THE INFLUENCE OF LAND USE, ZOOGEOGRAPHIC HISTORY, AND PHYSICAL HABITAT ON FISH COMMUNITY DIVERSITY IN THE LOWER BRAZOS WATERSHED

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THE INFLUENCE OF LAND USE, ZOOGEOGRAPHIC HISTORY, AND PHYSICAL HABITAT ON FISH COMMUNITY DIVERSITY IN THE LOWER BRAZOS WATERSHED

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ... iv

LIST OF TABLES ... vii

LIST OF FIGURES ... viii

CHAPTER

I. THE INFLUENCE OF LAND USE, ZOOGEOGRAPHIC HISTORY, AND PHYSICAL HABITAT ON FISH COMMUNITY DIVERSITY IN THE LOWER BRAZOS WATERSHED

Introduction ... 1

Methods ... 4

Results ... 11

Discussion ... 16

Tables and Figures ... 24

APPENDIX I. Abundances of fishes collected across sampling seasons for sites within the Central Brazos, Lampasas, Yegua, Lower Brazos, Little River, and Navasota subbasins ... 34

APPENDIX II. Summary of the environmental parameters for Lower Brazos subbasin sites ... 55

WORKS CITED ... 61

LIST OF TABLES

Table **Page**

1. Sampling site localities for the Brazos River watershed 24

2. National Land Cover Data (NLCD 2001) categories with reclassification scheme. 25

3. Watershed, subbasin, and site fish assemblage characteristics. 26

4. ANOSIM global and pair-wise tests 27

LIST OF FIGURES

Figure **Page**

1. Sampling sites and subbasins within the Lower Brazos River watershed 28

2. Land use relative abundances within subbasins (small pie charts) and across the watershed (large pie charts) at 3 spatial scales: 2km upstream of site, total riparian upstream of site, and total catchment upstream of site 29

3. Sample Scores of Principal Component (PCA) axes I and II illustrating sample scores...30

4. Multi-dimensional scaling (MDS) plot for Lower Brazos River watershed sample fish assemblages, with Central Brazos (CB),Lampasas (LM), Little River (LR), Lower Brazos (LB), Navasota (NV), and Yegua (YG) subbasin groupings represented by the respective grouping's sample score means encircled by 1 standard deviation. 31

5. CCA ordination plot of top 25 most abundant fish species and Central Brazos (CB), Lampasas (LM), Little River (LR), Lower Brazos (LB), Navasota (NV), and Yegua (YG) subbasin groupings represented by the respective grouping's sample score means (circles with abbreviations) and range along both axes (vertical and horizontal lines with range values indicated)...32

6. CCA ordination plot with 10 land use category-scale combinations as environmental variables and sample assemblage structure characteristics as species...33

CHAPTER I

THE INFLUENCE OF LAND USE, ZOOGEOGRAPHIC HISTORY, AND PHYSICAL HABITAT ON FISH COMMUNITY DIVERSITY IN THE LOWER BRAZOS WATERSHED

INTRODUCTION

River system communities are increasingly examined through the framework of hierarchical networks of aquatic habitats interacting with the landscape (Strahler 1964, Frissell et al. 1986, Ward et al. 2002). These "Riverscape" studies aim to investigate riverine habitat, connectivity, and biotic gradient interactions in a multi-scale catchment context (Allan et al. 2004). Stream researchers are increasing the scales by which they interpret species-habitat relationships through advancement of ecological theory and method concerning stream ecosystem functioning at larger watershed scales (Poff et al. 1997, Fausch et al. 2002, Benda et al. 2004, Ganio et al. 2005), through incorporation of landscape ecology (Turner 2005), and through the increased use of high resolution cover data combined with geographic information systems.

A large portion of riverscape studies have been conducted in response to increased awareness of the degree to which anthropogenic actions threaten large watershed health and community-level biodiversity (Folke et al. 1996, Angermeier and Winston 1999). Habitat degradation is attributed by most to be the primary factor leading to freshwater fish imperilment (Williams et al. 1989, Warren et al. 2000), and common anthropogenic causal mechanisms include hydrologic alteration (Poff and Allan 1995, Ligon et al. 1995, Wang et al. 2001) and land use patterns (Allan et al. 1997, Sponseller et al. 2001, Hascic 2006). Over the past decade, investigators have increasingly succeeded in implicating landform and land use practices as substantial influences on stream condition. Altered landscapes and their effects of sedimentation (Henley et al. 2000), contamination (Woodward et al. 1997), riparian degradation (Tabacchi et al. 1998), and altered flows (Winston et al. 1991), serve to mitigate natural disturbance regimes, alter physiochemical conditions, and homogenize riverine habitat by dampening environmental gradients. The partitioning and classification of habitat stressor mechanisms related to biotic indicators and diversity patterns contributes to our understanding of river health management, and is applicable to large watersheds when a corresponding scale is utilized for interpretation and analysis.

Ward and Stanford (2006) stated that ecological integrity of floodplain rivers is achieved through a diversity of water bodies with differing degrees of interaction with the mainstem, allowing a wide range of successional stages and forming a mosaic of habitat patches across the floodplain. This approach to river health can be applied to a large drainage network (Billen et al. 2007). Different subbasins within a watershed form habitat patches from which heterogeneity, thus community-level biodiversity, is gained. The incremental loss of watershed biodiversity is a function of local and regional extirpations that reflect populations sensitivities to decreasing habitat area and isolation (Angermeier 1995). This concern is prevalent in Western Gulf slope (WGS) drainages where diverse taxa includes many that experience the extent of their western or eastern geographic ranges within a context of sharp environmental clines (Hubbs 1957), a long history of water and land development (Ward 2000, Vogl and Lopes 2008), and projected stressor exacerbation due to population growth (Ward 2000) and global warming (Ficke et al. 2007). Recent evaluations of WGS fish community patterns point to network-scale factors affecting habitat degradation and the loss of local and regional diversity. The bulk of these studies are limited to analyses of either species population trends that offer little on fine-grain habitat associations (Warren 2000, Runyan 2007, Perkin et al. 2009), or species-habitat models particular to a small system or region (Winemiller et al. 2000, Ostrand and Wilde 2002, Williams et al. 2005, Li and Gelwick 2005, Robertson et al. 2008). The complementary characterization of taxonomic and environmental parameters applied to a large WGS drainage is a necessary step in addressing community diversity conservation within this region.

The present study examines spatial and temporal patterns of fish communities and environmental associations across the lower Brazos River watershed, a large WGS drainage, in an attempt to create a model for watershed assessment with regards to instream habitat and land use patterns. The objectives include: (1) quantifying habitat and land use gradients across local and landscape scales within the entire watershed and among its subbasins, (2) quantifying fish species occurrence and diversity patterns within the watershed and among its subbasins, (3) analyzing fish-environmental relationships to quantify variation explained by local habitat, geography, land use at multiple scales, and season, paying special attention to factoring out local habitat and geographic covariates of land use patterns. We attempt to utilize a hierarchical method for understanding species-environment association variability between site and subbasin in their response to local, regional, and temporal factors. In doing so, we provide a regional characterization of watershed diversity that emphasizes landscape-scale processes and allows insights relevant to conservation across watershed communities.

METHODS

Study Area

The Brazos River is one Texas' largest drainages, flowing 820 miles from its origin near the Texas-New Mexico border to its mouth at Freeport. Draining 71,000 km^2, the Brazos watershed provides approximately 25.55 billion liters of water per year for agriculture, industry, and consumption (Brazos River Authority, http://www.brazos.org/). The Lower Brazos River Watershed experiences environmental conditions similar to those of most major western Gulf slope drainages, in that it drains mostly range and agriculture land into a warm-water, meandering floodplain river known for both high turbidity and flow. The study area for this study encompasses 31,569 km^2 and is defined by the drainage area downstream of Waco, Texas excluding the Leon River watershed. The major tributaries and subbasins of the study area drain a number of ecoregions including the Central Texas Plateau, Texas Blackland Prairie, East Central Texas Plains, and the Western Gulf Coastal Plains. Thirty-three sampling sites were distributed among Brazos River subbasins in numbers approximately proportional to subbasin drainage areas (Figure 1). Subbasins sampled include the Central Brazos River basin, the Lower Brazos River basin, Yegua Creek, San Gabriel-Little River (excluding Leon and Lampasas River watersheds), Lampasas River, and Navasota River (Table 1). The Central Brazos River subbasin, encompassing 7,019 km^2, contains 6 sites (CB1-CB6) within McLennan, Falls, Milam, Robertson, and Burleson Counties. The Lower Brazos

River subbasin, encompassing 5,379 km^2, contains 8 sites (LB1-LB8) within Washington, Austin, Waller, and Fort Bend Counties. Yegua Creek subbasin, encompassing 3,408 km^2, contains 3 sites (Y1-Y3) within Lee, Washington, and Burleson Counties. San Gabriel-Little River subbasin, hereafter referred to as Little River subbasin, encompassing 6,083 km^2, contains 7 sites (LR1-LR7) within Williamson and Milam Counties. Lampasas River subbasin, encompassing 3,890 km^2, contains 3 sites (L1-L3) within Bell and Lampasas Counties. Navasota River subbasin, encompassing 5,789 km^2, contains 6 sites (N1-N6) within Grimes, Robertson, Madison, and Limestone Counties. Hydrologic conditions during the study period were characterized by mean daily, monthly, and annual discharge as recorded by the U.S. Geological Service (USGS) gaging station #08105700 (San Gabriel River at Laneport), #08106500 (Little River near Cameron), #08110800 (Navasota River near Bryan), #08108700 (Brazos River near Bryan), and #08116650 (Brazos River near Rosharon). Discharge data for the Brazos River near its mouth (USGS Station No. 08116650 at Rosharon, TX) showed overall watershed low flow conditions with mean discharge for the period of study of 126 m^3/s (28th percentile) compared to a mean of 229.7 m^3/s over the period of record (1967-2008). During the sample period, the Brazos River's daily mean discharge at Rosharon ranged from 643 m^3/s on May 20th, 2008 to 5.1 m^3/s on August 30th, 2008.

Land use Data

Land use/land cover (LULC) data were available in the form of the multi-resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset

(NLCD 2001, Homer et al. 2007). The NCLD contains 15 categories of land cover for the Brazos watershed. We utilized a simplified LULC scheme of five categories (urban, agriculture, forest, grassland, and wetland) based on Anderson et al. (1976) level I classification scheme created for natural resource applications. Utilizing ArcGIS (ArcView 9.3, 2007) and ArcHydro (Maidment, 2002), LULC data were quantified at local (100 meter buffer, extending 2km upstream of the site), riparian (100 meter buffer of total reach upstream of site), and catchment (cumulative catchment area upstream of site) spatial scales. These three scales are widely used in studies relating landscape variables to biotic or abiotic measures of stream condition (Allan 2004). To reduce the effects of multicollinearity in the 5 categories of land use among 3 nested spatial scales, a Spearman rank correlation matrix was performed using the statistical package R (R Development Core Team, http://www.R-project.org). Any significant ($\alpha \leq 0.05$) correlation across spatial scales for each category resulted in the exclusion of the smaller scale. By using this data reduction technique, we do not attempt to discover which scale best explains fish community variation, rather which individual land use category-scale combinations contribute most to explaining fish assemblage variation. The category reclassification schemes as well as the category-scale combinations retained are listed in Table 2.

Site habitat data

Sites were sampled in spring, summer, and winter from February 2008 to January 2009 representing 3 sampling seasons. Separate habitats (i.e., riffle, pool, and run) within each site were sampled and processed independently to address physical habitat and fish community geomorphic unit associations at the time of capture. Physical habitat surveyed included habitat length, width, water depth, current velocity, percent substrate, percent woody debris, percent aquatic vegetation, and percent canopy cover. Geomorphic unit mean water depth and velocity were calculated from measurements at three equidistant points along three equidistant transects perpendicular to flow. Water depths were measured to the nearest centimeter using a graduated wading rod and current velocity was measured to the nearest cm/s at 0.6 times the water depth above bottom using a Marsh-McBirney Flowmate 2000 electromagnetic flow meter. Percent substrate for each geomorphic unit was categorized along transects and classified as clay, silt, sand, gravel, cobble, boulder, or bedrock using a modified Wentworth scale (Rosgen 1996). Percent coverage of aquatic vegetation, percent woody debris, and overhanging riparian cover for each geomorphic unit were visually estimated along transects (Williams et al. 2005). Physicochemical parameters including temperature (°C), dissolved oxygen concentration (mg/L), conductivity (mS/cm), and pH were measured once on each site-date using a YSI-Model 650 multiprobe meter. Mean annual flow and cumulative drainage was determined for each site using the USGS National Hydrography Dataset (http://nhd.usgs.gov/).

Fish data

Fishes were collected using a combination of seines (2.4 x 1.8 m straight seine and 5 x 1.2 x 1.2 m bag seine with 3.2-mm mesh), a Smith-Root backpack electrofisher, and a boat-mounted electrofisher. Sample effort for each geomorphic unit was proportional to the amount of habitat found at the site. Fishes were collected from a geomorphic unit until few individuals and no additional species were collected following several successive seine hauls or electrofishing passes. Fishes were identified and enumerated in the field according to Hubbs et al. (1991). Fishes not identified in the field were preserved and identified in lab according to Hubbs et al. (1991). All fishes were released with the exception of voucher specimens of each species from each site-date combination. Vouchers were euthanized in tricane methanesulfonate (MS-222), and preserved in 10% formalin for ~14 days, rinsed with water, and transferred to 70% ethanol. Vouchers are catalogued and stored in the Texas Natural History Collection at the Texas Natural Science Center at University of Texas at Austin. Fishes too large to properly voucher were photographed, measured, and released at the capture site.

Statistical Analysis

Site specific physical habitat data were analyzed using the multivariate technique of Principal Component Analysis (PCA; ter Braak 2002) to assess spatial and temporal patterns of physical habitat variance (Rahel and Hubert 1991, Matthews and Marsh-Matthews 2006). Qualitative variables (i.e., season) were represented by dummy variables and quantitative variables (i.e., percent substrate, depth and velocity) were z-score transformed (Krebs 1999, Williams et al. 2005, Williams and Bonner 2006). Resulting component loadings and plots were used to illustrate habitat patterns seen across sites, subbasins, and sampling season.

Site fish assemblage structure within sampling and among sampling seasons and subbasins were characterized by species richness (*S*), species abundance (*n*), diversity (*H′*), and evenness (*J′*) indices calculated with PRIMER (version 6; Clarke and Gorley

2006). Diversity was calculated using Shannon-Wiener index (*H'*; Krebs, 1972), and evenness was represented by Pielou's evenness index (*J'*; Pielou, 1966). Bray-Curtis similarity indices (Bray and Curtis 1957) were calculated for species abundance data among samples. The resulting matrix was tested with analysis of similarities (ANOSIM (within PRIMER); Clarke and Green 1988, Clarke 1993), after data were fourth-root transformed to standardize the contributions of high and low abundant species (Warwick 1988). A one-way ANOSIM with sampling season as a factor was performed to assess seasonal effects on assemblage structure ($\alpha = 0.05$; 9,999 permutations), with site as a factor to test fish assemblage similarity among sites within the Lower Brazos watershed ($\alpha = 0.05$; 9,999 permutations), and with site assemblages pooled over sampling season with subbasin as a factor to test fish assemblage similarity among subbasins within the Lower Brazos watershed ($\alpha = 0.05$; 9,999 permutations). Multi-dimensional scaling (MDS) was used to characterize differences in site communities within the watershed and among subbasins by representing dissimilarity distances in a two-dimensional plane (Clarke and Gorley 2006) (Figure 4).

Canonical Correspondence Analysis (CCA; ter Braak 2002) was applied to identify: (1) species-environment relationships among site samples (n = 99) within the Lower Brazos watershed, and (2) site assemblage structure (richness (*S* (total species, *N*) & *d* ((*S*-1)/Log(*N*))), diversity (Shannon-Wiener (*H'*) and Simpon's (1-λ')), evenness (*J'*), and total abundance (*n*)) relationship with land use category-scale combinations retained from the Spearman-rank correlation reduction technique. CCA is a direct gradient analysis that uses multiple regression to find a linear combination of environmental variables that maximizes the dispersion of species' abundances using weighted averaging to maximize the covariance among species' sample scores (Jongman et al. 1995). Utilizing a derivation of CCA with Hill's scaling and focusing on inter-sample distances gave two advantages for the species-environment analysis. The first was that the samples scores are in standard deviation units (SD; Hill 1979, Hill and Gauch 1980) of species turnover (beta-diversity), allowing compositional turnover gradient length values for nominal environmental classes along axes to be interpreted and compared. A 50 percent change in species composition occurs within 1 to 1.4 SD units while a complete turnover in composition in approximately 4 SD units (Gauch, 1982). The second was that it allowed for the use of the distance rule, an extension of the centroid principle for long gradients (strong unimodal response), stating that samples that are close to a species' point are more likely to contain the species than a sample that is far from the species' point (ter Braak and Smilauer 2002). This allows one to interpret a joint plot of species-samples with the perspective that the rank order of abundance can be inferred from the distances of the samples to the species' point.

A variance partitioning method (pCCA)(Borcard et al. 1992) was used on the species-environment dataset to assess pure local habitat, land use, geographic, seasonal, and shared effects on fish community variation by producing a reduced CCA model for each effect with the remaining effects as covariates. Local habitat included the 14 variables with the highest loadings from the PCA performed on site habitat data, geographic variables included 6 subbasin dummy variables as well as site northing and easting, land use variables included the reduced set of 10 categories, and sampling season included dummy variables for spring, summer, and winter sampling season. To minimize the influence of highly skewed distributions of species abundances, data were log (x+1) transformed. Rare species were down-weighted using CANOCO as they can be misleading outliers in ordination plots (Gauch 1982). To test significance ($P < 0.05$) of variation explained, a Monte Carlo randomization test (1000 permutations) was performed on each CCA model (ter Braak and Smilauer 2002).

RESULTS

Land Use and Habitat Characterization

Relative abundance of land use categories varied among spatial scales and among major tributary subbasins of the Lower Brazos watershed (Figure 2). For the entire watershed, wetlands (43%) and grassland (29%) were the predominate land use at the local (2 km) scale, grassland (34%) and forest (28%) at the riparian scale, and grassland (47%) and forest (30%) at the catchment scale. Among subbasins, Western drainages contained high percentages of forest, drainages along the mainstem contained the highest proportions of agriculture land use, and eastern drainages contained the highest proportions of grassland and wetlands. Ten category-scale combinations were retained after collinear combinations were evaluated and the smaller of any two significantly correlated within-category scales were eliminated (Table 2).

Physical habitat parameters (Appendix I) varied within the watershed across a north to south substrate and precipitation gradient. Northwestern sites were associated with larger proportions of coarse sediment, riffles, and higher current velocities. Southeastern sites were associated with greater percentages of fine sediments, runs, pools, and woody debris. Principal Component axes I and II together explained 37.7% of the variation in habitat data among site samples within the Lower Brazos watershed (Figure 3). PC I (23.6 % of total variation) represented a woody debris-substrate gradient with strong positive loadings for riffle (0.75), cobble (0.71), and bedrock (0.62) and strong negative loadings for woody debris (-0.60), run (-0.55) and silt (-0.54). PC II (14.1 %) represented a geomorphic unit-substrate-velocity gradient. Samples with strong positive loadings for PCII were characterized by high proportions of pools (0.86), clay substrates (0.44), and woody debris (0.22), whereas those with strong negative loadings were characterized by high proportions of runs (-0.61), higher velocities (-0.44), and sand substrates (-0.42). Samples within the Lampasas subbasin and the uplifted Edwards Plateau portions of the Little River subbasin segregated from other subbasins with coarser substrates and higher proportions of riffle habitat, whereas Yegua Creek, Navasota, and Lower Brazos subbasin samples overlapped in habitat dominated by runs, silt, and woody debris. The Central Brazos subbasin samples scored intermediate between the former two groupings.

Fish Community Characterization

A total of 110,592 individuals representing 20 families and 72 species were collected from the Lower Brazos watershed (Appendix I-V). The most abundant families were Cyprinidae (75% in relative abundance), followed by Poeciliidae (11%), Centrarchidae (7%), and Fundulidae, Clupeidae, Atherinopsidae, and Percidae each comprising about 1% of the total fish assemblage. Cyprinidae and Centrachidae with 16 species each were the most species-rich families. *Cyprinella lutrensis* (41%), *Pimephales vigilax* (15%), *Cyprinella venusta* (12%), *Gambusia affinis* (10%), *Lepomis megalotis* (3%), and *Lythurus fumeus* (3%) were the most abundant species. Introduced species *Cyprinus carpio* (Common Carp), *Pterygoplichthys disjunctivus* (Vermiculated Sailfin

Catfish), and *Lepomis auritus* (Redbreast Sunfish) collectively represented 4.3% of the total lower Brazos watershed assemblage.

Among fishes with small geographic ranges or considered rare in Texas or this study area, one specimen of *Etheostoma parvipinne* (Goldstrip Darter) was collected at Yegua Creek site 3, and one specimen of *Macrhybopsis storerinana* (Silver Chub) was collected at Central Brazos site 3. Six *Lepomis marginatus* (Dollar Sunfish) and 15 *Elassoma zonatum* (Pygmy Sunfish) were collected at Lower Brazos site 6. Eight *Lepomis symmetricus* (Bantam Sunfish) were collected from Lower Brazos site 4. *Moxostoma congestum* (Gray Redhorse) was common in the Lampasas drainage (2.4% subbasin abundance), with only 13 specimens found in the Little River subbasin, and one at Central Brazos site 5. *Micropterus treculii* (Guadalupe Bass) was found in the Lampasas (57 individuals, < 1%), and Little River (66 individuals, < 1%) subbasins.

Fish abundance across all sampling seasons was highest at Little River Site 1 (*n* = 27,981) and Yegua Site 1 (*n* = 10,119) and lowest at Yegua Site 2 (*n* = 406) and Little River Site 3 (*n* = 555). Species richness (*S*) for sites among sampling seasons ranged from 5 (Lower Brazos Site 2, winter) to 33 (Yegua Site 1, winter), and 9 (Lower Brazos Site 2) to 42 (Yegua Site 1) for site assemblage data pooled over sampling season. Site evenness (Pielou's, *J'*) ranged from 0.146 (Little River Site 1, summer) to 0.855 (Yegua Site 2, spring) for all samples, and 0.270 (Little River Site 1) to 0.760 (Navasota Site 4) for site assemblage data pooled over sampling season. Shannon diversity (*H*') ranged from 0.43 (Little River Site 1, summer) to 2.50 (Navasota Site 4, spring) for all samples, and 0.89 (Little River Site 1) to 2.68 (Navasota Site 4) for site assemblage data pooled over sampling season. Watershed, subbasin, and site fish assemblage characteristics are shown in Table 3.

Fish assemblage similarity among sampling seasons differed overall (ANOSIM global $R = 0.012$, $P = 0.018$), but no pair-wise test was significant (Table 4). Small differences in seasonal assemblage structure can be attributed to increased abundances of *C. lutrensis* and *P. vigilax* during winter sampling. Site fish assemblages pooled across seasons (ANOSIM global $R = 0.853$, $P < 0.01$), and subbasin groupings of site fish assemblages (ANOSIM global $R = 0.3$, $P < 0.01$) differed across the Lower Brazos watershed. Pair-wise tests indicate three groupings of similar fish assemblages ($P < 0.05$): (1) Lampasas and Little River, (2) Navasota, Lower Brazos, and Yegua, and (3) the Central Brazos subbasin. The multi-dimensional scaling plot for sites pooled across seasons further substantiates this finding with high overlap in assemblages groupings listed above (Figure 4). The Lower Brazos watershed shows the largest spread of sample values, indicating high variance in assemblage structure within the subbasin. Conversely, the Lampasas River subbasin sample values are tightly clustered, indicating low assemblage structure variance relative to the other subbasins.

Fish-Environment Relationships

Physical habitat, land use, geography, and sampling season together accounted for 54.1% ($P < 0.01$) of the variation in the Lower Brazos watershed fish assemblage. Pure effects of physical habitat parameters accounted for 15.4% ($P < 0.01$), land use 14.8% ($P < 0.01$), geography 9.6% ($P < 0.01$), and sampling season 2.4% ($P < 0.01$) of fish assemblage variation. Shared effects among local habitat, geography, land use and sampling season accounted for 11.9% of fish assemblage variation. CCA I, explaining 21.1% of variation, described a substrate and land use gradient, and CCA axis II (16%) described a land use, geographic, and woody debris gradient. Habitat parameters with the strongest negative loadings (biplot scores) on CCA axis I were forest land use at catchment scale (-0.29), bedrock (-0.20), and cobble (-0.18). The strongest positive loadings for CCA axis I include agriculture land use at catchment scale (0.36), Central Brazos subbasin (0.25), and clay (0.17). The strongest loadings for CCA axis II include site easting (-0.35), riffle (-0.28), and Little River subbasin (-0.25) as negative values, and percent woody debris (0.28), wetland land use at catchment scale (0.26) and grassland land use at catchment scale (0.26) as positive values. Species with strong loadings for CCA axis I include *P. carbonaria* (-3.09), *C. anamolum (-2.37)*, and *M. congestum* (-2.30) for negative values, and *M. hyostoma* (3.40), *M. cephalus* (3.40) and *P. disjunctivis* (3.29) for positive values. Fish species expressing a strong interaction with CCA axis II include *L. auritus* (-3.38), *C. anomalum* (-2.78), and *A. monticola* (-2.76) with negative values, and *L. symmetricus* (5.17), *F. chrysotus* (4.63), and *L. gulosus (3.30)* with positive values. The species compositional turnover gradient length for samples among the Lower Brazos watershed was 3.5 SD units between Little River site 1 (summer) and Lampasas site 2 (winter) on axis 1, and 4 SD units between Lower Brazos site 4 (summer) and Lampasas 2 (winter) on axis 2 (Figure 5), indicating an approximately 100% compositional turnover between these two samples.

Patterns of land use category-scale combinations explained 20% of site assemblage structure characteristics (Figure 6). CCA axis I illustrated a land cover impaction gradient with positive loadings associated with catchment scale urban (0.66) and agriculture (0.59), and local scale grassland (0.36), and negative loadings associated with catchment scale wetland (-0.46), forest (-0.41) and grassland (-0.30). Samples with positive loadings on axis II were associated with forest at the riparian (0.61) and local (0.38) scale, and urban at the catchment scale (0.23), whereas samples resulting in negative loadings on axis II had high proportions of catchment scale wetland (-0.41) and agriculture (-0.34), and riparian scale urban (-0.34). Site assemblage characteristics of evenness (Peilou's *J*), diversity (Shannon and Simpson), and richness (*S* and *d*) grouped together on the opposite end of the primary axis from assemblage total abundance (*N*) as well as the impaction land use metrics of catchment agriculture and urban, and local grassland.

DISCUSSION

Comparison of the six subbasins within the Lower Brazos subbasin illustrated three assemblage groupings, which can be described as western, mainstem, and eastern affiliated fish communities. Western drainages within the Lampasas and Little River subbasins had high abundances of fluvial specialists such as Central Stoneroller (*C. anamolum)*, and Orangethroat Darter (*E. spectabile)*. The Central Brazos subbasin is an intermediate between the western upland region and the eastern and coastal drainages, by having a fish assemblage that closely mirrors what we know to be a mainstem Brazos River community (Bonner and Runyan 2007); including high abundances of Ghost Shiner (*Notropis buchanani*), Silverband Shiner (*Notropis shumardi*), and Shoal Chub (*Macrhybopsis hyostoma*). The eastern assemblage grouping within Yegua, Navasota, and Lower Brazos subbasins include high abundances of fluvial generalists and slackwater-associated taxa including Ribbon Shiner (*Lythurus fumeus*), Blackstripe Topminnow (*F. notatus*), and White Crappie (*P. annularis*). The distinctiveness of these three assemblage groupings is primarily related to a combination of habitat availability, zoogeographic history, and land use patterns.

Local physical habitat was the primary factor explaining patterns of assemblage variation among samples. Physical habitats within and among subbasins are directly related to the geological history of the region. Western catchments within the uplifted, limestone dominated Edwards Plateau region have higher gradients, swifter currents, and more shallow-water riffle habitat. The Little River subbasin for example, has instream habitat transitions from high gradient to low gradient streams, and not surprisingly, had the highest beta diversity for both physical environment and fish taxa. This faunal cline approaches a full compositional turnover within a relatively short geographic distance as the western and headwater assemblages transition into a mainstem assemblage near the confluence with the Brazos River, conforming to longitudinal gradient models for warm-water streams (Schlosser 1987). The central and eastern subbasin drainages, with Cenozoic alluvium deposits, have lower gradient streams with higher amounts of clay and fine substrates, greater depths, greater amounts of woody debris, and slower currents. The interconnected, avulsion-prone drainages within the southeastern portion of the watershed provide a wide range of physical habitat and relatively unimpeded fish dispersion. This has lead to eastern fishes moving westward into suitable low-gradient habitats such as Yegua Creek, where despite its orientation and proximity to the western assemblages of the hill country, the eastern affiliated fishes found there persist in habitats similar to the Navasota and Lower Brazos subbasins. This example reflects the role multi-scale environmental and geographic filters play on the structure of assemblages such that a local community is composed of species from the larger species pool that are able to persist through all filters (Smith and Powell 1971, Poff 1997).

Geologic histories of the subbasins not only influence physical habitat, and indirectly fish occurrences, but also directly influence contemporary fish diversity. The Lower Brazos River drainage captures at least two distinct fish faunal elements: the western, Edwards Plateau fishes, with high abundances of northern-derived taxa, and eastern fishes, consisting of many taxa of southeastern US origin. Stream captures (Wooddruff 1977) and preferred habitats (Fausch and Bestgen 1997) have allowed northern taxa to disperse and persist throughout Central Texas; examples include Guadalupe Bass (*M. treculii*), Central Stoneroller (*C. anamolum*), Orangethroat Darter (*E. spectabile*), Bigscale Logperch (*P. macrolepida*), and Texas Logperch (*P. carbonaria*). Eastern drainages are in closer proximity to the species pool in the southeast US, and various stream captures and sea level changes have allowed a number of eastern species to reach the lower Brazos drainage. Examples of fishes of SE origin reaching their natural westward extent in the Brazos River drainage include Redfin Pickeral (*E. americanus)*, Goldstripe Darter (*E. parvipinne)*, Pygmy Sunfish (*E. zonatum)*, Blackspot Topminnow (*F. olivaceaus)*, and Dollar Sunfish (*L. marginatus)*. Knapp (1953), and then Conner and Suttkus (1986) proposed that high sediment load and high turbidity of the Brazos River mainstream was a major barrier to southwest expansion of SE-origin fishes. However, this assertion was based on the claim that the western extents of the eastern taxa listed above were limited to the Navasota River, yet were found herein to extend westward into other Brazos drainages. An alternative explanation maybe that the paleoclimate after the last glacial maximum had extreme drought conditions, possibly leading to the extirpation of SE forms in west and central Texas (Horne and Kahn 1997, Al-Rabab'ah and Williams 2002, Johnson and Hill 2008). Adjacent western drainages such as the Colorado and Guadalupe Rivers are generally depauperate of southeastern forms except in lower reaches (e.g., *L. fumeus*, *N. texanus*, *O. emiliae*, *E. chlorosomum*, and *E. gracile)* and spring refugia (e.g., *E. fonticola*, *N. chalybaeus*, *E. parvipinne*, and *M. melanops*).

After local instream habitat, land use contributed the most to site assemblage variation. Catchment spatial scales were the primary contributors, supporting the concept that management at larger landscape scales offers greater influence to stream conditions (Doppelt et al., 1993, Allan et al., 1997). Catchment-scale agriculture, and urban and local-scale grassland are supporting impacted fish assemblages within the watershed, as indicated by low diversity, low evenness, and high abundances of habitat generalists and tolerant forms (Karr 1981). Numerous studies document declines in water quality, habitat, and biological assemblages due to the landscape metrics of agriculture (Richards et al. 1996, Wang et al. 1997, Roth et al. 1996, Sponseller et al. 2001), urban or impervious area (Walsh et al. 2005), and lack of an intact riparian corridor (Gregory et al. 1991, Stauffer et al. 2000). Many of the impacted sites fall within or near the Central Brazos subbasin, where gentle hills and rich soil of the Blackland prairies lend to agriculture. Over time, the conversion to cropland in this region has resulted in a near total replacement of original prairie habitat, and to the distinction of this large ecoregion being the most endangered in North America (Samson et al. 2004). Alternatively, high abundances of tolerant forms could be a response to the stream's position and relative size compared to the master stream. Having shorter drainage basins and many taxa found in the proximate mainstem, the Central Brazos tributary assemblages partially conformed to adventitious stream theory (Gorman 1986). The Central Brazos subbasin assemblage, as well as the Lower Brazos subbasin assemblages, departed from this theory in that they lacked high temporal beta-diversity common in adventitious streams. Additionally, the Lower Brazos contained high variability and diversity across sites similarly positioned in relation to the mainstem, and there were examples of impacted, non-adventitious sites outside the Central Brazos subbasin containing high amounts of catchment-level urban (Little River site 7) and agriculture (Little River site 1), and riparian-level grassland (Lower Brazos site 2) within their catchments. This further supports land use as being a driver in assemblages. From a watershed perspective, some level of impaction is ultimately tolerated within the Brazos River watershed, as indicated by an overall specious and diverse fish community, and few invasive species, especially in contrast to western and New England states (Rahel 2000). Western gulf slope drainages historically withstand frequent abiotic disturbances and high amounts of sedimentation (Conner and Suttkas 1986, Williams et al. 2005), allowing a relatively high capacity to withstand anthropogenic disturbances (Williams et al. 2007).

Watershed land use patterns generally mirror the region’s geologic and physiographic gradients. The covariation of anthropogenic and natural landscape features often provides difficulties in analysis of land use/land cover data (Fitzpatrick et al. 2001, Townsend et al. 2003). We attempt to meet the assumption that locations differing in land use are similar in all other aspects by partialling out local habitat, season, and geographic effects (Borcard et al. 1992). We therefore use caution in implying that for this watershed, land use is a robust measure of stream condition as indicated by fish assemblage. While accounting for assemblage structure constraints that are known to be important, we have not explicitly considered other landscape effects, such as geology or vegetation types that could be contributing to our land use results.

The findings of this study give credence to incorporating landscape metrics into biological stream assessment for a greater perspective on the extent of assemblage response to not only instream habitat and historic zoogeography, but also to human influences across the drainage landscape. Considering the dual pressures of anthropogenic influences (Vogl and Lopes 2008) and changing environmental conditions in the region (Nielsen-Gammon 2009), we view the Brazos watershed fish community as a particularly sensitive indicator of potential faunal regime change and homogenization within Western Gulf slope drainages. Humid-arid transitional zones across the world, such as seen in Texas, are characterized by high sensitivity to warming trends, drying processes, and anthropogenic land use transformations (Shoshany and Svoray 2002). Carpenter and Brock (2006) suggest that increases in variability of ecosystems foreshadow ecological regime shifts, which stem from large-scale changes in environments and reorganization of complex ecosystems due to persistent landform and hydrologic alteration or climate change. Assemblage homogenization can also foreshadow regime shifts through increases in population level variability by means of native and non-native invaders and extinction or extirpation of endemic forms (Scott and Helfman 2001). Past research has confirmed that the Brazos mainstem community persists in a drainage system where impacts on stream ecosystems through habitat degradation and surface water abstraction have resulted in increases in habitat generalists

(Bonner and Runyan 2007), decreases in native obligate riverine taxa (Perkin et al. 2010), and extirpations of some endemic forms such as *N. buccula* (Smalleye Shiner) and *N. oxyrhynchus* (Sharpnose Shiner) (Warren et al. 2000). The results of this analysis complement previous mainstem work by applying a hierarchical, landscape approach to identifying how the basin's fish communities exploit multi-scale environmental heterogeneity and at the same time detecting and correlating probable landscape-scale risk factors. Our results suggest opportunities for restorative conservation in impacted regions, such as riparian and land use management within the Central Brazos subbasin tributaries, and the identification and proactive protection of the least impacted and unique aquatic networks, such as the most western extent of the eastern-affiliated community in the Yegua Creek subbasin. Additionally, the riverscape interpretation herein supports a landscape model of stream fishes presented by Ward (1998), and emphasizes the connectivity, and heterogeneous and hierarchical nature of aquatic habitats.

Conservation of watershed biodiversity necessitates an appropriate scale of interpretation and management application, derived from understanding variation in assemblage composition across landscape gradients. Much work has been done to develop systematic protocols for characterizing community diversity, and to successfully recognize distinct communities through multi-scale combinations of drainage and physiography (Pflieger 1989, Moyle and Ellison 1991, Angermeier and Winston 1999). Aquatic community classification studies provide a framework for assessing community diversity, but lack specific recommendations or perspectives on which biotic and drainage elements warrant protection and which management practices warrant application. Conversely, past research within the Western Gulf Slope region have indicated assemblage impacts due to hydrologic alteration (Durham and Wilde 2006, Bonner and Runyan 2007, Perkin 2010), and increasing urban development (Shattock 2010, unpublished thesis), while lacking a community diversity perspective crucial for setting priorities of watershed biodiversity conservation. This riverscape analysis characterizes lower Brazos watershed community diversity patterns that reflect habitat patch dynamics resulting from differential ecosystem response to geology, zoogeographical history, and landform practices. This analysis can help conservation practitioners improve watershed health and biodiversity through a multi-scale riverscape perspective, placing emphasis on landscape-river linkages and ecosystem processes of connectivity and heterogeneity (Allan et al. 1997, Fausch et al. 2002, Allan 2004). Success or failure in applying models that link biological responses to mechanistic drivers hinges, in part, on paying attention to the appropriate ecological context in which the models are derived (Frissell and Bayles 1996).

Table 1. Sampling site localities for the Brazos River watershed.

Subbasin		Site	Latitude °N	Longitude °W	County
Central Brazos					
	1	Old River at FM444	30.4040264	-96.3140678	Burleson
	2	Thompsons Creek at 1688	30.6008885	-96.4435228	Brazos
	3	Little Brazos River at SH21	30.6409039	-96.5206297	Brazos
	4	Big Creek at SH6	31.2567854	-96.8597668	Falls
	5	Deer Creek at SH935	31.2648098	-97.0320237	Falls
	6	Tehuacana Creek at FM2491	31.5639615	-97.0481453	McLennan
Lampasas					
	1	Lampasas River at IH35	31.0018555	-97.4918558	Bell
	2	Lampasas River at SH195	30.9723781	-97.7782011	Bell
	3	Lampasas River at US190	31.0794292	-98.0158551	Lampasas
Little River					
	1	Little River at CR264	30.8254215	-96.7435651	Milam
	2	Big Elm Creek at US77	30.9030406	-96.9790851	Milam
	3	San Gabriel at CR428	30.6943662	-97.2787716	Williamson
	4	San Gabriel at ShadyRVcamp	30.6373391	-97.5724726	Williamson
	5	North San Gabriel at US183	30.7031423	-97.8773021	Williamson
	6	South San Gabriel at US183	30.6207162	-97.8609248	Williamson
	7	Brushy Creek at CR685	30.5261307	-97.5664998	Williamson
Lower Brazos					
	1	Big Creek at Brazos Bend State Park	29.378439	-95.6024479	Fort Bend
	2	Bullhead Bayou at SH99	29.6066179	-95.6866399	Fort Bend
	3	Allens Creek at Mixville Rd	29.7039007	-96.1289913	Austin
	4	Irons Creek at CR1458	29.8267771	-96.0363805	Waller
	5	Mill Creek at CR331	29.869463	-96.155018	Austin
	6	Clear Creek at CR3346	30.0544433	-96.0580244	Waller
	7	Caney Creek at CR1456	30.0621125	-96.2090383	Austin
	8	New Year Creek at CR2447	30.1657452	-96.22327	Washington
Navasota River					
	1	Navasota River at SH6	30.4183477	-96.106475	Grimes
	2	Navasota River at Sulphur Springs Rd.	30.5707004	-96.1664846	Grimes
	3	Navasota River at CR162	30.7203727	-96.1676675	Grimes
	4	Navasota River at US79	31.1694968	-96.2986485	Leon
	5	Navasota River at SH164	31.512466	-96.4510747	Limestone
	6	Navasota River at SH73	31.7018385	-96.7223061	Limestone
Yegua Creek					
	1	Yegua Creek at SH50	30.3681099	-96.3431751	Washington
	2	Yegua Creek at SH36	30.3215025	-96.5073441	Washington
	3	West Yegua Creek at SH21	30.2912744	-96.9604991	Lee

Table 2. National Land Cover Data (NLCD 2001) categories with reclassification scheme. Category-scale combinations retained from Spearman rank correlation test are indicated by ✓ .

Original categories	Reclassified categories	Spatial scales: Local (100m buffer, 2km upstream)	Spatial scales: Riparian (100m buffer, total upstream)	Spatial scales: Catchment (cumulative area upstream)
Developed, Open Space Developed, Low Intensity Developed, Medium Intensity High Intensity, Residential	Urban		✓	✓
Deciduous Forest Evergreen Forest Mixed Forest Shrub/Scrub	Forest	✓	✓	✓
Grasslands/Herbaceous Pasture/Hay	Grassland	✓		✓
Cultivated Crops	Agriculture			✓
Woody Wetlands Emergent Herbaceous Wetlands	Wetland		✓	✓

Table 3. Watershed, subbasin, and site fish assemblage characteristics. Maximum and minimum values for the study are indicated in bold.

	Site Code	Total Species (*S*)	Total individuals (N)	Pielou's evenness (J')	Shannon diversity (H')	Beta-Diversity (SD range) (axis 1, axis 2)
Lower Brazos Watershed	-	72	110,592	0.517	1.98	3.5, 4
Central Brazos (CB)	-	52	27,088	0.414	1.64	2.3, **1.1**
	CB1	33	1,550	0.684	2.39	-
	CB2	30	5,942	0.451	1.53	-
	CB3	35	2,374	0.576	2.05	-
	CB4	19	4,305	0.426	1.25	-
	CB5	23	7,222	0.396	1.24	-
	CB6	19	5,695	0.353	1.04	-
Lampasas (LM)	-	30	5,970	0.604	2.05	1.8, 1.6
	LM1	20	1,660	0.560	1.68	-
	LM2	22	1,602	0.692	2.14	-
	LM3	22	2,708	0.593	1.83	-
Little River (LR)	-	46	34,675	0.370	1.42	**3.5**, 1.6
	LR1	27	**27,981**	**0.270**	**0.89**	-
	LR2	23	1,336	0.502	1.57	-
	LR3	27	555	0.689	2.27	-
	LR4	18	1,562	0.527	1.52	-
	LR5	21	942	0.469	1.43	-
	LR6	13	608	0.706	1.81	-
	LR7	16	1,691	0.371	1.03	-
Lower Brazos (LB)	-	56	21,693	0.622	2.50	2.9, 2.7
	LB1	26	3,169	0.466	1.52	-
	LB2	**9**	4,459	0.565	1.24	-
	LB3	14	2,289	0.601	1.59	-
	LB4	24	584	0.666	2.12	-
	LB5	39	3,891	0.543	1.99	-
	LB6	29	1,865	0.602	2.03	-
	LB7	21	1,387	0.613	1.87	-
	LB8	34	4,049	0.399	1.41	-
Navasota River (NV)	-	52	9,563	0.635	2.51	2.5, 1.9
	NV1	33	1,571	0.611	2.14	-
	NV2	35	4,286	0.530	1.88	-
	NV3	25	865	0.644	2.07	-
	NV4	34	738	**0.760**	**2.68**	-
	NV5	27	1,362	0.656	2.16	-
	NV6	16	741	0.443	1.23	-
Yegua Creek (YG)	-	48	11,603	0.456	1.76	2.1, 1.6
	YG1	**42**	10,119	0.374	1.40	-
	YG2	27	**406**	0.707	2.33	-
	YG3	22	1,078	0.615	1.90	-

Table 4. ANOSIM global and pair-wise tests.

			R	*P* value
Sampling Season				
Global test			0.035	0.017
Pairwise Tests:				
Spring	vs.	Summer	0.007	0.286
Summer	vs.	Winter	0.003	0.359
Spring	vs.	Winter	0.024	0.1
Site				
Global Test:			0.853	< 0.01
Subbasin				
Global Test:			0.3	< 0.01
Pairwise Tests:				
Central Brazos	vs.	Lampasas	0.790	< 0.01
Central Brazos	vs.	Little River	0.377	< 0.01
Central Brazos	vs.	Lower Brazos	0.166	< 0.01
Central Brazos	vs.	Navasota	0.337	< 0.01
Central Brazos	vs.	Yegua	0.407	< 0.01
Lampasas	vs.	Little River	-0.038	0.619
Lampasas	vs.	Lower Brazos	0.167	0.047
Lampasas	vs.	Navasota	0.625	< 0.01
Lampasas	vs.	Yegua	0.677	< 0.01
Little River	vs.	Lower Brazos	0.300	< 0.01
Little River	vs.	Navasota	0.502	< 0.01
Little River	vs.	Yegua	0.505	< 0.01
Lower Brazos	vs.	Navasota	0.025	0.189
Lower Brazos	vs.	Yegua	-0.027	0.555
Navasota	vs.	Yegua	0.103	0.132

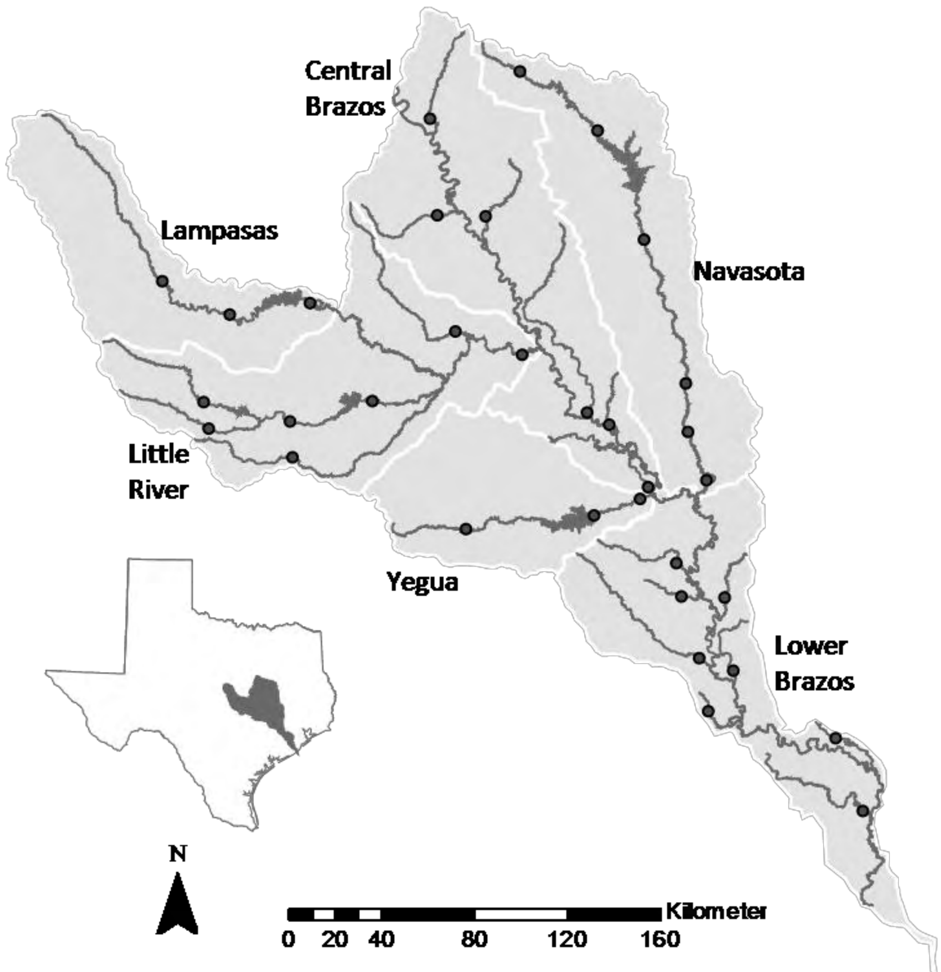

Figure 1. Sampling sites and subbasins within the Lower Brazos River watershed.

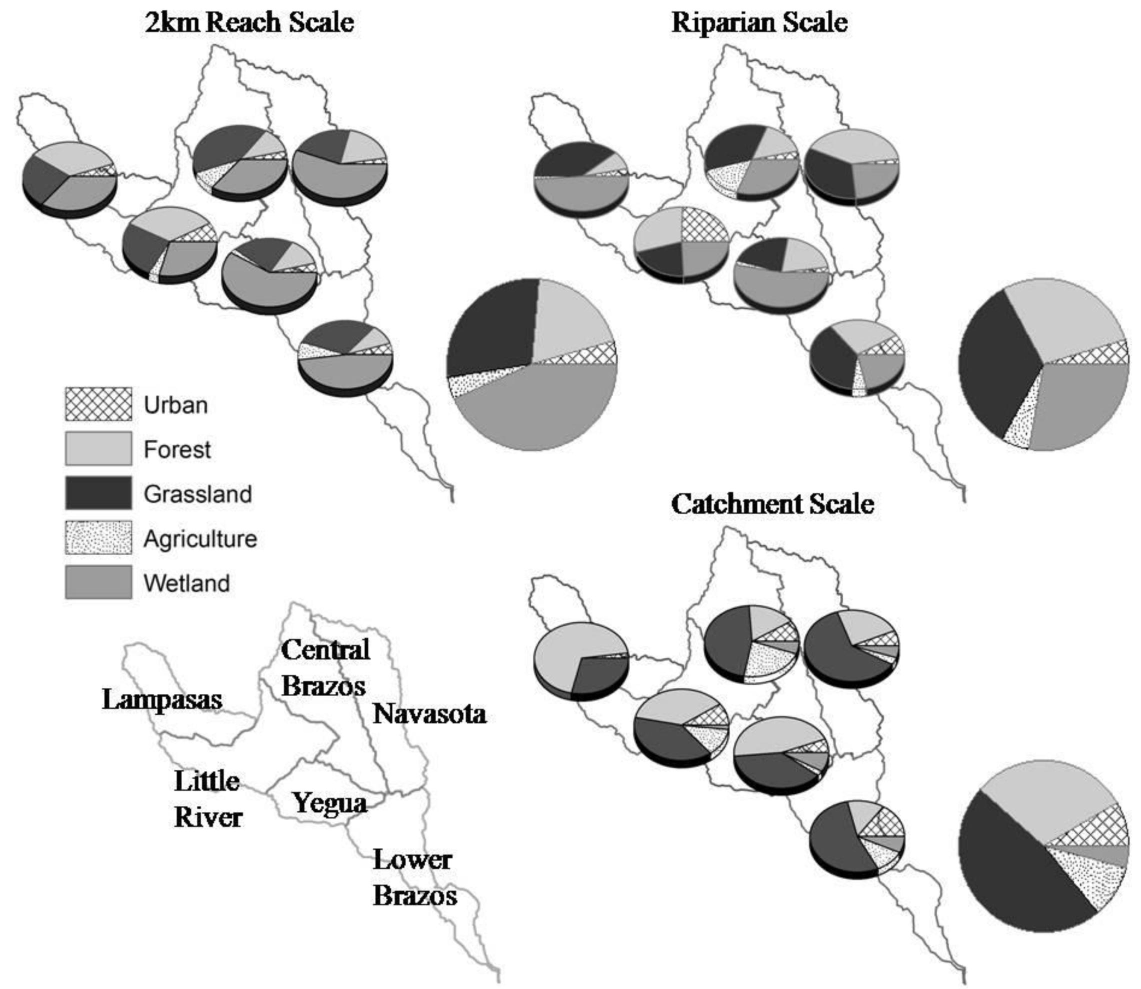

Figure 2. Land use relative abundances within subbasins (small pie charts) and across the entire watershed (large pie chart) at 3 spatial scales: 2km upstream of site, total riparian upstream of site, and total catchment upstream of site.

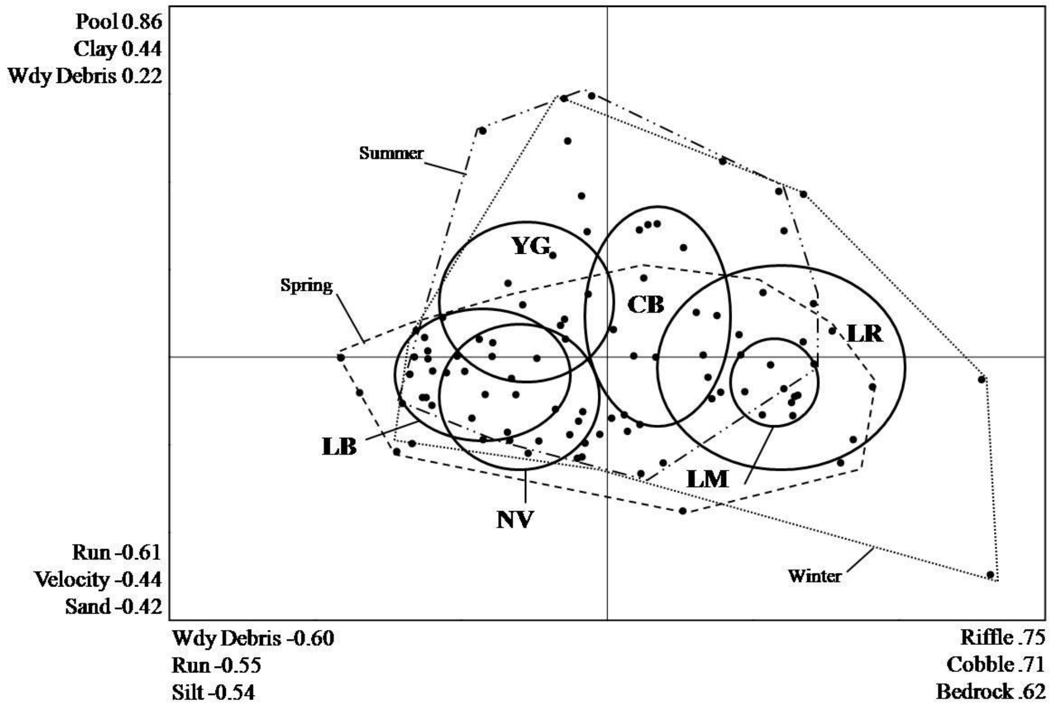

Figure 3. Sample scores of Principal Component (PCA) axes I and derived from physical habitat parameters (see text). Central Brazos (CB), Lampasas (LM), Little River (LR), Lower Brazos (LB), Navasota (NV), and Yegua (YG) subbasin groupings enclose 1 standard deviation of each group’s mean sample score. Seasonal polygons envelope all samples within respective sampling seasons.

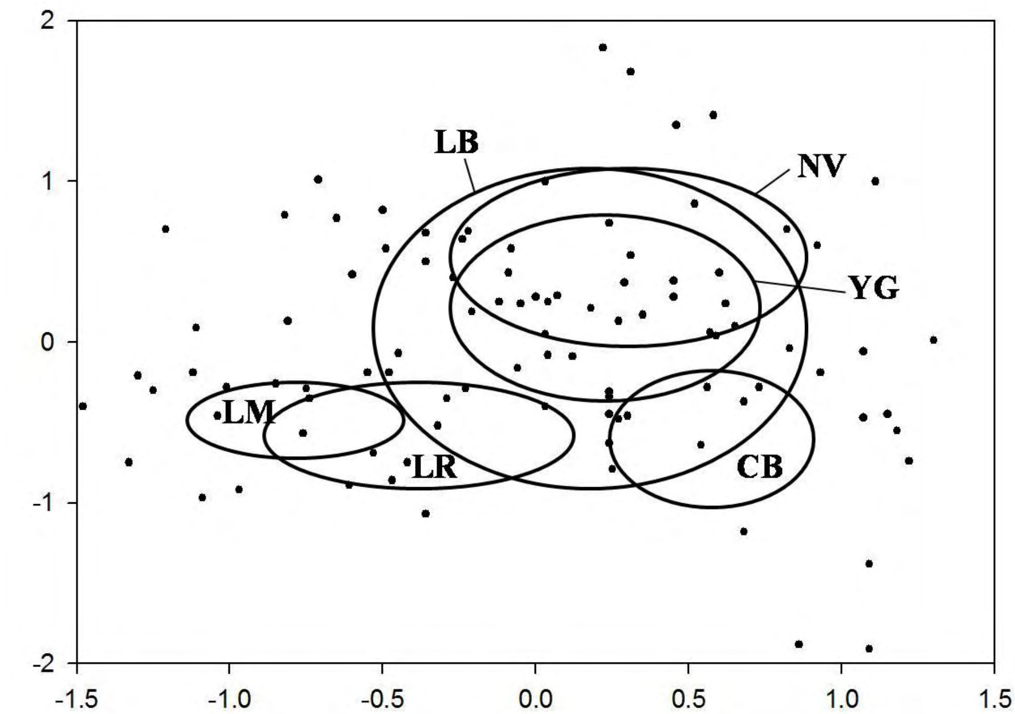

Figure 4. Multi-dimensional scaling (MDS) plot for Lower Brazos River watershed sample fish assemblages, with Central Brazos (CB), Lampasas (LM), Little River (LR), Lower Brazos (LB), Navasota (NV), and Yegua (YG) subbasin groupings. Each groups' sample score mean is encircled by 1 standard deviation.

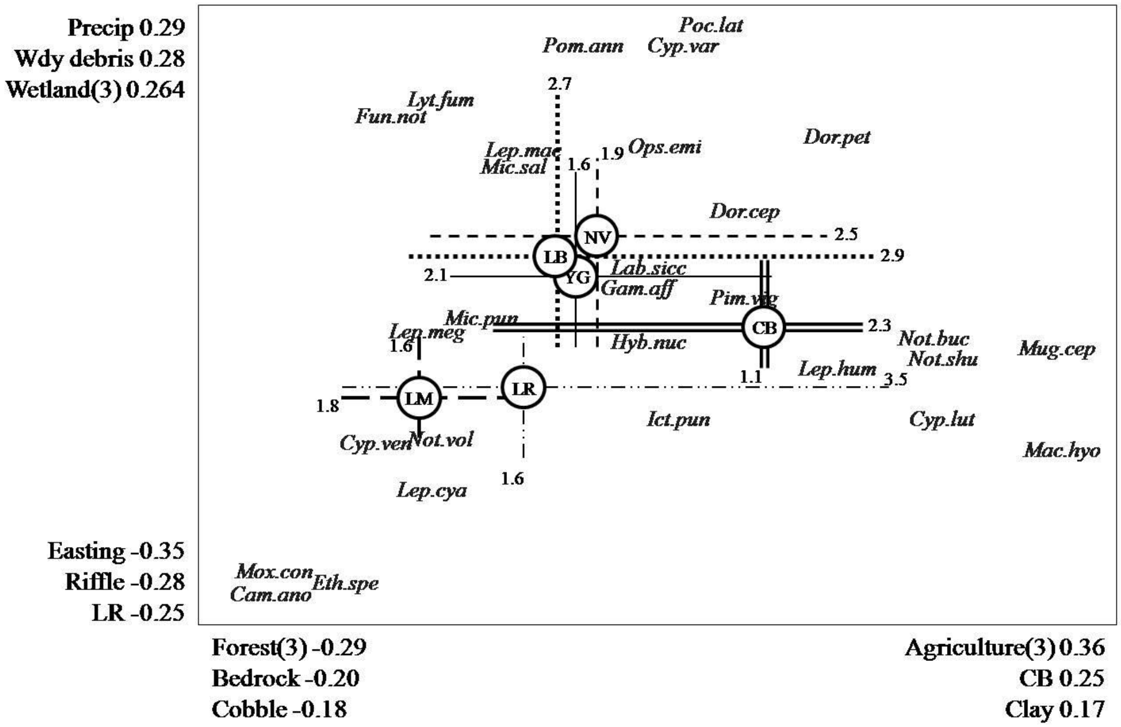

Figure 5. CCA ordination plot of the 25 most abundant fish species and Central Brazos (CB), Lampasas (LM), Little River (LR), Lower Brazos (LB), Navasota (NV), and Yegua (YG) subbasin groupings represented by the respective grouping's sample score means (circles with abbreviations) and range along both axes (vertical and horizontal lines with range values indicated). Graph scaling is in units of standard deviation (SD) of species turnover, with 50% compositional turnover in approximately 1 SD unit, and 100% turnover in 4 SD units. The 3 largest positive and negative environmental variables loadings are reported for each axis. Numbers 1-3 in parenthesis after land use categories represent the scale level for that category; 1 for local riparian 2km upstream of the site, 2 for total riparian upstream of the site, and 3 for total catchment area upstream of the site.

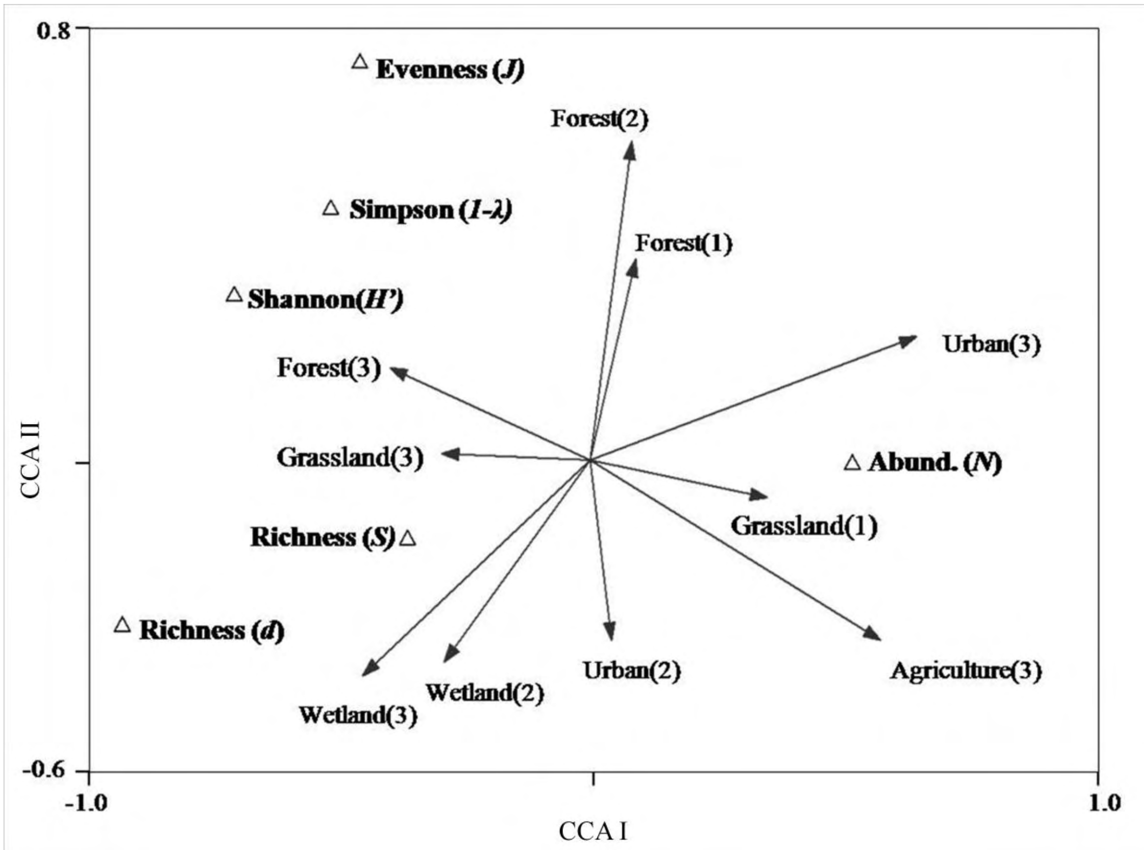

Figure 6. CCA ordination plot with 10 land use category-scale combinations as environmental variables and sample assemblage structure characteristics as species. Numbers 1-3 in parenthesis after land use categories represent the scale level for that category; 1 for local riparian 2km upstream of the site, 2 for total riparian upstream of the site, and 3 for total catchment area upstream of the site.

APPENDIX I

ABUNDANCES OF FISHES COLLECTED ACROSS SAMPLING SEASONS FOR SITES WITHIN THE CENTRAL BRAZOS, LAMPASAS, YEGUA, LOWER BRAZOS, LITTLE RIVER, AND NAVASOTA SUBBASINS

Appendix I: Abundance of fish collected across sampling seasons for sites within the Central Brazos subbasin

Family	Genus Species	Common name	Central					
			CB1	CB2	CB3	CB4	CB5	CB6
Lepisosteidae								
	Atractosteus spatula	Alligator Gar	0	0	0	0	0	0
	Lepisosteus oculatus	Spotted Gar	4	0	1	0	0	1
	Lepisosteus osseus	Longnose gar	1	0	0	0	0	0
Amiidae								
	Amia calva	Bowfin	0	0	0	0	0	0
Cluepidae								
	Dorosoma cepedianum	Gizzard Shad	82	14	1	51	31	0
	Dorosoma petenense	Threadfin Shad	0	75	5	0	0	1
Cyprinidae								
	Campostoma anomalum	Central Stoneroller	1	0	1	0	4	0
	Cyprinella lutrensis	Red Shiner	428	3169	844	2553	4856	4169
	Cyprinella venusta	Blacktail Shiner	6	109	348	0	46	170
	Cyprinus carpio	Common Carp	1	0	0	0	1	0
	Hybognathus nuchalis	Mississippi Silvery Minnow	11	3	3	0	0	0
	Lythrurus fumeus	Ribbon Shiner	18	167	334	0	0	0
	Macrhybopsis hyostoma	Shoal Chub	0	41	3	0	0	0
	Macrhybopsis storeriana	Silver Chub	0	0	1	0	0	0
	Notemigonus crysoleucas	Golden Shiner	4	1	0	0	0	0
	Notropis buchanani	Ghost Shiner	33	233	0	25	191	0
	Notropis shumardi	Silverband Shiner	10	297	0	0	0	0
	Notropis texanus	Weed Shiner	0	0	0	0	0	0
	Notropis volucellus	Mimic Shiner	28	65	7	0	4	61
	Opsopoeodus emiliae	Pugnose Minnow	10	14	1	2	0	0
	Pimephales promelas	Fathead Minnow	0	0	1	0	0	0
	Pimephales vigilax	Bullhead Minnow	102	1505	234	117	799	655

Catostomidae							
Carpiodes carpio	River Carpsucker	5	16	6	2	3	0
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	0	0	0
Minytrema melanops	Spotted Sucker	0	2	1	0	0	0
Moxostoma congestum	Grey Redhorse	0	0	0	0	1	0
Characidae							
Astyanax mexicanus	Mexican Tetra	0	0	0	0	0	0
Ictaluridae							
Ameiurus melas	Black Bullhead	0	0	1	0	1	0
Ameiurus natalis	Yellow Bullhead	1	0	0	0	0	0
Ictalurus punctatus	Channel Catfish	33	18	95	11	49	39
Ictalurus furcatus	Blue Catfish	0	3	2	0	0	0
Noturus gyrinus	Tadpole Madtom	11	0	9	3	0	0
Pylodictis olivaris	Flathead Catfish	2	0	7	0	1	0
Loricariidae							
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	0	0	0	0	0	0
Esocidae							
Esox americanus	Chain Pickerel	0	0	0	0	0	0
Aphredoderidae							
Aphredoderus sayanus	Pirate Perch	12	0	0	0	0	0
Mugilidae							
Agonostomus monticola	Mountain Mullet	0	0	1	0	0	0
Mugil cephalus	Stripped Mullet	0	0	3	0	0	0
Atherinidae							
Labidesthes sicculus	Brook Silverside	1	31	199	0	0	2
Menidia beryllina	Inland Silverside	0	0	3	0	0	2
Fundulidae							
Fundulus chrysotus	Golden Topminnow	0	0	0	3	0	0
Fundulus notatus	Blackstripe Topminnow	0	25	39	0	0	28

Fundulus olivaceus	Blackspotted Topminnow	0	0	0	0	0	0
Poecilidae							
Gambusia affinis	Western Mosquitofish	324	85	153	1081	656	330
Poecilia latipinna	Sailfin Molly	0	0	0	0	0	0
Cyprinidontidae							
Cyprinodon variegatus	Sheepshead Minnow	0	0	0	0	0	0
Moronidae							
Morone chrysops	White Bass	0	0	0	0	0	0
Centrarchidae							
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0
Lepomis cyanellus	Green Sunfish	3	2	12	10	44	29
Lepomis gulosus	Warmouth	17	1	0	3	0	0
Lepomis humilis	Orangespotted Sunfish	147	9	0	241	124	1
Lepomis macrochirus	Bluegill	72	7	7	24	76	32
Lepomis marginatus	Dollar Sunfish	0	0	0	0	0	0
Lepomis megalotis	Longear Sunfish	113	24	13	30	295	161
Lepomis microlophus	Redear Sunfish	0	0	0	0	0	0
Lepomis miniatus	Redspotted Sunfish	0	0	0	0	1	0
Lepomis symmetricus	Bantom Sunfish	0	0	0	0	0	0
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	0
Micropterus punctulatus	Spotted Bass	0	6	7	0	0	1
Micropterus salmoides	Largemouth Bass	1	2	15	1	30	9
Micropterus treculii	Guadalupe Bass	0	0	0	0	0	0
Pomoxis annularis	White Crappie	19	4	0	110	0	3
Pomoxis nigromaculatus	Black Crappie	0	0	0	0	0	0
Percidae							
Etheostoma chlorosoma	Bluntnose Darter	38	0	0	34	0	0
Etheostoma gracile	Slough Darter	8	7	2	4	0	1
Etheostoma parvipinne	Goldstripped Darter	0	0	0	0	0	0

Etheostoma spectabile	Orangethroat Darter	0	0	0	0	1	0
Percina carbonaria	Texas Logperch	0	0	0	0	0	0
Percina macrolepida	Bigscale Logperch	0	0	0	0	7	0
Percina sciera	Dusky Darter	0	7	14	0	0	0
Sciaenidae							
Aplodinotus grunniens	Freshwater Drum	4	0	0	0	1	0
Elassomatidae							
Elassoma zonatum	Pygmy Sunfish	0	0	0	0	0	0

Appendix I continued: Abundance of fish species collected across sampling season for sites within the Lampasas and Yegua subbasins

Family	Genus Species	Common name	Lampasas			Yegua		
			LM1	LM2	LM3	YG1	YG2	YG3
Lepisosteidae								
	Atractosteus spatula	Alligator Gar	0	0	0	0	1	0
	Lepisosteus oculatus	Spotted Gar	0	0	0	5	24	1
	Lepisosteus osseus	Longnose gar	0	0	1	2	1	0
Amiidae								
	Amia calva	Bowfin	0	0	0	0	0	0
Cluepidae								
	Dorosoma cepedianum	Gizzard Shad	0	0	2	22	9	0
	Dorosoma petenense	Threadfin Shad	0	0	0	48	9	0
Cyprinidae								
	Campostoma anomalum	Central Stoneroller	14	256	53	0	0	0
	Cyprinella lutrensis	Red Shiner	4	61	391	6552	6	1
	Cyprinella venusta	Blacktail Shiner	571	554	1285	172	0	148
	Cyprinus carpio	Common Carp	0	0	6	0	14	0
	Hybognathus nuchalis	Mississippi Silvery Minnow	0	0	0	3	0	0
	Lythrurus fumeus	Ribbon Shiner	0	0	0	2	0	446
	Macrhybopsis hyostoma	Shoal Chub	0	0	0	2	0	0
	Macrhybopsis storeriana	Silver Chub	0	0	0	0	0	0
	Notemigonus crysoleucas	Golden Shiner	0	0	0	0	0	0
	Notropis buchanani	Ghost Shiner	0	3	0	679	0	0
	Notropis shumardi	Silverband Shiner	0	0	0	9	0	0
	Notropis texanus	Weed Shiner	0	0	0	0	0	0
	Notropis volucellus	Mimic Shiner	61	28	254	7	0	0
	Opsopoeodus emiliae	Pugnose Minnow	0	0	0	37	0	0
	Pimephales promelas	Fathead Minnow	0	0	0	0	0	0

Pimephales vigilax	Bullhead Minnow	0	0	9	783	1	17
Catostomidae							
Carpiodes carpio	River Carpsucker	0	1	0	13	2	0
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	2	7	0
Minytrema melanops	Spotted Sucker	0	0	0	0	0	0
Moxostoma congestum	Grey Redhorse	10	80	62	0	0	0
Characidae							
Astyanax mexicanus	Mexican Tetra	2	0	3	0	0	0
Ictaluridae							
Ameiurus melas	Black Bullhead	0	0	0	1	0	0
Ameiurus natalis	Yellow Bullhead	5	0	0	1	0	22
Ictalurus punctatus	Channel Catfish	1	21	25	18	5	4
Ictalurus furcatus	Blue Catfish	0	0	0	3	1	0
Noturus gyrinus	Tadpole Madtom	0	0	0	1	0	17
Pylodictis olivaris	Flathead Catfish	2	1	0	3	0	1
Loricariidae							
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	0	0	0	0	0	0
Esocidae							
Esox americanus	Chain Pickerel	0	0	0	0	0	0
Aphredoderidae							
Aphredoderus sayanus	Pirate Perch	0	0	0	1	0	14
Mugilidae							
Agonostomus monticola	Mountain Mullet	0	0	0	0	0	0
Mugil cephalus	Stripped Mullet	0	0	0	0	15	0
Atherinidae							
Labidesthes sicculus	Brook Silverside	0	0	0	173	6	0
Menidia beryllina	Inland Silverside	0	0	0	27	1	0
Fundulidae							
Fundulus chrysotus	Golden Topminnow	0	0	0	0	0	0

Fundulus notatus	Blackstripe Topminnow	6	37	81	4	1	5
Fundulus olivaceus	Blackspotted Topminnow	0	0	0	1	0	0
Poecilidae							
Gambusia affinis	Western Mosquitofish	181	165	237	1060	28	197
Poecilia latipinna	Sailfin Molly	0	0	0	0	4	0
Cyprinidontidae							
Cyprinodon variegatus	Sheepshead Minnow	0	0	0	0	0	0
Moronidae							
Morone chrysops	White Bass	0	0	0	1	0	0
Centrarchidae							
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0
Lepomis cyanellus	Green Sunfish	6	7	6	10	0	8
Lepomis gulosus	Warmouth	3	0	1	13	22	14
Lepomis humilis	Orangespotted Sunfish	0	0	0	112	16	0
Lepomis macrochirus	Bluegill	36	6	38	66	162	107
Lepomis marginatus	Dollar Sunfish	0	0	0	0	0	0
Lepomis megalotis	Longear Sunfish	546	101	157	199	44	35
Lepomis microlophus	Redear Sunfish	2	0	0	0	0	9
Lepomis miniatus	Redspotted Sunfish	0	0	0	0	0	0
Lepomis symmetricus	Bantom Sunfish	0	0	0	0	0	0
Micropterus dolomieu	Smallmouth Bass	0	3	0	0	0	0
Micropterus punctulatus	Spotted Bass	17	17	6	5	0	0
Micropterus salmoides	Largemouth Bass	0	15	38	15	6	7
Micropterus treculii	Guadalupe Bass	3	42	12	0	0	0
Pomoxis annularis	White Crappie	0	0	0	17	3	0
Pomoxis nigromaculatus	Black Crappie	0	0	0	1	13	0
Percidae							
Etheostoma chlorosoma	Bluntnose Darter	0	0	0	14	0	11
Etheostoma gracile	Slough Darter	0	0	0	32	1	7

Etheostoma parvipinne	Goldstripped Darter	0	0	0	0	0	1
Etheostoma spectabile	Orangethroat Darter	187	183	40	0	0	0
Percina carbonaria	Texas Logperch	0	7	0	0	0	0
Percina macrolepida	Bigscale Logperch	0	0	0	0	0	0
Percina sciera	Dusky Darter	0	12	1	2	0	6
Sciaenidae							
Aplodinotus grunniens	Freshwater Drum	3	2	0	1	4	0
Elassomatidae							
Elassoma zonatum	Pygmy Sunfish	0	0	0	0	0	0

Appendix I continued: Abundance of fish species collected across sampling season for sites within the Little River subbasin

Family	Genus Species	Common name	Little River						
			LR1	LR2	LR3	LR4	LR5	LR6	LR7
Lepisosteidae									
	Atractosteus spatula	Alligator Gar	0	0	0	0	0	0	0
	Lepisosteus oculatus	Spotted Gar	2	0	1	0	1	0	1
	Lepisosteus osseus	Longnose gar	5	0	1	0	3	0	0
Amiidae									
	Amia calva	Bowfin	0	0	0	0	0	0	0
Cluepidae									
	Dorosoma cepedianum	Gizzard Shad	1	0	0	0	1	0	0
	Dorosoma petenense	Threadfin Shad	116	0	1	0	0	0	0
Cyprinidae									
	Campostoma anomalum	Central Stoneroller	4	5	1	109	49	140	19
	Cyprinella lutrensis	Red Shiner	16521	757	39	125	1	0	6
	Cyprinella venusta	Blacktail Shiner	7	183	167	955	608	222	1176
	Cyprinus carpio	Common Carp	2	0	0	3	0	0	0
	Hybognathus nuchalis	Mississippi Silvery Minnow	2	2	0	0	0	0	0
	Lythrurus fumeus	Ribbon Shiner	0	1	0	0	0	0	0
	Macrhybopsis hyostoma	Shoal Chub	128	0	0	0	0	0	0
	Macrhybopsis storeriana	Silver Chub	0	0	0	0	0	0	0
	Notemigonus crysoleucas	Golden Shiner	0	0	1	0	0	0	0
	Notropis buchanani	Ghost Shiner	574	2	0	0	0	0	0
	Notropis shumardi	Silverband Shiner	0	0	0	0	0	0	0
	Notropis texanus	Weed Shiner	0	0	0	0	0	0	0
	Notropis volucellus	Mimic Shiner	3	10	60	27	13	0	32
	Opsopoeodus emiliae	Pugnose Minnow	1	0	0	0	0	0	0
	Pimephales promelas	Fathead Minnow	0	0	0	0	0	0	0

Pimephales vigilax	Bullhead Minnow	10240	133	28	13	0	0	1
Catostomidae								
Carpiodes carpio	River Carpsucker	1	0	1	0	0	0	0
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	0	0	0	0
Minytrema melanops	Spotted Sucker	0	0	0	0	0	0	0
Moxostoma congestum	Grey Redhorse	0	1	4	0	0	0	8
Characidae								
Astyanax mexicanus	Mexican Tetra	0	0	0	0	0	0	0
Ictaluridae								
Ameiurus melas	Black Bullhead	0	0	0	0	0	0	0
Ameiurus natalis	Yellow Bullhead	0	0	0	0	1	0	0
Ictalurus punctatus	Channel Catfish	76	8	9	11	4	3	13
Ictalurus furcatus	Blue Catfish	8	0	1	0	0	0	0
Noturus gyrinus	Tadpole Madtom	0	1	1	0	0	0	0
Pylodictis olivaris	Flathead Catfish	0	2	2	1	0	1	0
Loricariidae								
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	0	0	0	0	0	0	0
Esocidae								
Esox americanus	Chain Pickerel	0	0	0	0	0	0	0
Aphredoderidae								
Aphredoderus sayanus	Pirate Perch	0	0	0	0	0	0	0
Mugilidae								
Agonostomus monticola	Mountain Mullet	0	0	0	0	0	0	8
Mugil cephalus	Stripped Mullet	0	0	0	0	0	0	0
Atherinidae								
Labidesthes sicculus	Brook Silverside	1	53	0	0	0	0	0
Menidia beryllina	Inland Silverside	0	0	1	0	0	0	0
Fundulidae								
Fundulus chrysotus	Golden Topminnow	0	0	0	0	0	0	0

Fundulus notatus	Blackstripe Topminnow	0	0	0	0	0	0	0
Fundulus olivaceus	Blackspotted Topminnow	0	0	0	0	0	0	0
Poecilidae								
Gambusia affinis	Western Mosquitofish	207	59	45	49	44	8	352
Poecilia latipinna	Sailfin Molly	0	0	0	0	0	0	5
Cyprinidontidae								
Cyprinodon variegatus	Sheepshead Minnow	0	0	0	0	0	0	0
Moronidae								
Morone chrysops	White Bass	0	1	0	0	0	0	0
Centrarchidae								
Lepomis auritus	Redbreast Sunfish	0	0	0	0	3	16	0
Lepomis cyanellus	Green Sunfish	1	21	31	63	11	76	12
Lepomis gulosus	Warmouth	1	0	1	0	0	0	0
Lepomis humilis	Orangespotted Sunfish	6	2	0	1	0	0	0
Lepomis macrochirus	Bluegill	2	10	10	23	73	23	0
Lepomis marginatus	Dollar Sunfish	0	0	0	0	0	0	0
Lepomis megalotis	Longear Sunfish	67	61	87	120	84	70	22
Lepomis microlophus	Redear Sunfish	0	0	0	0	10	4	0
Lepomis miniatus	Redspotted Sunfish	0	0	0	0	0	0	0
Lepomis symmetricus	Bantom Sunfish	0	0	0	0	0	0	0
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	0	0
Micropterus punctulatus	Spotted Bass	0	1	2	1	1	0	0
Micropterus salmoides	Largemouth Bass	3	0	0	6	5	9	1
Micropterus treculii	Guadalupe Bass	0	0	7	25	11	4	19
Pomoxis annularis	White Crappie	1	3	3	0	0	0	0
Pomoxis nigromaculatus	Black Crappie	0	0	0	0	0	0	0
Percidae								
Etheostoma chlorosoma	Bluntnose Darter	0	0	0	0	0	0	0
Etheostoma gracile	Slough Darter	0	6	2	0	0	0	0

Etheostoma parvipinne	Goldstripped Darter	0	0	0	0	0	0	0
Etheostoma spectabile	Orangethroat Darter	0	0	44	29	10	32	16
Percina carbonaria	Texas Logperch	0	0	0	0	4	0	0
Percina macrolepida	Bigscale Logperch	0	0	0	0	5	0	0
Percina sciera	Dusky Darter	0	14	5	1	0	0	0
Sciaenidae								
Aplodinotus grunniens	Freshwater Drum	1	0	0	0	0	0	0
Elassomatidae								
Elassoma zonatum	Pygmy Sunfish	0	0	0	0	0	0	0

Appendix I continued: Abundance of fish species collected across sampling season for sites within the Lower Brazos subbasin

Family	Genus Species	Common name	Lower Brazos							
			LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8
Lepisosteidae										
	Atractosteus spatula	Alligator Gar	2	0	0	0	0	0	0	0
	Lepisosteus oculatus	Spotted Gar	2	0	1	1	4	0	0	2
	Lepisosteus osseus	Longnose gar	0	0	0	0	1	0	0	1
Amiidae										
	Amia calva	Bowfin	1	0	0	1	1	0	0	0
Cluepidae										
	Dorosoma cepedianum	Gizzard Shad	7	0	0	10	28	2	0	2
	Dorosoma petenense	Threadfin Shad	58	0	0	0	85	0	0	0
Cyprinidae										
	Campostoma anomalum	Central Stoneroller	0	0	0	0	0	0	0	0
	Cyprinella lutrensis	Red Shiner	1936	42	2	0	1212	0	13	102
	Cyprinella venusta	Blacktail Shiner	2	0	334	0	1318	682	75	2722
	Cyprinus carpio	Common Carp	0	0	0	0	0	0	0	0
	Hybognathus nuchalis	Mississippi Silvery Minnow	18	0	0	0	36	0	0	7
	Lythrurus fumeus	Ribbon Shiner	0	1	785	0	23	450	317	65
	Macrhybopsis hyostoma	Shoal Chub	3	0	0	0	0	0	0	0
	Macrhybopsis storeriana	Silver Chub	0	0	0	0	0	0	0	0
	Notemigonus crysoleucas	Golden Shiner	0	0	0	2	2	3	0	0
	Notropis buchanani	Ghost Shiner	139	0	0	0	40	51	0	36
	Notropis shumardi	Silverband Shiner	109	0	0	0	31	0	0	1
	Notropis texanus	Weed Shiner	0	0	0	0	5	0	0	0
	Notropis volucellus	Mimic Shiner	1	0	53	0	17	80	0	16
	Opsopoeodus emiliae	Pugnose Minnow	10	0	0	22	4	4	1	25
	Pimephales promelas	Fathead Minnow	0	0	1	0	0	0	0	0

Pimephales vigilax	Bullhead Minnow	264	369	685	0	94	0	10	175
Catostomidae									
Carpiodes carpio	River Carpsucker	4	0	3	1	1	3	1	1
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	0	0	0	0	0
Minytrema melanops	Spotted Sucker	0	0	0	0	22	2	12	4
Moxostoma congestum	Grey Redhorse	0	0	0	0	0	0	0	0
Characidae									
Astyanax mexicanus	Mexican Tetra	0	0	0	0	0	0	0	0
Ictaluridae									
Ameiurus melas	Black Bullhead	0	0	0	0	0	0	3	0
Ameiurus natalis	Yellow Bullhead	0	0	0	0	0	5	0	0
Ictalurus punctatus	Channel Catfish	10	1	0	1	6	1	0	5
Ictalurus furcatus	Blue Catfish	131	0	0	0	0	0	0	0
Noturus gyrinus	Tadpole Madtom	1	0	0	0	1	6	0	19
Pylodictis olivaris	Flathead Catfish	0	0	0	0	1	0	0	1
Loricariidae									
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	1	0	0	0	0	0	0	0
Esocidae									
Esox americanus	Chain Pickerel	0	0	0	0	0	2	0	0
Aphredoderidae									
Aphredoderus sayanus	Pirate Perch	0	0	0	4	0	1	0	0
Mugilidae									
Agonostomus monticola	Mountain Mullet	0	0	0	0	0	0	0	0
Mugil cephalus	Stripped Mullet	179	0	0	0	2	0	0	2
Atherinidae									
Labidesthes sicculus	Brook Silverside	0	0	0	11	134	0	25	254
Menidia beryllina	Inland Silverside	12	0	0	0	2	0	0	0
Fundulidae									
Fundulus chrysotus	Golden Topminnow	0	0	0	38	0	0	0	0

Fundulus notatus	Blackstripe Topminnow	0	0	0	14	119	166	532	202
Fundulus olivaceus	Blackspotted Topminnow	0	0	0	0	0	0	0	0
Poecilidae									
Gambusia affinis	Western Mosquitofish	254	2283	236	26	404	62	176	94
Poecilia latipinna	Sailfin Molly	3	875	0	0	0	0	0	0
Cyprinidontidae									
Cyprinodon variegatus	Sheepshead Minnow	0	886	0	4	0	0	0	0
Moronidae									
Morone chrysops	White Bass	0	0	0	0	0	0	0	0
Centrarchidae									
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0	0	0
Lepomis cyanellus	Green Sunfish	0	1	6	0	2	0	5	1
Lepomis gulosus	Warmouth	4	0	0	105	1	21	20	1
Lepomis humilis	Orangespotted Sunfish	0	0	0	3	6	0	0	3
Lepomis macrochirus	Bluegill	7	1	1	186	45	155	47	32
Lepomis marginatus	Dollar Sunfish	0	0	0	0	0	6	0	0
Lepomis megalotis	Longear Sunfish	11	0	176	1	116	58	118	245
Lepomis microlophus	Redear Sunfish	0	0	0	6	1	1	5	1
Lepomis miniatus	Redspotted Sunfish	0	0	0	0	0	17	0	0
Lepomis symmetricus	Bantom Sunfish	0	0	0	8	0	0	0	0
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	0	0	0
Micropterus punctulatus	Spotted Bass	0	0	0	1	79	27	2	13
Micropterus salmoides	Largemouth Bass	0	0	4	16	25	5	16	8
Micropterus treculii	Guadalupe Bass	0	0	0	0	5	0	0	0
Pomoxis annularis	White Crappie	0	0	0	115	1	14	1	2
Pomoxis nigromaculatus	Black Crappie	0	0	0	6	3	10	0	1
Percidae									
Etheostoma chlorosoma	Bluntnose Darter	0	0	0	2	0	0	2	2
Etheostoma gracile	Slough Darter	0	0	2	0	2	3	6	1

Etheostoma parvipinne	Goldstripped Darter	0	0	0	0	0	0	0	0
Etheostoma spectabile	Orangethroat Darter	0	0	0	0	0	0	0	0
Percina carbonaria	Texas Logperch	0	0	0	0	0	0	0	0
Percina macrolepida	Bigscale Logperch	0	0	0	0	0	0	0	0
Percina sciera	Dusky Darter	0	0	0	0	12	13	0	3
Sciaenidae									
Aplodinotus grunniens	Freshwater Drum	1	0	0	0	0	0	0	0
Elassomatidae									
Elassoma zonatum	Pygmy Sunfish	0	0	0	0	0	15	0	0

Appendix I continued: Abundance of fish species collected across sampling season for sites within the Navasota subbasin

Family	Genus Species	Common name	Navasota					
			NV1	NV2	NV3	NV4	NV5	NV6
Lepisosteidae								
	Atractosteus spatula	Alligator Gar	0	0	0	0	0	0
	Lepisosteus oculatus	Spotted Gar	2	10	0	1	1	0
	Lepisosteus osseus	Longnose gar	1	0	0	1	0	0
Amiidae								
	Amia calva	Bowfin	0	0	0	0	0	0
Cluepidae								
	Dorosoma cepedianum	Gizzard Shad	0	6	8	5	37	0
	Dorosoma petenense	Threadfin Shad	0	2	0	3	503	0
Cyprinidae								
	Campostoma anomalum	Central Stoneroller	0	0	0	0	0	0
	Cyprinella lutrensis	Red Shiner	492	226	37	8	121	173
	Cyprinella venusta	Blacktail Shiner	205	380	337	71	0	0
	Cyprinus carpio	Common Carp	0	0	0	1	1	0
	Hybognathus nuchalis	Mississippi Silvery Minnow	325	544	0	1	0	0
	Lythrurus fumeus	Ribbon Shiner	34	280	40	35	55	0
	Macrhybopsis hyostoma	Shoal Chub	0	0	0	0	0	0
	Macrhybopsis storeriana	Silver Chub	0	0	0	0	0	0
	Notemigonus crysoleucas	Golden Shiner	1	0	0	1	2	2
	Notropis buchanani	Ghost Shiner	1	2	0	0	0	0
	Notropis shumardi	Silverband Shiner	55	0	0	0	0	0
	Notropis texanus	Weed Shiner	0	0	0	0	0	0
	Notropis volucellus	Mimic Shiner	1	1	0	0	0	0
	Opsopoeodus emiliae	Pugnose Minnow	1	12	1	0	11	0
	Pimephales promelas	Fathead Minnow	0	0	0	0	0	0

Pimephales vigilax	Bullhead Minnow	154	188	98	125	30	1
Catostomidae							
Carpiodes carpio	River Carpsucker	12	1	2	0	0	0
Ictiobus bubalus	Smallmouth Buffalo	1	0	0	3	15	0
Minytrema melanops	Spotted Sucker	0	0	1	0	0	0
Moxostoma congestum	Grey Redhorse	0	0	0	0	0	0
Characidae							
Astyanax mexicanus	Mexican Tetra	0	0	0	0	0	0
Ictaluridae							
Ameiurus melas	Black Bullhead	0	0	0	0	0	2
Ameiurus natalis	Yellow Bullhead	0	0	0	0	0	4
Ictalurus punctatus	Channel Catfish	2	7	1	1	1	0
Ictalurus furcatus	Blue Catfish	1	0	0	0	0	0
Noturus gyrinus	Tadpole Madtom	1	3	1	1	0	0
Pylodictis olivaris	Flathead Catfish	2	1	0	3	0	0
Loricariidae							
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	0	0	0	0	0	0
Esocidae							
Esox americanus	Chain Pickerel	0	1	1	5	0	0
Aphredoderidae							
Aphredoderus sayanus	Pirate Perch	8	8	2	0	0	0
Mugilidae							
Agonostomus monticola	Mountain Mullet	0	0	0	0	0	0
Mugil cephalus	Stripped Mullet	1	0	0	0	0	0
Atherinidae							
Labidesthes sicculus	Brook Silverside	6	42	23	13	1	0
Menidia beryllina	Inland Silverside	0	0	0	0	42	0
Fundulidae							
Fundulus chrysotus	Golden Topminnow	0	2	0	0	0	0

Fundulus notatus	Blackstripe Topminnow	3	19	99	77	2	2
Fundulus olivaceus	Blackspotted Topminnow	0	0	0	4	23	2
Poecilidae							
Gambusia affinis	Western Mosquitofish	101	2030	12	46	158	450
Poecilia latipinna	Sailfin Molly	0	0	0	0	0	0
Cyprinidontidae							
Cyprinodon variegatus	Sheepshead Minnow	0	0	0	0	0	0
Moronidae							
Morone chrysops	White Bass	0	0	0	0	4	0
Centrarchidae							
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0
Lepomis cyanellus	Green Sunfish	14	0	5	5	10	30
Lepomis gulosus	Warmouth	12	50	8	12	7	1
Lepomis humilis	Orangespotted Sunfish	0	16	0	2	11	0
Lepomis macrochirus	Bluegill	17	69	41	46	204	40
Lepomis marginatus	Dollar Sunfish	0	0	0	0	0	0
Lepomis megalotis	Longear Sunfish	71	22	115	128	83	10
Lepomis microlophus	Redear Sunfish	0	4	0	7	3	0
Lepomis miniatus	Redspotted Sunfish	0	0	0	0	0	0
Lepomis symmetricus	Bantom Sunfish	0	0	0	0	0	0
Micropterus dolomieu	Smallmouth Bass	2	0	0	0	0	0
Micropterus punctulatus	Spotted Bass	5	5	16	12	0	1
Micropterus salmoides	Largemouth Bass	5	2	5	51	20	20
Micropterus treculii	Guadalupe Bass	0	0	0	1	0	0
Pomoxis annularis	White Crappie	27	321	2	19	14	1
Pomoxis nigromaculatus	Black Crappie	0	7	0	14	0	0
Percidae							
Etheostoma chlorosoma	Bluntnose Darter	6	12	5	4	2	0
Etheostoma gracile	Slough Darter	2	4	2	6	0	2

Etheostoma parvipinne	Goldstripped Darter	0	0	0	0	0	0
Etheostoma spectabile	Orangethroat Darter	0	1	0	0	0	0
Percina carbonaria	Texas Logperch	0	1	0	0	0	0
Percina macrolepida	Bigscale Logperch	0	0	0	0	1	0
Percina sciera	Dusky Darter	0	7	3	26	0	0
Sciaenidae							
Aplodinotus grunniens	Freshwater Drum	0	0	0	0	0	0
Elassomatidae							
Elassoma zonatum	Pygmy Sunfish	0	0	0	0	0	0

APPENDIX II

SUMMARY OF THE ENVIRONMENTAL PARAMETERS FOR LOWER BRAZOS SUBBASIN SITES

Appendix VI. Summary of the environmental parameters for Lower Brazos subbasin sites.

	Central Brazos Subbasin Sites											
	CB1		CB2		CB3		CB4		CB5		CB6	
Mean Annual Flow[1]	46.24		21.81		174.14		122.02		34.90		47.85	
Drainage size (km²)	306.24		144.44		1153.27		808.07		231.12		482.98	
Habitat parameters - mean (Standard Error)												
Depth (cm)	46.72	(1.12)	46.43	(3.68)	44.18	(2.75)	25.77	(2.53)	40.30	(4.30)	39.99	(2.01)
Velocity (m/s)	0.06	(0.02)	0.19	(0.02)	0.28	(0.05)	0.08	(0.04)	0.04	(0.01)	0.15	(0.01)
Conductivity (mS/cm)	0.86	(0.20)	1.40	(0.18)	0.90	(0.24)	0.68	(0.08)	1.37	(0.39)	1.34	(0.27)
Temperature (°C)	18.56	(6.27)	19.34	(5.76)	20.11	(5.61)	18.20	(7.01)	19.88	(7.48)	19.33	(6.87)
Dissolved Oxygen (mg/l)	4.30	(0.26)	7.84	(1.60)	8.42	(1.49)	7.27	(1.04)	10.28	(2.73)	10.80	(1.38)
pH	7.55	(0.12)	8.31	(0.12)	8.07	(0.13)	8.15	(0.04)	8.29	(0.12)	8.26	(0.22)
Width:Depth	18.68	(0.69)	21.69	(1.04)	30.99	(3.72)	54.16	(15.21)	23.57	(3.03)	20.46	(0.80)
Habitat parameters - %												
Clay	25.83		-		26.11		77.78		26.11		50.00	
Silt	11.11		4.72		5.00		1.11		18.22		22.50	
Sand	6.67		38.06		8.33		1.11		10.67		0.83	
Gravel	21.67		47.22		5.56		8.89		18.89		23.33	
Cobble	8.89		4.44		10.83		10.00		8.33		3.33	
Boulder	24.72		3.33		3.61		1.11		-		-	
Bedrock	1.11		-		40.56		-		16.67		-	
Woody Debris	23.33		11.39		3.89		20.00		2.89		10.83	
Aquatic vegetation	-		4.17		5.28		-		2.22		4.17	
Cover	51.39		23.61		20.56		8.89		5.33		37.50	

	Lampasas Subbasin Sites						Yegua Subbasin Sites					
	LM1		LM2		LM3		YG1		YG2		YG3	
Mean Annual Flow[1]	238.71		216.01		147.54		300.17		232.13		24.56	
Drainage size (km²)	3422.03		3096.59		2115.05		3394.93		2625.42		277.73	
Habitat parameters - mean (SE)												
Depth (cm)	32.26	(0.77)	47.89	(3.54)	51.40	(1.44)	68.06	(11.71)	98.16	(33.00)	50.16	(2.56)
Velocity (m/s)	0.18	(0.03)	0.25	(0.03)	0.22	(0.05)	0.32	(0.05)	0.09	(0.08)	0.06	(0.03)
Conductivity (mS/cm)	0.49	(0.03)	1.28	(0.33)	1.89	(0.35)	0.66	(0.26)	0.54	(0.02)	0.79	(0.09)
Temperature (°C)	17.09	(5.51)	19.95	(7.18)	21.78	(7.64)	21.28	(5.25)	22.40	(4.29)	20.39	(3.88)
Dissolved Oxygen (mg/l)	7.72	(1.95)	9.04	(1.94)	12.49	(1.70)	6.56	(1.48)	5.65	(1.03)	5.42	(1.82)
pH	7.91	(0.16)	8.17	(0.01)	8.44	(0.07)	7.67	(0.23)	7.82	(0.21)	7.54	(0.24)
Width:Depth	49.45	(2.82)	34.55	(2.21)	38.42	(3.71)	16.29	(1.88)	31.01	(0.92)	28.24	(5.58)
Habitat parameters - %												
Clay	-		-		-		16.67		60.00		28.33	
Silt	11.11		2.22		7.78		30.83		26.67		24.17	
Sand	1.11		8.33		5.56		31.67		-		11.67	
Gravel	47.78		21.39		16.67		4.17		-		20.00	
Cobble	21.11		36.67		5.56		3.33		-		8.33	
Boulder	5.56		6.67		-		13.33		6.67		5.83	
Bedrock	13.33		21.39		65.56		-		-		-	
Woody Debris	14.44		7.50		7.78		24.17		36.67		31.67	
Aquatic vegetation	7.78		6.94		16.67		6.67		13.33		-	
Cover	52.22		10.83		20.00		9.17		23.33		69.17	

	Lower Brazos Subbasin Sites															
	LB1		LB2		LB3		LB4		LB5		LB6		LB7		LB8	
Mean Annual Flow[1]	77.03		4.04		11.34		25.52		191.09		27.24		22.80		65.51	
Drainage size (km²)	415.67		55.11		61.18		137.69		1031.16		147.02		123.03		433.84	
Habitat parameters - mean (SE)																
Depth (cm)	77.70	(19.26)	16.12	(0.94)	29.57	(11.32)	80.63	(1.73)	34.78	(1.31)	43.72	(1.52)	34.72	(7.37)	60.63	(6.38)
Velocity (m/s)	0.20	(0.05)	0.01	(0.00)	0.08	(0.03)	0.01	(0.00)	0.24	(0.01)	0.09	(0.02)	0.07	(0.03)	0.09	(0.04)
Conductivity (mS/cm)	1.55	(0.44)	0.99	(0.22)	0.60	(0.05)	0.80	(0.26)	0.45	(0.05)	0.38	(0.02)	0.53	(0.11)	0.64	(0.12)
Temperature (°C)	21.58	(6.28)	22.56	(5.67)	19.40	(6.26)	22.21	(4.89)	25.67	(6.20)	19.95	(4.75)	19.01	(5.87)	20.53	(5.89)
Dissolved Oxygen (mg/l)	7.76	(1.20)	7.04	(2.47)	7.46	(1.57)	10.20	(3.90)	11.62	(2.62)	8.61	(2.16)	6.52	(2.29)	7.99	(2.53)
pH	8.16	(0.21)	7.88	(0.24)	7.68	(0.27)	7.76	(0.50)	8.35	(0.19)	7.48	(0.09)	7.81	(0.21)	7.90	(0.18)
Width:Depth	17.65	(0.35)	28.92	(2.87)	16.20	(4.15)	23.18	(0.59)	35.47	(2.30)	18.44	(0.34)	29.19	(7.81)	21.29	(0.45)
Habitat parameters - %																
Clay	71.11		-		-		40.00		11.11		16.33		57.78		48.33	
Silt	15.56		50.00		10.00		50.00		8.17		4.67		13.33		10.00	
Sand	10.00		50.00		65.00		3.33		62.67		54.33		16.67		20.00	
Gravel	3.33		-		21.67		6.67		4.17		7.50		5.56		21.67	
Cobble	-		-		3.33		-		-		1.50		3.33		-	
Boulder	-		-		-		-		-		17.17		3.33		-	
Bedrock	-		-		-		-		13.89		-		-		-	
Woody Debris	20.00		-		26.67		33.33		6.61		10.67		30.00		15.83	
Aquatic vegetation	16.67		30.00		10.00		40.00		7.22		11.33		5.00		10.00	
Cover	23.33		-		58.33		56.67		7.72		53.33		66.67		45.00	

	Little River Subbasin Sites													
	LR1		LR2		LR3		LR4		LR5		LR6		LR7	
Mean Annual Flow[1]	1849.51		91.29		237.80		186.81		65.18		34.03		54.48	
Drainage size (km^2)	19688.32		818.48		1917.25		1506.12		525.52		274.34		439.24	
Habitat parameters - mean (SE)														
Depth (cm)	74.51	(5.82)	50.14	(6.70)	32.16	(0.57)	16.56	(4.10)	26.49	(2.70)	32.74	(2.58)	25.23	(2.07)
Velocity (m/s)	0.34	(0.05)	0.14	(0.03)	0.30	(0.08)	0.20	(0.02)	0.10	(0.04)	0.10	(0.04)	0.39	(0.05)
Conductivity (mS/cm)	0.64	(0.07)	0.79	(0.12)	0.45	(0.02)	0.81	(0.19)	0.50	(0.13)	0.39	(0.07)	0.77	(0.09)
Temperature (°C)	17.92	(5.83)	16.72	(6.06)	18.02	(5.23)	20.77	(5.99)	18.86	(4.26)	19.61	(6.52)	20.19	(3.96)
Dissolved Oxygen (mg/l)	9.30	(1.54)	8.17	(1.54)	8.99	(1.03)	14.49	(3.51)	7.94	(1.32)	11.63	(1.78)	8.46	(1.45)
pH	7.83	(0.11)	7.79	(0.04)	7.78	(0.20)	8.81	(0.44)	8.51	(0.20)	8.15	(0.03)	7.69	(0.34)
Width:Depth	36.31	(1.67)	12.84	(0.44)	39.67	(1.92)	146.72	(38.59)	52.36	(6.93)	27.17	(1.82)	54.34	(2.39)
Habitat parameters - %														
Clay	10.83		63.89		-		-		-		-		-	
Silt	25.28		-		4.44		-		0.83		2.83		2.50	
Sand	24.44		12.22		10.83		-		1.67		-		5.83	
Gravel	36.94		15.56		65.56		17.22		12.33		9.00		29.17	
Cobble	2.50		2.78		15.83		12.78		24.33		27.00		17.17	
Boulder	-		5.56		-		15.00		7.50		10.33		3.33	
Bedrock	-		-		3.33		53.89		53.33		50.83		42.00	
Woody Debris	8.89		16.67		22.50		-		9.17		4.83		7.17	
Aquatic vegetation	2.78		1.11		1.11		3.89		-		1.67		7.50	
Cover	1.94		39.44		53.33		28.89		19.17		9.67		56.17	

	Navasota Subbasin Sites											
	NV1		NV2		NV3		NV4		NV5		NV6	
Mean Annual Flow[1]	1131.46		964.14		860.88		486.12		160.57		30.86	
Drainage size (km^2)	5680.97		4840.86		4322.42		2440.75		806.21		154.96	
Habitat parameters - mean (SE)												
Depth (cm)	51.07	(2.34)	69.01	(6.76)	107.10	(14.36)	89.05	(18.96)	86.30	(25.08)	42.43	(17.69)
Velocity (m/s)	0.13	(0.03)	0.06	(0.01)	0.03	(0.00)	0.21	(0.03)	0.03	(0.01)	0.11	(0.11)
Conductivity (mS/cm)	0.54	(0.03)	0.47	(0.04)	0.37	(0.06)	0.26	(0.05)	0.91	(0.46)	0.32	(0.08)
Temperature (°C)	21.76	(5.59)	21.07	(5.71)	21.43	(5.83)	19.89	(4.99)	22.49	(5.97)	17.93	(6.11)
Dissolved Oxygen (mg/l)	7.16	(1.69)	7.59	(1.85)	8.24	(2.02)	8.30	(1.57)	9.44	(3.33)	4.37	(1.85)
pH	8.02	(0.14)	7.81	(0.07)	7.63	(0.07)	7.55	(0.13)	8.24	(0.28)	7.60	(0.18)
Width:Depth	35.98	(6.67)	17.66	(5.34)	25.67	(2.86)	29.93	(6.70)	34.11	(14.76)	24.85	(7.38)
Habitat parameters - %												
Clay	5.56		-		23.33		-		-		-	
Silt	40.00		52.78		30.00		44.44		-		10.00	
Sand	27.78		47.22		30.00		30.56		100.00		43.33	
Gravel	7.78		1.67		13.33		4.44		-		46.67	
Cobble	3.33		-		-		10.56		-		-	
Boulder	15.56		-		3.33		10.00		-		-	
Bedrock	-		-		-		-		-		-	
Woody Debris	10.00		23.89		33.33		19.44		15.00		10.00	
Aquatic vegetation	2.22		2.78		-		7.78		-		3.33	
Cover	10.00		31.11		46.67		57.78		56.67		96.67	

[1]National Hydrography Dataset Plus, (http://www.horizon-systems.com/nhdplus/)

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