Final Report

Fish Habitat Suitability Criteria Development for the Lower Brazos River

November 3, 2016

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Prepared for:

Texas Water Development Board

Austin, TX

TWDB Contract No. 1300011590

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ACKNOWLEDGMENTS

Funding provided by Texas Water Development Board Grant No. 130011590 and supported by the Wildlife and Sportfish Restoration Program. Without the collective effort of the following individuals this study would not have been possible:

Texas Parks and Wildlife Department, Inland Fisheries: Karim Aziz, Steve Boles, Jared Brown, Roy Kleinsasser, Kevin Kolodziejcyk, Gordon Linam, Steve Magnelia, Sarah Robertson, Ken Saunders, and Heather Williams;

Texas Parks and Wildlife Department, Water Resources: Dakus Geeslin, and Kyle Garmany

Texas Commission on Environmental Quality: George Gable, Robert Hanson, Leslie Patterson, and Lori Hamilton;

Texas Water Development Board: Mark Wentzel, Nolan Raphelt, and Michael Vielleux;

Brazos River Authority: Tiffany Morgan, Jack Davis, Jeremey Nickolai, and Nick Carmean; and

Landowners that provided access to study sites on the Brazos River.

INTRODUCTION

Senate Bill 2, enacted by the 77th Texas Legislature, established the Texas Instream Flow Program (TIFP) which is jointly administered by the Texas Commission on Environmental Quality (TCEQ), Texas Parks and Wildlife Department (TPWD), and Texas Water Development Board (TWDB). The purpose of the TIFP is to perform scientific and engineering studies to determine flow conditions necessary to support a sound ecological environment in the river basins of Texas (TIFP 2008). The TIFP identified the middle and lower Brazos River as a priority sub-basin study area. Furthermore, the 2017 State of Texas Water Plan (TWDB 2016[1]) recommends a future water supply project, Allens Creek Reservoir, which would divert flows from the lower Brazos River into a reservoir constructed on Allens Creek. An adaptive management approach has been stipulated within the state water right to refine the flow regimes under which diversions can occur from the Brazos River.

Instream flow studies utilize habitat models to determine the relationships between habitat and flow to quantify ecological flow requirements of fish and other aquatic biota in rivers and streams. A habitat model consists of a hydraulic model that predicts hydraulic conditions (current velocity and depth) coupled with habitat suitability criteria (HSC) of focal species or guilds, such as fish, to predict habitat utilization at a series of streamflows. Many approaches have been used to calculate HSC for fish (Vadas and Orth 2001; TIFP 2008) including nonparametric tolerance limits (Mosier and Ray 1992; Annear et al. 2005; TIFP 2008). These tolerance limits delineate a range of habitat conditions used by a proportion of the sampled population.

The primary objectives of this study were to develop HSC for guilds of fish in the Brazos River downstream of Waco, Texas with applicability to the Brazos River near the proposed Allens Creek Reservoir. The fish-habitat use data collected as part of this work augments an existing TIFP dataset compiled for the middle and lower Brazos River.

STUDY AREA

The Brazos River basin is one of the most diverse river basins in the state, spanning eight distinct ecoregions; rainfall conditions that vary from a mean average of 6 inches per year in headwater areas to more than 50 inches per year near its mouth (HDR 2001). The Brazos River flows for 1,280 miles (2,060 km) (Kammerer 1990) southeast and discharges into the Gulf of Mexico at Freeport, Texas. The upper and middle Brazos River main stem and tributaries have been altered by construction of 16 major reservoirs for flood control and water supply (Brazos BBEST 2012). Although the lower Brazos River remains unimpounded, flows are regulated by these upstream and tributary reservoirs. The US Geological Survey lists the river mileage from the mouth of the river to USGS gage 08096500, Brazos River at Waco, as 400.7 river miles (US Geological Survey 2016). Historical discharge records indicate highest flows generally occur during winter and spring (Zeug and Winemiller 2008); however, unpredictable rainstorms can generate high flow pulses and overbanking flows during any time of year.

Field efforts were focused on data collection from the Allens Creek Brazos River Study Site (ACRBRSS) as well as five existing instream flow study sites on the middle and lower Brazos River (Figure 1). The ACBRSS (site 12010 in Figure 1) was selected to complement previous work performed at this location. During a reconnaissance trip in May 2013, a large sand and gravel dredging operation was operating at

[1] http://www.twdb.texas.gov/waterplanning/swp/2017/doc/2017SWP_RecommendedProjects_062416.xlsx

the study site previously studied by Gelwick and Li (2002). In an effort to distance our efforts away from sand and gravel operations, we relocated our efforts approximately three river miles downstream of the FM 1093 bridge. The ACRBRSS is 3.7 river miles long between River Mile 129.5 and River Mile 125.8 (upstream boundary at 29°38'55.34"N, 96° 1'22.69"W; downstream boundary at 29°38'1.35"N, 95°59'25.94"W, respectively). The site is primarily represented by run and pool mesohabitats.

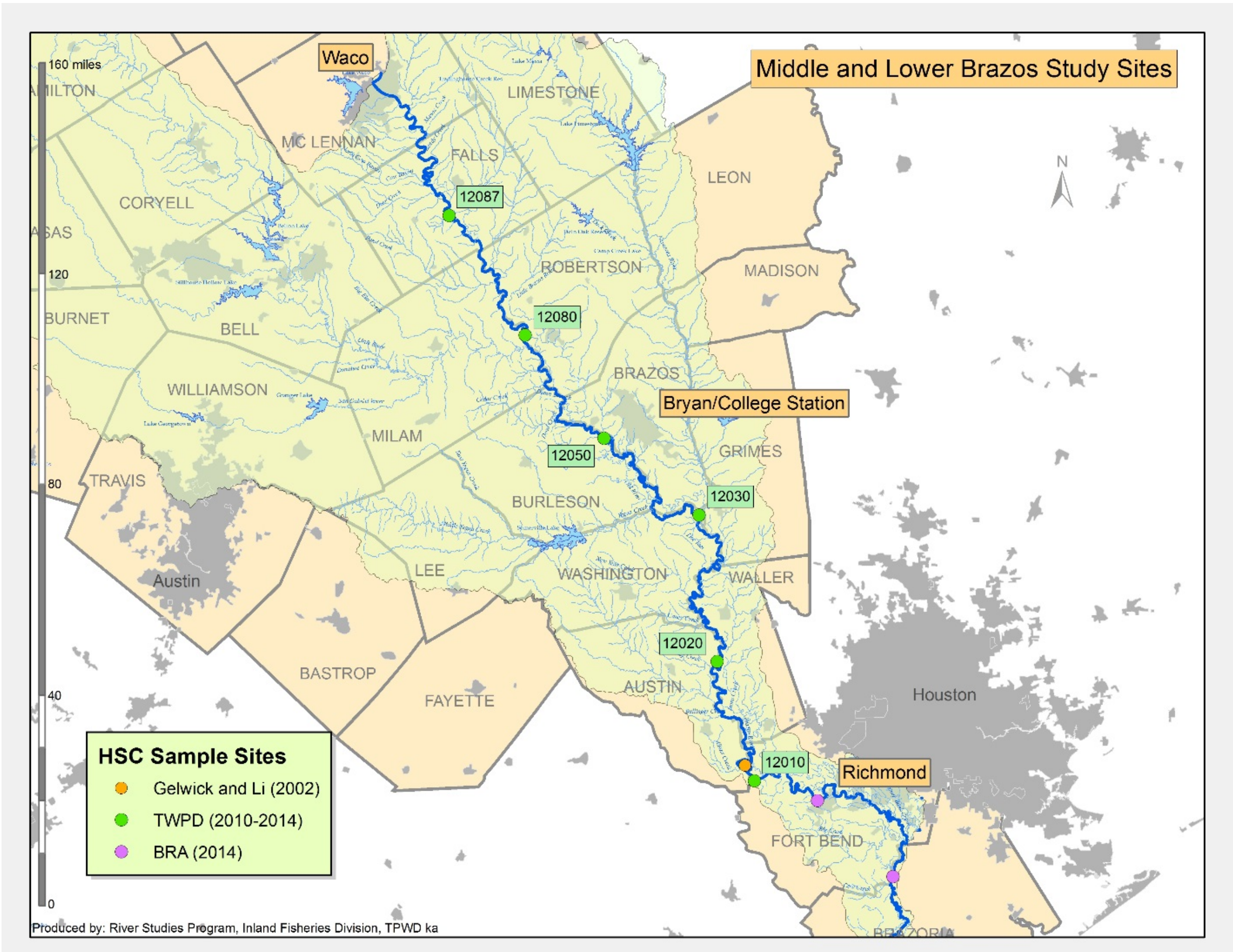

FIGURE 1.—Middle and lower Brazos River study sites and fish habitat suitability criteria sampling sites. The Allens Creek Brazos River Study Site is 12010.

METHODS

Flow Ranges

The main objective of this work was to collect and evaluate fish-habitat utilization data at three distinct baseflow conditions (low, medium and high) in the lower Brazos River. For the ACBRSS, target base flow ranges[2] were calculated by the Texas Water Development Board (TWDB) using daily data from the U.S. Geological Survey (USGS) streamflow gage, Brazos River at Richmond, Texas (USGS 08114000). Data collection during a variety of hydrologic conditions is desirable to ensure that instream flow study

[2] High base = 1,700-2,900 cfs; medium base = 900-1,699 cfs; low base = 500-899 cfs

results and determinations are valid across a range of baseflow conditions. However, climatic conditions and river flows did not facilitate collection of HSC data from low and medium baseflow conditions during the study period at the ACBRSS because of subsistence flow conditions (2011–2014 drought) followed by extended flooding. Subsistence flow conditions are not amenable to collection of HSC data because of environmental factors that override normal habitat utilization patterns in fish. For example, high water temperatures and low dissolved oxygen concentrations may preclude use of "preferred" habitat patches. In 2015, historic rainfall events produced extensive high flows in the river which presents safety concerns as well as prevents stable flow conditions necessary for fish and habitat data collection; high flows have continued through July 2016.

In March 2014 baseline fish assemblage data was collected during low flow conditions at the ACBRSS (methods outlined in BRA [2007] and TIFP [2008]). Two other baseline fish collections were made during 2014 from upstream sites on the Brazos River near Hempstead and Navasota (Figure 1) at low flow levels. Baseline fish data were examined to compare assemblages among sites but were not included in HSC datasets.

HSC Development

Habitat suitability criteria development is a multi-stage process that includes the following tasks: (1) substrate and mesohabitat mapping to employ a stratified random sampling design; (2) fish microhabitat sampling and habitat data collection to quantify habitat utilization; (3) evaluation of the suitability of integrating supplemental fish data; and (4) data analysis to generate habitat guilds and development of habitat suitability criteria for Brazos River key species and guilds.

Substrate and Mesohabitat Mapping

Substrate and mesohabitat mapping is used to generate a map of substrate and habitat combinations to support a stratified random sampling design. At the Allens Creek study site, in July 2013, substrate areas were mapped using a Trimble XT Global Positioning System (GPS); substrates were classified into the following categories: clay, silt, sand, gravel, or large rock. Raw GPS data was imported into a map layer or shapefile using Geographic Information System (GIS) software, ERSI ArcMap 10.x. Mesohabitat areas (i.e. backwater, pool, run, or riffle) were visually mapped using a Trimble XT GPS unit on September 23, 2014 at a high baseflow level of approximately 2,000 cubic feet per second (cfs). Next, a mesohabitat shapefile was created from the GPS field data and intersected with the substrate shapefile in ESRI ArcMap 10.x. in order to set up a stratified random sampling design for available mesohabitat-substrate combinations. GIS shapefiles are included in an electronic appendix.

Fish-Habitat Data Collection

A sampling matrix was generated for all of the Brazos River study sites including the ACBRSS to guide a stratified random sampling approach (Table 1). The sampling matrix was used to track total number of mesohabitat-substrate combinations or habitat areas sampled across Brazos TIFP sites.

The mesohabitat-substrate combination maps were used to randomly place sampling locations based on the distribution of points in the sampling matrix. The randomly selected sampling habitats were located using a GPS and marked by a weighted buoy, and left undisturbed for 30 minutes before fish collection to minimize the effects of disturbance. Fish were then sampled using the most appropriate sampling gear (i.e. seine, boat or barge electrofishing). Boat electrofishing was conducted using a Smith and Root 5.0 Generator Powered Pulsator (GPP) electrofisher and 8 amp generator. Generally electrofishing was conducted within the range of 60-70 pulses per second direct current. Usually two electrofish boat passes were conducted through the habitat area of interest while netters would collect all stunned fish to the maximum extent possible. For wadable habitat areas, straight seines of 15 or 30 ft in width and 3/16 and 3/8 inch mesh sizes respectively were utilized to collect fish. For wadable areas with dense vegetation and other cover, barge electrofishing was utilized using a similar set up as the boat electrofishing, however a wand and 300 ft cord were utilized to pulse electricity into the water. Where appropriate, a combination of these gear types was used to effectively sample each selected mesohabitat.

Sampled habitat areas were then delineated into a rectangular polygon and habitat measurements taken at five points, A-E (Figure 2). Depth (in feet) and velocity (in feet per second) were measured using a Marsh-McBirney Flowmate 2000 current velocity meter and top-setting wading rod (4, 6, or 10 foot wading rod). Primary and secondary substrate calls were made using a sounding pole and/or scoop for deeper sites or by hand at wadable locations. Substrate size was classified according to the modified Wentworth scale (TIFP 2008). At point C of each habitat area sampled, one water quality measurement for temperature (in ºC), dissolved oxygen (in milligrams per liter), conductivity (in Micro-Siemens per centimeter), and pH was taken using an YSI 600LS multiprobe instrument. At point C, other field parameters recorded included channel position (edge or mid-channel) as well as instream cover type (TIFP 2008) and percentage.

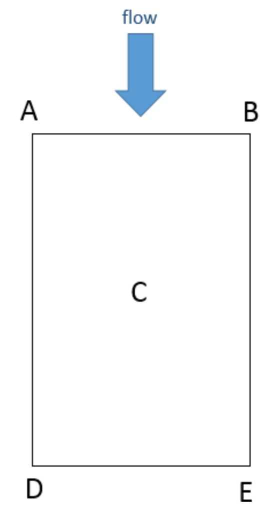

FIGURE 2.–Orientation of points A-E in each habitat area sampled.

In total 302 discrete fish-habitat samples were collected from the Brazos River study sites including the ACBRSS.

Fish Sample Processing

Fish were processed independently for each mesohabitat-substrate area sampled. Larger fishes were identified in the field, measured (total length), examined for anomalies, photographed, and released. Retained fishes were preserved in 10% formalin and returned to the laboratory. In the laboratory, fish samples were processed for curation (transferred to 70% ethanol), sorted by species, identified, enumerated, and selected species measured. Many fishes utilize different habitats as they grow and mature. Eight species were split into two life stages (large or small) based on Mayes et al. (2013); also see TIFP/SARA (2011). Fishes that were measured and their respective size thresholds are provided in Table 2. Initial identifications were confirmed and vouchered specimens permanently housed at the University of Texas Biodiversity Collections Facility in Austin, Texas. Data from all fish and habitat samples were entered into the GoFish database housed by TPWD Inland Fisheries.

Supplemental Fish Data

In addition to the HSC data, fish-habitat data were compiled from several other sources in order to assess their appropriateness for inclusion in HSC development analyses including:

- TPWD Brazos River HSC data, 2010-2014

- TPWD Brazos River baseline data, 2014
- Gelwick and Li Brazos River HSC data near ACBRSS, 2002
- Brazos River Authority HSC data near Richmond, 2014
- Brazos River Authority HSC data near Rosharon, 2014-15

Fish collection methodologies were reviewed for each supplemental fish data source. In addition, to methodological review, fish data from each supplemental sources were statistically analyzed for comparison. Relative abundance fish data from TPWD, Gelwick and Li (2002), and BRA (2014-2015) was fourth root transformed to account for differences in sampling gear types/efficiencies and also to reduce the influence of abundant species (Clarke, 1993). The Bray-Curtis similarity coefficient was calculated to generate similarity matrices. Variation of fish species assemblage across sites was examined using cluster analysis (CLUSTER) based on Bray-Curtis similarity matrix. All analyses were performed using PRIMER.

Data Analysis to Generate Fish Habitat Guilds and Habitat Suitability Criteria

Generating habitat suitability criteria for nearly 60 individual species/size class categories would complicate interpretation of study results, yet basing flow recommendations on the needs of a few key species may be detrimental to other species. Therefore, a fish habitat guild approach was used to best represent the habitat needs of the entire fish community and habitat guild is defined as a group of species that use similar habitat. Grouping species based on similar habitat use, and creating HSC for each resulting habitat guild simplifies interpretation of study results while still representing the flow requirements of the entire fish community. The habitat guild approach is often used for instream flow studies on warmwater streams with high species richness (TIFP/SARA 2011; Persinger et al. 2010; BIO-WEST 2008) such as the lower Brazos River.

To create guilds, habitat conditions were characterized for each sample area (N=302) by calculating the mean of the depth and velocity data for the five individual measurements taken at each sampling area. Mean depth and current velocity, and dominant substrate were combined with abundance data from each species/life stage and summarized in a Canonical Correspondence Analysis, or CCA (ter Braak 1986).

Habitat data from all species/life stage categories within a particular guild were combined to generate frequency histograms for the continuous variables depth and velocity. Data were binned using 0.25 ft increments for depth and 0.1 ft/s increments for velocity. Suitability criteria were then generated using nonparametric tolerance limits (NPTL) based on the central 50%, 75%, 90%, and 95% of the data (Bovee 1986) using custom software produced by Dr. Thom Hardy (Texas State University). Tolerance limits for the central 50% of the data were used as boundaries for the most selected habitat and the range of data between these two points was assigned a suitability of 1.0. Data between the 50% tolerance limits and the 75% tolerance limits were assigned a suitability of 0.5. Data between the 75% tolerance limits and the 90% tolerance limits were assigned a suitability of 0.2; and data between the 90% tolerance limits and the 95% tolerance limits received a suitability of 0.1. Data beyond the 95% tolerance limits were considered unsuitable and given a suitability of zero.

RESULTS

Substrate and Mesohabitat Mapping

Substrate and mesohabitat maps were generated in ArcMap 10.x for the Brazos River study sites including ACBRSS and included in electronic appendix.

HSC Development

Between August 2010 and September 2014, 302 fish samples were collected from discrete habitat-substrate combinations across all of the Brazos River sites and baseflow conditions (Table 3). On September 24-25, 2014, fish-habitat utilization data was collected at high baseflow conditions at the ACBRSS; due to extreme flooding conditions in the Brazos River during the study period this was the only baseflow condition sampled for HSC data at this site. At the Allens Creek site, fish-habitat data were collected in 21 discrete habitat patches representing the overall availability of mesohabitat-substrate combinations within the reach.

During HSC sampling, a total of 52,208 fish (49 species) were collected across all Brazos River sites (Table 4). Red Shiner *Cyprinella lutrensis* (N= 29,518) and Bullhead Minnow *Pimephales vigilax* (N=15,502) were the most abundant species collected and were ubiquitous.

Supplemental Fish Data

Fish-habitat utilization data were compiled from several sources in order to assess applicability for inclusion in the HSC dataset. Tables 3-7 provide the fish species names, abundance, and number of occurrences among sampled habitat areas for each of the datasets identified above.

CLUSTER dendrogram analysis across the sites shows site 12010 (near Allens Creek) and 12087 (near Marlin) are significantly different from each other and the rest of the sites (Figure 3). Significant difference between these sites is likely due to geomorphic differences of the Brazos River channel at the upstream (near Waco) and downstream (near the Richmond) ends of the study area. Among the remaining sites 12005 (BRA), 12020, 12080, and 12050 group out separately as significantly different from sites 12030 and 12015(Gelwick and Li) (Figure 3).

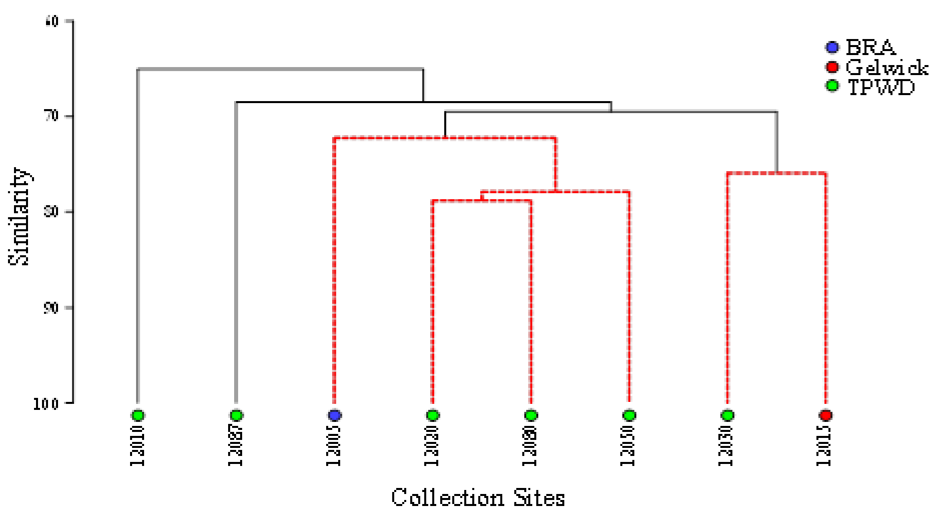

FIGURE 3.–Dendrogram for hierarchical clustering (using group-average linking) based on the Bray-Curtis similarity matrix of 4th-root transformed relative abundance of fish data on the Brazos River.

Although significant differences in fish assemblages were observed within TPWD HSC sites, and among the BRA and Gelwick and Li datasets, there were differences between sampling methodologies between the studies. For example, Gelwick and Li exclusively targeted large woody debris piles during electrofishing efforts, and the BRA data were collected at a mesohabitat scale rather than at the microhabitat scale, such as the TPWD HSC dataset. Hence the BRA and Gelwick and Li datasets were not used for subsequent species guilding analyses and HSC development.

Habitat Guilds and Habitat Suitability Criteria

For habitat guilding, Red Shiner and Bullhead Minnow were removed from the analysis since these two species made up more than 90% of the relative abundance of the overall assemblage and were found in all habitat types thus confounding habitat associations of other fish species. Without Red Shiner and Bullhead Minnow, relative abundances were recalculated and the CCA rerun. Based on the resulting CCA ordination plot, fish species were visually grouped into six habitat guilds (Figure 4). Where a particular species/life stage category fell in close proximity to guild boundaries, habitat descriptions from the literature and professional judgment were used to make final guild determination. The species/life stage categories and number of each collected within each of the resulting habitat guilds are presented in Table 8.

Categorical substrate data were used in the CCA analysis, and based on the resulting CCA plot, it was determined that current velocity and substrate were closely correlated, thus using substrate in habitat modeling for the Brazos River is not recommended.

Initial depth, velocity, and substrate HSC were developed for each habitat guild and reviewed. HSC modifications were made based on best professional judgment and previous experience. Given the known reduction in electrofishing capture efficiency at depths greater than approximately 6 ft, reductions in suitability for the Pool and Deep Pool guilds at depths greater than approximately 4-6 ft were more likely a result of sampling limitations rather than a pattern in habitat utilization. Fishes of the Deep Pool guild are known to commonly inhabit areas considerably deeper than those from which they were captured in this study. As a result, the depth HSC curve for Deep Pool was modified to exhibit a suitability of 1.0 for all depths of approximately 1.18 ft or greater. Similarly, to account for sampling limitations, the tail of the Pool HSC curve was also extended at a 0.5 suitability for all depths of approximately 0.96 ft or greater. Figure 5 shows the depth suitability for all six habitat guilds. Likewise, Figure 6 shows the current velocity suitability for all habitat guilds. Coordinates for each of these curves is provided for habitat modeling input (Table 9). Figure 7 shows the substrate suitability for each guild. However, our recommendation is to apply guild curves for only depth and current velocity to all six sites on the lower Brazos River to model hydraulic habitat at a range of streamflows and subsequent instream flow regime development.

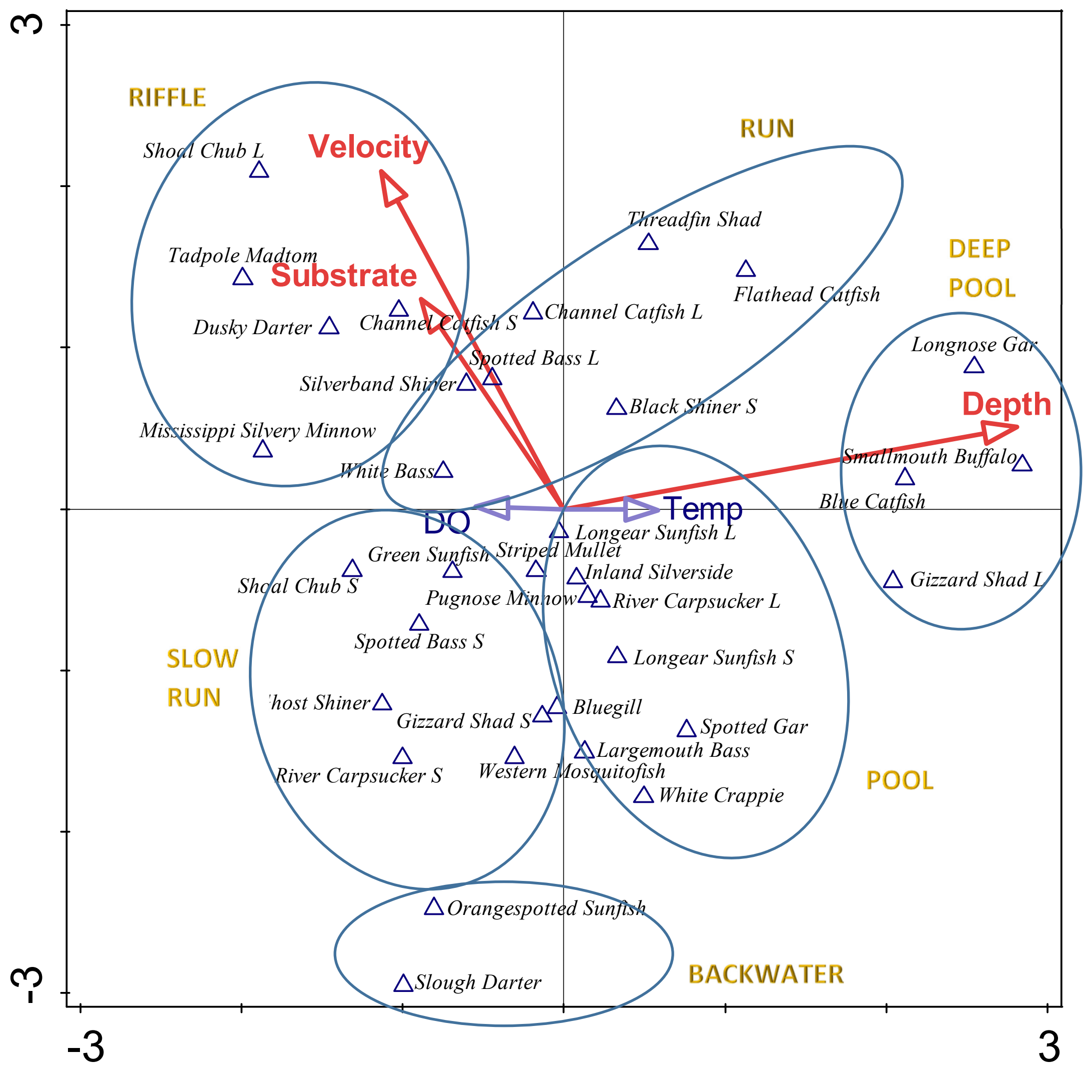

FIGURE 4.–CCA ordination plot with six fish habitat guilds for the middle and lower Brazos River (blue ovals) and associated name.

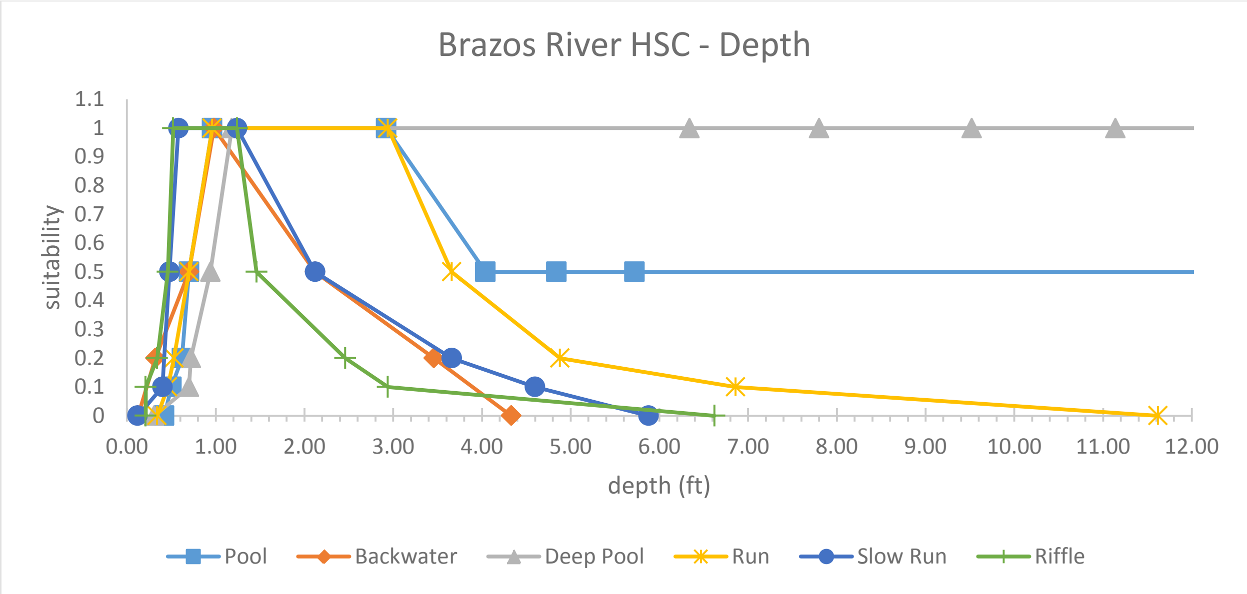

FIGURE 5.–Habitat suitability curves for depth of six fish habitat guilds.

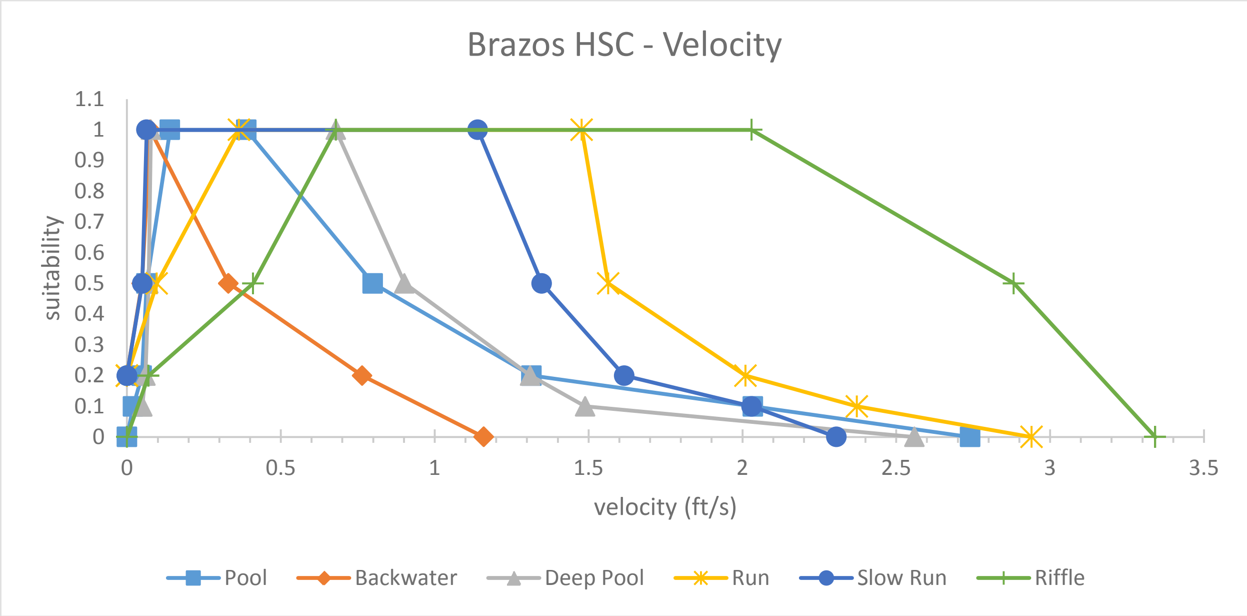

FIGURE 6.–Habitat suitability curves for current velocity of all six fish habitat guilds.

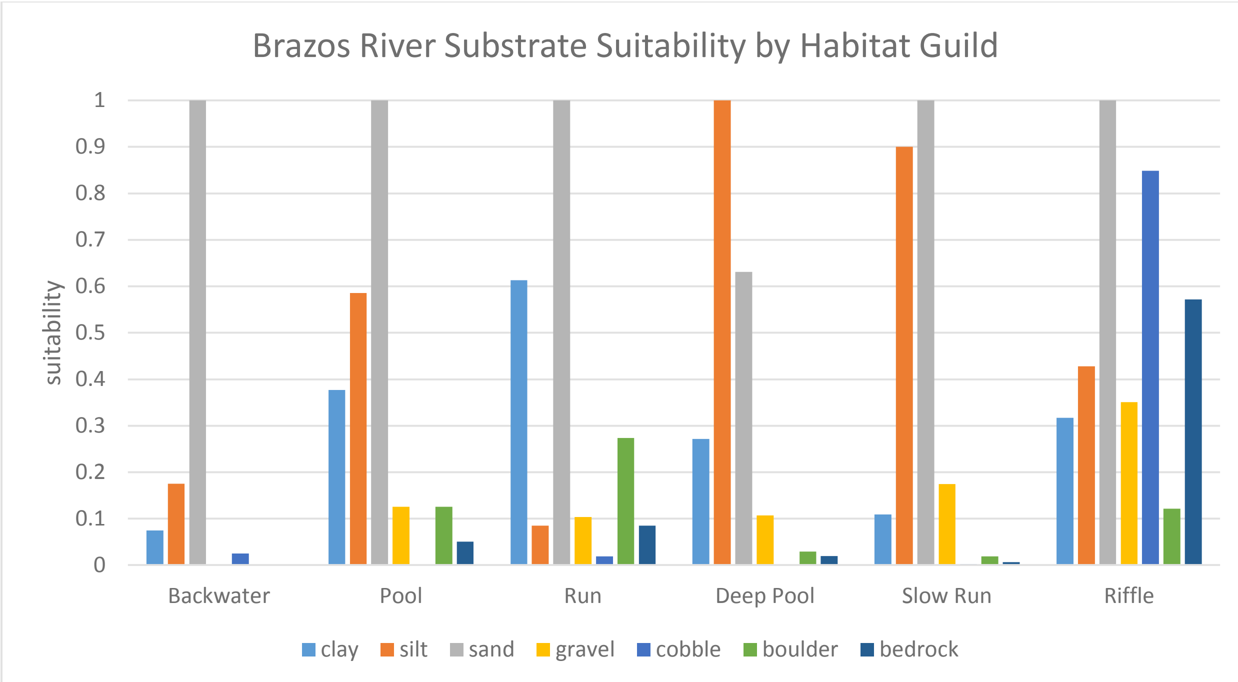

FIGURE 7.–Categorical substrate suitability for each of the six fish habitat guilds.

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TABLES

TABLE 1.–Sampling matrix for Brazos River used as a guide to distribute sampling locations among available mesohabitat-substrate combinations at low, medium, high, and all base flows at each of six study sites (see Figure 1). Upper table represents overall sample allocation across mesohabitat and substrate types.

Overall Sample Allocation	clay	silt	sand	gravel	large rock	
backwater	16	21	10	7	1	55
pool	10	16	21	3	6	56
riffle	1	0	10	35	7	53
run	25	28	129	74	15	271
	52	65	170	119	29	435

All Flows		clay	silt	sand	gravel	large rock	
12010	backwater	0	3	3	0	0	
12010	pool	3	6	8	0	0	
12010	riffle	0	0	0	3	0	
12010	run	6	7	28	13	0	76
12020	backwater	3	5	1	2	0	
12020	pool	2	2	2	0	0	
12020	riffle	1	0	1	7	0	
12020	run	9	9	26	11	0	81
12030	backwater	4	2	2	1	1	
12030	pool	0	1	4	1	2	
12030	riffle	0	0	2	5	1	
12030	run	1	1	23	20	2	73
12060	backwater	1	4	0	0	0	
12060	pool	1	0	3	0	0	
12060	riffle	0	0	4	5	6	
12060	run	0	2	18	12	2	58
12080	backwater	4	4	0	1	0	
12080	pool	2	6	0	0	2	
12080	riffle	0	0	0	5	0	
12080	run	8	6	26	7	9	80
12087	backwater	4	3	4	3	0	
12087	pool	2	2	6	2	2	
12087	riffle	0	0	3	10	0	
12087	run	2	3	8	11	2	67

Medium Base Flow		clay	silt	sand	gravel	large rock	
12010	backwater	0	1	1	0	0	
12010	pool	1	2	2	0	0	
12010	riffle	0	0	0	1	0	
12010	run	1	2	8	6	0	25
12020	backwater	0	2	1	1	0	
12020	pool	1	1	1	0	0	
12020	riffle	1	0	0	3	0	
12020	run	2	4	8	3	0	28
12030	backwater	2	0	1	1	1	
12030	pool	0	0	1	0	1	
12030	riffle	0	0	0	2	1	
12030	run	0	1	7	8	1	27
12060	backwater	0	2	0	0	0	
12060	pool	0	0	2	0	0	
12060	riffle	0	0	4	0	3	
12060	run	0	0	7	6	1	25
12080	backwater	2	0	0	1	0	
12080	pool	1	2	0	0	1	
12080	riffle	0	0	0	1	0	
12080	run	3	2	7	3	3	26
12087	backwater	2	1	1	0	0	
12087	pool	0	1	2	1	1	
12087	riffle	0	0	1	4	0	
12087	run	0	0	3	2	1	20
						151	

Low Base Flow		clay	silt	sand	gravel	large rock	
12010	backwater	0	1	1	0	0	
12010	pool	1	2	3	0	0	
12010	riffle	0	0	0	2	0	
12010	run	2	3	7	4	0	26
12020	backwater	2	2	0	1	0	
12020	pool	1	1	1	0	0	
12020	riffle	0	0	1	3	0	
12020	run	4	3	5	4	0	28
12030	backwater	0	0	1	0	0	
12030	pool	0	1	2	1	1	
12030	riffle	0	0	1	2	0	
12030	run	0	0	6	8	1	24
12060	backwater	0	1	0	0	0	
12060	pool	1	0	1	0	0	
12060	riffle	0	0	0	5	3	
12060	run	0	0	7	5	1	24
12080	backwater	1	3	0	0	0	
12080	pool	0	1	0	0	0	
12080	riffle	0	0	0	2	0	
12080	run	3	2	9	1	4	26
12087	backwater	0	1	2	2	0	
12087	pool	2	1	2	0	1	
12087	riffle	0	0	2	6	0	
12087	run	1	1	2	4	1	28
						156	

High Base Flow		clay	silt	sand	gravel	large rock	
12010	backwater	0	1	1	0	0	
12010	pool	1	1	1	0	0	
12010	riffle	0	0	0	0	0	
12010	run	2	2	12	4	0	25
12020	backwater	1	1	0	0	0	
12020	pool	0	0	0	0	0	
12020	riffle	0	0	0	1	0	
12020	run	3	2	13	4	0	25
12030	backwater	2	2	0	0	0	
12030	pool	0	0	1	0	0	
12030	riffle	0	0	1	1	0	
12030	run	1	0	10	4	0	22
12060	backwater	1	1	0	0	0	
12060	pool	0	0	0	0	0	
12060	riffle	0	0	0	0	0	
12060	run	0	2	4	1	0	9
12080	backwater	1	1	0	0	0	
12080	pool	1	3	0	0	1	
12080	riffle	0	0	0	2	0	
12080	run	2	2	10	3	2	28
12087	backwater	2	1	1	1	0	
12087	pool	0	0	2	1	0	
12087	riffle	0	0	0	0	0	
12087	run	1	2	3	5	0	19
						128	

sampled

TABLE 2.–Fish species measured and separated into large and small classes for habitat guilding analysis

Species	Common Name	Size Threshold
Carpoides carpio	River Carpsucker	100 mm
Cyprinella lutrensis	Red Shiner	35 mm
Cyprinella venusta	Blacktail Shiner	35 mm
Dorosoma cepedianum	Gizzard Shad	150 mm
Ictalurus punctatus	Channel Catfish	200 mm
Lepomis megalotis	Longear Sunfish	35 mm
Macrhybopsis hyostoma	Shoal Chub	35 mm
Micropterus punctulatus	Spotted Bass	125 mm

TABLE 3.–Fishes included in the TPWD Brazos HSC field collections, 2010-2014 (N=302 samples).

Common Name	Abundance	Occurrences	Species	Abundance	Occurrences
Red Shiner (large)	16899	262	Channel Catfish (large)	12	12
Bullhead Minnow	15502	210	Tadpole Madtom	12	8
Red Shiner (small)	12619	254	Smallmouth Buffalo	11	9
Channel Catfish (small)	1636	106	*Chub Shiner	10	2
Ghost Shiner	1021	46	Inland Silverside	10	9
Western Mosquitofish	1005	58	Slough Darter	10	5
Shoal Chub (large)	639	45	Mississippi Silvery Minnow	9	5
Longear Sunfish (large)	604	87	White Bass	9	8
Gizzard Shad (small)	432	45	Largemouth Bass	8	6
River Carpsucker (small)	347	58	*Redear Sunfish	7	2
Silverband Shiner	221	26	*Blacktail Shiner (large)	6	4
Longear Sunfish (small)	165	41	Spotted Bass (large)	5	5
Blue Catfish	163	40	*Warmouth	5	3
Flathead Catfish	129	49	*Silver Chub	3	2
River Carpsucker (large)	125	55	*Bigscale Logperch	2	2
Orangespotted Sunfish	84	17	*Blackstripe Topminnow	2	2
Bluegill	56	22	*Freshwater Drum	2	2
Green Sunfish	56	30	*Ribbon Shiner	2	1
Blacktail Shiner (small)	53	5	*Yellow Bullhead	2	2
Longnose Gar	45	29	*Alligator Gar	1	1
White Crappie	45	12	*Bluntnose Darter	1	1
Striped Mullet	44	29	*Brook Silverside	1	1
Dusky Darter	41	17	*Central Stoneroller	1	1
Spotted Bass (small)	39	21	*Gray Redhorse	1	1
Shoal Chub (small)	29	15	*Sailfin Molly	1	1
Spotted Gar	22	20	*Spotted Sucker	1	1
Gizzard Shad (large)	20	17	*Striped Basses (*Morone*)	1	1
Threadfin Shad	16	9	*Texas Logperch	1	1
Pugnose Minnow	15	9			

*removed from analysis due to low sample sizes (<5 samples)

TABLE 4.–Fishes collected in the TPWD Brazos baseline field collections, 2014. (N=62)

Species	Abundance	Occurrences	Species	Abundance	Occurrences
Red Shiner	13548	61	Spotted Gar	5	5
Bullhead Minnow	3050	50	Warmouth	5	4
River Carpsucker	435	23	Dusky Darter	4	2
Ghost Shiner	322	25	Blue Catfish	3	2
Longear Sunfish	187	36	Green Sunfish	3	2
Western Mosquitofish	177	10	Spotted Bass	3	3
Channel Catfish	79	14	Freshwater Drum	2	2
Mountain Mullet	69	10	Inland Silverside	2	1
Shoal Chub	50	12	Redear Sunfish	2	2
Striped Mullet	28	12	Tadpole Madtom	2	2
Orangespotted Sunfish	16	5	Bluntnose Darter	1	1
Flathead Catfish	9	6	Brook Silverside	1	1
Bluegill	8	3	Golden Shiner	1	1
Longnose Gar	5	2	Pugnose Minnow	1	1
Silverband Shiner	5	4	Threadfin Shad	1	1
Smallmouth Buffalo	5	3	White Bass	1	1

TABLE 5.–Fishes collected by Gelwick and Li, 2002. (N=131)

Species	Abundance	Occurrences	Species	Abundance	Occurences
Red Shiner	29522	98	Blue Catfish	9	5
Bullhead Minnow	7226	90	Redear Sunfish	8	2
Silverband Shiner	2123	67	Blacktail Shiner	6	6
Mosquitofish	1741	45	Spotted Gar	6	4
Striped Mullet	1116	16	White Crappie	5	2
Ghost Shiner	963	41	Brook Silverside	4	1
Threadfin Shad	148	23	Warmouth	3	2
Speckled Chub (*Shoal)	145	30	Spotted Bass	3	2
Channel Catfish	52	24	Ribbon Shiner	3	3
Gizzard Shad	49	14	Sharpnose Shiner	3	1
Silver Chub	45	13	Spotted Sunfish	2	1
Inland Silverside	33	9	Pugnose Minnow	2	2
River Carpsucker	18	8	Blackstripe Topminnow	2	2
Juvenile Sunfish	15	6	Tadpole Madtom	2	2
Orangespotted Sunfish	13	7	Pirate Perch	1	1
Bluegill Sunfish	13	7	Hybrid Sunfish	1	1
Longear Sunfish	13	10	Largemouth Bass	1	1
Flathead Catfish	11	7	Smallmouth Buffalo	1	1
Longnose Gar	11	7	Slough Darter	1	1
Green Sunfish	9	5			

TABLE 6.–Fishes collected by Brazos River Authority (2014) near Richmond, Texas. (N=40)

Species	Abundance	Occurrences	Species	Abundance	Occurrences
Red Shiner	1373	20	White Crappie	5	3
Bullhead Minnow	431	16	Bluegill	3	2
Western Mosquitofish	126	11	Flathead Catfish	3	2
Striped Mullet	78	13	Green Sunfish	3	2
Longear Sunfish	69	14	Largemouth Bass	3	2
Gizzard Shad	26	9	Threadfin Shad	3	3
Ghost Shiner	11	5	Shoal Chub	2	2
River Carpsucker	10	6	Warmouth	2	2
Smallmouth Buffalo	10	5	Blue Catfish	1	1
Channel Catfish	6	6	Inland Silverside	1	1
Longnose Gar	5	5	Orangespotted Sunfish	1	1
Silverband Shiner	5	3			

TABLE 7.–Fishes collected by Brazos River Authority (2014-2015) near Rosharon, Texas. (N=5)

Species	Abundance	Occurrence	Species	Abundance	Occurrence
Red Shiner	1545	5	White Crappie	5	4
Gizzard Shad	522	5	Green Sunfish	4	1
Bullhead Minnow	488	4	Blue Tilapia	3	2
Striped Mullet	409	4	Bluegill	3	1
Western Mosquitofish	93	3	Silverband Shiner	3	2
Longear Sunfish	28	4	Dusky Darter	2	1
Flathead Catfish	22	3	Freshwater Drum	2	1
Threadfin Shad	22	4	Redear Sunfish	2	1
Blue Catfish	20	3	Smallmouth Buffalo	2	1
Channel Catfish	20	3	Ribbon Shiner	1	1
Spotted Gar	9	3	Shoal Chub	1	1
River Carpsucker	8	3	Silver Chub	1	1
Brook Silverside	7	2	Suckermouth Catfish	1	1
Gray Redhorse	7	2	Warmouth	1	1
Longnose Gar	7	1	White bass	1	1

TABLE 8.–Number of individuals and locations observed for each habitat guild and their component species (size category).

Habitat Guild	Common Name	Species	Total Number Observed	Number of Locations Observed
	River Carpsucker (large)	*Carpiodes carpio (≥100 mm)*	125	55
	Gizzard Shad (small)	*Dorosoma cepedianum (<100 mm)*	423	45
	Spotted Gar	*Lepisosteus oculatus*	22	20
	Bluegill	*Lepomis macrochirus*	56	22
	Longear sunfish (large)	*Lepomis megalotis (≥45 mm)*	604	87
POOL	Longear Sunfish (small)	*Lepomis megalotis (<45 mm)*	157	41
	Inland Silverside	*Menidia beryllina*	10	9
	Largemouth Bass	*Micropterus salmoides*	8	6
	Striped Mullet	*Mugil cephalus*	44	29
	Pugnose Minnow	*Opsopoeodus emiliae*	15	9
	White Crappie	*Pomoxis annularis*	46	12
	Guild Total		**1510**	**335**
	Orangespotted Sunfish	*Lepomis humilis*	85	18
BACKWATER	Slough Darter	*Etheostoma gracile*	10	5
	Guild Total		**95**	**23**
	Ghost Shiner	*Notropis buchanani*	1021	46
	Green Sunfish	*Lepomis cyanellus*	56	30
	River Carpsucker (small)	*Carpiodes carpio (<100 mm)*	347	58
SLOW RUN	Shoal Chub (small)	*Macrhybopsis hyostoma (<35mm)*	29	15
	Spotted Bass (small)	*Micropterus punctulatus (<125mm)*	39	21
	Western Mosquitofish	*Gambusia affinis*	1008	58
	Guild Total		**2500**	**228**
	Blacktail Shiner (small)	*Cyprinella venusta (<35mm)*	53	5
	Channel Catfish (large)	*Ictalurus punctatus (≥200mm)*	12	12
	Flathead Catfish	*Pylodictis olivaris*	129	48
RUN	Silverband Shiner	*Notropis shumardi*	221	24
	Spotted Bass (large)	*Micropterus punctulatus (≥125mm)*	5	5
	Threadfin Shad	*Dorosoma petenense*	16	8
	White Bass	*Morone chrysops*	9	8
	Guild Total		**445**	**110**
	Blue Catfish	*Ictalurus furcatus*	163	46
	Gizzard Shad (large)	*Dorosoma cepedianum (≥100 mm)*	20	17
DEEP POOL	Longnose Gar	*Lepisosteus osseus*	45	29
	Smallmouth Buffalo	*Ictiobus bubalus*	11	9
	Guild Total		**239**	**101**
	Channel Catfish (small)	*Ictalurus punctatus (<200mm)*	1636	114
	Dusky Darter	*Percina sciera*	41	35
RIFFLE	Mississippi Silvery Minnow	*Hybognathus nuchalis*	9	9
	Shoal Chub (large)	*Macrhybopsis hyostoma (≥35mm)*	639	75
	Tadpole Madtom	*Noturus gyrinus*	12	12
	Guild Total		**2337**	**245**

TABLE 9.–Depth and velocity suitability indices (SI) of each habitat guild developed for Brazos River study sites. Coordinates provided for hydraulic habitat modeling.

POOL				BACKWATER				DEEP POOL			
Depth (ft)	SI	Velocity (ft/s)	SI	Depth (ft)	SI	Velocity (ft/s)	SI	Depth (ft)	SI	Velocity (ft/s)	SI
0	0	0	0	0	0	0	0.2	0	0	0	0
0.42	0	0.02	0.1	0.12	0	0.05	0.5	0.31	0	0.05	0.1
0.50	0.1	0.05	0.2	0.32	0.2	0.08	1	0.70	0.1	0.06	0.2
0.62	0.2	0.06	0.5	0.70	0.5	0.33	0.5	0.72	0.2	0.07	0.5
0.70	0.5	0.14	1	0.98	1	0.76	0.2	0.94	0.5	0.08	1
0.96	1	0.39	1	2.12	0.5	1.16	0	1.18	1	0.68	1
2.92	1	0.80	0.5	2.12	0.5	99	0	99	1	0.90	0.5
4.04	0.5	1.32	0.2	3.46	0.2					1.31	0.2
99	0.5	2.03	0.1	4.33	0						
		2.74	0	99	0						
		99	0								

RUN				SLOW RUN				RIFFLE			
Depth (ft)	SI	Velocity (ft/s)	SI	Depth (ft)	SI	Velocity (ft/s)	SI	Depth (ft)	SI	Velocity (ft/s)	SI
0	0	0	0.2	0	0	0	0.2	0	0	0	0
0.34	0	0.10	0.5	0.12	0	0.05	0.5	0.20	0	0.07	0.2
0.46	0.1	0.36	1	0.40	0.1	0.06	1	0.21	0.1	0.41	0.5
0.53	0.2	1.48	1	0.48	0.5	1.14	1	0.34	0.2	0.68	1
0.70	0.5	1.56	0.5	0.58	1	1.35	0.5	0.46	0.5	2.03	1
0.96	1	2.01	0.2	1.24	1	1.62	0.2	0.52	1	2.88	0.5
2.94	1	2.37	0.1	2.12	0.5	2.03	0.1	1.24	1	3.34	0
3.66	0.5	2.94	0	3.66	0.2	2.31	0	1.46	0.5	99	0
4.88	0.2	99	0	4.60	0.1	99	0	2.46	0.2		
6.86	0.1			5.88	0			2.94	0.1		
11.62	0			99	0			6.62	0		
99	0							99	0		

APPENDIX I: TWDB report comments and TPWD response

Fish Habitat Suitability Criteria Development for the Lower Brazos River

Draft-final report to the Texas Water Development Board

Contract number 1300011590

General Draft Final Report Comments:

Overall, the report is well written and documents a research effort that achieved the objectives of the Scope of Work.

REQUIRED CHANGES

1. Please reference "TWDB Contract No. 1300011590" on the cover of the report.
2. On page 1, 4th paragraph, 2nd sentence states that the entire Brazos River is approximately 1,700 miles in length. It's unclear where this number comes from. The US Geological Survey lists the length of the Brazos River as 1,280 miles (Kammerer 1990). Please use the USGS value to refer to the length of the entire Brazos River.
3. On page 1, 4th paragraph, 5th sentence states that the Brazos River extends 205 miles from Waco, Texas to the coast. This appears to be an "as the crow flies" measurement of the distance from the City of Waco to the coast. Please use the more typical "river mile" measurement to describe the length of the lower Brazos River. The US Geological Survey lists the river mileage from the mouth of the river to USGS gage 08096500 Brazos River at Waco as 400.7 river miles (US Geological Survey 2016).
4. Page 3, 2nd paragraph, 1st sentence says fish assemblage data was collected "following BRA (2007)." It is unclear if this means that sampling occurred subsequent to sampling completed by BRA (2007) or if sampling occurred following the methods employed by BRA (2007). Please rewrite to clarify.

Kammerer, J.C., 1990, Largest rivers in the United States, Water Fact Sheet: Open File Report 87-242, pubs.usgs.gov/of/1987/ofr87-242/.

US Geological Survey, Water-year summary for site USGS 08096500, waterdata.usgs.gov/nwis/wys_rpt/?site_no=08096500&agency_cd=USGS.

ALL REQUIRED CHANGES HAVE BEEN FULLY ADDRESSED IN THE FINAL REPORT.