse habitat and ichthyofauna, and will be threatened by urbanization (e.g., urban sprawl) in the near future. Similarly, this study provides an opportunity to fill in knowledge gaps of species of greatest conservation need inhabiting streams of this area, in-turn contributing to conservational planning, implementation of large-scale monitoring programs, and predictions of anthropogenic alterations in stream ecosystems.

METHODS

Study Area

Surveys were conducted in 75 wadeable streams within the Brazos, Cypress, Neches, Sabine, and Trinity River basins in east Texas (Fig. 1.1; Appendix S1). Stream sites were selected to specify an extensive geographic coverage, land cover, and variety of instream habitat conditions (Appendix S2-S3). The Brazos River basin is the second largest basin by area within the state of Texas, and is dominated by rangeland, pastures, and prairies (TCEQ, 2002). The Cypress basin is primarily dominated by pine and oak forests, but also contains a small amount of range and pastureland that is dedicated to the production of beef cattle (Robertson et al., 2016). The Neches River basin contains tracts of dense pine forests used for timber production, but also includes areas of pastureland used for the agricultural production in rural areas (Robertson et al., 2018). The upper extent of the Sabine basin is largely comprised of a mixture of pastureland and bottomlands, while the lower extent consists of dense stands of pine forests that form the border between Louisiana and Texas (TCEQ, 2002). The Trinity River basin is historically dominated by row-crop agriculture and large extents of pasture land (TCEQ, 2002). Throughout the Trinity, streams are subjected to impacts by the increase in developed land near the Dallas Fort Worth metropolitan areas.

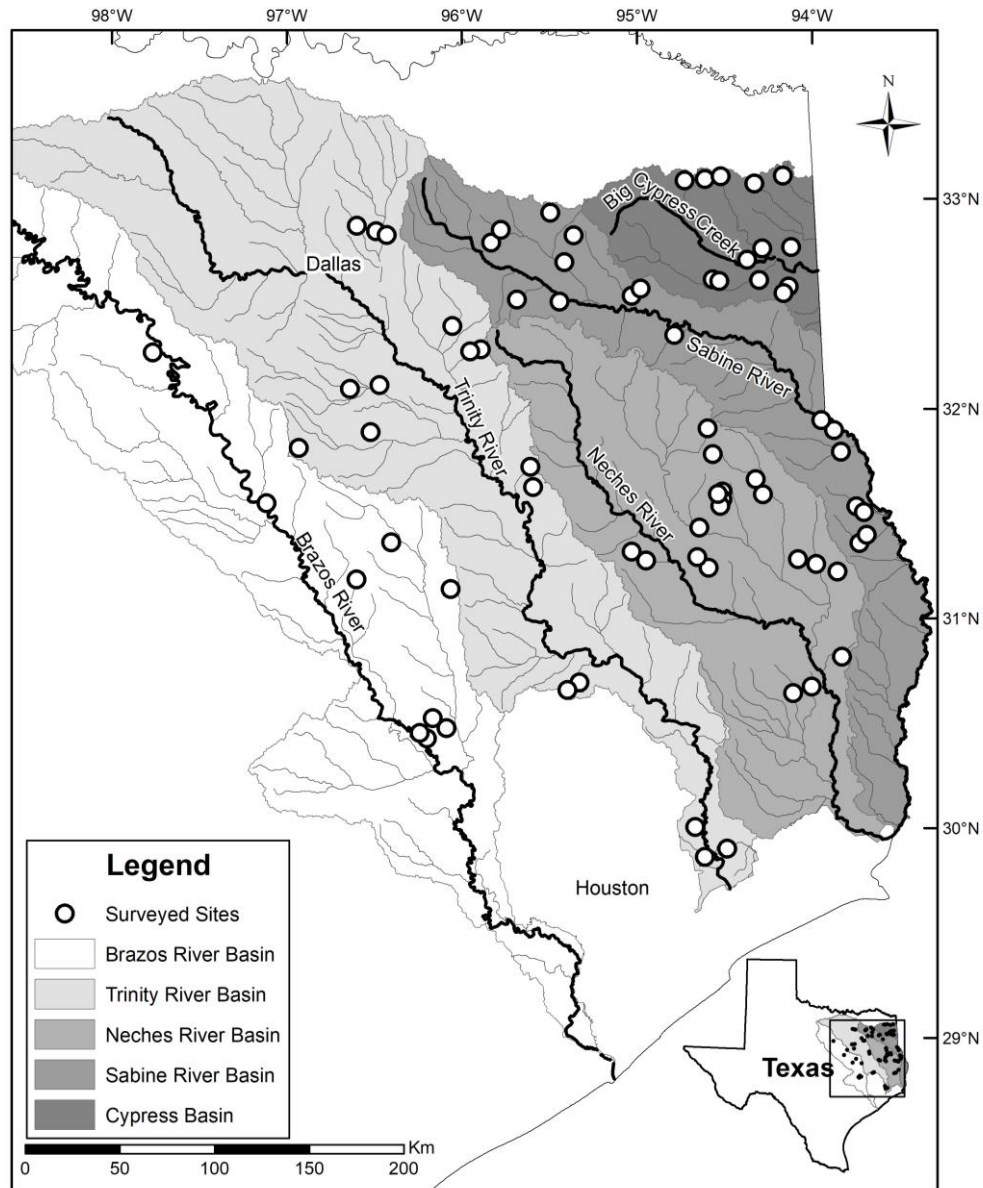


Figure 1.1 Study region depicting the five river basins and sampling locations in east Texas including the Brazos (n = 9 sites), Trinity (n = 17 sites), Neches (n = 19 sites), Sabine (n = 17 sites), and Cypress (n = 13 sites). White dots represent the stream locations surveyed within each basin during April – October of 2020 and 2021. Additional maps with stream sampling sites within each basin are in Appendix S4 – S8.

Data Collection

I sampled stream sites during May-October of 2020 and 2021 following methods modified from United States Environmental Protection Agency (USEPA 2017) for both fishes and stream habitats. At each study site, local fish assemblage and habitat data were collected within a 60-300 m stream reach. Study reach length was established upon the average wetted width, multiplied by 20 channel widths. While the traditional procedure for standardizing the sampling reach is to multiply the average wetted width by 40 channel widths (Kaufman & Robinson, 1998), this method was modified as a result of logistical constraints.

Within each study reach, all available habitats were sampled using a backpack electrofisher (Smith-Root LR-24) and seine net (4.6 m x 1.8 m or 1.8 m x 1.8 m, 5-mm mesh). First, the reach was sampled using a seine net in available habitat types (e.g., sand banks, vegetation) and flow regime (e.g., riffle, run, pool) for a minimum effort of fifteen 4-m hauls per sample site. The study reach was then electrofished in an upstream direction by a crew of 2-3 people for a minimum of 900 s sampling every habitat thoroughly until the final transect. Large specimens were identified, counted, measured, and released downstream, while smaller individuals were identified using taxonomic keys, counted, and either released or anesthetized using clove oil for preservation in a 10% buffered formalin solution. To quantify the fish community, individuals of all species not collected were counted before being released.

Within the study reach, 33 habitat measurements including substrate composition, flow regime, wetted channel width, percent instream habitat, average channel depth, and canopy cover were collected at 5 evenly spaced transects during the same visit as fish surveys (Table 1.1). Some measurements, such as wetted channel width, bank-full channel width, average transect depth, thalweg depth, number of stream bends, bank angle, percent exposed soil, and percent canopy cover, were summarized across the entire study reach. Because surface runoff has direct implications to local habitat parameters (Schueler, 1994), percent impervious surface cover was quantified within a 1 km circular buffer surrounding the center transect of the stream site, and considered a local environmental variable. Instantaneous flow velocity (m/s) was measured at a representative transect within the stream reach using a Marsh-McBirney Model 201D portable flow meter. *In-situ* water parameters including dissolved oxygen (mg/L), pH, specific conductance (μ s), total dissolved solids (mg/L), and water temperature ($^{\circ}$ C) were measured using a ProDSS YSI multi-probe meter at the center of the sampling reach.

Fifteen landscape scale variables characterizing land cover, latitude, longitude, topography, and physical characteristics were quantified for the Huc-10 watershed surrounding each stream site (Richards et al. 1996; Pease et al. 2015; Table 1.2). Huc-10 boundaries for each study site were established in ArcGIS 10.6.1 using the U.S. Geological Survey (USGS) watershed boundaries dataset obtained from Texas Natural Resources Information System (TNRIS) (<https://data.tnris.org/>). Mean elevation was calculated for each catchment using a 30 meter resolution digital elevation model (DEM)

from the 2013 National Elevation Dataset obtained from TNRIS. Mean annual precipitation for each catchment was determined using average monthly and annual precipitation for the climatological period of 1981-2010 using Natural Resource Conservation Services (NRCS) data obtained from Texas Water Development Board (TWDB) (<https://www.twdb.texas.gov/mapping/gisdata.asp>). The number of wastewater outfalls was recorded for each catchment using data from the Texas Commission on Environmental Quality (TCEQ) municipal and industrial wastewater outfall shapefile available from (<https://gis-tceq.opendata.arcgis.com/>). Land-cover class percentages were calculated for each catchment using National Land Cover Database (NLCD 2016) obtained from Texas Natural Resources Information System (TNRIS). All GIS analysis was performed with ArcGIS 10.6.1 (ESRI, Redlands, CA).

Twenty-nine morphological traits (Table 1.3) associated with feeding, locomotion, and habitat preference (Gatz 1979; Webb 1984; Winemiller 1991) were measured in five adult individuals, when collected, of each species collected at a site. Morphological traits related to habitat use and mobility include fin length and shape, body depth, and dimensionality of the caudal peduncle, while those related to feeding ecology include eye diameter, mouth arrangement, gut length, and head dimensions (Gatz 1979). Measurements were taken to the nearest 0.1 mm using vernier digital calipers (Montaña et al. 2014). Snout length open was divided by snout length shut to create a relative measure of mouth protrusibility (mouth position; Winemiller 1991). The use of

quantitative morphological traits allowed for the measurement of multidimensional functional diversity indices (Villéger et al., 2008).

Table 1.1 Local-scale environmental variables (n = 33) measured within each stream site across five river basins in east Texas, USA.

Category	Measurement	Variable code	Description
Stream morphology	Wetted channel width	WET_WID	Average wetted channel width (m)
	Bank-full channel width	BANKFULL	Average bank-full width (m)
	Average depth	AVE_DEP	Average stream depth (m)
	Max depth	MAX_DEP	Max stream depth (m)
	Stream bends	STR_BEN	Number of stream bends
	Thalweg depth	THAL_DEP	Average stream channel depth (m)
	Number of pools	POOL	Number of pools in sampling reach
	Number of riffles	RIFFLE	Number of riffles in sampling reach
	Number of runs	RUN	Number of runs in sampling reach
Riparian characteristics	Bank angle	BANK_ANGL	Average angle of stream banks
	Exposed soil	EXP_SOIL	(%) Exposed soil on banks
	Canopy cover	CAN_COV	(%) Stream shaded by canopy
	Impervious surface	IMPERV	(%) Impervious surfaces within 1 km buffer
Instream habitat	Algae	ALGAE	(%) Abundance of algae
	Emergent macrophytes	EME_MAC	(%) Abundance of emergent macrophytes
	Submerged macrophytes	SUB_MAC	(%) Abundance of submerged macrophytes
	Large woody debris	LWD	(%) Large woody debris (>.3m)
	Small woody debris	SWD	(%) Small woody debris and detritus (<.3m)
Substrate composition	Live trees/roots	TRE_ROOT	(%) Live trees and roots
	Bedrock	BED_ROCK	(%) Substrate bedrock
	Large boulder	LRG_BOUL	(%) Substrate large boulder (>45 cm)

Table 1.1 Continued

Category	Measurement	Variable code	Description
Substrate composition	Small boulder	SMA_BOUL	(%) Substrate small boulder (25-45 cm)
	Cobble	COBBLE	(%) Substrate cobble (6-25 cm)
	Gravel	GRAVEL	(%) Substrate gravel (2-60 mm)
	Sand	SAND	(%) Substrate sand (0.06-2 mm)
	Mud/Silt	MUD_SILT	(%) Substrate mud/silt (<0.06 mm)
	Hard pan clay	HARD_PAN	(%) Substrate hard pan clay
Water parameters	Temperature	TEMP	Water temperature (°C)
	Dissolved oxygen	DO	Instantaneous dissolved oxygen (mg/L)
	Specific conductivity	COND	Specific conductivity (µs)
	pH	PH	pH
	Total dissolved solids	TDS	Total dissolved solids (mg/L)
	Flow velocity	FLO_VEL	Instantaneous flow velocity (m/s)

Table 1.2. Landscape-scale environmental variables (n = 15) measured within the Huc-10 watershed of each stream site across five river basins in east Texas, USA.

Category	Measurement	Variable code	Description
Spatial relation	Latitude	LAT	Latitude, decimal degrees
	Longitude	LONG	Longitude, decimal degrees
Topography	Area	AREA	Huc-10 area (km ²)
	Elevation	ELEV_M	Mean elevation (m)
Precipitation	Precipitation	ANNU_PREC	Mean annual precipitation (cm)
Disturbance point	Outfalls	OUTFALL	Number of outfalls in Huc-10 watershed
Land cover	Barren	BARREN	(%) Barren land cover
	Developed	DEVELOP	(%) Developed land cover
	Forest	FOREST	(%) Forest land cover
	Grassland	GRASS	(%) Grassland land cover
	Pasture	PASTURE	(%) Pasture land cover
	Row Crop	ROW_CROP	(%) Row crop land cover
	Shrubland	SHRUB	(%) Shrub land cover
	Water	WATER	(%) Land covered by water
	Wetland	WET_LAND	(%) Wetland land cover

Table 1.3. Morphological traits (n = 29) measured in specimens collected across five river basins in east Texas, USA.

Trait	Variable code	Measurement	Relevance
Standard length	SL	Maximum standard length collected for a species	Habitat, forage, life history
Head length	HEAD_L	Distance from apex of upper jaw to the most-caudal extension of the operculum	Forage
Head depth	HEAD_D	Vertical distance from dorsum to ventrum through the pupil	Forage
Gape width	GAPE_W	Horizontal distance measured inside of a fully open mouth at tallest point	Forage
Eye position	EYE_P	Vertical distance from the center of the pupil to ventrum	Habitat
Eye diameter	EYE_D	Horizontal distance from eye margin to eye margin	Forage
Mouth position	MOUTH_P	Coded as 1 for superior (10°-80°), 2 for terminal ($\approx 90^\circ$), 3 for subterminal (100°-170°), and coded 4 for inferior ($\approx 180^\circ$)	Forage, habitat
Snout length shut	SNL_SHUT	Distance from the pupil of the eye to tip of the upper jaw with mouth shut	Forage
Snout length open	SNL_OPEN	Distance from the pupil of the eye to the tip of the upper jaw with mouth fully open	Forage
Maximum body depth	BODY_D	Maximum vertical distance from dorsum to ventrum	Mobility
Body depth below midline	BODY_DBML	Vertical distance from midline to ventrum	Mobility, habitat
Maximum body width	BODY_W	Maximum horizontal distance	Mobility

Table 1.3 continued

Trait	Variable code	Measurement	Relevance
Caudal peduncle length	PED_L	Distance from the posterior proximal margin of anal fin to the caudal margin	Mobility
Caudal peduncle depth	PED_D	Minimum vertical distance from dorsum to ventrum of the caudal peduncle	Mobility
Caudal peduncle width	PED_W	Horizontal width of caudal peduncle at mid-length	Mobility
Caudal fin length	CAUD_L	Maximum distance from proximal to distal margin of the caudal fin	Mobility
Caudal fin height	CAUD_H	Maximum vertical distance across the fully spread caudal fin	Mobility
Dorsal fin length	DORS_L	Distance from anterior proximal margin to the posterior proximal margin of the dorsal fin	Mobility
Dorsal fin height	DORS_H	Maximum distance from proximal to distal margin of the dorsal fin	Mobility
Pectoral fin length	PECT_L	Maximum distance from proximal to distal margin of pectoral fin	Mobility, habitat
Pectoral fin height	PECT_H	Maximum vertical distance across the fully spread pectoral fin	Mobility
Pelvic fin length	PELV_L	Maximum distance from proximal to distal margin of the anal fin	Mobility, habitat
Pelvic fin height	PELV_H	Maximum vertical distance across the fully spread pelvic fin	Mobility, habitat
Anal fin length	ANAL_L	Distance from anterior proximal margin to posterior proximal margin of the anal fin	Mobility

Table 1.3 continued

Trait	Variable code	Measurement	Relevance
Anal fin height	ANAL_H	Maximum distance from proximal to distal margin of the anal fin	Mobility
Adipose fin length	ADIP_L	Distance from anterior proximal margin to posterior proximal margin of the adipose fin	Mobility
Adipose fin height	ADIP_H	Maximum distance from proximal to distal margin of the adipose fin	Mobility
Gut length	GUT_L	Length of the gut from the beginning of the esophagus to the anus (extended without stretching)	Forage
Gill raker length	RAKER_L	Length of the longest gill raker	Forage

Statistical Analyses

To visualize the diversity in land cover types and topography across the study area, landscape scale environmental variables (y-axis) were arranged in a scatterplot to conceptualize a west to east longitudinal (x-axis) gradient. To identify the main gradients of variation among local habitat parameters of stream sites, I performed a principal component analysis (PCA) on the log transformed site by environmental variable matrix at the local scale. Site symbols were defined based on their respective river basin, and the association of sites grouped by basin were assessed visually in ordination space.

To test the hypothesis that fish assemblage composition will respond to environmental variables acting at both the basin and local scale, I performed a non-metric multidimensional scaling (NMDS) on log transformed species abundances by stream site. A NMDS is an appropriate method for analyzing the arrangement of community structure because assumptions of linearity are avoided and units are ordinated in space according to ecological distance (McCune et al. 2002). McCune et al. (2002) suggests the removal of species with less than 5% occurrence across the sampling sites to reduce the possibility of identifying a gradient that does not exist. For this analysis, I found no difference in the NMDS ordination after the removal of the rare species, therefore, all species except those that only occurred at one survey site were retained. Comparisons of fish assemblage structure were tested using a permutational multivariate analysis of variance (PERMANOVA) and a permutational analysis of multivariate dispersion (PERMDISP). This non-parametric analysis uses Euclidian distances to describe how variation is

associated with differences in experimental approach or uncontrolled covariates (Oksanen, 2015).

To test the hypothesis that morphological traits associated with locomotion, habitat use, and feeding ecology traits of the fish assemblage will be correlated with habitat descriptors, I performed a PCA to visualize the variation among-species morphological traits. Prior to the PCA analysis, all morphological traits were converted into ratios of standard length, body depth, body width, and head length, and log transformed (Winemiller 1991). This conversion was necessary to reduce bias associated with allometry when analyzing the physical characteristics of individual species (Winemiller 1990; Montaña et al. 2014). The PCA was then performed using the mean-transformed values for each morphological trait for each species averaged across stream sites.

To quantify functional diversity of each fish assemblage across the study area, I calculated four community diversity metrics including functional richness (FRic), mean nearest neighbor distance (MNND), functional divergence (FDiv), and functional evenness (FEve), (Villéger et al., 2008). Functional richness (FRic), also known as convex hull volume, quantifies the multidimensional functional niche space occupied by a community (Villéger et al. 2008). A higher functional richness value indicates a larger functional space occupied by an assemblage. Mean nearest neighbor distance (MNND) is an index of species packing in morphological space, where low values indicate patterns

of functional redundancy (Montaña et al., 2020). Functional evenness (FEve) is a measure of the regularity of species distribution in morphological space weighted by abundance (Villéger et al., 2008). This index ranges from zero to one, where low scores indicate a less even distribution among species. Functional divergence (FDiv), a metric that ranges from zero to one, evaluates how species abundance is distributed in relation to the centroid of an assemblage (Villéger et al., 2008). Low FDiv scores suggest species dispersion near the centroid, while higher scores indicate species distribution at the periphery of morphological space, farther from the centroid. The dbFD function from the *FD* package in R was used to calculate the FRic, FEve, and FDiv metrics weighted by species abundance (Laliberté et al., 2014). The *picante* package in R was used to calculate the MNND metric (Kembel et al., 2010). Before analyses, the assumptions of linear regression were tested and three outliers (sites) were detected and removed from subsequent regression analysis due to low species richness (< 3 spp.). The remaining data met the assumptions of regression, and the relationship between trait diversity and species richness were then modelled with linear regression. (Montaña and Winemiller 2010; Pease et al. 2012; Montaña et al. 2014). All statistical analyses were performed in R version 4.0.3 (The R Foundation for Statistical Computing).

RESULTS

Landscape Habitat

Landscapes of the 75 stream sites were primarily influenced by a west-east longitudinal gradient across the river basins, primarily influenced by differences in annual precipitation, elevation, and land cover (Fig. 1.2). Annual precipitation increased and elevation decreased along the west-east longitudinal gradient within the river basins (Fig. 1.2). The amount of forest and shrubland increased and grassland and row-crop decreased from west to east (Fig. 1.2). Pastureland was highest at intermediate longitudes of the Brazos, Sabine, and Trinity River basins and decreased at more western longitudes and eastern longitudes (Fig. 1.2). Developed land exhibited the most variability among the sites, with the highest percentage occurring in the Trinity basin (58%), near the Dallas-Fort Worth metroplex (Fig. 1.2). Wetland cover was relatively low throughout the 75 stream sites with the majority of sites below 5% coverage (Fig. 1.2).

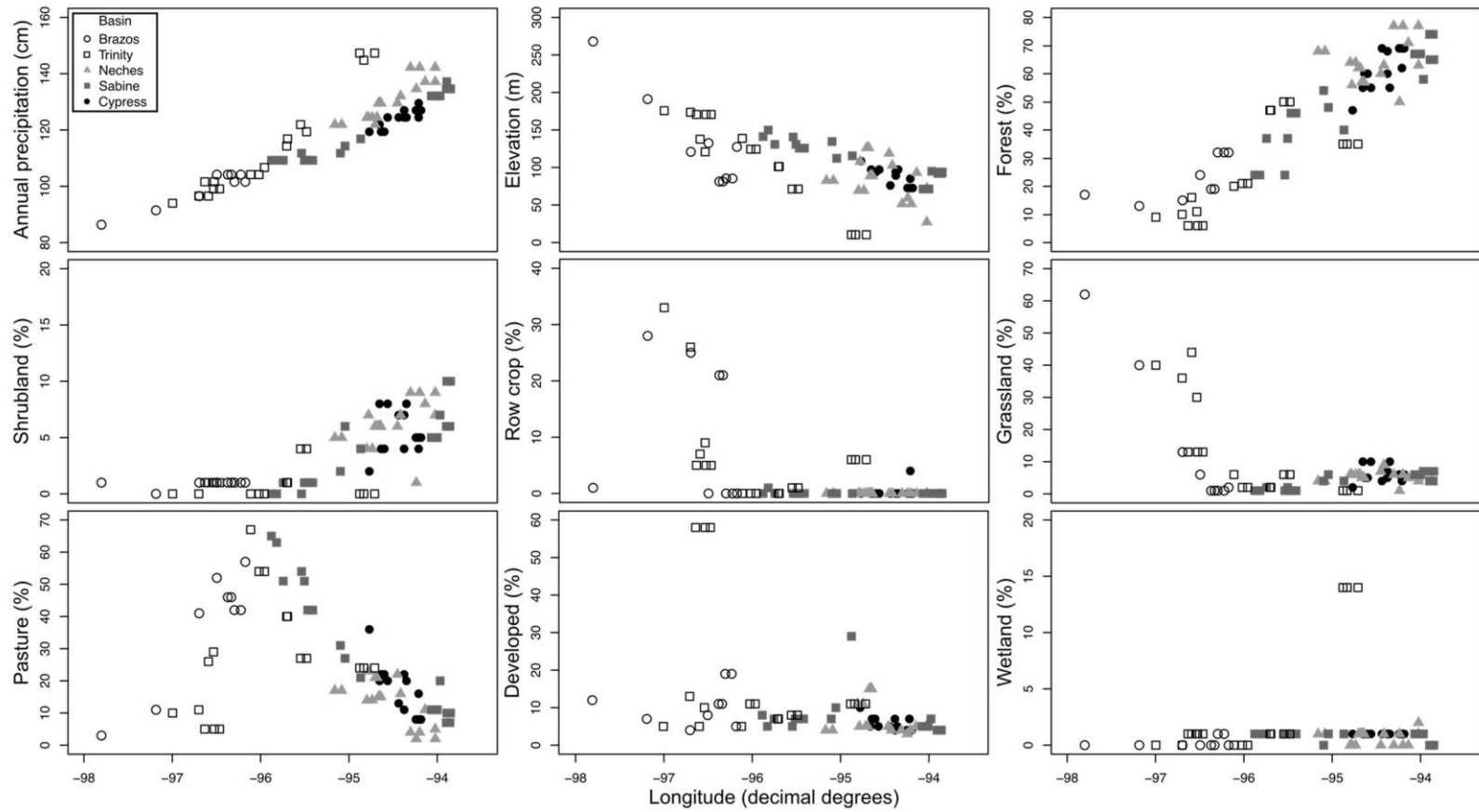


Figure 1.2 Longitudinal relationship between river basins and nine landscape environmental variables. Symbols represent the sites occurring within one of the five river basins.

Local Habitat

The first two PCA axes on local habitat variables explained 30.7% of the total variation among local habitat conditions (Fig. 1.3; loadings of local habitat variables are in Appendix S9). The first PCA axis (PC1, 18.5% of variance) revealed a gradient strongly associated with substrate type, canopy cover percentage, bank angle, wetted and bank-full channel width, percentage instream woody debris, percentage of tree roots, percentage of impervious surface, percentage of algae, and *in-situ* water parameters (Fig. 1.3; Appendix S9). Positive scores on PC1 were associated with stream sites occurring in eastern longitudes and contained greater canopy cover, finer substrates, more live trees and roots for in-stream cover, and steeper stream banks with little vegetation cover (Fig. 1.3; Appendix S9). Negative scores on PC1 were associated with stream sites in western longitudes and contained coarser substrates, conductive and alkaline *in-situ* conditions, wider stream channels, more algae, and were surrounded by greater impervious surfaces (Fig. 1.3; Appendix S9). The second PCA axis (PC2, 12.2% of variance) exhibited differences among sites in stream depth, substrate composition, instream habitat, and flow regime (Fig. 1.3; Appendix S9). Positive scores on PC2 were associated with streams having greater depth, mud-silt substrate, more pools, and a greater percentage of woody debris, while negative scores on PC2 were associated with stream sites containing more riffle-runs, coarser substrate, and a higher instantaneous flow velocity (Fig. 1.3; Appendix S9).

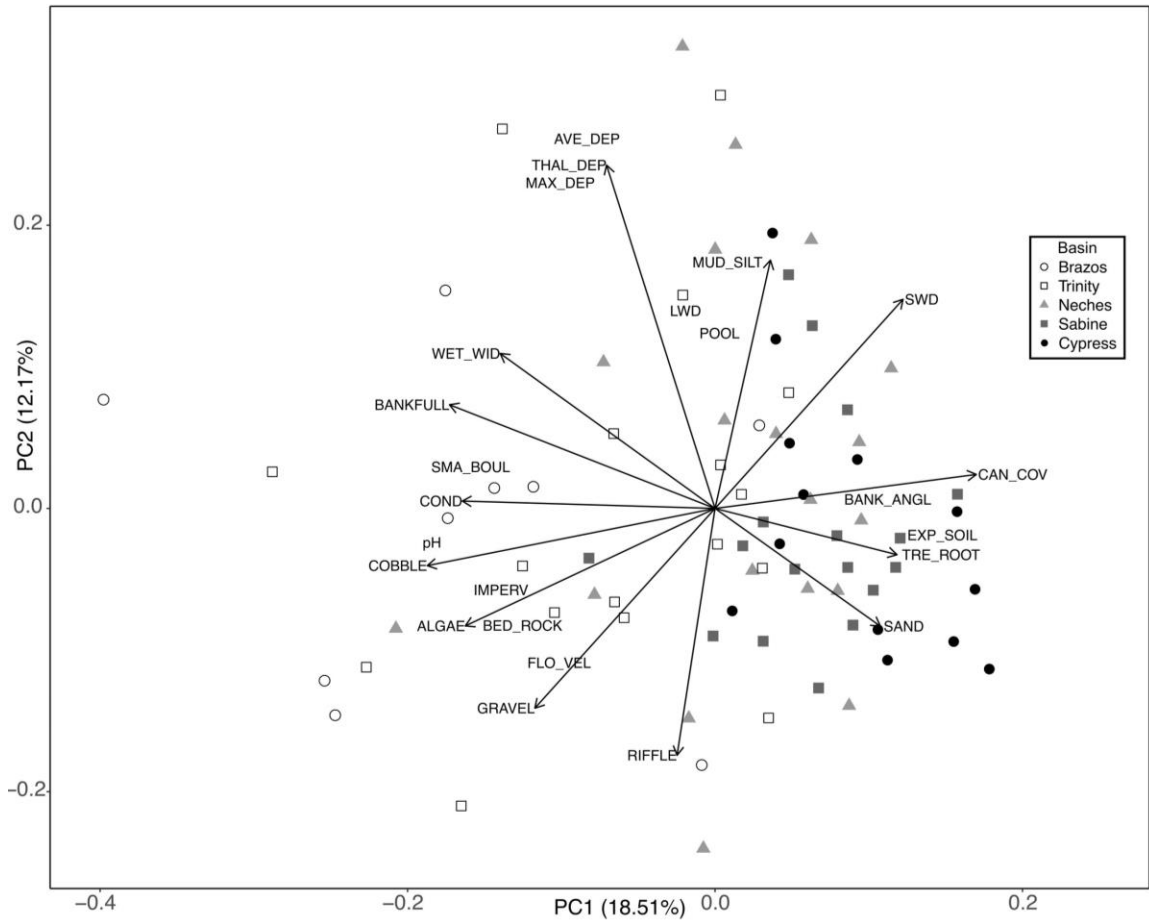


Figure 1.3 Principal component analysis (PCA) based on local environmental variables collected from stream sites of east Texas (n =75). Symbols represent sites occurring within one of the five river basins. See Table 1.1 for abbreviations of environmental variables. Loadings of local habitat variables are in Appendix S9.

Taxonomic Composition

Sixty-three fish species from 15 families were captured during the stream surveys (Table 1.4). Species richness per site ranged from 1 to 21 species, with a mean richness of 11 species per site (total species richness per basin: Brazos = 33 spp., Cypress, = 43 spp., Neches = 38 spp., Sabine = 39 spp., Trinity = 33 spp.). Blacktail Shiners *Cyprinella venusta*, Red Shiners *Cyprinella lutrensis*, Redfin Shiners *Lythrurus umbratilis*, Ribbon Shiners *Lythrurus fumeus*, Western Mosquitofish *Gambusia affinis*, Bluegill *Lepomis macrochirus*, and Longear Sunfish *Lepomis megalotis* comprised 64% of the total sample collected (Table 1.4). Other species were restricted to specific river basins. For example, Striped Shiners *Luxilus chrscephalus* were captured only in tributaries of the Cypress basin. Creek Chubs *Semotilus atromaculatus* were only collected in the eastern extent of our study area within streams of the Cypress and Sabine River basins whereas Central Stonerollers *Camptostoma anomalum* were only collected in western tributaries of the study area in the Brazos and Trinity River basins. Weed Shiners *Notropis texanus*, Freckled Madtoms *Noturus nocturnus*, and Dusky Darters *Percina sciera* were collected in all river basins excluding the Brazos River basin. Non-native fish species collected within these stream sites included Common Carp *Cyprinus carpio* within the Sabine and Trinity River basins, and Redbreast Sunfish *Lepomis auritis* collected within the Brazos and Neches River basins.

Table 1.4. Species collected from five river basins in east Texas, USA. n represents the number of sites sampled within each river basin.

Species	Species Code	River Basin				
		Brazos (n = 9)	Cypress (n =13)	Neches (n =19)	Sabine (n = 17)	Trinity (n =17)
Lepisosteidae						
Spotted Gar						
<i>Lepisosteus oculatus</i>	LEPI_OCUL	0	0	0	1	0
Longnose Gar						
<i>Lepisosteus osseus</i>	LEPI_OSSE	1	0	0	0	0
Amiidae						
Bowfin						
<i>Amia calva</i>	AMIA_CALV	0	0	0	1	0
Clupeidae						
Gizzard Shad						
<i>Dorosoma cepedianum</i>	DORO_CEPE	1	0	0	0	0
Threadfin Shad						
<i>Dorosoma petenense</i>	DORO_PETE	2	0	0	2	0
Cyprinidae						
River						
Carp sucker						
<i>Carpiodes carpio</i>	CARP_CARP	2	0	0	0	0
Red Shiner						
<i>Cyprinella lutrensis</i>	CYPR_LUTR	673	0	4	5	139
Blacktail Shiner						
<i>Cyprinella venusta</i>	CYPR_VENU	414	3	176	48	179
Common Carp						
<i>Cyprinus carpio</i>	CYPR_CARP	0	0	0	9	2

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Cyprinidae						
Mississippi						
Silvery						
Minnow	HYBO_NUCH	16	0	0	0	0
<i>Hybognathus</i>						
<i>nuchalis</i>						
Striped Shiner						
<i>Luxilus</i>						
<i>chrysocephalus</i>	LUXI_CHRY	0	94	0	0	0
Ribbon Shiner						
<i>Lythrurus</i>						
<i>fumeus</i>	LYTH_FUME	32	94	313	348	82
Redfin Shiner						
<i>Lythrurus</i>						
<i>umbratilis</i>	LYTH_UMBR	0	258	123	85	73
Golden Shiner						
<i>Notemigonus</i>						
<i>crysoleucas</i>	NOTE_CRYS	0	81	7	3	0
Blackspot						
Shiner						
<i>Notropis</i>						
<i>autrocaudalis</i>	NOTR_ATRO	1	30	31	37	12
Ironcolor						
Shiner						
<i>Notropis</i>						
<i>chalybaeus</i>	NOTR_CHAL	0	2	0	0	0
Sabine Shiner						
<i>Notropis</i>						
<i>sabinae</i>	NOTR_SABI	0	0	22	0	0
Silverband						
Shiner						
<i>Notropis</i>						
<i>shumardi</i>	NOTR_SHUM	22	0	0	0	0
Weed Shiner						
<i>Notropis</i>						
<i>texanus</i>	NOTR_TEXA	0	26	21	83	28

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Cyprinidae						
Pugnose						
Minnow						
<i>Opsopoeodus emiliae</i>	OPSO_EMIL	0	0	4	0	0
Bullhead						
Minnow						
<i>Pimephales vigilax</i>	PIME_VIGI	112	20	23	32	49
Creek Chub						
<i>Semotilus atromaculatus</i>	SEMO_ATRO	0	15	0	19	0
Catostomidae						
Central						
Stoneroller						
<i>Campostoma anomalum</i>	CAMP_ANOM	3	0	0	0	182
Creek						
Chubsucker						
<i>Erimyzon claviformis</i>	ERIM_CLAV	0	14	0	1	0
Lake						
Chubsucker						
<i>Erimyzon sucetta</i>	ERIM_SUCE	0	1	1	1	0
Spotted						
Sucker						
<i>Minytrema melanops</i>	MINY_MELA	0	1	0	3	1
Blacktail						
Redhorse						
<i>Moxostoma poecilurum</i>	MOXO_POEC	0	0	6	3	0
Ictaluridae						
Black						
Bullhead						
<i>Ameiurus melas</i>	AMEI_NATA	4	6	4	11	15

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Ictaluridae						
Yellow Bullhead						
<i>Ameiurus natalis</i>	AMEI_MELA	15	38	40	38	34
Channel Catfish						
<i>Ictalurus punctatus</i>	ICTA_PUNC	6	0	0	0	3
Tadpole Madtom						
<i>Noturus gyrinus</i>	NOTU_GYRI	2	2	2	10	1
Freckled Madtom						
<i>Noturus nocturnus</i>	NOTU_NOCT	0	3	25	4	19
Esocidae						
American Pickerel <i>Esox americanus</i>						
<i>Esox americanus</i>	ESOX_AMER	0	23	13	5	1
Aphredoderidae						
Pirate Perch						
<i>Aphredoderus sayanus</i>	APHR_SAYA	1	158	20	41	15
Atherinopsidae						
Brook Silverside						
<i>Labidesthes sicculus</i>	LABI_SICC	0	6	1	0	0
Poeciliidae						
Western Mosquitofish						
<i>Gambusia affinis</i>	GAMB_AFFI	158	87	152	76	221

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Fundulidae						
Starhead						
Topminnow <i>Fundulus</i> <i>dispar</i>	FUND_DISP	0	1	0	0	0
Blackstripe						
Topminnow <i>Fundulus</i> <i>notatus</i>	FUND_NOTA	50	65	51	29	37
Blackspotted						
Topminnow <i>Fundulus</i> <i>olivaceus</i>	FUND_OLIV	8	23	55	42	21
Moronidae						
White Bass						
<i>Morone</i> <i>chrysops</i>	MORO_CHRY	1	0	0	0	0
Centrarchidae						
Flier						
<i>Centrarchus</i> <i>macropterus</i>	CENT_MACR	0	6	4	10	0
Redbreast						
Sunfish <i>Lepomis</i> <i>auritus</i>	LEPO_AURI	24	0	23	0	0
Green Sunfish						
<i>Lepomis</i> <i>cyanellus</i>	LEPO_CYAN	43	36	14	12	247
Warmouth						
<i>Lepomis</i> <i>gulosus</i>	LEPO_GULO	5	19	16	15	31
Orangespotted						
Sunfish <i>Lepomis</i> <i>humilus</i>	LEPO_HUMI	1	3	0	0	0

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Centrarchidae						
Bluegill <i>Lepomis macrochirus</i>	LEPO_MACR	106	101	184	80	170
Dollar Sunfish <i>Lepomis marginatus</i>	LEPO_MARG	0	5	0	0	0
Longear Sunfish <i>Lepomis megalotis</i>	LEPO_MEGA	72	170	225	221	348
Redear Sunfish <i>Lepomis microlophus</i>	LEPO_MICR	1	1	4	0	1
Redspotted Sunfish <i>Lepomis miniatus</i>	LEPO_MINI	0	1	14	20	29
Spotted Bass <i>Micropterus punctulatus</i>	MICR_PUNC	53	20	29	31	18
Largemouth Bass <i>Micropterus salmoides</i>	MICR_SALM	0	2	2	6	18
White Crappie <i>Pomoxis annularis</i>	POMO_ANNU	3	0	0	1	0
Black Crappie <i>Pomoxis nigromaculatus</i>	POMO_NIGR	2	0	0	0	1

Table 1.4. Continued

Species	Species Code	River Basin				
		Brazos	Cypress	Neches	Sabine	Trinity
Elassomatidae						
Banded						
Pygmy Sunfish	ELAS_ZONA	0	1	3	0	0
<i>Elassoma zonatum</i>						
Percidae						
Scaly Sand						
Darter	AMMO_VIVA	0	0	1	0	0
<i>Ammocrypta vivax</i>						
Redspot						
Darter	ETHE_ARTE	0	2	12	6	0
<i>Etheostoma artesia</i>						
Mud Darter						
Darter	ETHE_ASPR	0	1	0	0	0
<i>Etheostoma asprigene</i>						
Bluntnose						
Darter	ETHE_CHLO	0	9	15	3	6
<i>Etheostoma chlorosomum</i>						
Slough Darter						
Darter	ETHE_GRAC	8	32	11	6	22
<i>Etheostoma gracile</i>						
Harlequin						
Darter	ETHE_HISTR	0	3	0	0	0
<i>Etheostoma histrio</i>						
Goldstripe						
Darter	ETHE_PARV	2	8	0	0	1
<i>Etheostoma parvipinne</i>						
Dusky Darter						
Darter	PERC_SCIE	0	4	13	15	3
<i>Percina sciera</i>						

Species composition differed among river basins (PERMANOVA: $F = 3.60$, $P < 0.001$) and followed a geographic trend from west to east. Brazos and Cypress basins (study region extremes) were taxonomically distinct from one another, whereas the Neches, Sabine, and Trinity basins shared portions of taxonomic overlap, indicating similarity among species composition. Stream sites within each basin did not exhibit strong differences in their taxonomic dispersion, but sites of the Neches, Sabine, and Trinity basins were more dispersed in taxonomic space when compared to sites of the Brazos and Cypress basins (PERMDISP: $F = 2.27$, $P = 0.075$). The first two axes of the NMDS analysis were retained to represent the dissimilarity among sites based on taxonomic composition (stress = 0.24, 999 iterations; Fig. 1.4). The NMDS axis 1 depicts differences in a land cover and environmental stress gradient, where species abundances at sites plotted on the outside boundary of the ordination were low as a result of environmental stress acting upon them (e.g., flooding, fragmentation; Fig. 1.4). Sites with positive scores on this axis were primarily found within forested streams of the Neches and lower Sabine basins, where species such as Weed Shiner, Dusky darter, Redspot Darter *Etheostoma artesiae*, Blacktail Shiner, and Ribbon Shiner scored positive (Fig. 1.4). Stream sites with negative scores on NMDS axis 1 were primarily found within the Brazos, upper Sabine, and Trinity basins and generally surrounded by land cover associated with agricultural production (e.g., pasture, row-crop; Fig. 1.4). Species that scored negative on axis 1 included Central Stoneroller, Redear Sunfish *Lepomis microlophus*, black basses (*Micropterus spp.*), and Western Mosquitofish. NMDS axis 2

reflected a gradient of instream habitat conditions influencing the structure of the fish communities (Fig. 1.4). Stream sites with positive scores on NMDS axis 2 contained finer substrates (e.g., sand, mud/silt), greater depth, more pool habitat, greater quantities of instream woody debris, and the presence of emergent macrophytes. Creek Chubsucker *Erimyzon claviformis*, Dollar Sunfish *Lepomis marginatus*, Flier *Centrarchus macropterus*, Redfin Pickerel *Esox americanus*, and Pirate Perch *Aphredoderus sayanus* all scored positive on NMDS axis 2. Sites with negative scores on NMDS axis 2 contained coarse substrate (e.g., bedrock, cobble-gravel), shallow depth, more riffles, and the presence of algae. Species that scored negative on NMDS axis 2 included: Central Stoneroller, Red Shiner, White Crappie *Pomoxis annularis*, Channel Catfish *Ictalurus punctatus*, and Redbreast Sunfish.

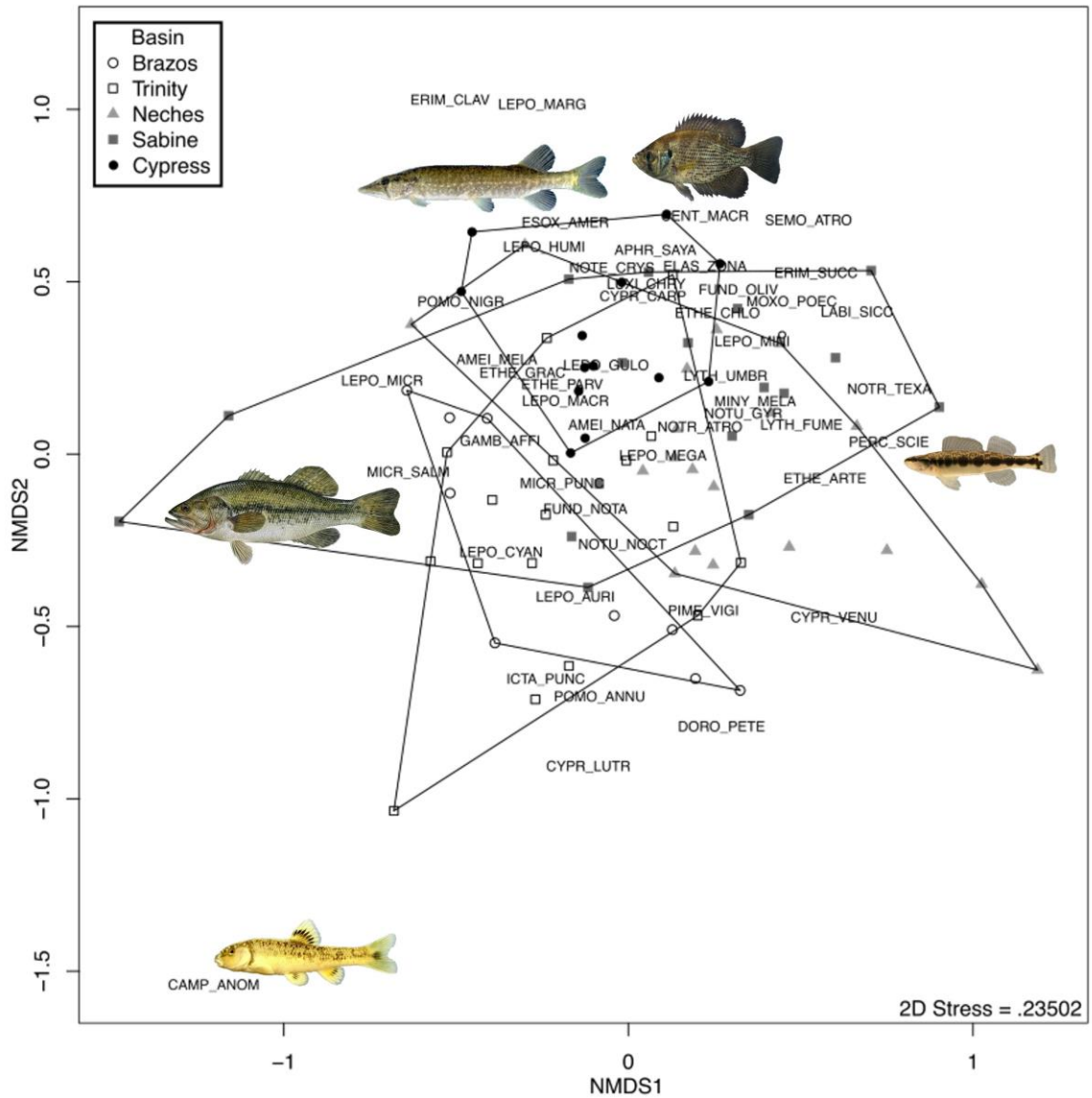


Figure 1.4 Non-metric multidimensional scaling (NMDS) ordination of fish species according to stream sites within each river basin. Symbols represent the community composition of individual stream sites within the five river basins. Species names represent the score of the species in ordination space. See Table 1.4 for species abbreviations. Fish images obtained from public domain.

Functional Structure

The first two axes of the PCA performed on morphological traits explained 45.5% of the variance among species (Fig 1.5; loadings of morphological variables are in Appendix S10). The first PCA axis (PC1, 31.9% of variance) revealed a gradient influenced by differences in body depth, fin lengths, head length, body width, and mouth gape width (Fig 1.5; Appendix S10). Positive scores on PC1 were associated with fishes having very compressed bodies and long fins (e.g., family Centrarchidae) (Fig 1.5; Appendix S10). Species with elongated bodies, wider mouth gapes, and relatively long snouts such as black basses (*Micropterus* spp.), Redfin Pickerel, gars (*Lepisosteus* spp.), Spotted Sucker *Minytrema melanops*, and Freckled Madtom were all negatively correlated with PC1 (Fig 1.5; Appendix S10). The second PCA axis (PC2, 13.6% of variance) revealed a gradient influenced by traits related to trophic ecology and habitat use including caudal peduncle length, head depth, eye diameter, eye position, gut length, and gill raker length (Fig 1.5; Appendix S10). Positive scores on PC2 were occupied by species such as darters (family Percidae) and minnows (family Cyprinidae) with relatively long caudal peduncles, less head depth, superiorly positioned eyes, and longer gut lengths adapted for lotic stream conditions (Fig 1.5; Appendix S10). Fishes with carnivorous and piscivorous habits including catfish (family Ictaluridae), Green Sunfish *Lepomis cyanellus*, Warmouth *Lepomis gulosus*, and White Crappie correlated with negative scores on PC2 for possessing long gill rakers, protrusible jaws, laterally

positioned eyes, and relatively short gut lengths had low scores on PC2 (Fig 1.5; Appendix S10).

The functional richness among stream sites was positively correlated with species richness ($R^2 = 38.3\%$, $P < 0.001$; Fig 1.6A). Functional richness increased as species were added to the local assemblage, but this relationship was fairly weak ($R^2 = 38.3$), most likely due to assemblages with intermediate species richness exhibiting the highest functional richness, suggesting that these assemblages supported more specialized and functionally unique specialized species. River basins that supported a high species richness (e.g., Cypress, Neches) generally had a higher functional richness than those with a low species richness (e.g., Sabine, Trinity). However, the Brazos basin supported a lower species richness, but yielded the second highest functional trait space among basins, likely attributed to the collection of a few morphologically distinct fishes including a juvenile Longnose Gar *Lepisosteus osseus*, herbivorous minnows (e.g., Central Stoneroller), Threadfin Shad *Dorosoma petenense*, and White Bass *Morone chrysops*.

The mean nearest neighbor distance among fish assemblages, or species packing in morphospace, increased with increasing species richness ($R^2 = 35.5\%$, $P < 0.001$; Fig 1.6B). As fish species were added to local assemblages, the mean nearest neighbor distance decreased, suggesting that species are packing closer together in morphological space and increasing redundancy among coexisting species. Functional evenness, a measure of regularity between species in morphological trait space, showed a positive

relationship with increasing species richness ($R^2 = 4.3\%$, $P < 0.05$; Fig 1.6C). However, the fit of this relationship was not strong ($R^2 = 4.3\%$), implying the distribution of species in morphological space remains relatively even in the functional distances between them as species are being added to local assemblages. This pattern of increasing functional evenness as species were added to assemblages was observed in every river basin, except for the Cypress, where functional evenness decreased as species were added. Decreasing functional evenness suggests that the relative abundance of new species (e.g., Dollar Sunfish *Lepomis marginatus*) being added to assemblages of the Cypress basin were functionally complementary to other similar such as Longear Sunfish and Bluegill.

The functional divergence from trait space centroid showed a positive relationship with species richness ($R^2 = 13.2\%$, $P < 0.01$; Fig 1.6D). As species were added to assemblages, functional divergence increased, suggesting that functionally unique species found at the edges of functional trait volumes are becoming relatively more abundant. However, the regression fit was weak ($R^2 = 13.2\%$), perhaps as a result of assemblages with intermediate species richness displaying the highest functional divergence since functional overlap among species is minimal. Stream sites such as Ash Creek in the Trinity River basin and Big Sandy Creek in the Sabine River basin supported assemblages with high functional divergence values. These assemblages were associated with unique species such as the algivorous Central Stoneroller, that possess a very long intestine and a cartilaginous ridge on the lower jaw, and Flier, a sunfish with a very compressed body and long anal fin adapted for movement in lentic systems. Assemblages

with low functional divergence lacked specialist species and were comprised of generalist species such as Longear Sunfish, Bluegill Sunfish, and Blacktail Shiner.

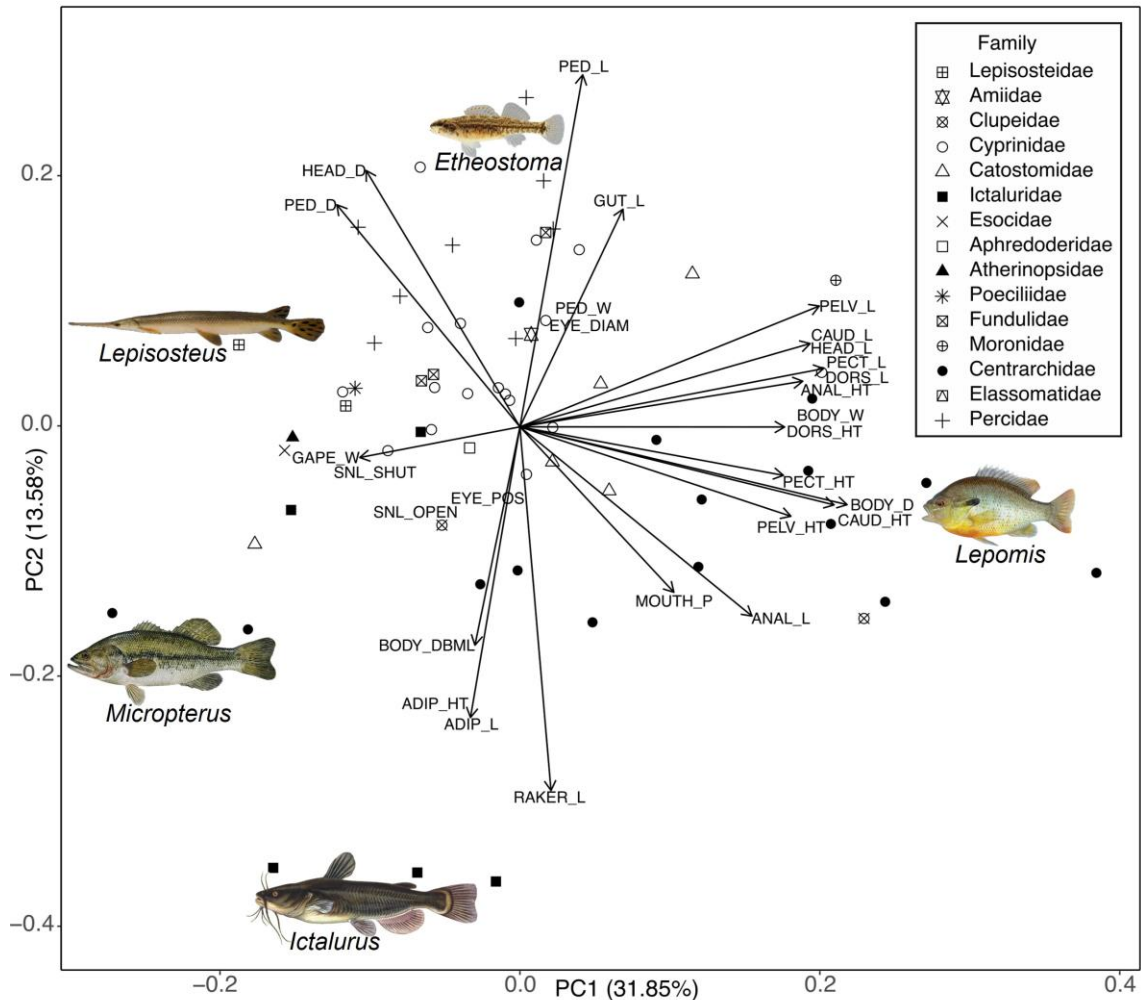


Figure 1.5 Principal component analysis (PCA) ordination on the morphological traits of sixty-three species collected in east Texas stream sites. Trait loadings on the two axes are depicted as vectors. Each symbol represents the average of individual species in accordance to each fish family. See Table 1.3 for morphological trait abbreviations. Loadings of traits can be found in Appendix S9. Fish images obtained from public domain.

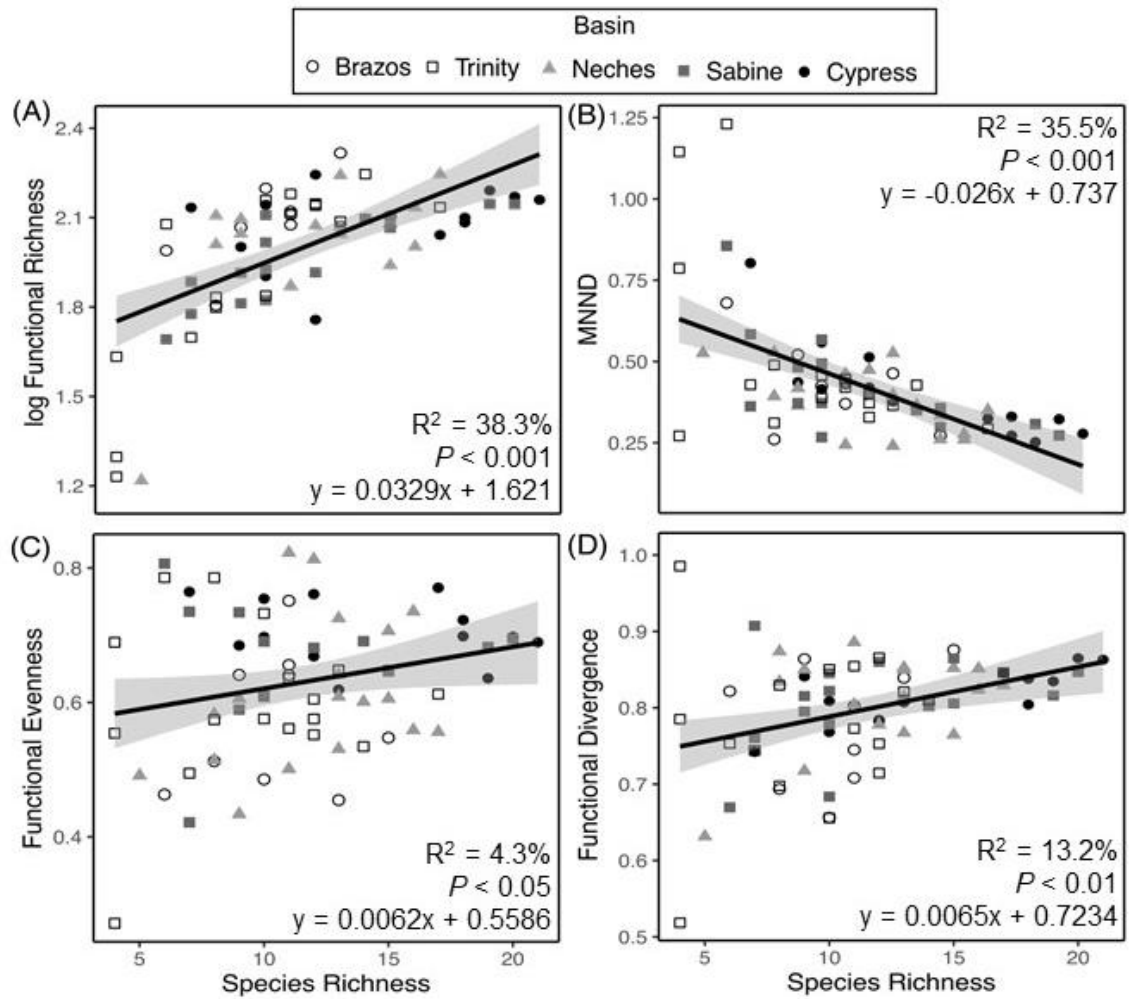


Figure 1.6 Linear regressions of (A) functional richness, (B) mean nearest neighbor distance, (C) functional evenness, and (D) functional divergence of assemblages ($n = 72$) plotted against per site species richness. All linear regressions were statistically significant ($P < 0.05$).

DISCUSSION

Freshwater biodiversity in east Texas streams is represented by highly diverse fish assemblages, and the taxonomic and functional diversity of fishes in east Texas streams are structured from environmental variables interacting at the local and landscape scale. I found support for the first hypothesis in which taxonomic diversity and fish assemblage structure among the five river basins will vary in response to specific landscape and local environmental variables occurring within each river basin. My findings suggest that land cover type contributed the most in structuring the regional species pool, while local environmental variables such as flow regime and percent instream woody debris contributed the most in structuring the local assemblage, a pattern which has been consistently observed in both temperate (Anderson et al. 1995; Hoeinghaus et al. 2007) and tropical rivers (Pease et al. 2012; Montag et al. 2019). Second, the functional diversity of east Texas fish assemblages varied in relation to inter-basin differences of local environmental variables. For instance, larger and deeper streams that contained instream woody debris had species with deeper bodies, longer fin lengths, and longer gill rakers, while smaller, shallower streams with a more heterogenous flow regime supported more species with smaller, more streamlined bodies that possessed smaller, superiorly positioned eyes and long caudal peduncles.

Fish Assemblage-Habitat Associations across Basins

Assemblages within the Brazos and Cypress River basins did not appear to overlap in taxonomic space, a pattern that contrasts assemblages of the Trinity, Neches, and Sabine River basins, where the taxonomic composition of assemblages were more similar to each other, but patterns of species richness per basin reflected previous observations of the east-west faunal trend of freshwater fishes in Texas (Hubbs et al. 1991; Linam et al. 2002; Hoeinghaus et al. 2007). A pattern of increasing taxonomic diversity from west to east appears to be influenced by the relative role of landscape environmental variables in structuring the regional species pool. Hubbs (1957) found the distributional patterns of fish assemblages in Texas are derived from differences in climatic and geological components influencing hydrology. Hydrologic regimes and land cover have been identified as a key component in influencing the taxonomic assemblage composition at regional scales via indirect connections with local habitat (Poff and Allan 1995; Allan 2004), in-turn influencing species distributions (Troia & Gido, 2013) and local abundance (Montaña and Winemiller 2010). I found that assemblages within drier regions and more extensive agriculture land cover (i.e., Brazos, Trinity) generally lacked intolerant species, and were dominated by widely distributed, habitat generalist species such as Red Shiner, Blacktail Shiner, Western Mosquitofish, and Green Sunfish. While these species generally occurred across all river basins, it should be noted that these species made up 54% of the total collection from the Brazos and Trinity basins and only 14% from the Cypress, Neches, and Sabine. Range and row-crop agriculture have been

linked to higher abundance of generalist species within watershed as they possess a higher tolerance to abiotic stressors such as increases in flood pulses, nutrient loads, and siltation (Walser & Bart, 1999a; Taylor et al., 2014). Alternatively, assemblages within wetter and more forested landscapes (i.e., Neches, Sabine, Cypress) supported more taxonomically diverse assemblages. For example, I found that minnow and darter richness was higher in the Neches, Cypress, and Sabine basins than those of the Brazos and Trinity. This pattern is consistent with studies addressing the regional distribution of fishes within Texas (Hubbs et al. 1991; Anderson et al. 1995; Linam et al. 2002), in which they found a higher richness of darters and minnows in the eastern half of the state. Species such as Weed Shiner, Blackspot Shiner, and Dusky Darter all showed associations with more forested streams of the eastern extent. The occurrence of specialist species such as Weed Shiner and Blackspot Shiner indicate that the hydrologic dynamic is being maintained with the presence of riffle-run flow regime (Robertson et al., 2016), and the presence of intolerant species such as Dusky Darter are an indicator of healthy stream systems and high quality habitat (Linam & Kleinsasser, 1998).

Although landscape scale environmental variables underlie the structure of fish assemblages, local environmental variables such as substrate composition, stream depth, flow regime, and amount of instream habitat also correlate with the structure of local assemblages from west to east. Such variables are consistent with those from other studies of wadeable streams in regions of North America (D'Ambrosio et al. 2009; Rowe et al. 2009) as well as central Texas (Pease et al., 2011). Coarser substrates, algae,

increased flow velocity, and shallow stream depth were associated with stream sites of the Brazos and Trinity basins, and the occurrence of species such as Central Stoneroller were strongly associated with shallower, bedrock lined streams, that contained abundant algae, while the more habitat generalist Red Shiner, occurred more commonly within these basins, likely a result of this species tolerance to environmental stressors. Increased coarse substrate and algae have been linked with increases in surface runoff and nutrient concentrations, resulting in sediment loss and increased stream primary productivity (Taylor et al., 2014). The more forested streams of the Neches, Sabine, and Cypress were generally deeper and contained finer sediments and more woody debris. Instream woody structure provides greater microhabitat availability to a variety of species, as well as playing a role in the maintenance of hydrologic stream dynamics (Wright & Flecker, 2004). Species such as Pirate Perch, Redfin Pickerel, and Flier were correlated with the presence of pools and instream habitat such as exposed root banks, woody debris, and emergent macrophytes found in eastern basins. Furthermore, stream sites of the Neches, Sabine, and Cypress supported a greater flow regime heterogeneity, in-turn supporting more fluvial specialist species. Fluvial specialist species occurring in these basins included Creek Chubsucker, Dusky Darter, Blackspot Shiner, and Goldstripe Darter *Etheostoma parvipinne*. Stream sites with heterogenous flow regimes have been associated with habitat stability and increased microhabitat availability, in-turn resulting in greater assemblage diversity (Poff et al. 1997; Allan 2004). The higher taxonomic diversity observed in assemblages of the Neches, Sabine, and Cypress compared to those

of the Brazos and Trinity suggests that a greater stability, and complexity of local habitat parameters provide more available niche opportunities for species to exploit.

While previous studies have documented the importance of landscape (Snyder et al., 2003) and local environmental variables (Roa-Fuentes and Casatti 2017; Montag et al. 2019) in structuring fish assemblages, these variables interact simultaneously and can underlie the stress that affects the strength of environmental filters on fish assemblages. Environmental stress has been shown to homogenize instream habitat and flow dynamics, reducing taxonomic diversity (Poff & Zimmerman, 2010). For example, Dala-Corte et al. (2019) found that high levels stress associated with agriculture reduced the taxonomic diversity of stream fish assemblages by the loss of microhabitats. Additionally, instability in hydrologic dynamics (e.g., high current variability) is another factor that has been demonstrated being a key component in structuring stream fish assemblages (Ross, 1986). During my sampling season, extreme precipitation events that occurred throughout east Texas during early spring (April-May) of 2020-2021 may have influenced the taxonomic diversity of some fish assemblages across this region. Shuffle Creek, in the upper Sabine basin, showed signs of recent intense flooding such as a lack of bank vegetation and channel scouring and only contained juvenile black basses (*Micropterus* spp.). The assemblage of Naconiche Creek (n = 3 spp) was mainly comprised of generalist minnow species (e.g., Blacktail Shiner) adapted to high flow conditions. Yet, Robertson et al. (2018) reported 19 species with affinities for both lentic and lotic habitat conditions in Naconiche Creek. The disparity in my results of species

richness may have resulted from increased water velocity released from the upstream impoundment of Lake Naconiche during the stream survey, reducing the number of species collected.

Functional Diversity-Habitat Associations across Basins

Patterns of functional diversity of fish assemblages across river basins were consistent with the observed patterns of taxonomic diversity. Across the study region, the morphological gradient was mainly influenced by species such as sunfish (*Lepomis* spp.) and black basses (*Micropterus* spp.) which occurred across all river basins, and species such as darters, which show a strong relationship with more forested river basins of the east such as the Neches, Sabine, and Cypress. Previous studies have found that sunfish species are able to persist in stream reaches throughout Texas despite habitat alterations, drought, and water quality degradation (Linam et al., 2002; Pease et al., 2011; Driver & Hoeinghaus, 2016), whereas more specialist species such as darters, exhibit the strongest constraints on their distribution for Texas fishes (Hubbs et al. 1991; Linam et al. 2002), and were less common in western river basins of the Brazos and Trinity.

Across the study region, I found that larger and deeper stream reaches with more pool and more instream woody debris contained larger fishes with deeper bodies and longer fins such as sunfish (*Lepomis* spp.), as well as more predatory species with elongated bodies, short fins, and wider mouth gapes such as Redfin Pickerel. These findings agree with other studies across geographic regions that identified traits such as

body size and fin length as important predictors of fish habitat use (Hoagstrom & Berry, 2008; Pease et al., 2015; Bower & Winemiller, 2019). Fishes with long fins and deep laterally compressed bodies such as have improved mobility in lentic habitats (Gatz 1979), whereas fishes elongated bodies and wider pectoral fins such as are associated with maintaining their position in dense instream habitat and use sudden bursts of acceleration to ambush prey (Webb, 1984). Traits related with trophic ecology such as gill raker length and gut length been associated with predatory feeding (Gelwick & McIntyre, 2017) as well the presence of pool habitat (Pease et al., 2015). My results are consistent with this pattern in which species such carnivorous catfish (*Ameiurus* spp.) with short guts and long, thin gill rakers, were more common in reaches with pools and abundant instream woody debris across the study area.

Smaller and shallower streams with more riffles contained smaller fishes but also had more species with streamlined bodies, longer caudal peduncles, and longer gut lengths, which is consistent with observations made in other regional studies (Lamouroux et al., 2002; Pease et al., 2015). These adaptations increase the ability of these fishes to withstand periods of increased water flow (Bower & Piller, 2015). Fishes with long gut lengths, such as minnows (family Cyprinidae) and suckers (family Catostomidae), were frequently observed in reaches with more riffle habitat. Long gut length is associated with benthic foraging (Gatz, 1979), and the presence of fishes within this trophic guild have been related to the amount of vegetative detritus within smaller stream reaches (Hoagstrom & Berry, 2008). Generalist and tolerant species such as Red Shiner,

Blacktail Shiner, and juvenile Green Sunfish dominated shallow reaches of the Brazos and Trinity basins. Smaller fishes, such as juvenile Green Sunfish, are more adapted to exploit available microhabitat around shallow stream edges to avoid predators in open water (Townsend & Hildrew, 1994). Disturbances (e.g., flooding events) within Texas river basins are common (Linam et al., 2002), and while these generalist fish species are able to persist in response to these events, more specialized species do not appear to endure such events. For example, the occurrence of fluvial specialist species such as darters, were less common within the Brazos and Trinity basins. Darters, with small superiorly positioned eyes and long caudal peduncles, are adapted for making sudden bursts upward from benthic habitat to strike drifting macroinvertebrates. Therefore, the presence of these species was likely limited due to environmental conditions associated with water quality degradation (e.g., increased turbidity) or habitat homogenization (e.g., loss of riffles) (Karr, 1986). While the western river basins did not contain as many specialized species as the eastern basins, a portion of less disturbed reaches of the Brazos and Trinity basins did contain the herbivorous Central Stoneroller, which has long guts and subterminal positioned mouths adapted for grazing on algae attached to coarse substrate within shallow, clear streams (Hubbs et al. 1991). This species has shown some intolerance to heavy siltation and pollutants (Edwards, 1997), as these effects of environmental stress likely reduce the quantity of algae on coarse substrate in pools and riffles.

Functional richness has been observed to be greater in more species rich assemblages (Winemiller 1991; Hoagstrom and Berry 2008). However, I found that functional richness of assemblages was greater in assemblages with intermediate species richness, a pattern also observed in fish assemblages of central Texas, that contained morphologically distinct fishes such as gars, herbivorous minnows, shad, and darters (Pease et al., 2015). Local habitat filters are known to limit the available trait space that an assemblage can occupy (Keddy, 1992), and the amount of trait space is restricted to an equivalent, or smaller volume of space which can lead to a minimization of niche overlap between coexisting species (Mason et al., 2008). In an analysis of fish functional trait convergence across regions, Bower and Winemiller (2019) found that water velocity and physical habitat complexity acted as universal filters across biogeographic regions. Water velocity appears to filter out species with more compressed bodies, and reaches with greater microhabitat complexity supported a more functionally diverse assemblage (Bower & Winemiller, 2019). Forested streams (e.g., Neches, Cypress, Sabine) across my study area supported a greater species richness, as well as greater functional richness when compared to those in agriculturally influenced landscapes (e.g., Brazos, Trinity). Stream sites with more forest cover typically support greater flow regime heterogeneity, stable hydrologic cycles, more instream habitat, and greater diversity of macroinvertebrates, in-turn providing greater niche opportunities for specialized species (Allan, 2004). However, once trait space is maximized, the likelihood of a new species being added that is functionally unique decreases, increasing the functional redundancy

within these assemblages as new species are added. One potential explanation to this observation is the west to east increase in richness of small bodied fishes (e.g., minnows and darters). Although this may represent a pattern of convergence in body size due to habitat filtering, coexistence of darters and minnows can still occur given the trophic and microhabitat specialist habits of these species.

Despite species becoming more packed in trait space, functional evenness of species distribution increased with increasing species richness. While this relationship was weak, this finding suggests that even spacing among dominant species of an assemblage are being relatively maintained in trait space with the addition of new, functionally unique species. The maintenance of functional evenness among species in trait space contradicts the idea that functionally redundant species dominated my studied assemblages (i.e., MNDD), but is supported by an increase in functional divergence. Functional divergence is a relative measure of an assemblages ability to efficiently use resources (Mason et al., 2005). Functional divergence of fish assemblages across river basins increased as species richness increased, suggesting that the increase in species richness is being facilitated by the addition of functionally unique species (Villéger et al., 2010). Increases in both functional evenness and functional divergence have been shown to indicate high degrees of niche differentiation, because the relative abundance of specialist species is highest when overlap of functional trait space is the lowest (Mason et al., 2008; Mouchet et al., 2010). However, it should be recognized that the number of individuals per species was not consistent across the study area. Metrics of functional

diversity are largely driven by the occurrence of rare, specialized species that have intolerance to changes in environmental conditions (Leitão et al., 2016; Rodrigues-Filho et al., 2018). In this study, functionally unique species (those at the periphery of trait space) such as gars, Redfin Pickerel, Flier, Central Stoneroller, and darters (e.g., Scaly Sand Darter) showed associations to specific river basins (e.g., Central Stoneroller in the Brazos and Trinity) and habitat types (e.g., darters in riffles of the Cypress, Neches, Sabine).

Implications for Environmental Assessment

Understanding how assemblages change in response to environmental variables across multiple spatial scales is crucial for developing and refining conservation efforts. Findings from this study further emphasize the use of a multi-scale approach in evaluating the roles that environmental variables play in structuring the taxonomic and functional diversity of stream fish assemblages. By including an extensive collection of environmental variables across multiple spatial scales, this study not only contributes to the understanding of how environmental variables influence assembly processes, but also provides baseline fish community and habitat data on stream systems within an understudied region of east Texas, as well as establishing areas of focus for species of greatest conservation need (SCGN). As habitat alterations associated with anthropogenic disturbance are more likely in the future, the integration of both a taxonomic and functional approach in monitoring will greatly assist conservation managers in assessing

the ecological integrity of streams as well as fully comprehending the relationship between fish and stream habitat.

Given that my findings show higher taxonomic and functional diversity of fish assemblages within forested river basins compared to assemblages within more agriculture influenced basins, the connective relationship between landscape and local scale environmental variables play an important role in structuring fish assemblages through the increase in microhabitat availability, which results in greater system stability. Ultimately, by providing further insight into the underling mechanisms in the community assembly process, ecologists can further develop our capability to make predictions of species distributional response to factors associated with environmental change.

Historical and Contemporary Occurrence of Blackspot Shiner (*Notropis atrocaudalis*) In Texas and Correlates with Local Habitat Variables

INTRODUCTION

Lotic systems in both temperate (Benke, 1990; Richter et al., 1997; Mayes et al., 2019) and tropical (Dala-Corte et al. 2016; Roa-Fuentes and Casatti 2017; Montag et al. 2019) regions have been subjected to anthropogenic alterations in habitat (e.g., land cover, fragmentation) over the last 70 years, and such alterations have resulted in significant changes in freshwater biodiversity (Perkin et al. 2015). Streams in particular, are sensitive to changes in land cover type (e.g., urbanization, agriculture, deforestation) and fragmentation (e.g., dewatering, low head dams) because of their hydrologic connectivity between catchment and local extents that regulate instream habitat, physicochemical properties, and species diversity (Allan 2004; Sweeney et al. 2004; Leal et al. 2018). For instance, urban development has shown to increase the probability of flooding, the input of pollutants and surface runoff, consequently affecting both instream habitat and water quality (Wang et al., 2000, 2001). Similarly, streams impacted by deforestation and agriculture are associated with increases in sediment load, surface runoff, and habitat homogeneity, accompanied by local reductions in channel depth, instream woody debris, and substrate complexity (Walser and Bart 1999; Teresa et al. 2015; Zeni et al. 2017).

Increases in hydrological variability due to human extraction or dam development have led to homogenization of stream fish communities (Pelicice et al., 2014) and caused declines in the abundance and distribution of stream fish (Herbert & Gelwick, 2003; Matthews & Marsh-Matthews, 2003; Roberts et al., 2013).

Studies examining the historical and contemporary trends of species distributions have been useful to develop distributional models to assess how species would respond to changing land use practices and alterations in stream habitat (Wenger et al., 2011; Jaeger et al., 2014; Labay et al., 2015). Thus, assessing the distribution and conservational status of species to environmental alteration requires a combination of extensive periods of observation, historical records from natural history museums, and extensive field sampling (Ponder et al., 2001). For instance, Piller et al. (2004) used historical museum records and contemporary surveys to assess the decline of Frecklebelly Madtom *Noturus munitus* in the Pearl River basin of the southeastern United States. They found that populations of Frecklebelly Madtom were relatively stable in the 1950s, but increased anthropogenic activities occurring in the 1960s reduced the stability of stream geomorphology, which drastically reduced the presence of coarse substrate, a critical component of their habitat (Robison & Buchanan, 1988; Piller et al., 2004). When contemporary records are lacking, historical records are a useful tool to evaluate where conservation resources need to be allocated. In an attempt to establish the historical distribution of the cryptic, Bluehead Shiner *Pteronotropis hubbsi*, Hargrave and Gary (2016) compiled 100 independent historical records and identified 4 population centers

on the perimeter of their native range in Arkansas, Oklahoma, Louisiana, and Texas. However, the large geographic extent between these population centers generated a need for modern sampling effort to evaluate this species of greatest conservation need (Hargrave & Gary, 2016).

While the effects of environmental change on stream fish communities is well documented throughout the United States (Hoagstrom et al., 2011; Roberts et al., 2013), some of the major concerns have been identifying negative shifts in population sizes, in particular the occurrence of small bodied fishes (e.g., family Cyprinidae, hereafter cyprinids) (Gido et al. 2010; Perkin et al. 2015). In the Great Plains region of central United States, the occurrence of cyprinid species have shown declines within their native ranges (Hoagstrom et al. 2011; Perkin et al. 2015). For example, the federally threatened Arkansas River Shiner *Notropis girardi* was once well distributed throughout its native range, as a result of habitat fragmentation and reductions in flooding, it is now missing from 80% of its historical range (Wilde, 2002). In Texas, multiple cyprinid species have exhibited long-term declines with major river basins (Anderson et al., 1995; Bonner & Wilde, 2000; Durham & Wilde, 2009). In eastern Texas, the construction of Toledo Bend Reservoir reduced the diversity and richness of cyprinids, and also caused local extirpations of several species due to increased discharge and decreased water temperatures, inhibiting cyprinid spawning behavior (Suttkus & Mettee, 2009). While the decline of cyprinid species is clearly evident as a result of anthropogenic impacts, increased efforts addressing the response of native cyprinid species to habitat alterations,

in particular those species listed as conservation concern, are needed to provide better recommendations for management and preservation of critical habitat.

Populations of Blackspot Shiner *Notropis atrocaudalis* appear to be declining across its native range of Arkansas, Oklahoma, and Texas (Anderson 2006; TPWD 2012; ODWC 2016). In Texas, this species has been historically distributed from the southwestern extent of their range in small order streams of the lower Brazos River to the eastern edge of Texas in the Sabine River Basin (Hubbs et al., 1991), as well as portions of the Red River Basin between Texas and Oklahoma (Warren et al., 2000). Information on the ecology of Blackspot Shiner is fairly limited and restricted to a few localities in a narrow geographic scope (Evans & Noble, 1979; Herbert & Gelwick, 2003; Bean et al., 2010). The species is described to occupy smaller order streams that contain sand and cobble substrates (Moore & Cross, 1950), with aquatic vegetation (Pigg, 1977), and clear lotic water (Douglas, 1974). The species has also been described as a highly mobile, fluvial specialist, that is adapted to seasonal changes in variable baseflow conditions (Herbert and Gelwick 2003). Whereas Bean et al. (2010) suggested that the species is a habitat generalist, but observed higher abundance in streams with a shallower depth profile, slower currents, and a less diverse flow regime. In Big Sandy Creek, Texas, the abundance of the species declined with increasing stream order (Evans & Noble, 1979). While Blackspot Shiner possesses several traits that enable it to occupy a variety of habitats and disperse within river basins, a combination of natural disturbances (e.g., flooding, drought) and anthropogenic habitat alterations (e.g., channelization, loss of flow

regime; Williams & Bonner, 2006; Perkin et al., 2013, 2016) have caused their distribution to contract as well as resulting in decreased relative abundance, resulting in listing this species as of greatest conservation need in the state of Texas (TPWD, 2012).

In this study, I used a combination of historical occurrence records and contemporary surveys to assess the status of the Blackspot Shiner within its native range in Texas. The two objectives were (1) to compare historical and contemporary data to examine Blackspot Shiner distribution, and (2) to examine the relationship between contemporary occurrence of the species and local stream environmental variables. I expected that changes in local environmental factors were limiting the local catch per unit effort (CPUE) of Blackspot Shiner within its distributional range in Texas since habitat complexity is regularly homogenized from natural (e.g., drought, flooding) and anthropogenic (e.g., water quality, fragmentation) alterations across multiple spatial scales (Casatti et al. 2006; Gido et al. 2010; Perkin et al. 2015). Findings from this study will provide insights for better conservation action practices within surveyed river basins by establishing patterns of Blackspot Shiner occurrence related to local habitats, and revealing a species distributional response to changes in environmental conditions.

METHODS

Historical Observations

Data were acquired from Fishes of Texas (Hendrickson & Cohen, 2015), Sam Houston State University Ichthyology Collection, Texas Natural History Collection, and the University of Texas Biodiversity Collection (Appendix S11). I extracted all available records of Blackspot Shiner, and georeferenced these data where the species was deemed present and within the native Texas range using ArcGIS 10.6.1. I chose to only use sites where the species was deemed present because of inconsistencies in sampling methodology from various assessments. Because these data are based on direct observations and preserved specimens, these data do not reflect population trends over time, but instead serve as a baseline to visualize changes in distribution based on species occurrence. These data from these locations should be considered as a secondary source because the identification of all specimens was not confirmed. These historical records can be used to reveal gaps in the native Texas range of Blackspot Shiner that can be targeted for assessment efforts.

Contemporary Survey

Contemporary surveys occurred in 75 stream sites within the Brazos, Cypress, Neches, Sabine, and Trinity River basins in eastern Texas (Figure 2.1). The Brazos River basin is dominated by pasture, prairies, and rangeland throughout its transition from the

panhandle of Texas to the Gulf of Mexico (TCEQ, 2002). The Cypress basin of northeast Texas primarily consists of pine and oak forests, but has influences of rangeland used for the production of agriculture (Robertson et al., 2016). The Neches River basin contains dense stands of pine forests utilized for timber production, but also encompasses small areas of range and pastureland used for agricultural production (Robertson et al., 2018). The Sabine River basin forms the border between Texas and Louisiana, and the upper extent consists of a mixture of range and pastureland, while the lower extent includes large tracts of pine forests (TCEQ, 2002). In central Texas, the Trinity River basin is dominated by range, pastureland, and row-crop agriculture (TCEQ, 2002).

Stream sites were sampled during April-October of 2020 and 2021 following methods modified from the United States Environmental Protection Agency (2017). Within the study reach of the stream, all available habitat were first sampled using a seine net (4.6 m x 1.8 m or 1.8 m x 1.8 m, 5-mm mesh) for a minimum of 15 4-m hauls, and then by a backpack electrofisher (Smith-Root LR-24) for a minimum of 900s. All collected specimens were then identified, counted, and either released or euthanized in clove oil and preserved in a 10% buffered formalin solution.

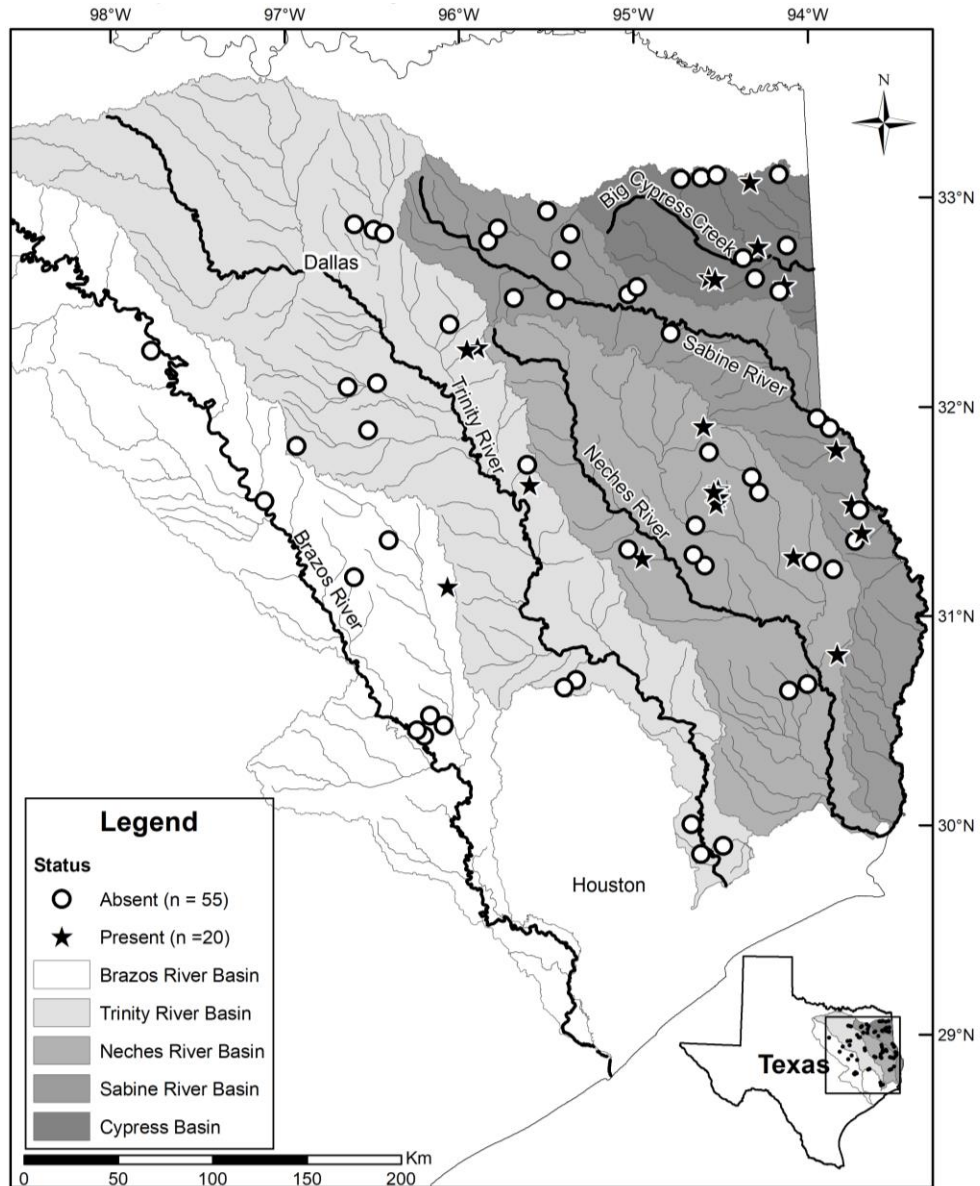


Figure 2.7 Study region depicting the five river basins and sampling locations in east Texas including the Brazos (n = 9 sites), Trinity (n = 17 sites), Neches (n = 19 sites), Sabine (n = 17 sites), and Cypress (n = 13 sites). White dots represent the stream locations where Blackspot Shiner was not collected (n = 55) and stars represent the stream site where it was collected (n = 20) within each basin during April – October of 2020 and 2021.

Prior to conducting the habitat assessment, *in-situ* water parameters such as dissolved oxygen (mg/L), pH, specific conductance ($\mu\text{s}/\text{cm}$), total dissolved solids (mg/L), and water temperature ($^{\circ}\text{C}$) were measured using a ProDSS YSI multiprobe meter. Average flow velocity (m/s) was measured using a Marsh-McBirney Model 201D portable flow meter. Following USEPA (2017) protocol, a local physical habitat assessment was conducted within a stream reach of 60 – 300 m. Within the designed study reach, 33 local habitat parameters describing stream morphology (e.g., wetted channel width, average channel depth), riparian characteristics (e.g., percent exposed soil, percent canopy cover), and instream habitat (e.g., percent woody debris, percent substrate composition) were collected at 5 transects. Measurements including wetted channel width, bank-full width, average channel depth, thalweg depth, bank angle, percent exposed soil, and percent canopy cover were averaged across the entire study reach of each site.

Statistical Analyses

To identify the main gradients among local habitat parameters at sites where Blackspot Shiner was present and sites where it was absent, I performed principal components analysis (PCA) on the log transformed site and environmental variable matrix of all sites. To distinguish taxonomic differences among sites where Blackspot Shiner was present and sites where it was absent, a permutational multivariate analysis of variance (PERMANOVA) and permutational analysis of multivariate dispersion (PERMDISP), based on Euclidian distances, was used to describe the variation among

sampled sites (Oksanen, 2007). In addition, I calculated the relative abundance (catch per unit effort; CPUE), percentage composition, and frequency of occurrence of cyprinids collected at all sites, to provide an indirect measure of the relative abundance of Blackspot Shiner collected in stream sites. CPUE was calculated as:

$$CPUE = \frac{\# \text{ of fish collected}}{\text{sample reach length (m)}} \times 10$$

and summarized across collection sites. All statistical analyses were performed in R version 4.0.3 (The R Foundation for Statistical Computing).

RESULTS

Historical Trends in Distribution

Of the six databases used to acquire historical records, our search yielded 652 independent observations of Blackspot Shiner across nine decades within streams of the Brazos, Cypress, Neches, Red River, Sabine, San Jacinto, Sulphur, and Trinity River Basins. Blackspot Shiner collection records existed for the following decades (Fig 2.2): before 1940 (11 records; Appendix S12); 1940 – 1949 (45 records; Appendix S13); 1950 – 1959 (133 records; Appendix S14); 1960 – 1969 (50 records; Appendix S15); 1970 – 1979 (81 records; Appendix S16); 1980 – 1989 (44 records; Appendix S17); 1990 – 1999 (144 records; Appendix S18); 2000 – 2009 (69 records; Appendix S19); 2010 – 2019 (75 records; Appendix S120). In the Brazos River basin, records were observed from all decades except the 1950s, 1980s, 2000s, and 2010s, and were collected from Bryan, TX (Fig 2.2). The Cypress basin lacked records from before the 1950s and 1960s, but were observed more frequently in the 1970s and 2010s (Fig 2.2). Blackspot Shiner occurred within the Neches basin in every decade since before the 1940s (Fig 2.2). Records from the Red River basin only occurred in the 1960s, 1990s, and 2000s from a few streams near Paris, TX (Fig 2.2). The Sabine basin contained records in every decade except before 1940 (Fig 2.2). The San Jacinto basin had records in every decade except for the 2010s (Fig 2.2). Records in the Sulphur basin occurred from the 1950s, 1960s, and from

the 1980s to the 2020s (Fig 2.2). The Trinity basin had records in every decade since before the 1940s, but the number of observations has decreased in recent years (Fig 2.2). The 1950s, 1970s, and 1990s made up over half (359; 55%) of the observations over nine decades and may reflect a period of intensive sampling by field ichthyologists (Fig 2.2).

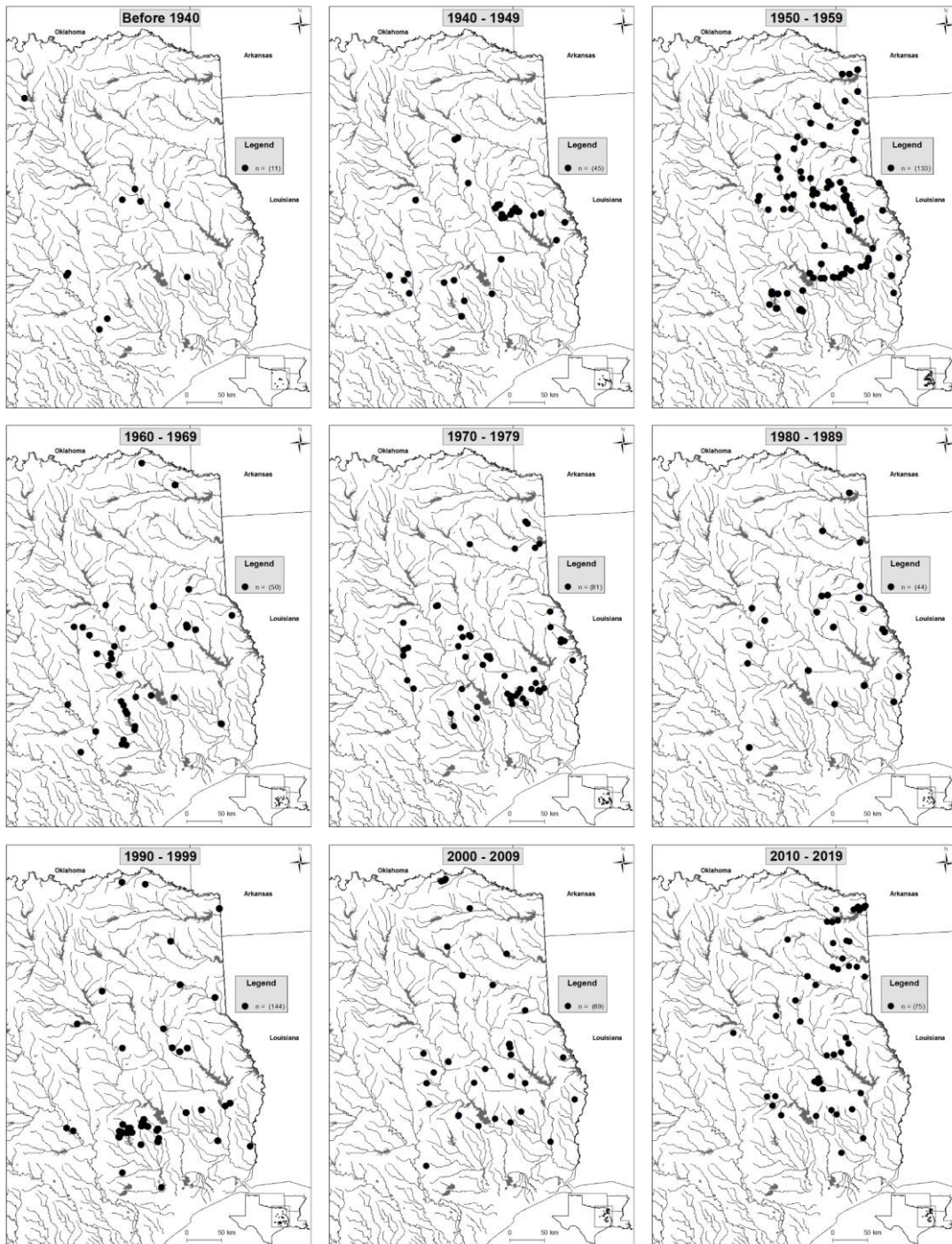


Figure 8.2 Study region depicting the nine decades of Blackspot Shiner records (n = 652) in east Texas. Black dots illustrate an occurrence of Blackspot Shiner representing an observation or collected specimen.

Contemporary Survey

The first two axes of the PCA performed on local habitat variables explained 30.7% of the total variation (Fig 2.3; loadings of local habitat variables are in Appendix S9). The primary gradient (PC1, 18.5% of variance) was associated with substrate type, canopy cover percentage, bank angle, wetted and bank-full channel width, percentage instream woody debris, percentage of tree roots, percentage of impervious surface, percentage of algae, and *in-situ* water parameters (Fig 2.3; Appendix S9). Stream sites with positive scores on PC1 primarily occurred in eastern longitudes and contained greater canopy cover, finer substrates, more live trees and roots for in-stream cover, and steeper stream banks with little vegetation cover (Fig 2.3; Appendix S9). Most stream sites with negative scores on PC1 were found in western longitudes and contained coarser substrates, conductive and alkaline *in-situ* conditions, wider stream channels, more algae, and were surrounded by greater impervious surfaces (Fig 2.3; Appendix S9). The second gradient (PC2, 12.2% of variance) displayed differences among sites in stream depth, substrate composition, instream habitat, and flow regime (Fig 2.3; Appendix S9). Positive scores on PC2 were represented by deep streams with mud-silt substrate, more pool habitats, and a greater percentage of large and small woody debris (Fig 2.3; Appendix S9). Stream sites with negative scores on PC2 contained a riffle-run flow regime, coarser substrate, and faster instantaneous flow velocity (Fig 2.3; Appendix S9). Sites where Blackspot Shiner occurred were predominately surrounded by forested riparian areas, contained a diverse flow regime, and were dominated by sandy substrate,

with the exception of Lanana Creek (Neches Basin) and Town Creek (Trinity Basin), which occurred in urbanized areas and contained more structured habitats composed of gravel and cobble substrate.

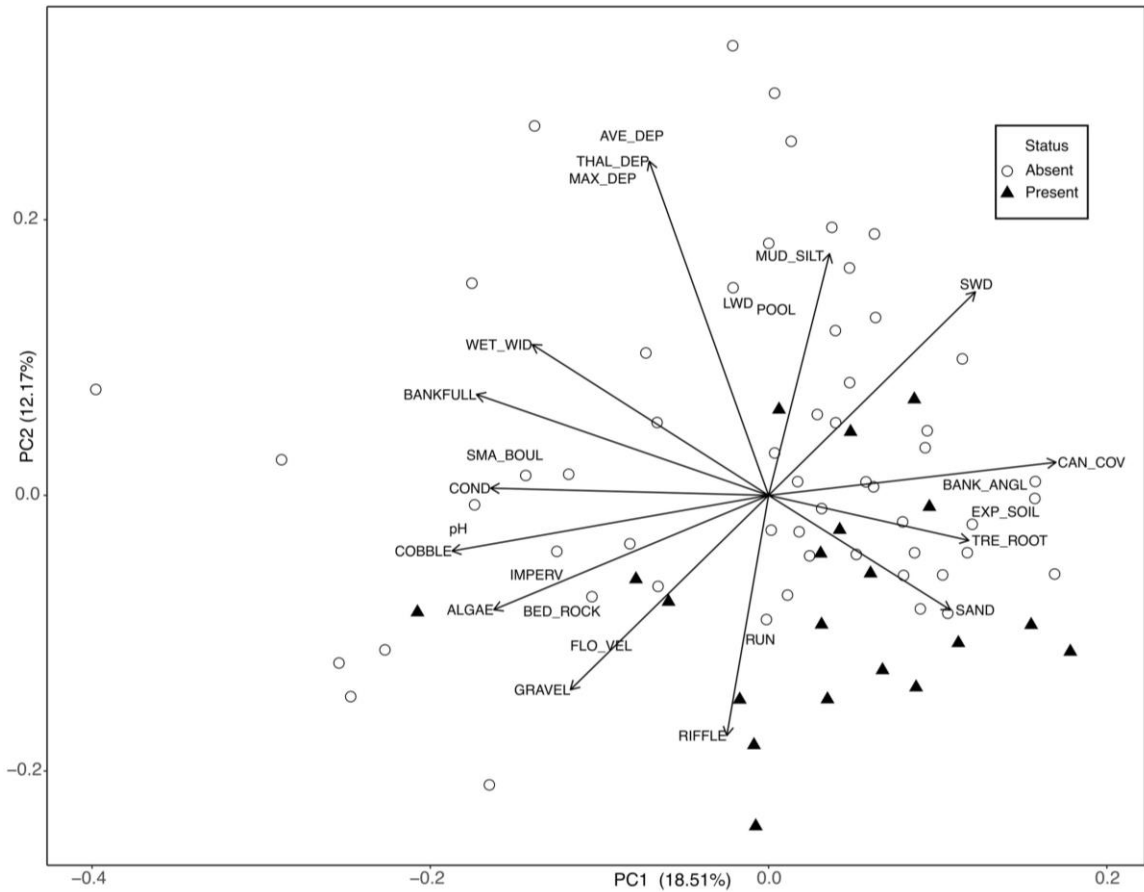


Figure 2.9 Principal component analysis (PCA) based on 33 environmental variables collected from stream sites in east Texas (n =75). Symbols represent sites where Blackspot Shiner were collected (black triangle) or not collected (open circle). Loadings of local habitat variables are in Appendix S9.

A total of 111 Blackspot Shiner were collected at 20 of 75 stream sites from the five river basins during 2020 – 2021 (Fig 2.1; see Appendix S1 for site coordinates). Individuals occurred in relatively low numbers across the study area, and total captures ranged from 1 to 18 individuals, with the highest per site CPUE occurring in the Cypress and Sabine River basins (Table 2.1). There was a significant difference between the taxonomic community composition of sites where Blackspot Shiner was present and sites where it was absent (PERMANOVA: $F = 3.69$, $P < 0.001$). Assemblages that contained Blackspot Shiner were less dispersed than assemblages where it was not collected, and occupied significantly less assemblage space (PERMDISP: $F = 19.167$, $P < 0.001$). Blackspot Shiner were always collected with the occurrence of other cyprinid species, and stream sites with the highest proportion of Blackspot Shiner out of the total cyprinid catch occurred at sites where Blacktail Shiner *Cyprinella venusta* were absent or less common (Table 2.1). Blacktail Shiner were commonly collected in every river basin except for the Cypress, where it was only collected at three sites. Within the 20 sites where Blackspot Shiner were collected, Redfin Shiner *Lythrurus umbratilis*, Blacktail Shiner, and Ribbon Shiner *Lythrurus fumeus* were the most frequently collected cyprinid and accounted for 66% of cyprinids collected (Table 2.2). Creek Chub *Semotilus atromaculatus* made up 5% of the total cyprinid collection and were only collected at two sites (Table 2.2). Striped Shiner *Luxilus chrysocephalus* accounted for 4% of the collection, and only occurred within sites of the Cypress basin (Table 2.2). Red Shiner

Cyprinella lutrensis and Sabine Shiner *Notropis sabinae* only occurred at two urban streams within the Neches basin (Table 2.2).

Table 2.1. Cyprinid (Minnows and Shiners) richness (family Cyprinidae), total cyprinids collected, length of reach sampled at stream sites (m), catch per unit effort (CPUE), and proportion of Blackspot Shiner and Blacktail Shiner collected at stream sites within respective river basins in east Texas, USA.

Survey Site	Basin	Cyprinid richness	Total cyprinids collected	Blackspot Shiner CPUE	% of Blackspot Shiner of cyprinids collected	% of Blacktail Shiner of cyprinids collected
Aquilla Creek	Brazos	4	96	0	0%	53%
Buck Creek	Brazos	2	8	0.13	13%	88%
Carters Creek	Brazos	5	542	0	0%	18%
Hopes Creek	Brazos	1	1	0	0%	100%
Hudson Creek	Brazos	4	133	0	0%	83%
Little Brazos River	Brazos	2	4	0	0%	0%
Montgomery Creek	Brazos	0	0	0	0%	0%
Rough Creek	Brazos	0	0	0	0%	0%
White Creek	Brazos	3	486	0	0%	31%
Boggy Creek	Cypress	2	44	0	0%	0%
Butler Creek	Cypress	1	56	0	0%	0%
Eagle Creek	Cypress	5	70	1.63	19%	0%
Frazier Creek	Cypress	3	39	0.80	21%	0%
French Creek	Cypress	5	63	0	0%	3%
Grays Creek	Cypress	8	200	0	0%	1%
Haggerty Creek	Cypress	1	5	0	0%	0%
Karnack Creek	Cypress	3	53	0.38	6%	0%
Kitchens Creek	Cypress	2	37	0	0%	0%
Pope Creek	Cypress	4	19	0.25	11%	0%
Scotts Creek	Cypress	4	37	0.50	11%	0%
Sweet Creek	Cypress	0	0	0	0%	0%
Watson Creek	Cypress	0	0	0	0%	0%
Bear Creek	Neches	3	12	0	0%	0%
Beech Creek	Neches	3	14	0	0%	71%
Beech Creek	Neches	3	23	0	0%	13%
Bonaldo Creek	Neches	1	7	0	0%	0%

Table 2.1 Continued

Survey Site	Basin	Cyprinid richness	Total cyprinids collected	Blackspot Shiner CPUE	% of Blackspot Shiner of cyprinids collected	% of Blacktail Shiner of cyprinids collected
Banita Creek	Neches	3	43	0.50	7%	42%
Banita Creek	Neches	3	44	0.38	9%	89%
Hager Creek	Neches	2	23	0.17	4%	0%
Ham Creek	Neches	5	34	1.50	26%	38%
Harvey Creek	Neches	4	28	0.25	7%	14%
Hurricane Creek	Neches	3	157	0	0%	6%
Jack Creek	Neches	3	108	0	0%	3%
Lanana Creek	Neches	3	26	0.35	15%	70%
Lanana Creek	Neches	5	47	0.33	15%	38%
Lee Creek	Neches	0	0	0	0%	0%
Little Walnut Run	Neches	4	21	0.13	5%	10%
Naconiche Creek	Neches	3	14	0	0%	79%
Sand Creek	Neches	2	46	0	0%	0%
Terrapin Creek	Neches	4	26	0	0%	42%
Theuvinins Creek	Neches	5	51	0	0%	20%
Big Sandy Creek	Sabine	2	24	0	0%	0%
Boregas Creek	Sabine	4	44	1.14	36%	5%
Carroll Creek	Sabine	2	43	2.25	42%	0%
Colorow Creek	Sabine	3	30	0.30	10%	23%
Dry Creek	Sabine	4	93	0	0%	29%
Honey Creek	Sabine	0	0	0	0%	0%
Little White Oak Creek	Sabine	1	2	0	0%	0%
Morris Creek	Sabine	1	37	0	0%	0%
Peavine Creek	Sabine	5	38	0	0%	3%
Reeves Creek	Sabine	2	10	0	0%	90%
Rock Creek	Sabine	5	266	0	0%	0%

Table 2.1 Continued

Survey Site	Basin	Cyprinid richness	Total cyprinids collected	Blackspot Shiner CPUE	% of Blackspot Shiner of cyprinids collected	% of Blacktail Shiner of cyprinids collected
Running Creek	Sabine	2	24	0	0%	0%
Grand Saline Creek	Sabine	3	11	0	0%	0%
Shuffle Creek	Sabine	0	0	0	0%	0%
Styles Creek	Sabine	0	0	0	0%	0%
Tebo Creek	Sabine	4	43	0	0%	5%
Turkey Creek	Sabine	1	4	0	0%	0%
Ash Creek	Trinity	1	7	0	0%	0%
Big Caney Creek	Trinity	0	0	0	0%	0%
Big Onion Creek	Trinity	2	94	0	0%	0%
Cedar Creek	Trinity	2	4	0	0%	0%
Cottonwood Creek	Trinity	0	0	0	0%	0%
Cummins Creek	Trinity	0	0	0	0%	0%
Harmon Creek	Trinity	4	221	0	0%	49%
Keechie Creek	Trinity	3	40	0	0%	78%
Linney Creek	Trinity	1	28	0	0%	0%
North Twin Creek	Trinity	5	43	0.08	2%	2%
Purtis Creek	Trinity	2	22	1.25	45%	0%
Rowlett Creek	Trinity	2	22	0	0%	0%
Rush Creek	Trinity	2	6	0	0%	0%
Shiloh Creek	Trinity	3	35	0	0%	11%
Squabble Creek	Trinity	0	0	0	0%	0%
Town Creek	Trinity	4	39	0.08	3%	87%
Town Branch	Trinity	1	3	0	0%	0%

TABLE 2.2. Total number, percentage composition, and frequency of occurrence of cyprinid species (family Cyprinidae) occurring with Blackspot Shiner in 20 stream sites in east Texas, USA.

Species Common name/scientific name	Number of individuals collected	% of all cyprinids collected	Frequency of occurrence at 20 sites
Red Shiner <i>Cyprinella lutrensis</i>	4	1%	2
Blacktail Shiner <i>Cyprinella venusta</i>	170	24%	12
Striped Shiner <i>Luxilus chrysocephalus</i>	29	4%	5
Ribbon Shiner <i>Lythrurus fumeus</i>	126	18%	8
Redfin Shiner <i>Lythrurus umbratilis</i>	173	24%	12
Golden Shiner <i>Notemigonus crysoleucas</i>	23	3%	2
Blackspot Shiner <i>Notropis atrocaudalis</i>	111	16%	20
Sabine Shiner <i>Notropis sabiniae</i>	22	3%	1
Bullhead Minnow <i>Pimephales vigilax</i>	22	3%	4
Creek Chub <i>Semotilus atromaculatus</i>	33	5%	2
Total collected	713		

DISCUSSION

Using a combination of historical occurrence records and contemporary surveys of Blackspot Shiner within its native Texas range, I found that this species has historically persisted for over 90 years, despite a decline in the number of observations occurring in the western edge of its range (i.e., Brazos and Trinity basins). My contemporary findings suggest that Blackspot Shiner, while present in stream reaches of east Texas, did not occur at majority of sampling sites and CPUE was relatively low. This observed pattern could be indicative of their decline within Texas, or as a result of their low detectability at these sites.

Historical Distribution

Historical records of Blackspot Shiner corroborate the distribution of this species within its native range in Texas (Hubbs et al. 1991; Warren et al. 2000; Linam et al. 2002). Across the five river basins, the contemporary survey revealed patterns of Blackspot Shiner occurrence similar to the past patterns observed from the historical observations. For example, the 26 stream sites surveyed within the Brazos and Trinity basins yielded 4 localities where Blackspot Shiner was present, and is consistent with the limited number of occurrences within these two basins over the last 20 years ($n = 15$). During these two decades, one-third of the occurrences ($n = 5$) were collected by field ichthyologists at Sam Houston State University within Harmon Creek and Town Branch

in the Trinity basin, and despite sampling both of these localities, the contemporary survey did not yield a collection of Blackspot Shiner. The 36 stream sites within the Neches and Sabine basins resulted in 11 sites where Blackspot Shiner was present. Despite the species occurring at less than the majority of stream sites, this finding supports the consistent historical occurrence of this species over the last 90 years within these two river basins. In the Cypress and Sulphur River basins, recent surveys (2010-2019) conducted by Texas Parks and Wildlife (Robertson et al., 2016), United States Geological Survey (Braun & Moring, 2013), and the Texas Commission on Environmental Quality's Clean Rivers Program have reported an increase in the number of occurrences of Blackspot Shiner within stream reaches of the Cypress and Sulphur basins over the last decade.

Blackspot Shiner were consistently observed in stream reaches of the Neches and Sabine River basins through time, although occurrences were more limited in river basins of its western range in Texas (e.g., Brazos, Trinity). One possible explanation for the low number of occurrences in the Brazos and Trinity River basins could be a consequence of alterations in local habitat associated with the land cover conversion for more agricultural production, which has been observed to alter flow regime dynamics and substrate composition (Allan, 2004). It is common for streams of the Brazos and Trinity basins to experience water quality degradation (e.g., low dissolved oxygen), variable flow (e.g., loss of riffle-runs), and increased nutrient and sediment loads due to agriculture production and increased urban sprawl (Griffith et al., 2007). Low sampling effort within

these two western river basins could have also resulted in the low number of records. Annual stream monitoring programs are critical for providing baseline data regarding water quality, in-stream habitat, and species of concern within localities susceptible to habitat alterations (Linam et al., 2002). The historical occurrence data showed patterns of occurrence every 20 years (e.g., 1950s, 1970s, 1990s), which is reflected by intensive sampling periods by field ichthyologists (Hubbs, 1957; Hubbs et al., 1991; Herbert & Gelwick, 2003) . However, the vast majority (78%) of Blackspot Shiner occurrence records I gathered were over 20 years old; therefore, it is possible that there are stream reaches within east Texas, and more specifically in the Brazos and Trinity basins, that still support Blackspot Shiner, but further assessment is needed to fully assess the status of this species within these drainages.

Local Habitat Association

Contemporary surveys of Blackspot Shiner across river basins of east Texas revealed a close association between this species and stream reaches containing sandy substrate along with some gravel, a well-maintained riffle-run flow regime, and more forest cover within the riparian zone. Collections of Blackspot Shiner occurred within streams varying in surrounding land cover. For example, the species was observed within urbanized (e.g., Town Creek, Trinity), agricultural (e.g., Buck Creek, Brazos), and forested (Eagle Creek, Cypress) influenced stream sites that contained a riffle-run flow regime and sand-gravel substrate. This result appears to contrast the study by Bean et al. (2010), in which they described the species to have no strong local habitat associations

within two urbanized streams in Nacogdoches, Texas (e.g., Lanana Creek and Banita Creek). On the other hand, my findings agree with Moore & Cross (1950) and Herbert and Gelwick (2003), whom suggested that Blackspot Shiner is a fluvial specialist associated with sand-cobble substrate. Fishes with fluvial specialist features prefer habitats with flowing water consisting of riffles and runs, and the affinity of this species for this type of habitat may be associated with aspects of their reproductive life history. Several species of cyprinids, including Blackspot Shiner use a broadcast spawning behavior in which eggs and larvae drift freely downstream (Durham & Wilde, 2009). By having this type of life history and habitat affinity, fluvial specialists are at a greater risk of being filtered out and being replaced with habitat generalist species as a result of local habitat alterations such as substrate and flow regime homogenization.

Other studies have documented the decline of broadcast spawning cyprinids (e.g., Sabine Shiner, Arkansas River Shiner) after an alteration in flow dynamics and local habitat within streams in Texas (Suttkus & Mettee, 2009; Perkin & Gido, 2011). For example, within the lower Guadalupe and San Marcos Rivers, Perkin and Bonner (2011) documented shifts in fish assemblage structure over a span of 70 years, in which they found that habitat generalist sunfishes (family Centrarchidae) and cyprinids increased in abundance, while specialist cyprinids and darters (family Percidae) decreased in abundance as a result of flow alteration (Perkin & Bonner, 2011). The discordance in collection outcomes between the historic and contemporary surveys could be attributed to shifts in stream habitat quality. For example, Blackspot shiner were collected in Harmon

Creek in the Trinity basin in 2017 (C. G. Montaña, unpublished data), but not during the contemporary surveys. One potential explanation could be alterations in local habitat as a consequence of increased surface runoff as a result of riparian buffer loss and increased human impacts within the watershed. Harmon Creek experiences fluctuating surges in stream flow that often erode stream banks, deposit logs and debris, and wash sandy substrate downstream (Dent & Lutterschmidt, 2001). The reach of Harmon Creek that I surveyed was dominated by four tolerant cyprinids such as Bullhead Minnow *Pimephales vigilax*, Blacktail Shiner, Red Shiner, and Redfin Shiner, and contained habitat consisting of sandy runs, bedrock riffles, and shallow stream depth, which show some similarities with the described habitat affinity of Blackspot Shiner. Stream reaches such as Harmon Creek, which experience frequent environmental stress over time, may result in community compositional shifts and the loss of more specialized species such as Blackspot Shiner.

Cyprinid Co-Occurrence Patterns

The PERMANOVA analysis suggests that other cyprinid species may correlate with the presence/absence of Blackspot shiner. For example, in sites where Blackspot Shiner occurred with other cyprinids (e.g., Sabine Shiner, Striped Shiner), it occupied a much smaller taxonomic space, while sites that lacked Blackspot Shiner were more dispersed in taxonomic space and contained more habitat generalist cyprinids (e.g., Blacktail Shiner, Ribbon Shiner) and species with adaptations to lentic conditions such as sunfish (family Centrarchidae). Specialized species such as Blackspot Shiner play a role

in structuring stream fish communities (Hargrave, 2006; Bean et al., 2010); therefore, an increase in the relative abundance of habitat generalist cyprinids such as Blacktail Shiner could potentially alter the occurrence of more specialized species.

The relative proportion of Blackspot Shiner appeared to vary when Blacktail Shiner was either present or absent from stream sites. For example, when Blackspot and Blacktail Shiner were both collected at a stream site, the number of Blacktail Shiner collected was greater, with the exception of Boregas Creek (Sabine basin). On the other hand, when Blacktail Shiner occurred in relatively low abundance or was absent from a stream site, Blackspot Shiner occurred in higher proportions. Both shiners have been described as invertivorous species (Goldstein & Simon, 1999; Bean et al., 2010), but Blacktail Shiner are habitat generalists with the capability to endure a broad range of environmental conditions, which has facilitated their persistence throughout every river basin of Texas (Linam et al., 2002). In the Chattahoochee River basin of Alabama, Casten and Johnston (2008) found that a major factor contributing to the persistence of Blacktail Shiner in stream systems could be the ability of this species to alter life-history parameters such as body size (SL) to better acclimate them in stream conditions where the occurrence of other species might be declining, which might lead to a competitive advantage. While my results are based solely on the species occurrences within a few localities, future studies should address major differences in the ecology, morphology, and life history characteristics of Blackspot and Blacktail Shiners to provide further

insight into how habitat generalist cyprinids such as Blacktail Shiner might affect a more specialized species such as Blackspot Shiner.

Implications for Environmental Assessment

Assessing the distributional patterns of a species through time within its native range is critical for identifying areas for conservation, in which populations have persisted, and to invest in resampling efforts to fully assess the status of a species of greatest conservation need. This study emphasized the importance of using both historical occurrence records and contemporary surveys in assessing distributional changes, status, and habitat associations of the Blackspot Shiner in Texas. By including an extensive collection of historical records (9 decades) and contemporary surveys across major river basins, this study updated the status of Blackspot Shiner, as well as illustrated the habitat associations of this species across its native Texas range, whereas previous studies have focused on smaller regions or even single localities, in-turn providing habitat types of focus for future assessments to target for the collection of this species across river basins of east Texas.

Given that my findings show consistent occurrences of Blackspot Shiner within more eastern basins (e.g., Cypress, Neches, Sabine), it is likely that there are still stream reaches that support Blackspot Shiner across its Texas range, but future surveys should concentrate efforts at the western extent of its range. Ultimately, by comparing historical

occurrences and contemporary surveys, one can begin to understand the complexities of the declines of rare cyprinids across Texas.

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APPENDIX

S1. River basin, huc-10 watershed, and coordinates (WGS 1984, decimal degrees) of sampling locations (n =75) across five river basins in east Texas, USA.

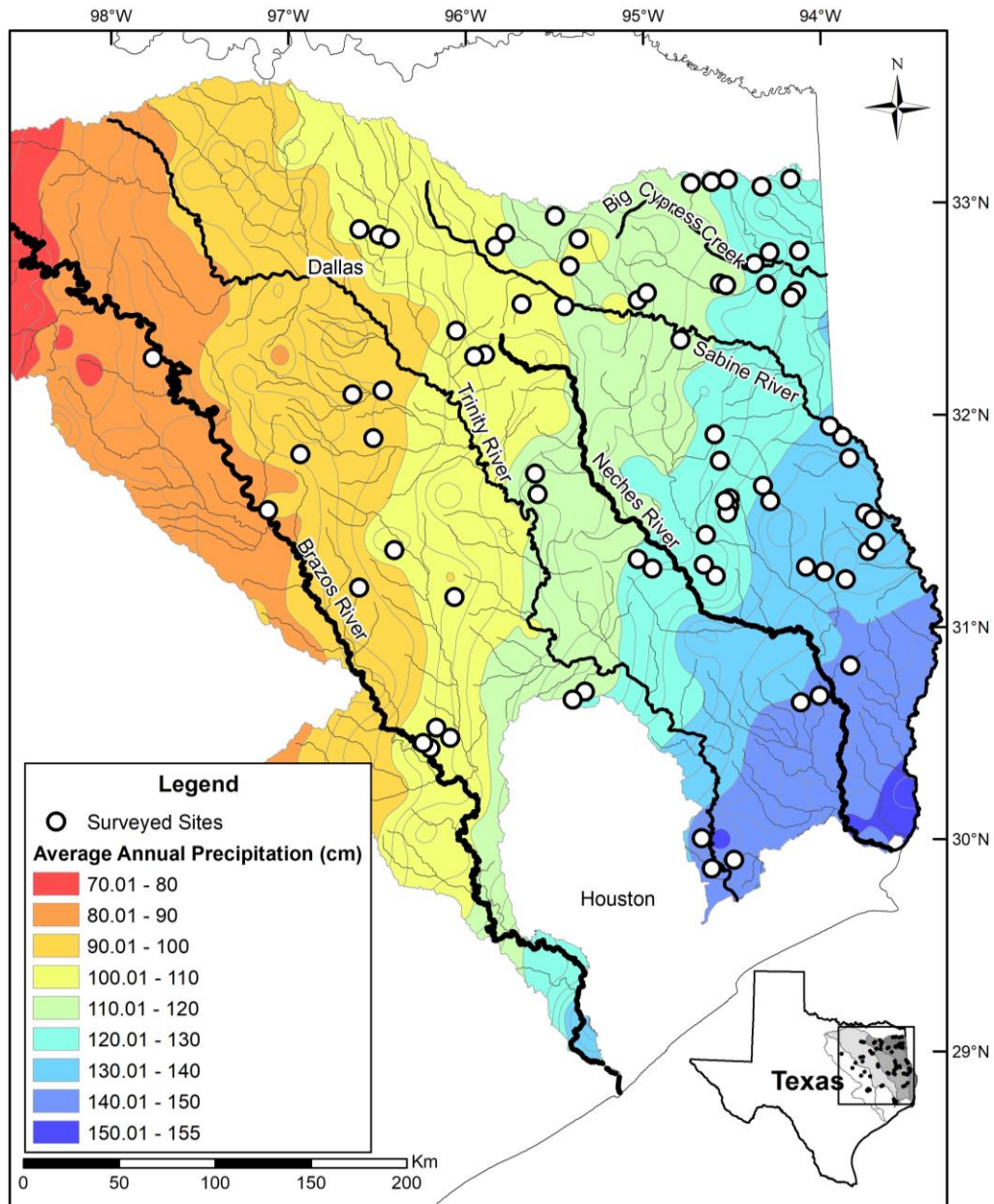
Basin	Huc-10 watershed	Site	Latitude	Longitude
Brazos	Aquilla Creek	Aquilla Creek	31.68628	-97.18420
Brazos	Duck Creek	Buck Creek	31.24973	-96.17300
Brazos	Gibbons Creek	Carters Creek	30.58705	-96.22302
Brazos	Old River – Brazos	Hopes Creek	30.54049	-96.33194
Brazos	Gibbons Creek	Hudson Creek	30.63560	-96.29620
Brazos	Little Brazos River	Little Brazos River	31.30910	-96.69492
Brazos	Sanders Creek	Montgomery Creek	31.48098	-96.49475
Brazos	Lake Granbury	Rough Creek	32.41679	-97.80163
Brazos	Old River – Brazos	White Creek	30.56702	-96.37134
Cypress	Boggy Creek	Boggy Creek	33.15258	-94.76875
Cypress	Black Bayou	Butler Creek	33.15181	-94.21072
Cypress	Little Cypress Bayou	Eagle Creek	32.67523	-94.63481
Cypress	Jim Bayou	Frazier Creek	33.12144	-94.37438
Cypress	French Creek	French Creek	32.76072	-94.43628
Cypress	Little Cypress Bayou	Grays Creek	32.66093	-94.37526
Cypress	Big Cypress Bayou	Haggerty Creek	32.59332	-94.24118
Cypress	Big Cypress Bayou	Karnack Creek	32.62163	-94.21021
Cypress	Big Cypress Bayou	Kitchens Creek	32.81081	-94.18418
Cypress	Little Cypress Bayou	Pope Creek	32.66510	-94.59941
Cypress	Black Cypress Creek	Scotts Creek	32.81010	-94.34838
Cypress	Black Cypress Creek	Sweet Creek	33.16397	-94.56169
Cypress	Black Cypress Creek	Watson Creek	33.15446	-94.65305
Neches	Bear Creek	Bear Creek	31.25107	-94.02266
Neches	East Fork Angelina River	Beech Creek	31.84100	-94.68200
Neches	Theuvenins Creek	Beech Creek	30.70967	-94.19923
Neches	Bayou Loco	Bonaldo Creek	31.49385	-94.77783
Neches	La Nana Bayou	Bonita Creek	31.59235	-94.65393
Neches	La Nana Bayou	Bonita Creek	31.65096	-94.66486
Neches	Cochino Bayou	Hager Creek	31.34776	-95.08176
Neches	East Fork Angelina River	Ham Creek	31.96620	-94.70380
Neches	Harvey Creek	Harvey Creek	31.32086	-94.23749
Neches	Cedar Creek	Hurricane Creek	31.29969	-94.73536

S1. Continued

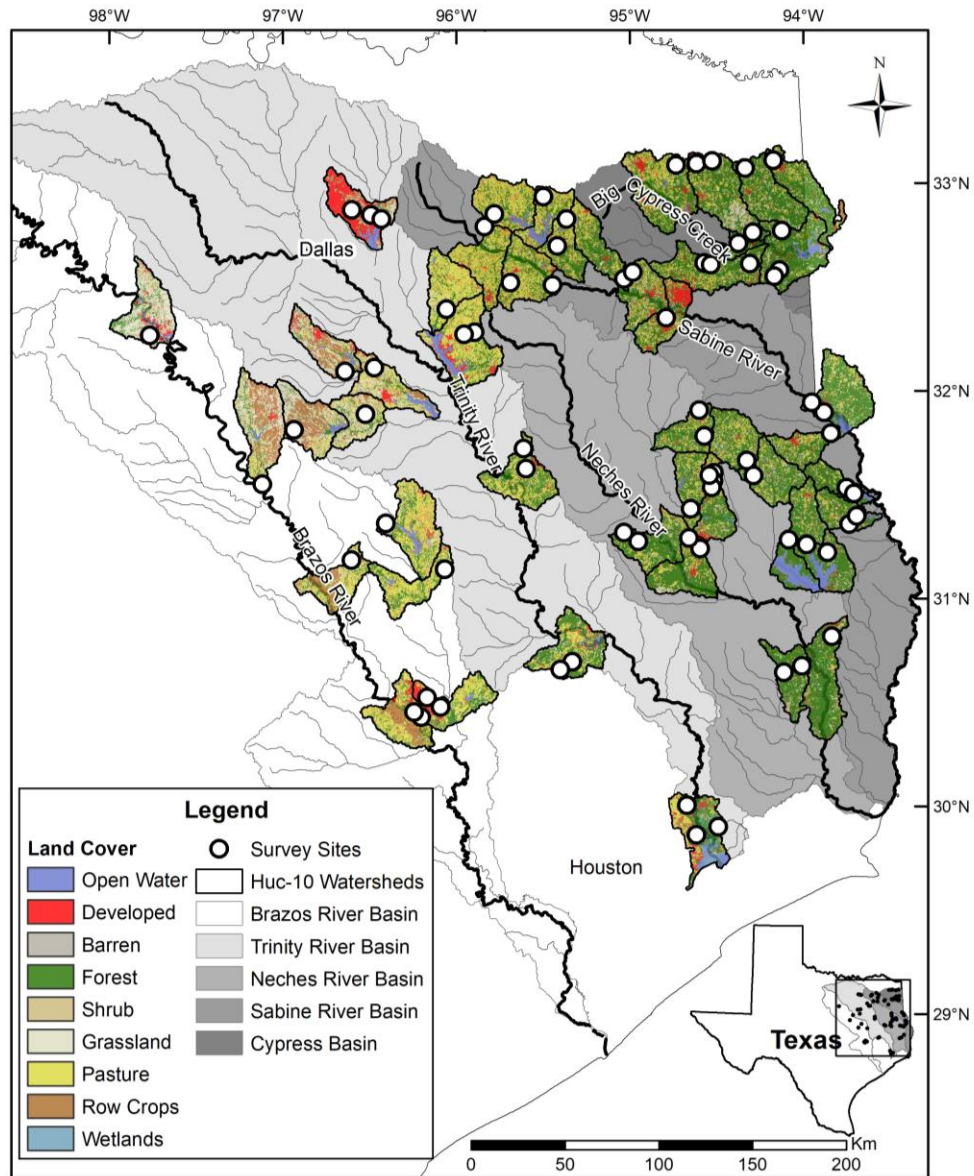
Basin	Huc-10 watershed	Site	Latitude	Longitude
Neches	Cedar Creek	Jack Creek	31.35377	-94.79663
Neches	La Nana Bayou	Lanana Creek	31.66114	-94.63860
Neches	La Nana Bayou	Lanana Creek	31.62310	-94.64200
Neches	Cochino Bayou	Lee Creek	31.39415	-95.15937
Neches	Big Walnut Run	Little Walnut Run	30.84430	-94.02361
Neches	Naconiche Creek	Naconiche Creek	31.71230	-94.45030
Neches	Ayish Bayou	Sand Creek	31.29285	-94.13770
Neches	Big Iron Ore Creek	Terrapin Creek	31.63900	-94.41500
Neches	Theuvenins Creek	Theuvenins Creek	30.68319	-94.30306
Sabine	Lake Winnsboro	Big Sandy Creek	32.61502	-95.09646
Sabine	Palo Gaucho Bayou	Boregas Creek	31.41809	-93.84906
Sabine	Tenaha Creek	Carroll Creek	31.82238	-93.96728
Sabine	Patroon Bayou	Colorow Creek	31.55698	-93.89745
Sabine	Dry Creek	Dry Creek	32.78856	-95.46739
Sabine	Dry Creek	Honey Creek	32.91501	-95.40955
Sabine	Prairie Creek	Little White Oak Creek	32.64632	-95.04377
Sabine	Grand Cane Bayou	Morris Creek	31.97762	-94.06599
Sabine	Rabbit Creek	Peavine Creek	32.41933	-94.86721
Sabine	Patroon Bayou	Reeves Creek	31.52761	-93.85673
Sabine	Town of Grand Saline	Rock Creek	32.60112	-95.50452
Sabine	Running Creek	Running Creek	33.02752	-95.53634
Sabine	Town of Grand Saline	Grand Saline Creek	32.61967	-95.74374
Sabine	Mill Creek	Shuffle Creek	32.89520	-95.87748
Sabine	Grand Cane Bayou	Styles Creek	31.92610	-93.99933
Sabine	Palo Gaucho Bayou	Tebo Creek	31.38061	-93.89196
Sabine	Lake Fork Creek	Turkey Creek	32.95401	-95.81881
Trinity	Richland Creek	Ash Creek	31.94517	-96.99662
Trinity	Old River – Trinity	Big Caney Creek	29.92129	-94.83141
Trinity	Waxahachie Creek	Big Onion Creek	32.22012	-96.69916
Trinity	Cedar Creek Reservoir	Cedar Creek	32.50404	-96.11258
Trinity	East Fork Trinity River	Cottonwood Creek	32.96904	-96.52438
Trinity	Lower Chambers Creek	Cummins Creek	32.23366	-96.53280
Trinity	Nelson Creek	Harmon Creek	30.78088	-95.47925
Trinity	Box Creek	Keechie Creek	31.81806	-95.70470
Trinity	Old River - Trinity	Linney Creek	30.06588	-94.87769
Trinity	Cedar Creek Reservoir	North Twin Creek	32.38022	-96.01745
Trinity	Cedar Creek Reservoir	Purtis Creek	32.38754	-95.95681
Trinity	East Fork Trinity River	Rowlett Creek	32.99738	-96.63216

S1. Continued

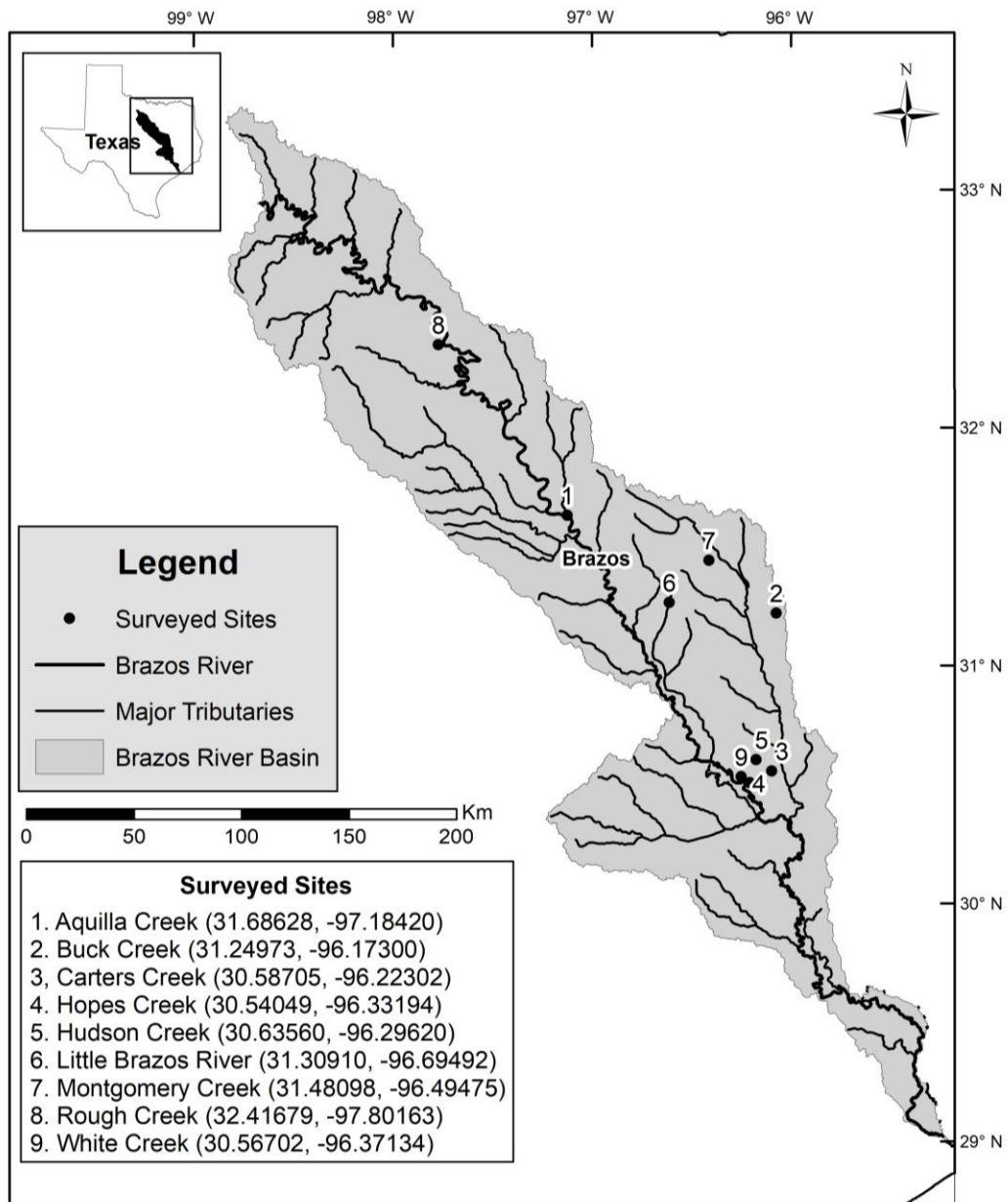
Basin	Huc-10 watershed	Site	Latitude	Longitude
Trinity	Post Oak Creek	Rush Creek	32.01057	-96.59031
Trinity	Old River – Trinity	Shiloh Creek	29.95609	-94.70869
Trinity	East Fork Trinity River	Squabble Creek	32.94848	-96.46475
Trinity	Box Creek	Town Creek	31.72102	-95.69456
Trinity	Nelson Creek	Town Branch	30.74596	-95.54763



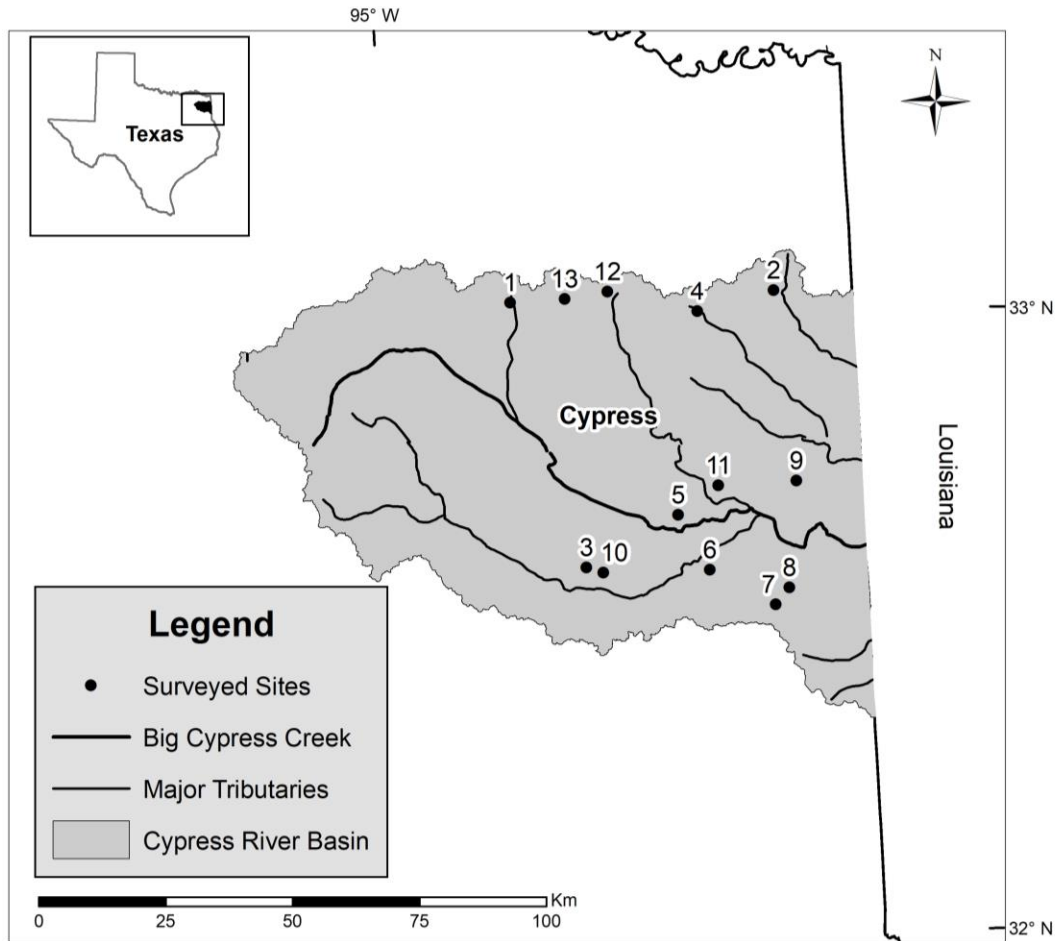
S2. Study region depicting the annual precipitation and sampling locations in east Texas including the Brazos (n = 9 sites), Trinity (n = 17 sites), Neches (n = 19 sites), Sabine (n = 17 sites), and Cypress (n = 13 sites). White dots represent the stream locations (n) surveyed.



S3. Study region depicting the five river basins, sampling locations, and land cover type within Huc-10 watersheds in east Texas including the Brazos (n = 9 sites), Trinity (n = 17 sites), Neches (n = 19 sites), Sabine (n = 17 sites), and Cypress (n = 13 sites). White dots represent the stream locations (n) surveyed.

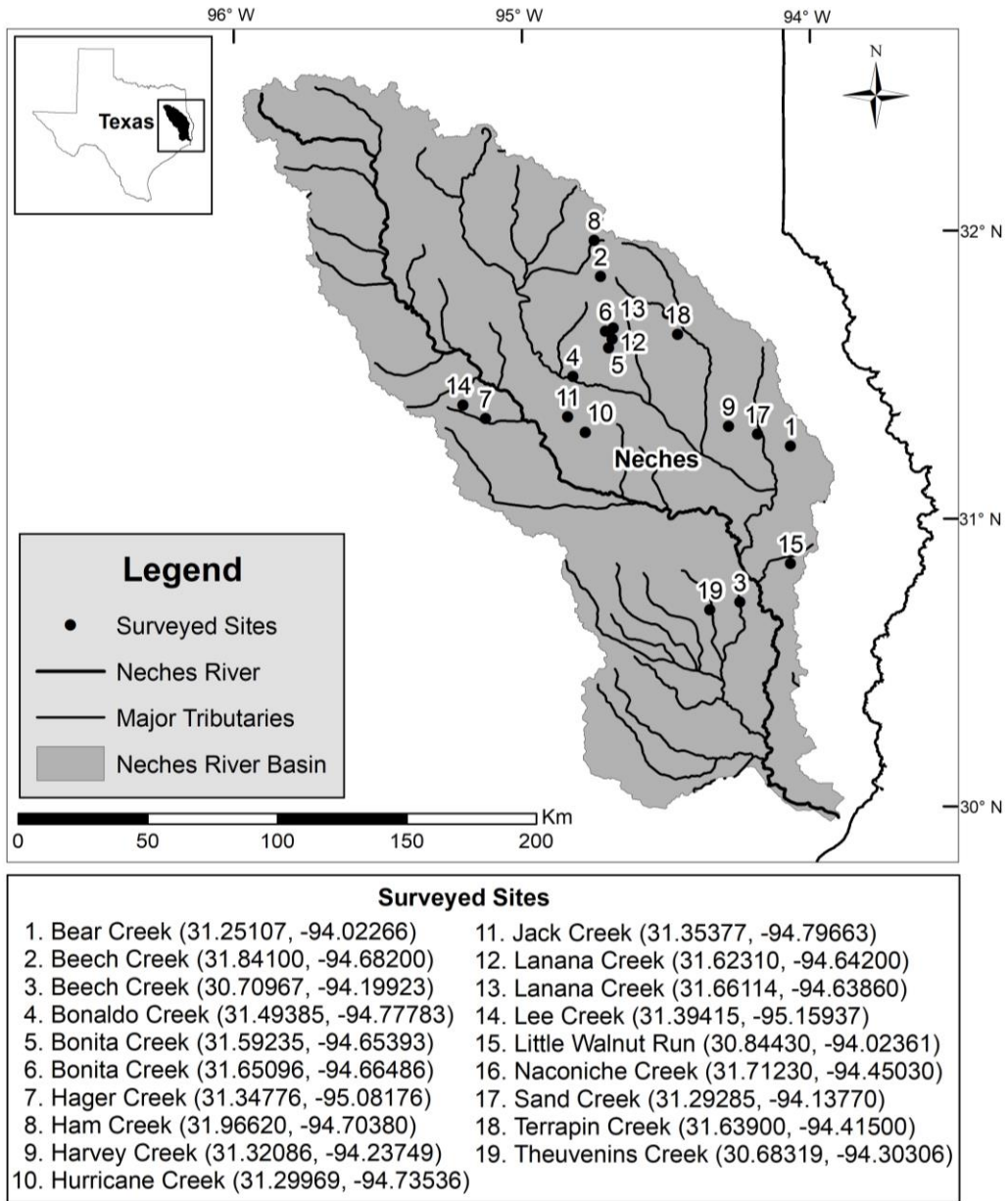


S4. Brazos River basin depicting sampling locations ($n = 9$) and major tributaries in east Texas. Black dots represent the stream locations (n) surveyed.

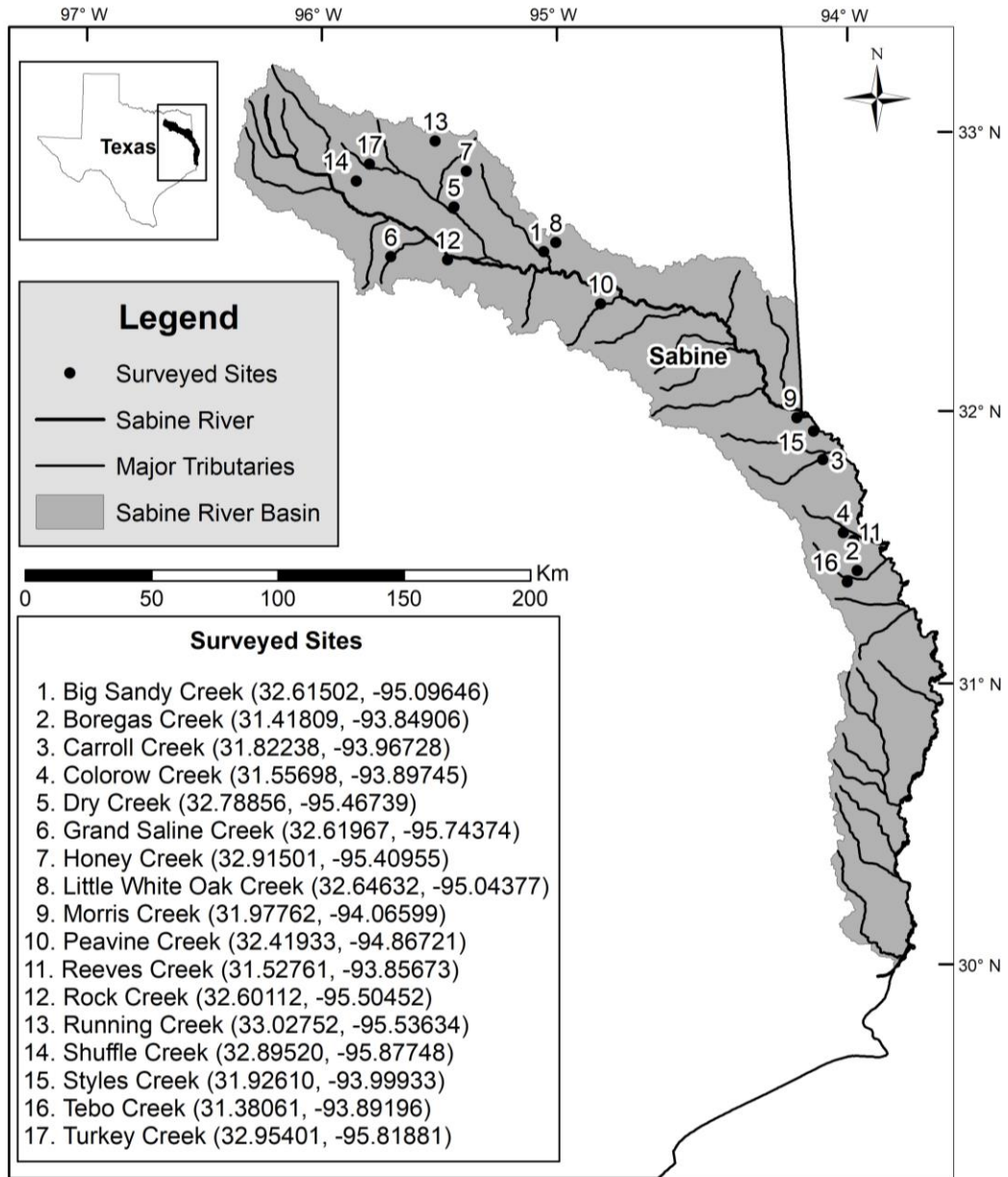


Surveyed Sites	
1. Boggy Creek (33.15258, -94.76875)	8. Karnack Creek (32.62163, -94.21021)
2. Butler Creek (33.15181, -94.21072)	9. Kitchens Creek (32.81081, -94.18418)
3. Eagle Creek (32.67523, -94.63481)	10. Pope Creek (32.66510, -94.59941)
4. Frazier Creek (33.12144, -94.37438)	11. Scotts Creek (32.81010, -94.34838)
5. French Creek (32.76072, -94.43628)	12. Sweet Creek (33.16397, -94.56169)
6. Grays Creek (32.66093, -94.37526)	13. Watson Creek (33.15446, -94.65305)
7. Haggerty Creek (32.59332, -94.24118)	

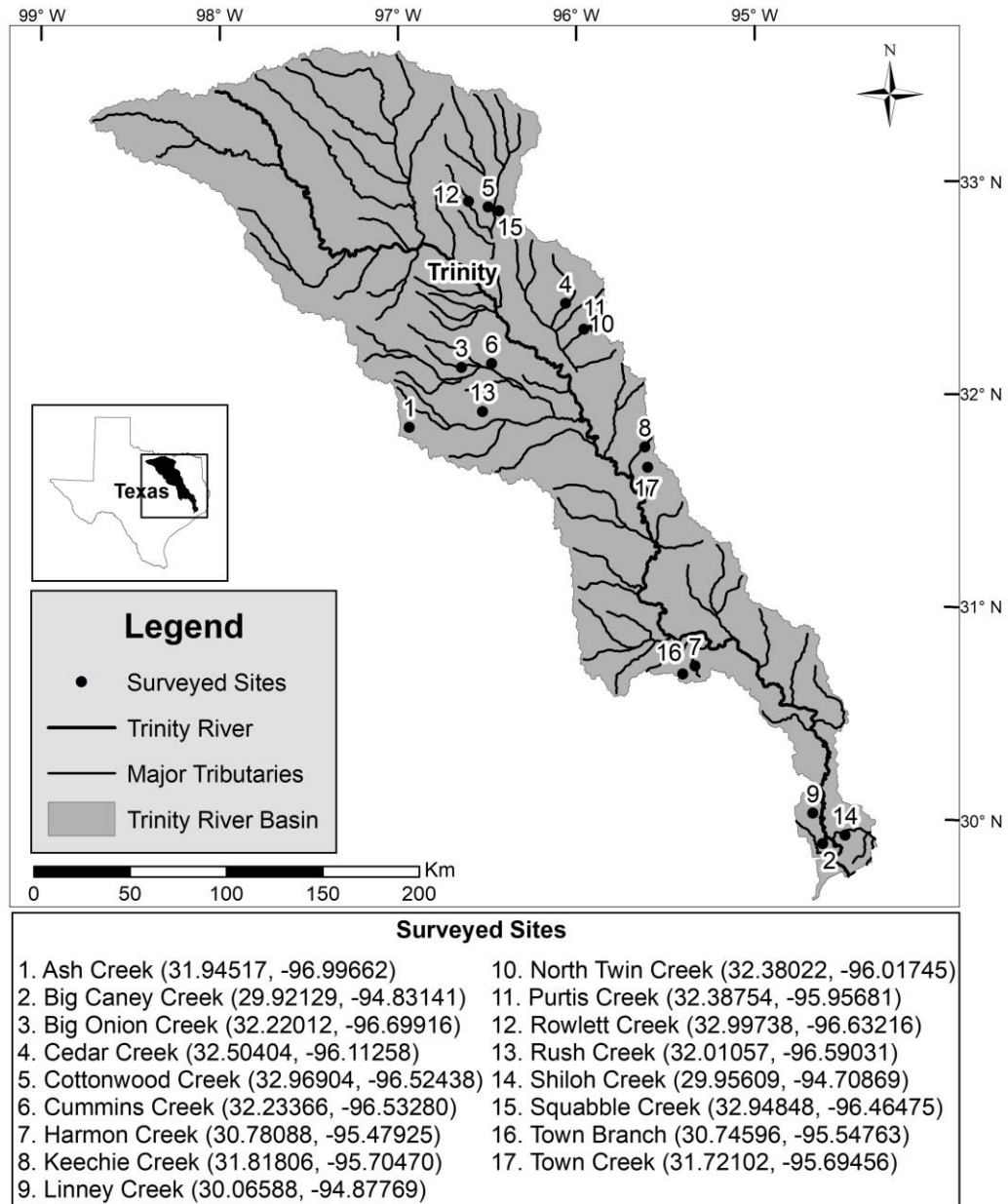
S5. Cypress River basin depicting sampling locations (n = 13) and major tributaries in east Texas. Black dots represent the stream locations (n) surveyed.



S6. Neches River basin depicting sampling locations (n = 19) and major tributaries in east Texas. Black dots represent the stream locations (n) surveyed.



S7. Sabine River basin depicting sampling locations (n = 17) and major tributaries in east Texas. Black dots represent the stream locations (n) surveyed.



S8. Trinity River basin depicting sampling locations (n = 17) and major tributaries in east Texas. Black dots represent the stream locations (n) surveyed.

S9. Local-scale environmental variables (n = 33) and the loadings on the first two axes of the PCA analysis.

Measurement	Variable code	Variable loadings	
		PCA axis 1	PCA axis 2
Wetted channel width	WET_WID	-0.22088	0.17297
Bank-full channel width	BANKFULL	-0.27305	0.11574
Average depth	AVE_DEP	-0.09785	0.41256
Max depth	MAX_DEP	-0.12355	0.36349
Stream bends	STR_BEN	0.01324	-0.05395
Thalweg depth	THAL_DEP	-0.11155	0.38324
Number of pools	POOL	0.02527	0.19556
Number of riffles	RIFFLE	-0.03903	-0.27549
Number of runs	RUN	-0.00821	-0.15634
Bank angle	BANK_ANGL	0.22025	0.01673
Exposed soil	EXP_SOIL	0.18846	-0.02968
Canopy cover	CAN_COV	0.26862	0.03794
Impervious surface	IMPERV	-0.19194	-0.09091
Algae	ALGAE	-0.2568	-0.1311
Emergent macrophytes	EME_MAC	-0.10657	0.04338
Submerged macrophytes	SUB_MAC	-0.01049	0.09583
Large woody debris	LWD	-0.01431	0.22062
Small woody debris	SWD	0.19331	0.23342
Live trees/roots	TRE_ROOT	0.18709	-0.05164
Bedrock	BED_ROCK	-0.15709	-0.12618
Large boulder	LRG_BOUL	-0.17515	0.10886
Small boulder	SMA_BOUL	-0.21067	0.04635
Cobble	COBBLE	-0.29586	-0.06382
Gravel	GRAVEL	-0.18523	-0.2229
Sand	SAND	0.17003	-0.13145
Mud/Silt	MUD_SILT	0.05697	0.27707
Hard pan clay	HARD_PAN	0.09307	0.04995
Temperature	TEMP	0.11874	0.07809
Dissolved oxygen	DO	-0.16232	-0.05725
Specific conductivity	COND	-0.25979	0.00827
pH	PH	-0.28154	-0.0379
Total dissolved solids	TDS	-0.1676	0.01671
Flow velocity	FLO_VEL	-0.12755	-0.17221

S10. Morphological traits (n = 29) and the loadings on the first two axes of the PCA analysis.

Trait	Variable code	Variable loadings	
		PCA axis 1	PCA axis 2
Head length	HEAD_L	0.22635	0.07627
Head depth	HEAD_D	-0.14383	0.28742
Gape width	GAPE_W	-0.14979	-0.03437
Eye position	EYE_P	0.00431	-0.07982
Eye diameter	EYE_D	0.10219	0.11610
Mouth position	MOUTH_P	0.14393	-0.18539
Snout length shut	SNL_SHUT	-0.09692	-0.05081
Snout length open	SNL_OPEN	-0.05814	-0.09772
Maximum body depth	BODY_D	0.30596	-0.08723
Body depth below midline	BODY_DBML	-0.04207	-0.24470
Maximum body width	BODY_W	0.20882	0.04953
Caudal peduncle length	PED_L	0.05872	0.39462
Caudal peduncle depth	PED_D	-0.17120	0.24894
Caudal peduncle width	PED_W	0.08552	0.13326
Caudal fin length	CAUD_L	0.27138	0.09339
Caudal fin height	CAUD_H	0.29377	-0.08748
Dorsal fin length	DORS_L	0.21564	0.05794
Dorsal fin height	DORS_H	0.24748	-0.00016
Pectoral fin length	PECT_L	0.28389	0.06535
Pectoral fin height	PECT_H	0.24638	-0.05438
Pelvic fin length	PELV_L	0.27996	0.13548
Pelvic fin height	PELV_H	0.25339	-0.10020
Anal fin length	ANAL_L	0.21699	-0.21210
Anal fin height	ANAL_H	0.26447	0.05118
Adipose fin length	ADIP_L	-0.04625	-0.32583
Adipose fin height	ADIP_H	-0.04204	-0.32212
Gut length	GUT_L	0.09634	0.24402
Gill raker length	RAKER_L	0.02904	-0.40770

S11. Records were obtained from The Academy of Natural Sciences (ANSP), Baylor University, Mayborn Museum Complex (BU, SMBU), California Academy of Sciences (CAS), Canadian Museum of Nature Fish Collection (CMNFI), Cornell University Museum of Vertebrates, Cornell University (CU), Field Museum of Natural History (FMNH), Fishes of Texas (FoTX), Illinois Natural History Survey (INHS), Bell Museum of Natural History, University of Minnesota (JFBM), Natural History Museum and Biodiversity Research Center, University of Kansas (KU), North Carolina State Museum of Natural Sciences (NCSM), University of Louisiana at Monroe (NLU), Oklahoma Museum of Natural History, University of Oklahoma (OMNH), Oklahoma State University (OSU), Sam Houston State University (SHSU, SHVM), Texas Cooperative Wildlife Collections, Texas A&M University (TCWC), Texas Natural History Collections, University of Texas at Austin (TNHC), Texas Parks and Wildlife, Inland Fisheries Division (TPWD), Tulane Museum of Natural History, Tulane University (TU), University of Arkansas Fort Smith (UAFS), University of Alabama Ichthyological Collection, University of Alabama (UAIC), Florida Museum of Natural History, University of Florida (UF), University of Michigan (UMMZ), University of Southern Mississippi (USM), National Museum of Natural History (USNM), and the University of Texas Biodiversity Collection (UTBC).

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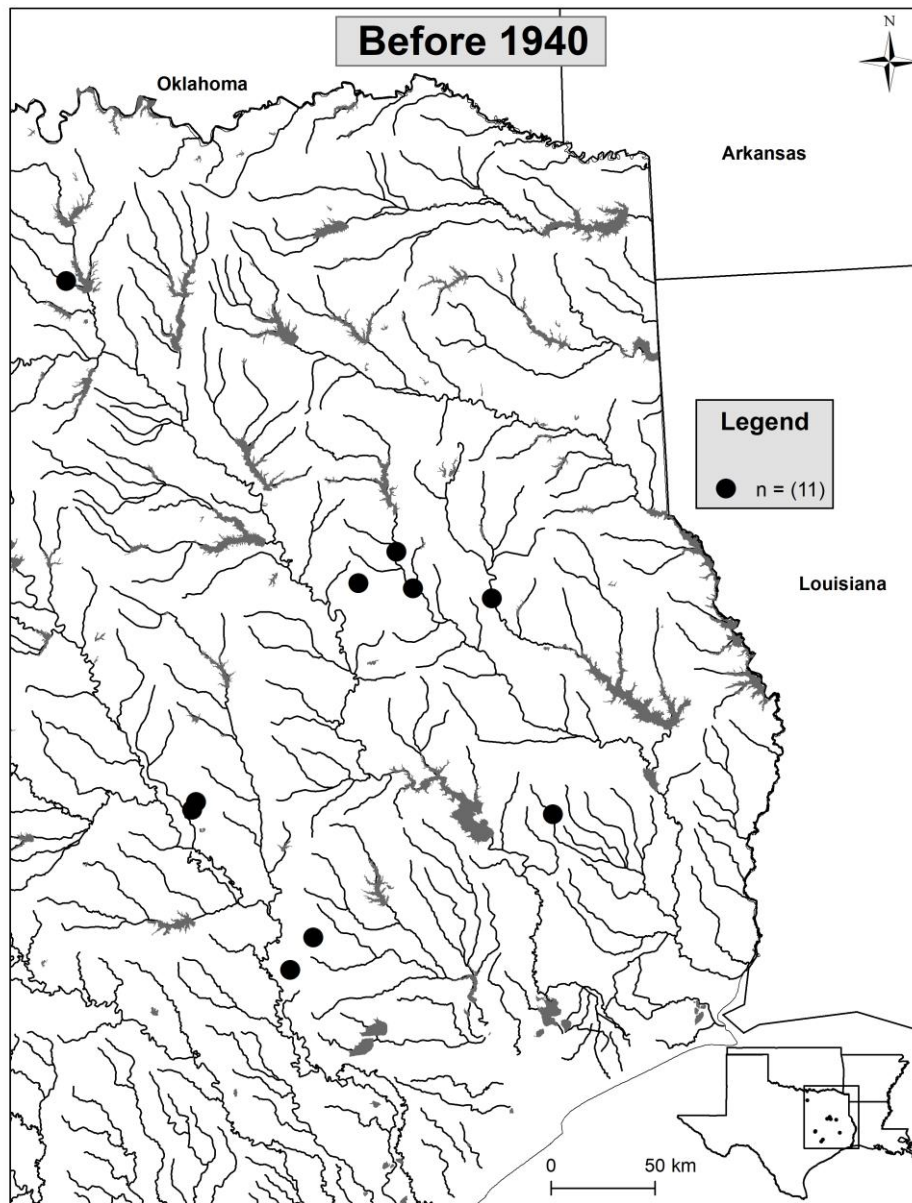
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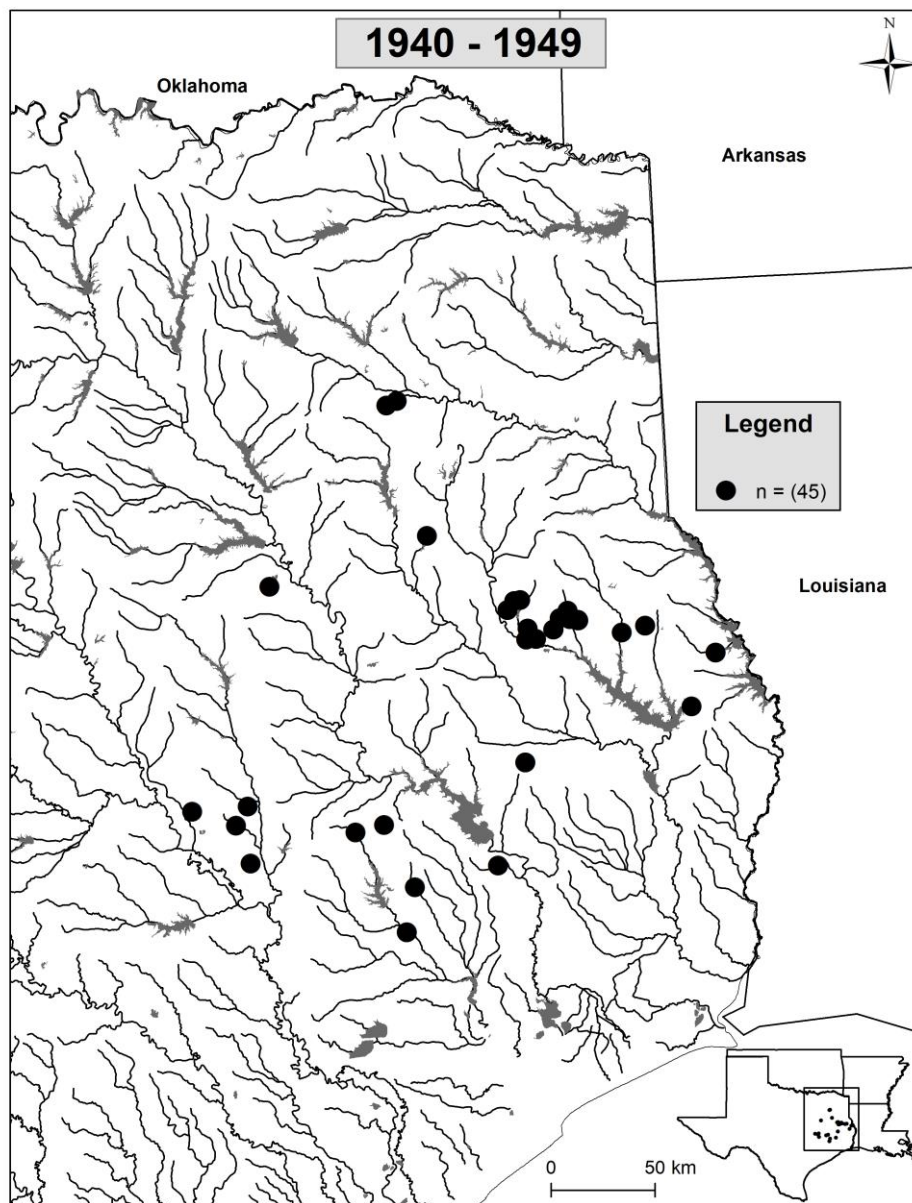
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S11. Continued

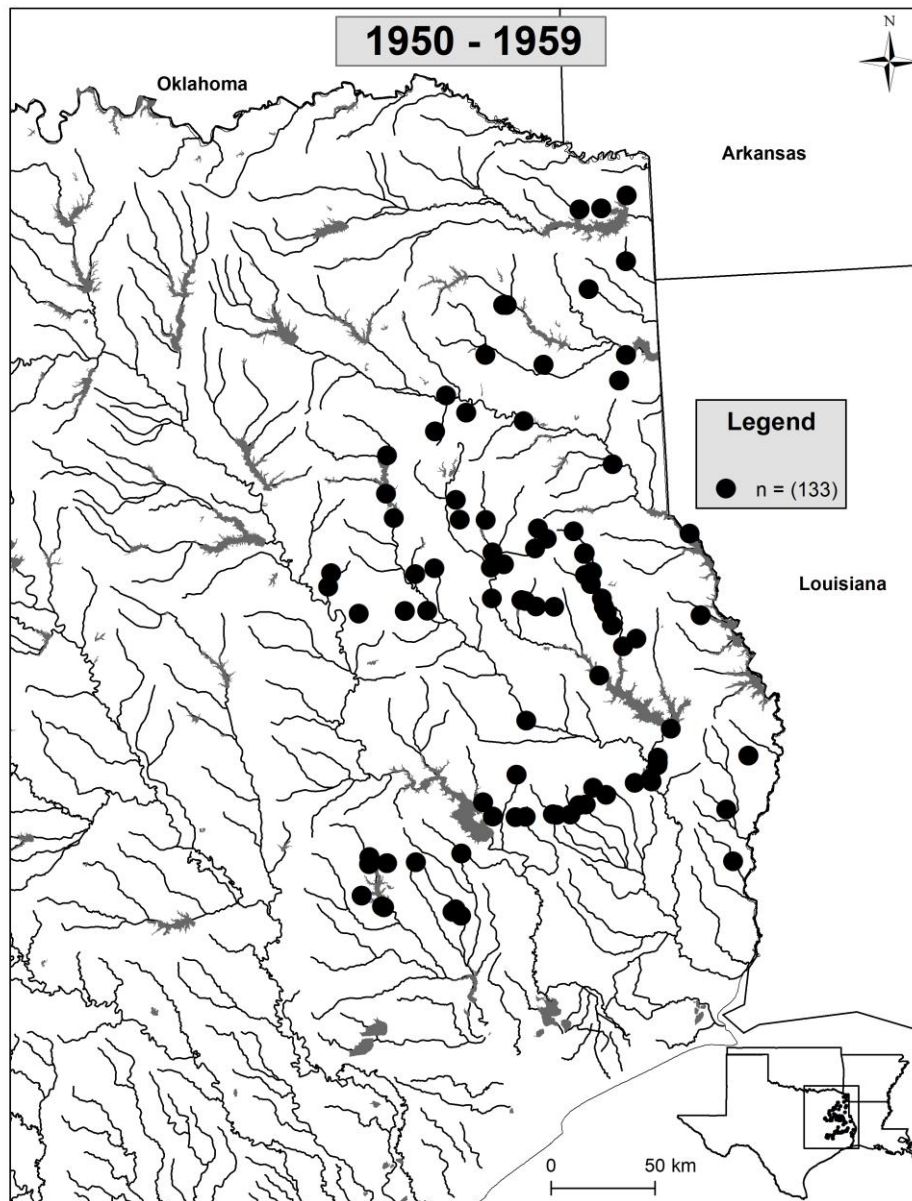
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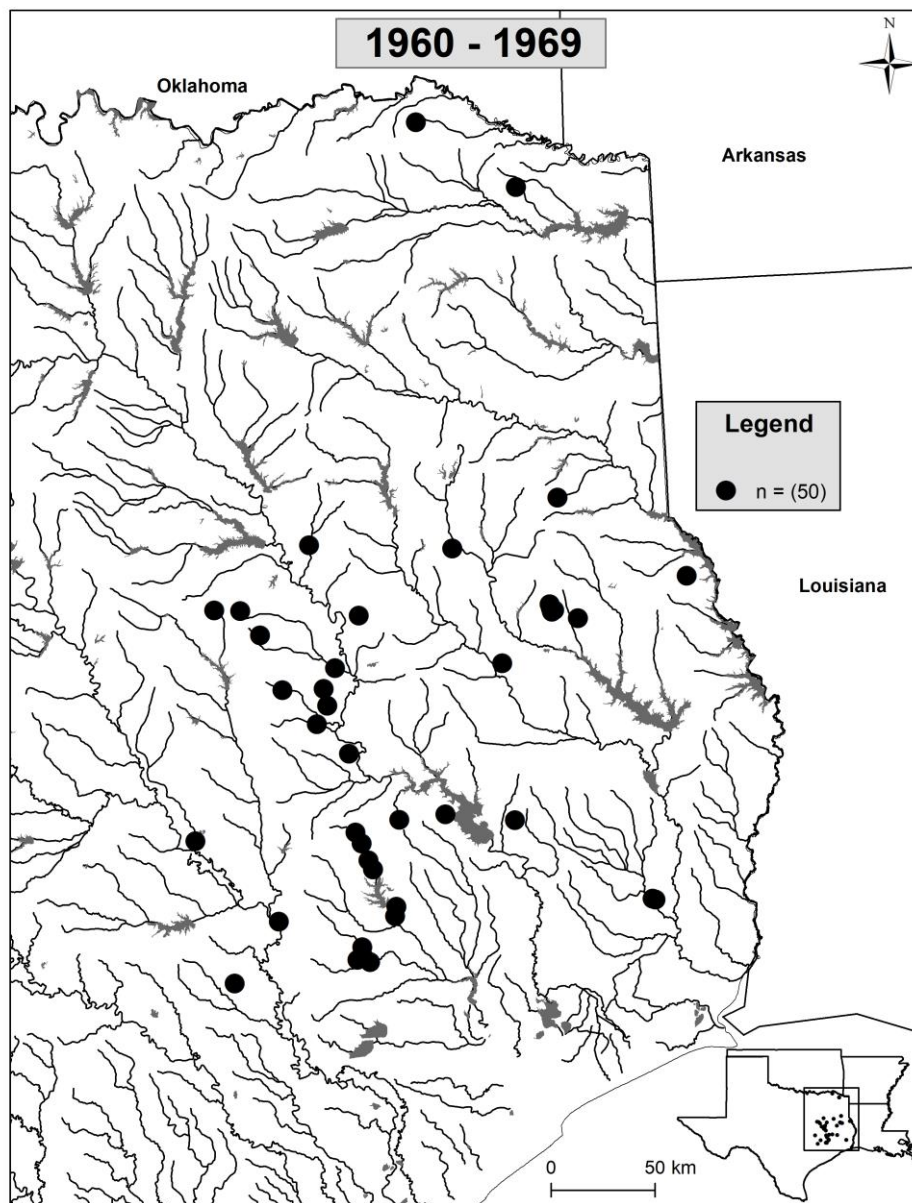
S12. Blackspot Shiner occurrence records (n = 11) before 1940 across east Texas.



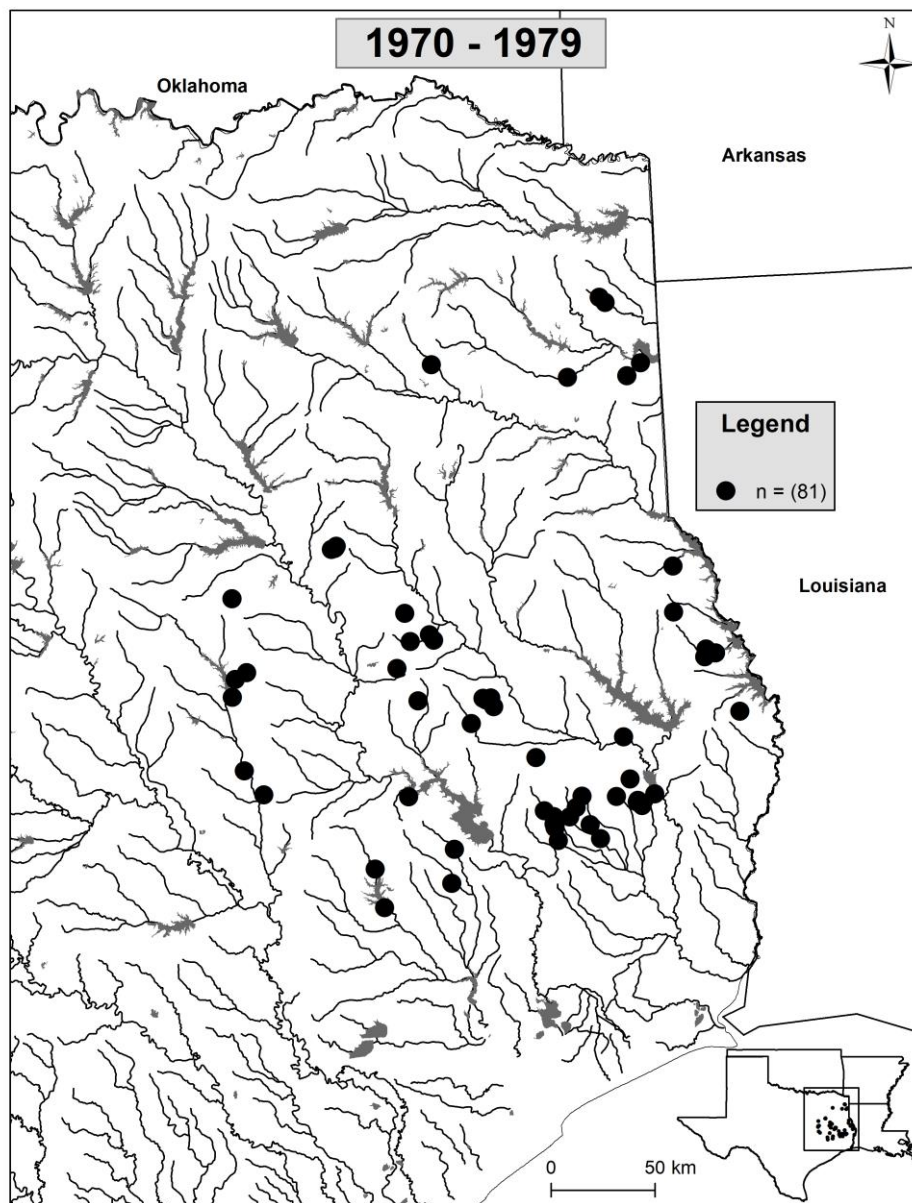
S13. Blackspot Shiner occurrence records (n = 45) from 1940 - 1949 across east Texas.



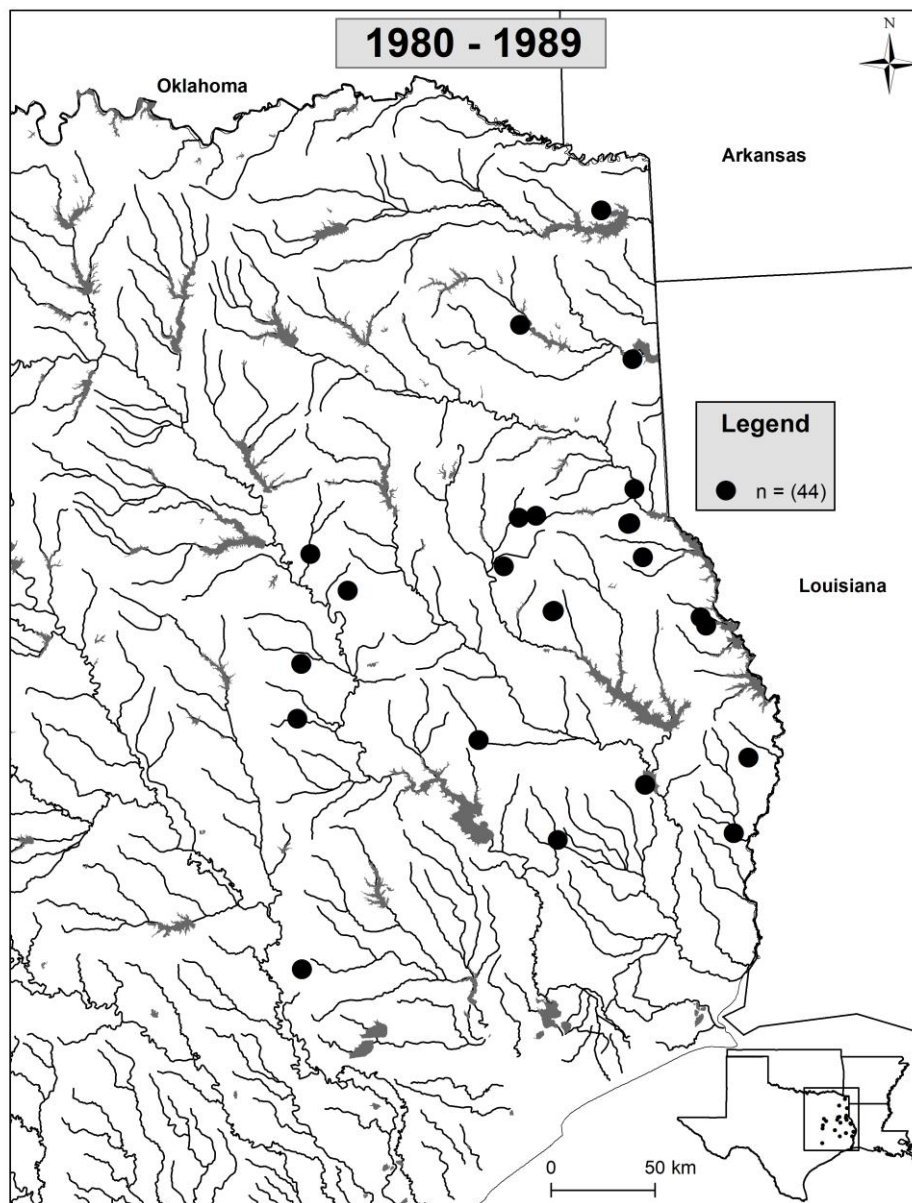
S14. Blackspot Shiner occurrence records (n = 133) from 1950 - 1959 across east Texas.



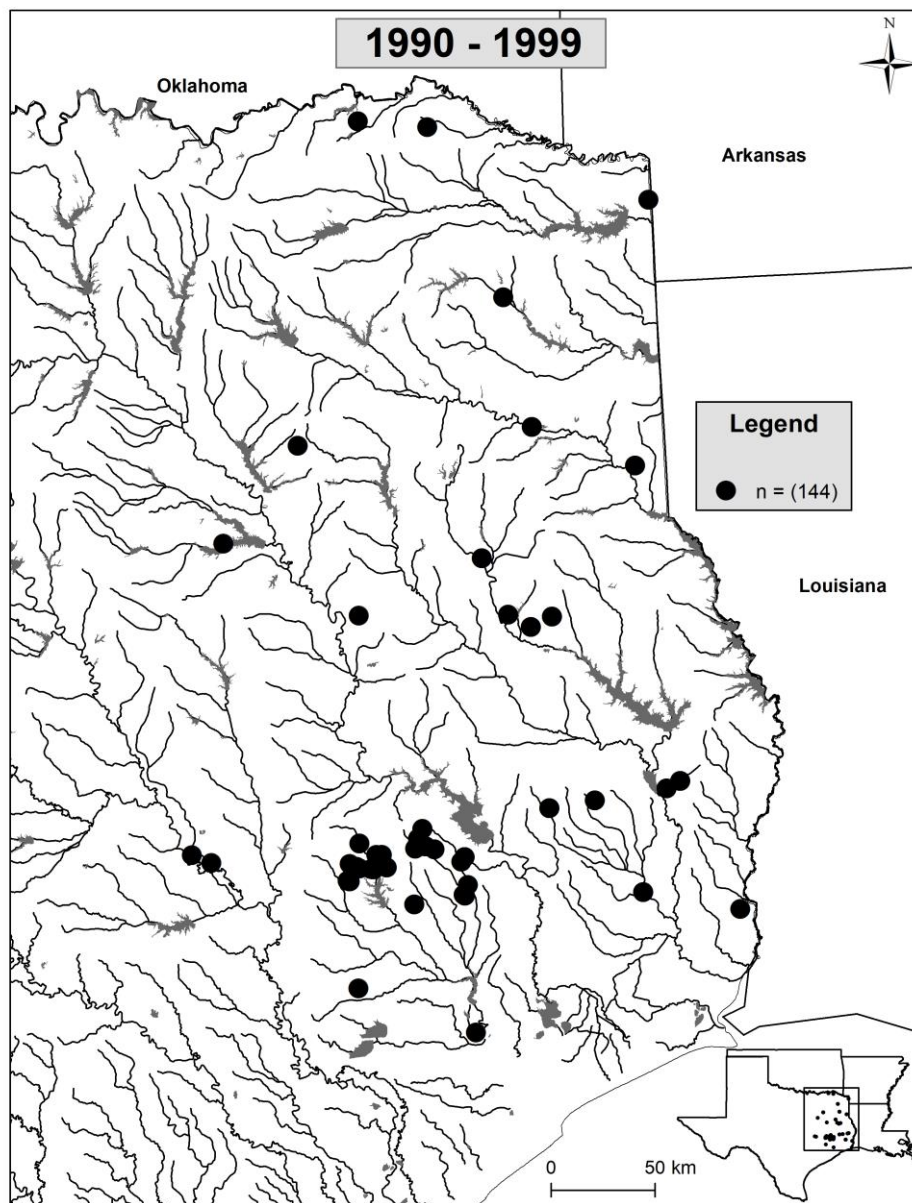
S15. Blackspot Shiner occurrence records (n = 50) from 1960 - 1969 across east Texas.



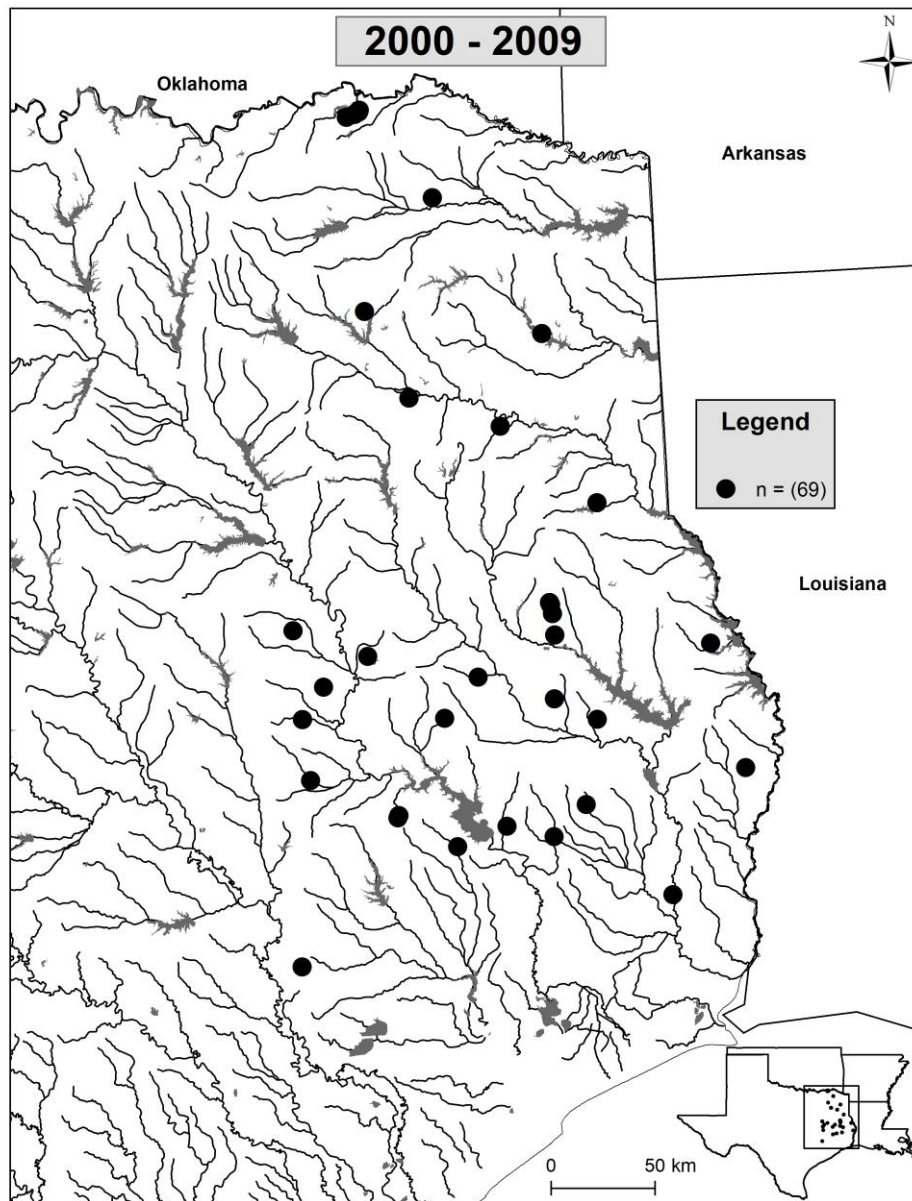
S16. Blackspot Shiner occurrence records (n = 81) from 1970 - 1979 across east Texas.



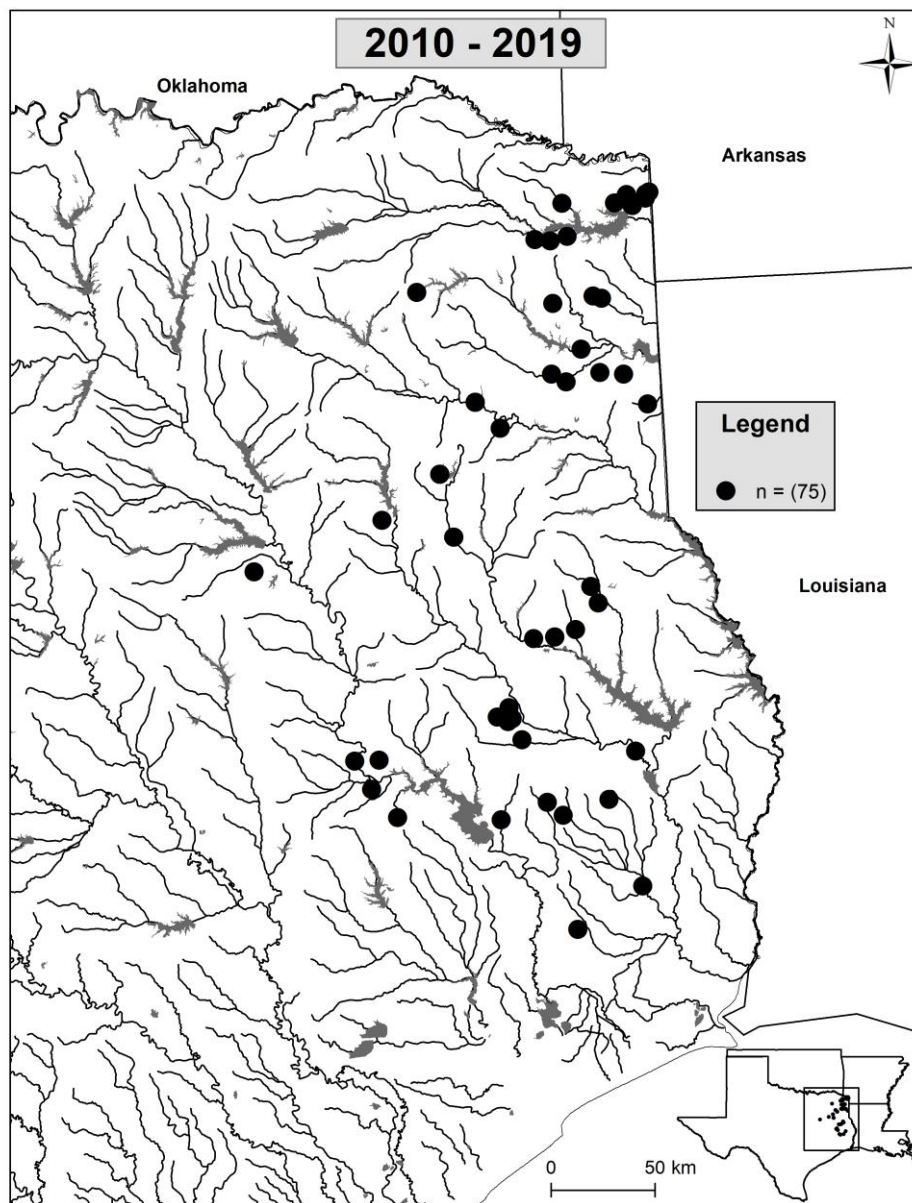
S17. Blackspot Shiner occurrence records (n = 44) from 1980 - 1989 across east Texas.



S18. Blackspot Shiner occurrence records (n = 144) from 1990 - 1999 across east Texas.



S19. Blackspot Shiner occurrence records (n = 69) from 2000 - 2009 across east Texas.



S20. Blackspot Shiner occurrence records (n = 75) from 2010 - 2019 across east Texas.

VITA

JAKE R. SWANSON

Spring 2022

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EDUCATION

M.S. Environmental Science — May 2022 — Stephen F. Austin State University, Nacogdoches, TX. Thesis Title: Fish community assembly at multiple scales in east Texas streams. Advisors: Dr. Carmen G. Montaña and Dr. Christopher M. Schalk

B.S. Natural Resource Ecology and Management — May 2019 — Oklahoma State University, Stillwater, OK.

A.S. Pre-Professional Science — May 2016 — Carl Albert State College, Poteau, OK.

PROFESSIONAL EXPERIENCE

Graduate Research Assistant — January 2020 – present — Division of Environmental Science, Arthur Temple College of Forestry & Agriculture, Stephen F. Austin State University, Nacogdoches, TX.

Advisors: Carmen G. Montaña and Christopher M. Schalk

Freshwater Ecology Field Technician — June 2019 – October 2019 — Great Lakes Environmental Center, Traverse City, MI.

Duties: Assessed physical habitat and fish community assessments in wadeable and non-wadeable streams of Minnesota, North Dakota, and South Dakota during the EPA's National Rivers and Streams Assessment. Duties included: following sampling protocol for habitat parameters set forth by the EPA, navigating riverine waterways, collecting variables that summarized water quality, riparian zones, instream habitat, flow regiment, sinuosity, and stream slope.

Supervisor: James Stricko

Research Assistant — September 2018 – March 2019 — Department of Integrative Biology, Oklahoma State University, Stillwater, OK.

Duties: Sorted and identified macroinvertebrates from samples collected using various techniques from Nebraska wetlands.

Supervisor: Dr. Andrew R. Dzialowski

Freshwater Ecology Field Technician — May 2018 – August 2018 — Environmental Institute of Houston, University of Houston-Clear Lake, Houston, TX.

Duties: Assessed physical habitat and fish community assessments in wadeable and non-wadeable streams of Texas during the EPA's National Rivers and Streams Assessment. Duties included: following sampling protocol for habitat parameters set forth by the EPA, navigating riverine waterways, water filtration, macroinvertebrate collection, and using a 2.5 and 5.0 barge electrofisher, Smith-Root LR-24 backpack electrofisher, and seine net to sample fish communities.

Supervisor(s): Mandi Gordon, Dr. Jenny Oakley, Cory Scanes

TEACHING EXPERIENCE

Stephen F. Austin State University, Arthur Temple College of Forestry & Agriculture

Vertebrate Natural History (Fall 2020, Spring 2021, Fall 2021, Spring 2022)

Stephen F. Austin State University, Department of Biology

Aquatic Ecology (Fall 2021)

CONFERENCE ACTIVITY/PARTICIPATION

Swanson J.R., C.G. Montaña, C.M. Schalk. 2022. Functional diversity of fish communities across environmental gradients in east Texas streams. Stephen F. Austin Graduate Research Conference, Nacogdoches, TX. Oral. Virtual Conference.

Swanson J.R., C.G. Montaña, C.M. Schalk. 2021. Local-landscape environmental factors influence the structure of fish communities in east Texas streams. Southwest Association of Naturalists. Oral. Virtual Conference.

Swanson J.R., C.G. Montaña, C.M. Schalk. 2021. Fish community assembly at multiple spatial scales in east Texas. Stephen F. Austin Graduate Research Conference, Nacogdoches, TX. Oral. Virtual Conference.

Swanson J.R., C.G. Montaña, C.M. Schalk. 2021. Fish community assembly at multiple spatial scales in east Texas. Texas Chapter of the American Fisheries Society. Oral. Virtual Conference.

Hutchens Z., **J.R. Swanson**, C.G. Montaña. 2021. Occurrence, movements, and ecomorphological aspects of the Sabine Shiner in an east Texas urban watershed. American Fisheries Society. Oral. Virtual Conference.

Reese B., **J. R. Swanson**, C.G. Montaña. 2021. Spatial distribution and ecological aspects of the Blackspot Shiner in streams in east Texas. American Fisheries Society. Poster. Virtual Conference.

Castillo V., **J.R. Swanson**, C.G. Montaña. 2021. Assessing the ecology and abundance of the Pirate Perch in east Texas streams. American Fisheries Society. Poster. Virtual Conference.

SCHOLARSHIPS

2021. Swanson J.R. McCullough Family Scholarship, Arthur Temple College of Forestry & Agriculture. (\$959.77).

2021. Swanson J.R. STMicroelectronics Scholarship, Arthur Temple College of Forestry & Agriculture. (\$2000).

RELEVANT SKILLS

- Identification and preservation of scientific specimens
- Time management
- Geographic Information Systems (GIS)
- Management of large datasets
- Proficiency in R statistical programming
- Community outreach/interaction with public
- Experience towing and operating boats of varying size