FRESHWATER FLOW, SALTWATER INTRUSION, PAPER MILL EFFLUENT, AND FISH ASSEMBLAGE STRUCTURE IN THE LOWER NECHES RIVER, TEXAS

A Thesis

by

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ABSTRACT

In 2011, Texas experienced the worst drought in recorded history. This has escalated concerns regarding environmental flows needed to sustain freshwater and estuarine systems as human needs are addressed during drought periods. In this thesis, I analyze fish assemblages and water quality variables in order to observe the effects of drought in the lower Neches River below the saltwater barrier located upstream from Beaumont, Texas. Fish and water quality samples were taken during drought conditions during fall 2011 and summer 2012, after a season of rain. During fall 2011, sites surveyed above the barrier had lower salinity but similarly low dissolved oxygen (DO) levels compared with sites surveyed below the barrier. Salinity levels during fall 2011 were relatively high (reaching up to 15 ppt), whereas salinity during summer 2012 never rose above 1.5 ppt. For gillnet samples obtained during fall 2011, fish species richness was higher in December following a series of rain events than during drought conditions in October and November. Although fish species richness was similar between fall 2011 and summer 2012, species composition varied greatly. For seine samples obtained during summer 2012, species richness was higher during May and July (when the barrier was open) than during June and August (when the barrier was closed). Species richness was lowest for sites in closest proximity to a paper mill effluent discharge pipe located below the barrier. Also, species richness was higher at sites above the barrier than at sites below the barrier regardless of whether or not the barrier was closed. Multivariate statistical analyses of gillnet samples revealed a large amount of compositional overlap among fish assemblages, regardless of time period and location; however, analyses of seine samples revealed that fish assemblages above the barrier were different than those from samples obtained below the barrier and that fish assemblages varied based on time period. Results indicate that, during periods of low flow, water quality deteriorates in the Lower Neches River below the saltwater barrier. During these periods of environmental degradation, fish assemblages have reduced diversity and sensitive freshwater species decline in abundance, with some absent from survey samples.

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DEDICATION

I dedicate this thesis to my family. Thank you for a lifetime of support and for always pushing me to do my best.

ACKNOWLEDGEMENTS

First and foremost, I must thank Dr. Kirk Winemiler for seeing and acknowledging my potential and accepting me as a graduate student in his lab. If not for his guidance, support, and encouragement, this thesis would not have been possible. I must also thank Dr. Kevin Conway and Dr. Georgianne Moore for agreeing to serve on my committee and for your help and advice regarding my research. Thanks to Dr. Conway for your assistance in identifying the smaller, unrecognizable fish among my samples and to Heather Prestridge for your help navigating around the Biodiversity Research and Teaching Collections and pulling out species I needed for identification. A special thanks goes to Nathan Lujan who was in charge of sampling efforts for the Fall of 2011 and passed on his data, advice, and guidance as I took over the project upon his departure from our lab. Individuals I cannot thank enough would be my fellow Winemiller Lab members (Carmen Montana, Chouly Ou, and Daniel Fitzgerald), lab alumni (Katherine Roach and Andrew Jackson), and our undergraduate research assistants (Monika Libson and Coral Lozada) for all of their assistance in the writing process, data analyses, experimental design, organization of field materials, sorting and identification of specimens, and (most of all) assistance in the field; without all of your help, the completion of this thesis would have been far more difficult. A huge thanks goes to the individuals of TAMU's NSF Louis Stokes Alliance for Minority Participation Bridge to the Doctorate (LSAMP-BTD) program for accepting me to the program and funding my graduate studies.

I save the most special thanks for my family and my fiancé. Thank you for constantly pushing, supporting, and encouraging me during my journey here and, of course, thank you for listening to me during all the times I really needed it. Times have been fun and wonderful and they have been stressful, nerve-wrecking, and non-stop and you all have been more than wonderful bearing with me through it all. Further, without the sacrifices and efforts of my parents, the educational path I took to get to where I am would not have been financially possible. You have done more than I could ever ask for to make sure I get the most out of life and I could never thank you enough.

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1. INTRODUCTION

In October 2011, the U.S. Drought Monitor classified approximately 97% of Texas as extreme or exceptional drought; the remaining 3% was classified as moderate to severe. The 12 months prior to this are recognized as the driest 12 consecutive months on record, with precipitation averaging far below the 27 inch historical average at slightly over 11 inches (Nielsen-Gammon 2012). Drought conditions, along with human demand, can have severe negative effects on surface waters and freshwater inflows to bays and estuaries (Smith and Hunt 2010). In Texas, drought poses a great challenge for water planning. Not only is the state experiencing growing water demands from an increasing population, but droughts are expected to be more severe and frequent in the future (Allen et al. 2011).

For rivers that flow directly into the Gulf of Mexico, decreasing freshwater inflow results in saltwater intrusion that may extend several kilometers upstream. It is for this reason that the Lower Neches Valley Authority maintains a permanent saltwater barrier along the Lower Neches River. Installed in 2003, the barrier succeeds in preserving water quality above the barrier by preventing intrusion of the saltwater wedge further upstream; however, it does not protect the river and freshwater wetlands located downstream from the barrier (Nickerson 1998, GC-CESU 2011).

The complex of habitats in the Lower Neches consists of cypress-tupelo swamp, bottomland hardwood forest, and freshwater marsh, which are rapidly vanishing wetland habitats and among the most severely altered ecosystems in the United States (LNVA

2010, Hoeppner and Rose 2011). Preservation of these habitats is crucial to the maintenance of the current state of the ecosystem; they function to maintain water quality, recharge groundwater, and stabilize water supplies by mitigating flood and drought effects (Mitsch and Gosselink 2000). In addition, the swamps and hardwood forests create habitat for a variety of wildlife, including many endangered bird and mammal species (LNVA 2010). Many coastal areas, such as those in Louisiana, have already experienced the loss and deterioration of such habitats.

One of the main factors causing habitat loss in freshwater ecosystems of the Gulf coastal plains is saltwater intrusion (Shaffer et al. 2009). Decreased freshwater inflow results in greater saltwater intrusion upstream that threatens salt-sensitive habitats, such as cypress-tupelo swamps (Nickerson 1998, Stiller 2009). Under the impact of increased saltwater intrusion, forest structure and growth potential of the dominant trees changes in these ecosystems (Krauss et al. 2009). One previous study found two sites (with salinities of 2.1 and 3.4 ppt) that converted from a forested wetland to an understory marsh environment within the four years of the experiment. Sites with lower salinities (2.0 ppt) converted to marshland at a slower rate, but exhibited signs of degradation. In another study, Hackney et al. (2007) identified 2 ppt as the salinity threshold for a habitat to convert from a freshwater swamp forest into oligohaline and brackish marshes in North Carolina.

As freshwater inflows decrease, salinity in the lower Neches is expected to increase due to increased saltwater intrusion. This raises concern for the National Park Service’s recently acquired Lower Cypress Tract, which is located along this portion of the river. The Lower Cypress Tract is dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatic*) trees, which are flood-tolerant yet salt-sensitive species (Pezeshki 1990, GC-CESU 2011). Previous studies have documented that trees exposed to salinity levels higher than 2 ppt may be damaged from the accumulation of salt ions (Na^+ and Cl^-) that produce leaf-level ion ratio imbalances. This results in leaf shedding, mottling, necrotic patches on leaves, and twig die back (Krauss et al. 2009). In addition, Bald cypress and water tupelo observe decreases in growth rates due to osmotic stress causing trees to lose their capacity for nutrient retention and reabsorption (Pezeshki et al. 1989, Krauss et al. 2009). Mature trees subjected to prolonged exposure to increasing salinities (over 1.3 ppt) exhibit basal areas more than half that of trees subject to lower salinity levels (Krauss et al. 2009).

Prolonged exposure to high salinity levels is fatal to bald cypress and tupelo seedlings because it results in reduced growth and photosynthetic rates; however, younger seedlings are more susceptible to osmotic stress than older plants (Conner et al. 1997). Higher salinity levels inhibit water uptake by lowering the osmotic potential of the soil and inducing xylem cavitation and dysfunction (Kozlowski 1997, Stiller 2009). In addition, rising salinity levels can also prohibit seed germination (Kozlowski 1997).

Overall, when exposed to increasing salinities, bald cypress and tupelo trees exhibit declines in photosynthetic activity, vertical growth (Pezeshki 1990), diameter growth, root biomass (Conner et al. 1997), and basal area, and increased mortality rates (Krauss et al. 2009) and xylem cavitation (Stiller 2009). Reduced survival in these species increases chances of survival and dominance of more salinity-tolerant species, such as Chinese tallow (*Sapium sebiferum*) (Conner 1994).

In addition to the deterioration of riparian vegetation communities, an increase in saltwater intrusion can affect the structure and processes of aquatic ecosystems by altering community composition and species distributions (Purcell et al. 2010). Freshwater fish are generally observed in salinities lower than 5 ppt; their low abundance in saline environments can be attributed to osmotic stress that can lead to mortality after prolonged exposure (Renfro 1959, Gelwick et al. 2001). Some freshwater fishes exhibit adaptations for tolerance to salinity fluctuations. These adaptations are species-specific and include alterations in metabolic rates, oxygen consumption, movement, water intake, and actively reducing the osmotic gradient between cells and ambient water. However, most fishes are only capable of reducing the osmotic gradient up to the isosmotic point (approximately 9 ppt for most freshwater fishes). Beyond this isosmotic point, most freshwater fishes have difficulty, or are incapable of, reducing the osmotic gradient. While many freshwater fishes can tolerate salinity levels higher than 9 ppt, prolonged exposure beyond the isosmotic point requires extensive use of energy and can result in deterioration of cell function (Peterson and Meador 1994). Many estuarine and freshwater fishes migrate across salinity gradients between rivers and estuaries; however, many of these migrations are often short lived and serve a foraging or reproductive purpose (Peterson and Meador 1994, Gelwick et al. 2001).

Fish assemblages are structured by a variety of interacting biotic and abiotic factors. Many studies have shown a strong influence of salinity gradients on fish assemblages of coastal streams. For example, Martino and Able (2003) identified salinity as one of the most important factors (among those examined) shaping the fish community assemblage along the Mullica River in New Jersey. An increase in salinity may lead to greater abundance of marine species, alterations in predator-prey interactions and recruitment, and detrimental consequences for migratory fishes that require freshwater habitats for a portion of their life cycle. The Blackwater River drainage system in Maryland includes rivers of varying salinities due to saltwater intrusion. Two neighboring rivers within this system, Little Blackwater River (low salinity) and Blackwater River (high salinity), contain different species assemblages (Love et al. 2008). The Blackwater River is subject to saltwater intrusion (9 – 12 ppt) and is dominated by euryhaline species such as killifish and silversides, whereas the Little Blackwater River remains mostly freshwater (0 – 5 ppt) and is dominated by freshwater-dependent species such as brown bullhead and black crappie. As salinity levels of Little Blackwater River increased seasonally, the abundance of freshwater-dependent species decreased (Love et al. 2008).

Decreasing freshwater flow not only threatens to increase salinity levels but also to increase pollutant concentrations. Below the saltwater barrier, the Lower Neches River serves as the receiving water body for effluent from the MeadWestvaco paper mill in Evadale, Texas; decreasing freshwater flows in the lower Neches River reduces dilution of paper mill effluent. Paper mill effluent is among the most challenging to treat and typically results in the overloading of dissolved organic matter which is usually associated with high biochemical and chemical oxygen demand (BOD and COD, respectively) (Antony et al. 2012). High biochemical oxygen demand can cause marked decreases in dissolved oxygen below levels required for sustaining aquatic life (Lima Neto et al. 2007).

Prior to the construction of the permanent saltwater barrier, temporary barriers were installed in the Lower Neches River to mitigate saltwater intrusion during times of decreased flow. Studies observing the effects of these barriers on the quality of the river revealed decreased water quality below the barriers (Harrel 1975), particularly in sampling sites surrounding the effluent discharge. Harrel (1975) sampled the Neches River and determined that water quality deteriorated below the temporary saltwater barriers, as evidenced by low dissolved oxygen levels and reduced macrobenthos abundance and diversity; water quality deteriorated the most during times of low flow (summer months). Approximately 17 years later, Harrel and Smith (2002) conducted a second study of Neches River water quality following implementation of the Clean Water Act. Overall, their results showed increased water quality in all areas of the river except those surrounding the paper mill effluent discharge area. Sampling sites in this area revealed increased organic enrichment (indicated by low dissolved oxygen) and reduced benthic macroinvertebrate species diversity relative to other locations that were surveyed.

The intent of the present study was to observe spatiotemporal variation of fish assemblages and water quality along the Lower Neches River by comparing fish abundance and water quality data from samples obtained above the saltwater barrier to samples obtained below the barrier throughout the summer of 2012 and to compare gillnet and water quality samples from summer 2012 to samples taken during the extreme drought conditions of the previous year (fall 2011). I hypothesized that reduction of freshwater inflow below the barrier would result in higher salinity levels and a lack of dilution of dissolved organic material from paper mill effluent. I expected this to result in less diverse or altered fish assemblages below the barrier relative to above the barrier. I also hypothesized that, as freshwater inflows decline, saltwater intrusion from the receiving bay system (Sabine Lake) would increase from the mouth of the Neches River to the saltwater barrier. This would increase the salinity of the river adjacent to the Lower Cypress Tract and the bayous within the Tract to levels harmful to bald cypress and water tupelo. I also expected that higher salinities would cause an increase in the abundance of marine fishes and saltwater-tolerant freshwater fishes.

2. METHODS

2.1 Field Surveys

Fish samples and measurements of water quality parameters were taken along the Neches River at localities above and below the saltwater barrier from October 2011 – December 2011 and May 2012 – August 2012 (Figures 1 and 2). All water quality, seine, and gillnet sample sites were sampled once per month (Tables 1 and 2). Water quality and gillnet samples were obtained between 0700-1000 h, whereas seine samples were taken between 1000-1200 h. Sites were chosen based on accessibility (wadeable areas of river), availability of anchoring structures for gill nets, and proximity to the saltwater barrier.

Fishes were surveyed along the river and within bayous using experimental gillnets. A 36.6-m x 1.8-m (4 panels: 1.3-, 2.5-, 5.1-, and 7.6-cm bar mesh), two 9.8-m x 1.8-m (4 panels: 2.5-, 5.1-, 7.6-, and 8.9-cm bar mesh), two 9.8-m x 0.9-m (4 panels: 1.3-, 2.5-, 5.1-, and 7.6-cm bar mesh), and two 38.1-m x 2.4-m (5 panels: 1.3-, 2.5-, 5.1-, 7.6-, and 8.9-cm bar mesh) monofilament experimental gillnets were used in various combination during fall 2011 and four 38.1-m x 2.4-m gillnets (5 panels: 1.3-, 2.5-, 5.1-, 7.6-, and 8.9-cm bar mesh) were deployed at each site during summer 2012. Gillnets were deployed at approximately 1700 h and retrieved at approximately 0800 h the following day. Data were standardized using CPUE (number of individuals or species per hour of deployment per 10-m of gillnet) due to variation in deployment time and gillnet size.

	Sample	Sample Date
Seine	October Seine 1	October 10, 2011
	October Seine 2	October 11, 2011
	October Seine 3	October 11, 2011
	November Seine 1	November 12, 2011
Gillnet	October	October 10, 2011
	October	October 10, 2011
	November	November 14, 2011
	November	November 14, 2011
	December	December 12, 2011
	December	December 12, 2011
	December	December 12, 2011
	December	December 12, 2011
Water Quality	November Site 1	November 14, 2011
	November Site 2	November 14, 2011
	November Site 4	November 14, 2011
	November Site 5	November 14, 2011
	November Site 6	November 14, 2011
	November Site 7	November 14, 2011
	December Site 1	December 12, 2011
	December Site 2	December 12, 2011
	December Site 4	December 12, 2011
	December Site 5	December 12, 2011
	December Site 6	December 12, 2011
	December Site 7	December 12, 2011

Table 1. Sampling dates for each water quality, seine, and gillnet sample taken during fall 2011.

	Site	Gillnet	Water Quality	Seine
May	1	May 16, 2012	May 16, 2012	May 16, 2012
	2	May 16, 2012	May 16, 2012	May 16, 2012
	3	May 17, 2012	May 17, 2012	May 17, 2012
	4	May 17, 2012	May 17, 2012	May 17, 2012
	5	May 18, 2012	May 18, 2012	May 17, 2012
	6	May 18, 2012	May 18, 2012	May 18, 2012
	7	May 19, 2012	May 19, 2012	May 18, 2012
	8	May 19, 2012	May 19, 2012	May 19, 2012
June	1	June 20, 2012	June 20, 2012	June 20, 2012
	2	June 20, 2012	June 20, 2012	June 20, 2012
	3	June 21, 2012	June 21, 2012	June 21, 2012
	4	June 21, 2012	June 21, 2012	June 21, 2012
	5	June 23, 2012	June 23, 2012	June 21, 2012
	6	June 23, 2012	June 23, 2012	June 23, 2012
	7	June 22, 2012	June 22, 2012	June 22, 2012
	8	June 22, 2012	June 22, 2012	June 22, 2012
July	1	July 18, 2012	July 19, 2012	July 19, 2012
	2	July 18, 2012	July 19, 2012	July 19, 2012
	3	July 20, 2012	July 20, 2012	July 19, 2012
	4	July 20, 2012	July 20, 2012	July 19, 2012
	5	July 21, 2012	July 22, 2012	July 20, 2012
	6	July 21, 2012	July 22, 2012	July 20, 2012
	7	July 22, 2012	July 22, 2012	July 21, 2012
	8	July 22, 2012	July 22, 2012	July 21, 2012
August	1	August 22, 2012	August 22, 2012	August 22, 2012
	2	August 22, 2012	August 22, 2012	August 22, 2012
	3	August 23, 2012	August 23, 2012	August 23, 2012
	4	August 23, 2012	August 23, 2012	August 23, 2012
	5	August 24, 2012	August 24, 2012	August 24, 2012
	6	August 24, 2012	August 24, 2012	August 24, 2012
	7	August 25, 2012	August 25, 2012	August 24, 2012
	8	August 25, 2012	August 25, 2012	August 25, 2012

Table 2. Sampling dates for each water quality, seine, and gillnet sample taken during summer 2012.

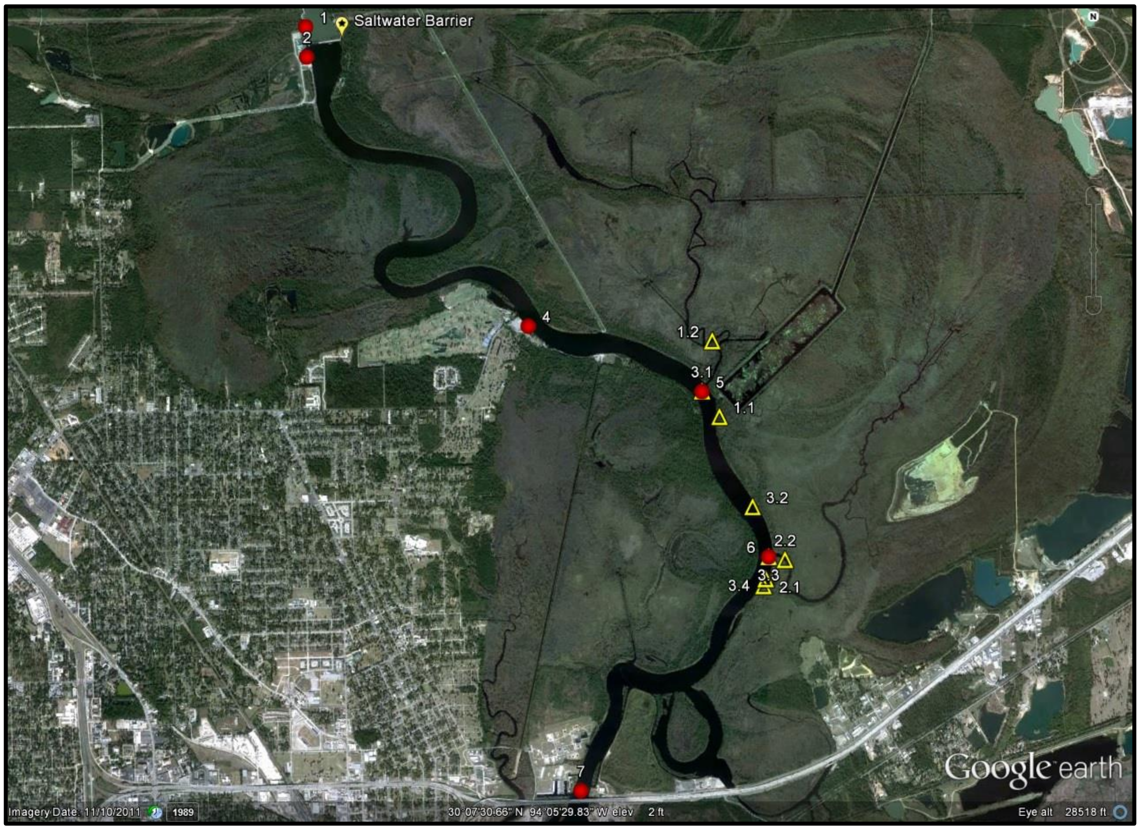

Figure 1. Water quality (circles) and gillnet sample sites (triangles; series 1: December, series 2: November, Series 3: December) during fall 2011

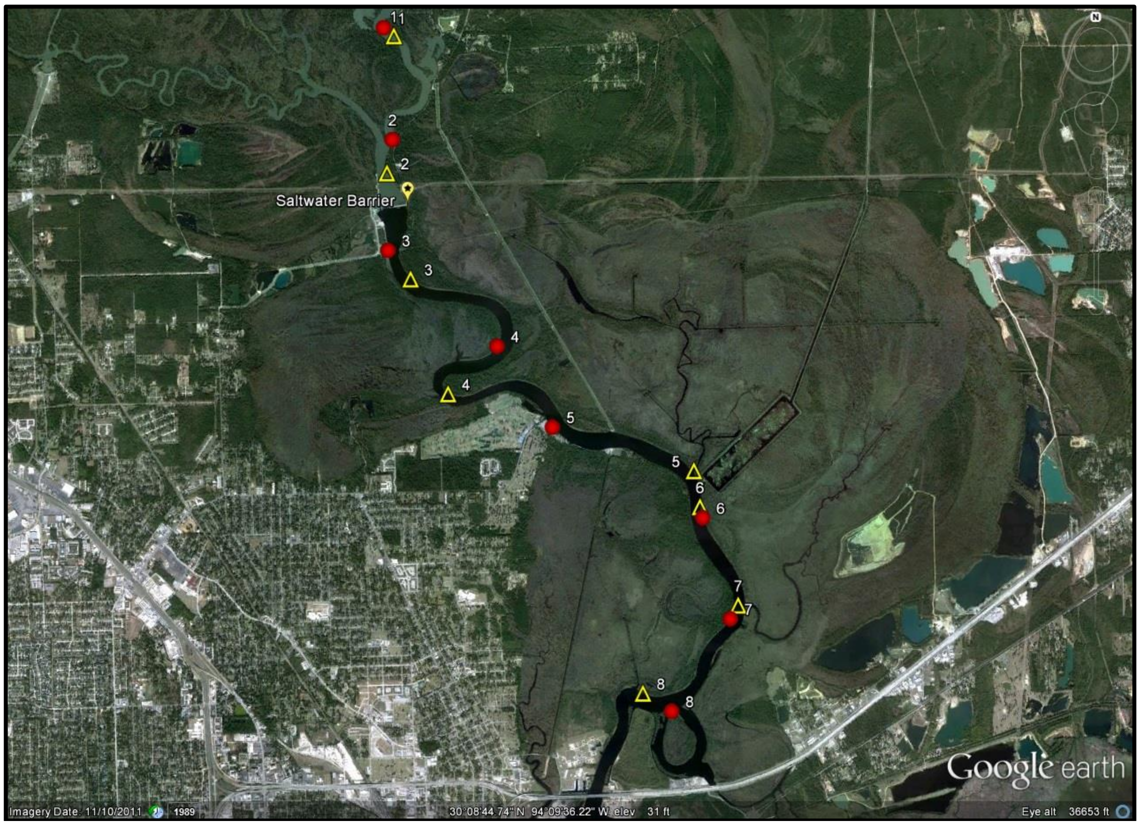

Figure 2. Seine (circles) and gillnet and water quality sites (both represented by triangles) during summer 2012

A 1.8-m x 4.6-m seine (0.3 cm mesh) was used during 2011 and a 3-m x 6-m seine (0.3 cm mesh) was used during summer 2012 to sample shallow habitat for fishes. During fall 2011, data were recorded and percent relative abundance was calculated for each locality. During summer 2012, multiple contiguous seine hauls were performed at each locality, and the distance of each seine haul was estimated in meters. The number of seine hauls and total distance of hauls per site depended on the area accessible for seining; to account for variation in seining effort, data were standardized using CPUE (number of individual fish or species obtained per meter of seine haul). Larger individuals obtained through either method were identified in the field and released; small- and medium-sized individuals were anesthetized using tricaine methanesulfonate (MS-222), preserved in 10% formalin, and later transferred to 70% ethanol. Preserved specimens were sorted and identified to species (or lowest taxonomic unit possible) in the laboratory.

To characterize water quality along the river gradient, pH was measured using an handheld digital meter, and measurements of temperature (ºC), dissolved oxygen concentration (DO, mg/L), salinity (ppt), and conductivity (µs) were measured at each sampling locality using a Yellow Springs Instruments (YSI) model 85. Water quality parameters were measured during November and December 2011 and from May – August 2012.

2.2 Analysis of Species Assemblage Structure

For each sampling locality, species richness (calculated as the total number of species per 10 m of habitat seined for seine samples and as the number of species per 10 m of gillnet per h of deployment for gillnet samples), abundance catch-per-unit-effort (CPUE) of each species (calculated as the number of individuals collected per 10 m of habitat seined for seine samples and as the number of individuals per 10 m of gillnet per h of deployment for gillnet samples), and relative abundances (% of total number of individuals) were calculated for seine and gill net samples separately. Analysis of variance (ANOVA) was used to test for significant differences in abundance CPUE and species richness between samples obtained above and below the saltwater barrier, between individual sampling events, and between samples obtained when the barrier was closed and when it was open. Further, nonmetric multidimensional scaling (NMDS) analysis based on Bray-Curtis distances was used to characterize the relationship between species assemblage structure above and below the saltwater barrier based on abundance CPUE. Associations between species CPUE and environmental variables were examined using Canonical Correspondence Analysis (CCA). Prior to performing ANOVA, NMDS and CCA, the raw data were $\log_1(n + 1)$ transformed to make data distributions more closely approximate normal distributions. Statistical analysis was carried out using PAST and PC-ORD (McCune et al. 2002, Hammer 2011).

3. RESULTS

3.1 Neches River Flow Patterns

Texas experienced extreme drought conditions during most of 2011 as evidenced by the flow patterns of the Neches River at the saltwater barrier (Figure 3). From late 2010 to late 2011, the Neches River exhibited a low, mostly consistent, flow with few large flow pulses. Two of the three fall sampling events in 2011 occurred during drought conditions, with a third sampling event occurring during December after a period of rainfall (Figure 4). From January 2012 until May 2012, drought conditions lessened and the Neches River exhibited more frequent high flow pulses. Daily mean discharge was relatively stable during summer 2012, with the exception of a large flow pulse during July (Figure 5). Average discharge during summer 2012 (3,425 cubic feet per second [cfs]) was significantly greater than discharge during fall 2011 (323.2 cfs) (ANOVA; $F_{1,195} = 44.45$; $P < 0.001$).

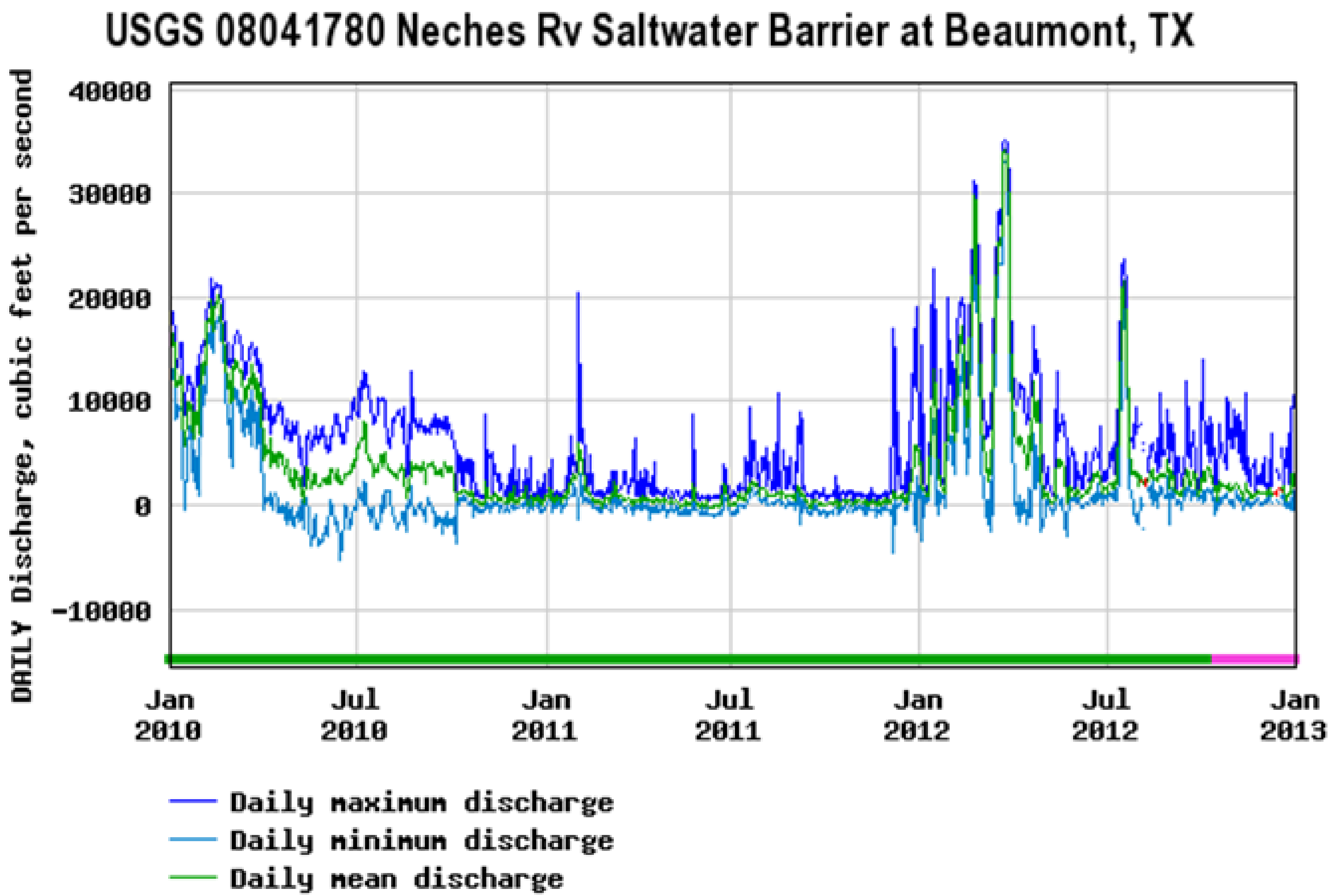

Figure 3. Daily maximum, minimum, and mean discharge rates (cubic feet per second) for the Neches River at the saltwater barrier near Beaumont, Texas from January 2010 to January 2013.

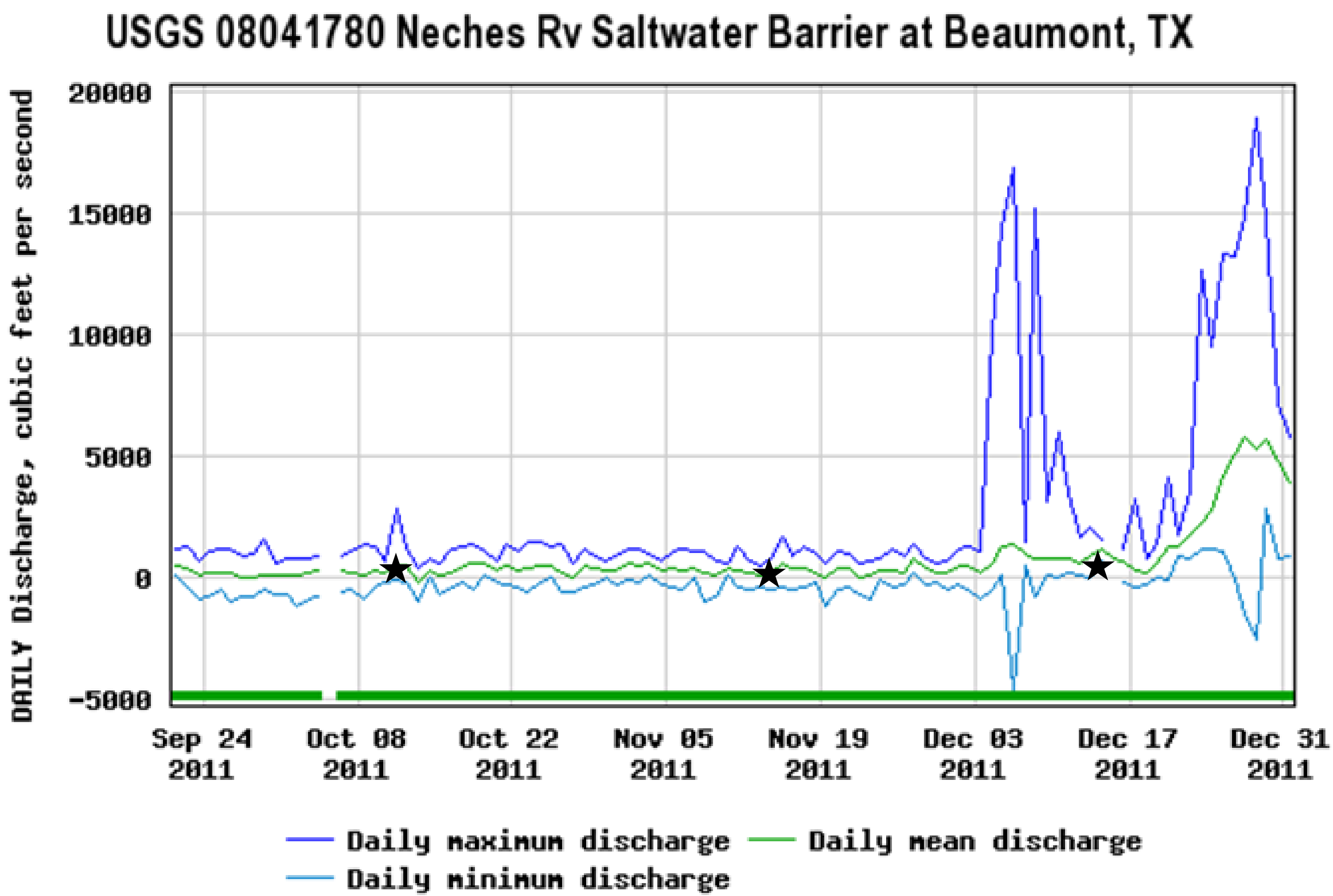

Figure 4. Daily maximum, minimum, and mean discharge rates (cubic feet per second) for the Neches River at the saltwater barrier near Beaumont, Texas from September 2011 to December 2011. Stars indicated the occurrence of a sampling event.

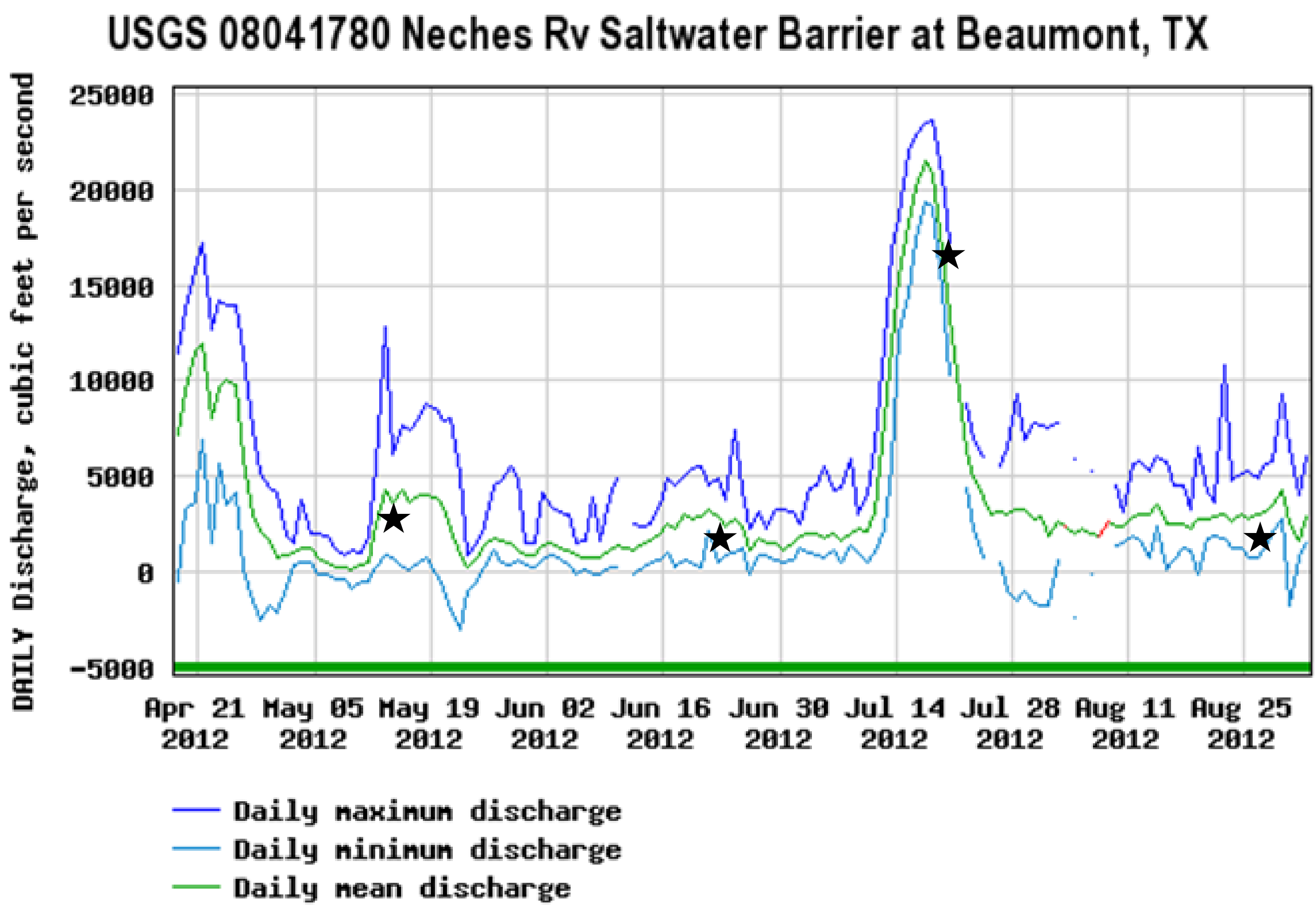

Figure 5. Daily maximum, minimum, and mean discharge rates (cubic feet per second) for the Neches River at the saltwater barrier near Beaumont, Texas from April 2012 to August 2012. Stars indicate the occurrence of a sampling event.

3.2 Environmental Variation

During fall 2011, water temperature measurements ranged from 19.6 – 22.0ºC during November and from 13.2 – 14.7ºC during December. Water temperature during the summer sampling period was less variable; the lowest temperature was recorded during May at 24.6ºC (Site 1) and warmest during August at 30.6ºC (Site 5).

Salinity levels above the barrier were 0.08 and 0.1 parts per thousand (ppt) in November 2011 and December 2011, respectively. Below the barrier, salinity levels ranged from 13.3 – 15.8 ppt in November 2011 and dropped to 6.1 – 8.0 ppt in December 2011 (Figure 6a). Salinity ranged from 0.0 – 0.1 ppt above the barrier and from 0.0 – 1.3 ppt below the barrier throughout summer 2012 (Figure 6b). Salinity below the barrier was significantly higher during the months the barrier was closed than months the barrier was open (ANOVA; $F_{1,22} = 20.7$; $P < 0.0001$). Salinity levels above the barrier remained relatively constant throughout the summer of 2012.

Dissolved oxygen (DO) above the barrier was 7.8 and 8.4 mg/L during November and December 2011, respectively. Below the barrier DO averaged 5.3 mg/L in November and increased significantly in December to an average of 6.9 (ANOVA; $F_{1,8} = 80.1$; $P < 0.0001$)(Figure 7a). DO levels during May 2012 were similar to levels measured during December 2012, but were significantly higher than levels measured during all other summer months in 2012 and November 2011 (ANOVA; $F_{1,14} > 15.3$; $P < 0.01$). DO levels measured during June and August were similar, whereas levels measured during July were significantly lower than all months during both fall 2011 and summer 2012 (ANOVA; $F_{1,14} > 41.9$; $P < 0.0001$) (Figure 7b).

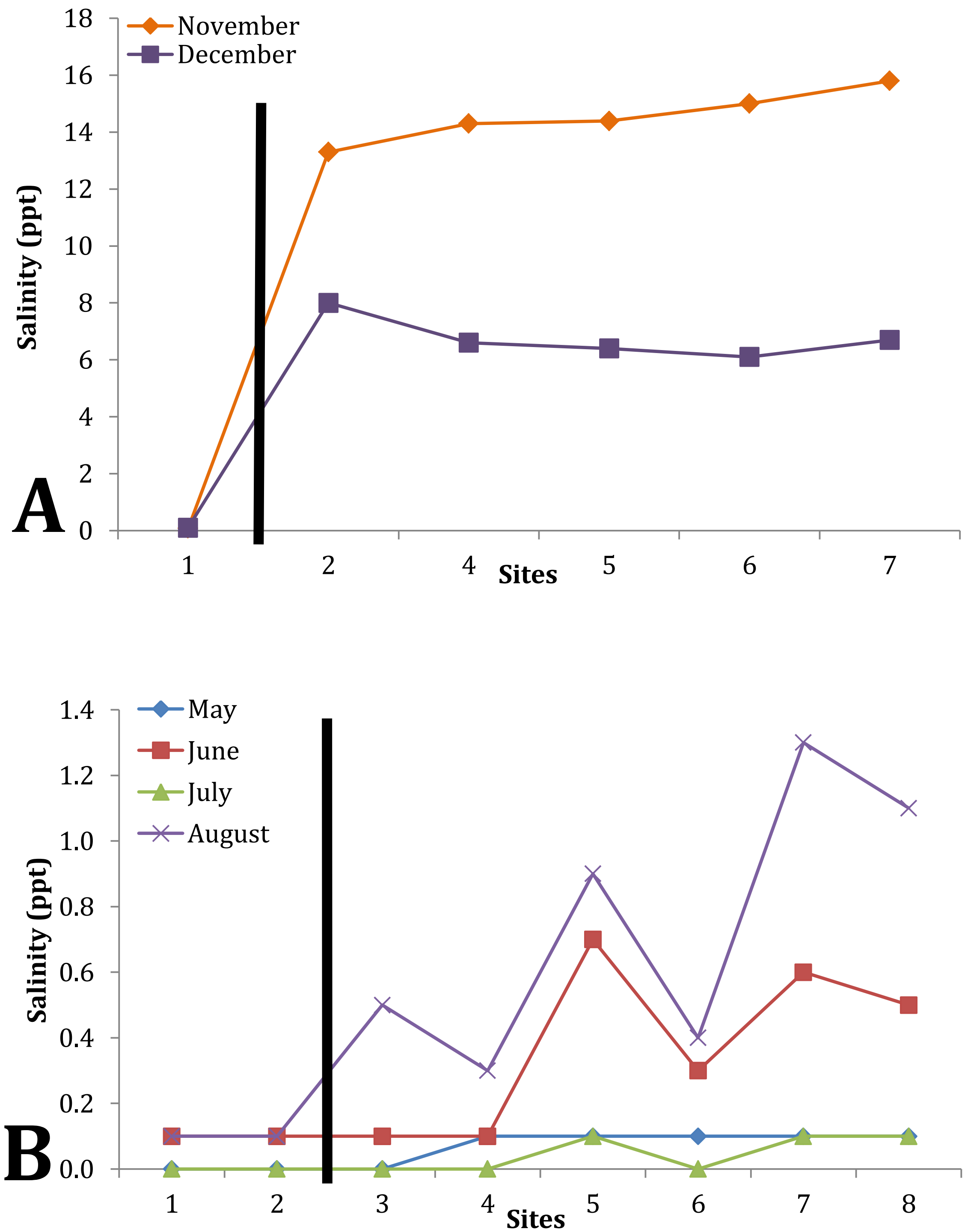

Figure 6. Salinity measurements (3 meters below the surface) along the Neches River during A) fall 2011 and B) summer 2012. The vertical bar represents the location of the saltwater barrier.

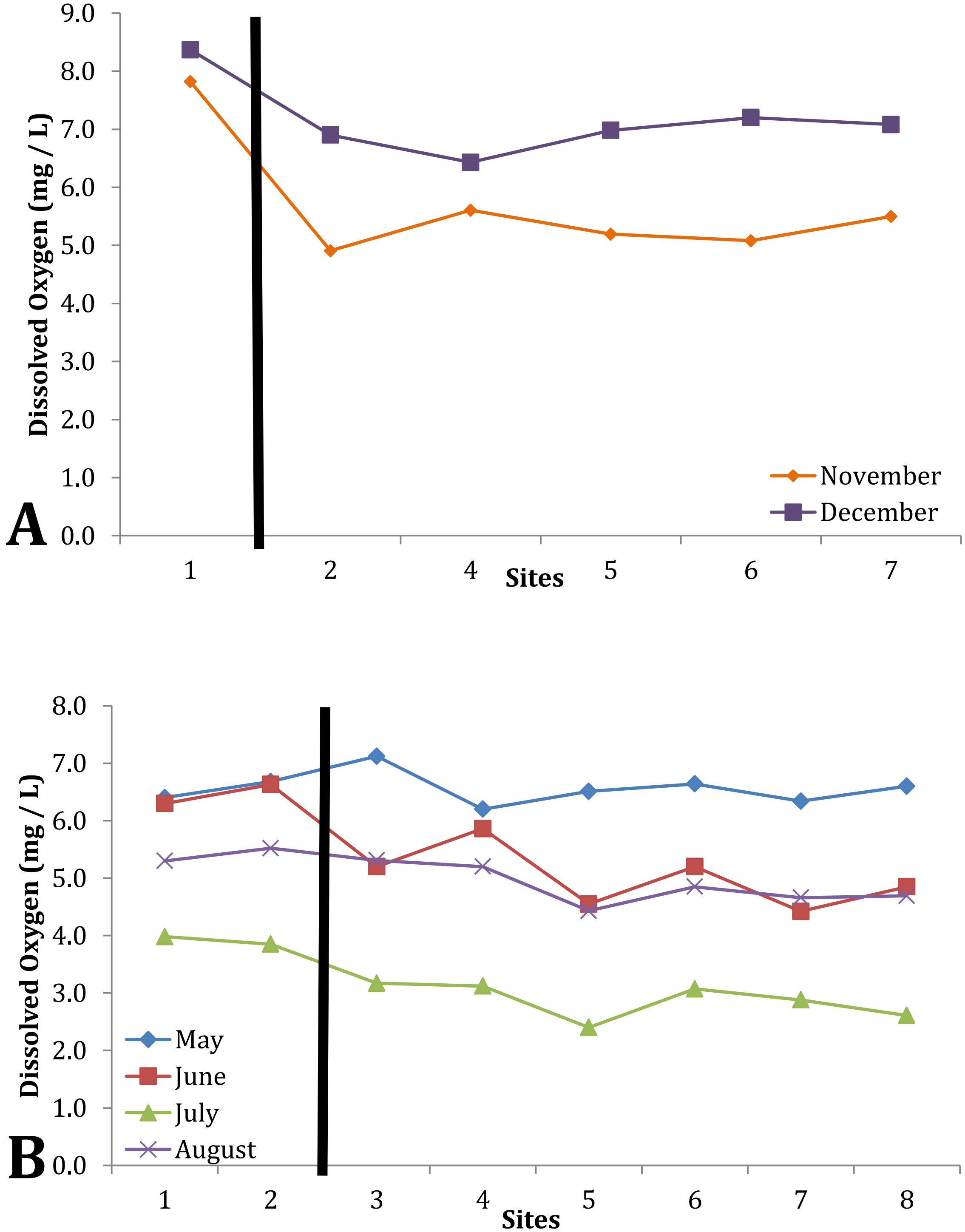

Figure 7. Dissolved oxygen measurements along the Neches River during A) fall 2011 and B) summer 2012. The vertical bar represents the location of the saltwater barrier.

3.3 Fish Surveys

Gillnet sampling during fall of 2011 yielded a total of 43 specimens (approximately 12 species); 11 in October, 2 in November, and 30 in December; however, due to a data recording error in the field, a sample obtained during October was not included in data analysis. During summer 2012, a total of 489 specimens (representing 38 species) was collected from gillnets; 91 in May (25 species), 188 in June (25 species), 81 in July (20 species), and 129 in August (21 species). Gillnet samples during the fall 2011 were dominated by *Ictalurus punctatus, Ictiobus bubalus,* and *Dorosma petenense*. None of the species collected during summer 2012 were present during all months (Appendix 1). During summer 2012, gillnet samples were dominated by *Lepisosteus* spp., *I. bubalus, Ictalurus furcatus,* and *Dorosoma cepedianum.* Twelve of the thirty-eight species obtained through gillnet surveys during the summer 2012 were only found during one sampling month, whereas nine species were present during all months (Appendix 2).

Seine sampling during fall 2011 was conducted with the objective of obtaining qualitative data on assemblages of small-bodied fishes. A total of 789 specimens (representing approximately 15 species) were collected via seine; 557 (10 species) were collected during October and 232 (approximately 8 species, Appendix 3) were collected during November. Samples were dominated by *Anchoa mitchilli, Cyprinodon variegatus,* and *Menidia beryllina.* Based on the results from qualitative surveys during fall 2011, seine sampling during fall 2012 was conducted in a standardization manner to allow for quantitative comparisons of species richness and abundance CPUE among locations and sampling periods. In 2012, a total of 27,180 specimens (representing 57 species) was collected via seine; 16,377 specimens (40 species) were collected during May, 3,611 specimens (27 species) were collected during June, 3,998 specimens (37 species) were collected during July, and 3,194 specimens (24 species) were collected during August. Seine samples were dominated by *A. mitchilli* and species of the families Cyprinidae, Clupeidae, and Centrarchidae. Approximately 18 species were captured during all four sampling months of 2012 (Appendix 4).

3.4 Species Richness and Abundance

Among all seven gillnet sampling periods, CPUE (number of fish per 10 meter of gillnet per hour of deployment) was lowest at the end of the extreme drought period in 2011 (November) and then increased nearly tenfold in December 2011. In 2012, CPUE was highest during months the barrier was closed (June and August), with CPUE in June matching CPUE estimated for December, and lowest CPUE during months the barrier was open (May and July). However, the lowest CPUE (summer 2012) was still larger than the CPUE obtained during October and November 2011 (Figure 8). Species richness (number of species per 10 m of gillnet per h of deployment) for gillnet samples was similar to patterns observed for CPUE. Richness was lowest at the end of the drought period in November 2011 and increased in December after it had rained. In 2012, species richness was highest in June (which matched richness observed during December 2011). Intermediate CPUE values were obtained during October 2011 and May, July, and August 2012 (Figure 9).

A similar pattern in species richness was observed among gillnet samples from May, July, and August 2012. Species richness increased from sites 1 to 3, was lower at sites 5-7, and was high at site 8. Richness was highest for all sites, except site 8, during June; species richness for site 8 was highest during August. During June, species richness was similar for sites 1-4 and 7-8; richness was lowest for site 5 (bayou sample) and highest for site 6 (Figure 10).

Analyses of seine samples from 2012 revealed that sites located above the saltwater barrier were significantly richer in species than sites located below the barrier (ANOVA; $F_{1,30} = 7.1$; $P = 0.012$), with species richness per unit effort (number of species per meter of seine haul) equal to 0.48 above the barrier and 0.30 below the barrier. Further, species richness was significantly higher in samples obtained during months the barrier was open (May and July, ANOVA; $F_{1,32} = 22.1$; $P < 0.01$). Species richness per unit effort was 0.46 while the barrier was open and 0.24 while the barrier was closed.

Species richness was lowest for sites 4 through 6 and was highest at site 2 for all months (Figure 11). Sites within close proximity to the effluent discharge pipe (Sites 4,5, and 6) had significantly lower species richness than site 2 (just above the barrier) which had the highest species richness of all sites (ANOVA; $F_{1,6} > 7.7$; $P < 0.05$); all other site values were not found to be significantly different (ANOVA; $F_{1,6} < 5.8$; $P > 0.05$). Sites 4, 5, and 6 had average species CPUE of 0.28, 0.26, and 0.24, respectively, whereas site 2 had an average species CPUE of 0.61.

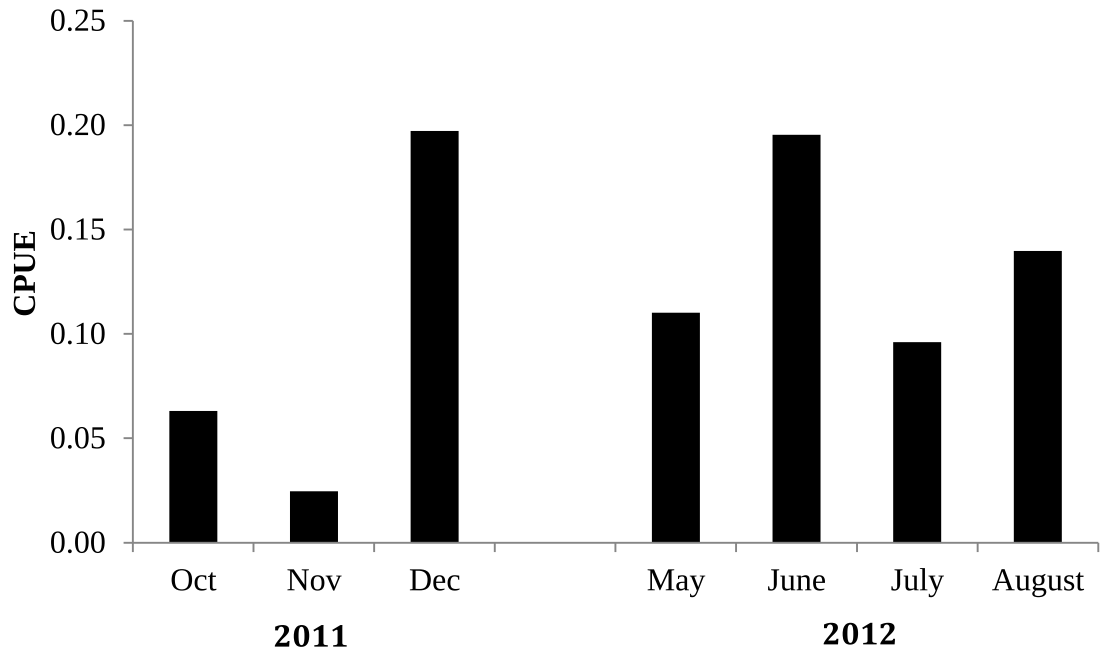

Figure 8. Average CPUE for gillnet samples (number of fish per 10 m of gillnet per h of deployment) per month during fall 2011 and summer 2012.

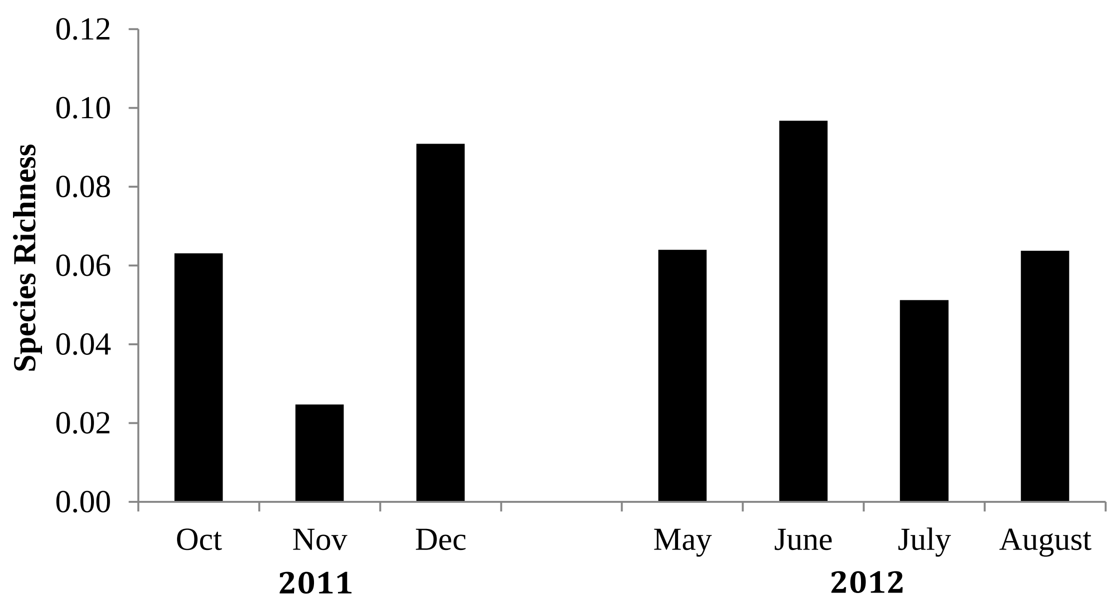

Figure 9. Average species richness for gillnet samples (number of species per 10 m of gillnet per h of deployment) per month during fall 2011 and summer 2012.

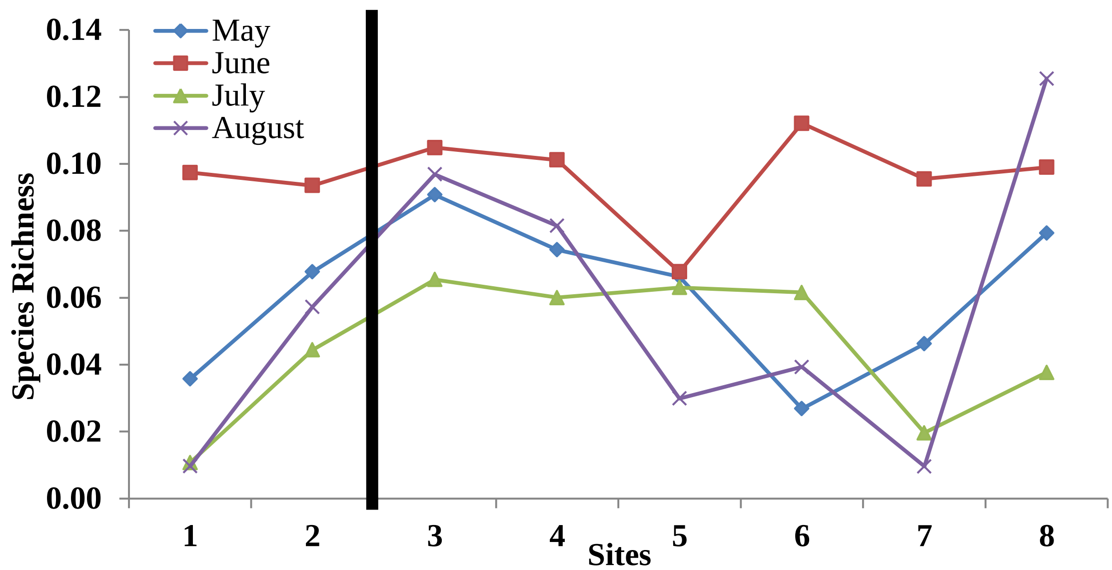

Figure 10. Species richness (number of species / 10 m of gillnet / h of net deployment) across gillnet sites per month during summer 2012. The black bar represents the location of the saltwater barrier.

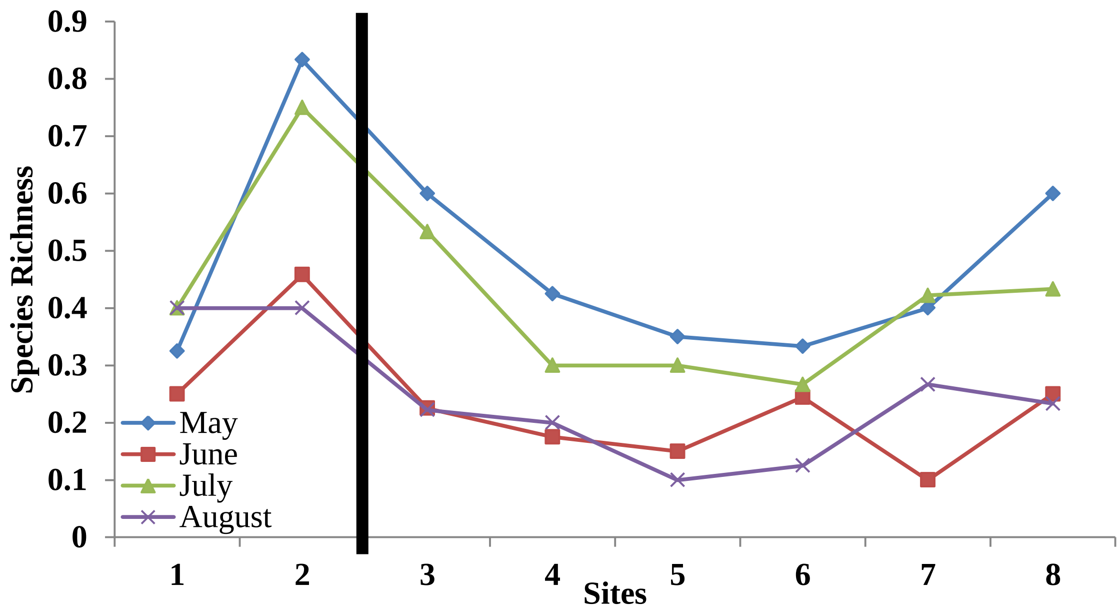

Figure 11. Species richness (number of species / m seined) across seine sites per month during summer 2012. The black bar represents the location of the saltwater barrier.

3.5 Assemblage Structure

The first two axes from nonmetric multidimensional scaling analysis (NMDS) had a stress value of 15.3 for seine data and a value of 26.6 for gillnet data, which indicate the ordinations modeled variation in community structure with fair (seine data) and poor (gillnet data) reliability (Figures 12 and 13).

For gillnet data, NMDS analysis indicated large overlap in assemblage structure among samples regardless of survey location (above or below the barrier, Figure 12a) or period (e.g., barrier was closed vs. open, in Figure 12b). During August, sites above the barrier and sites within the bayous (indicated with “1” and “2”, respectively, Figure 12b) had assemblage structures that were divergent from all other sites. With the exception of these points, samples taken when the barrier was closed were more tightly clustered than samples taken when the barrier was open.

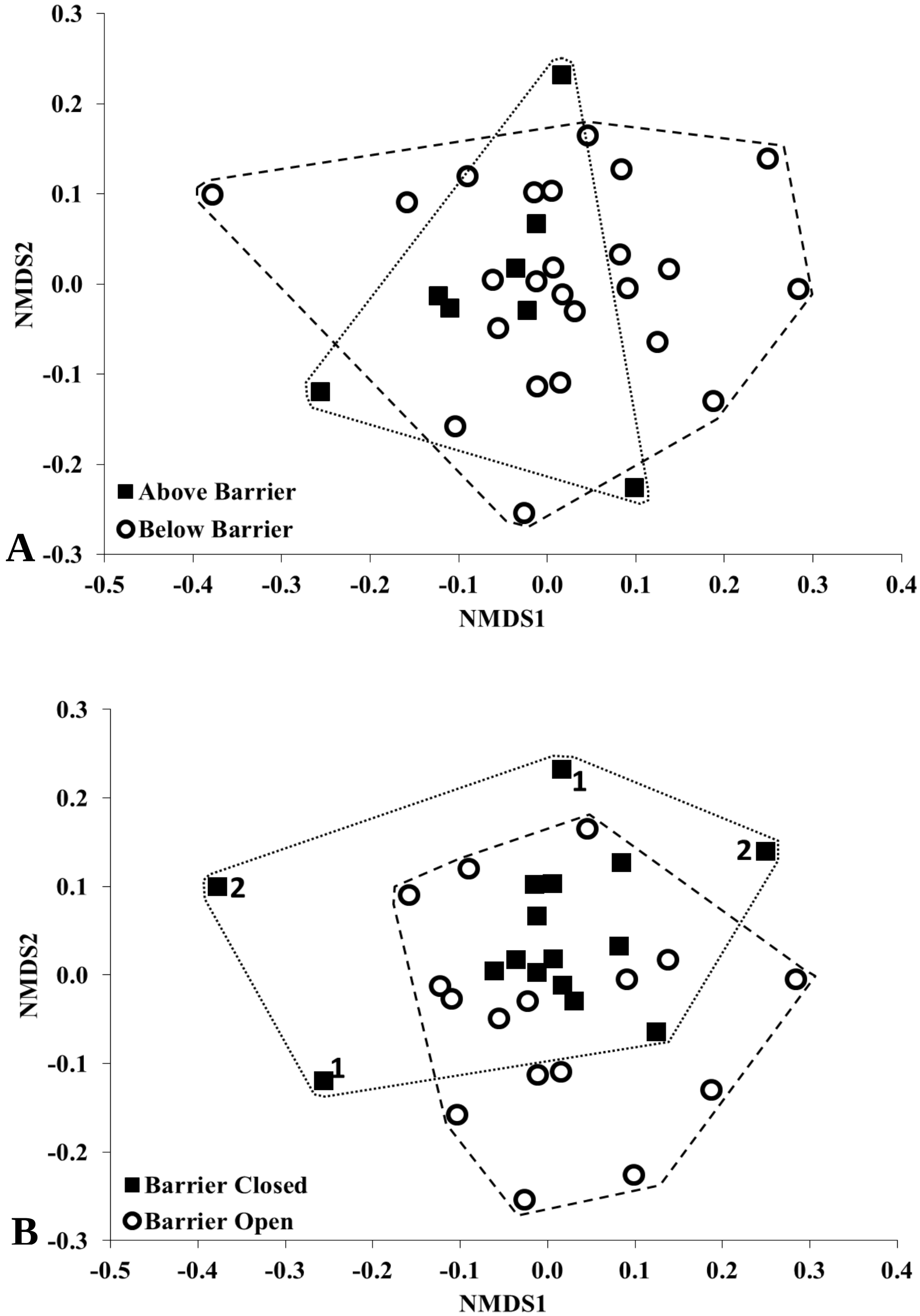

Figure 12. NMDS ordination plots of gillnet samples classified by A) the sampling location relative to the saltwater barrier (dotted line surrounds samples above the barrier; dashed line surrounds samples below the barrier) and B) when the barrier was closed (dotted line) or open (dashed line) during the survey (the two outliers are 1 = August 2012 sample taken above the barrier; 2 = August 2012 sample taken within the bayous).

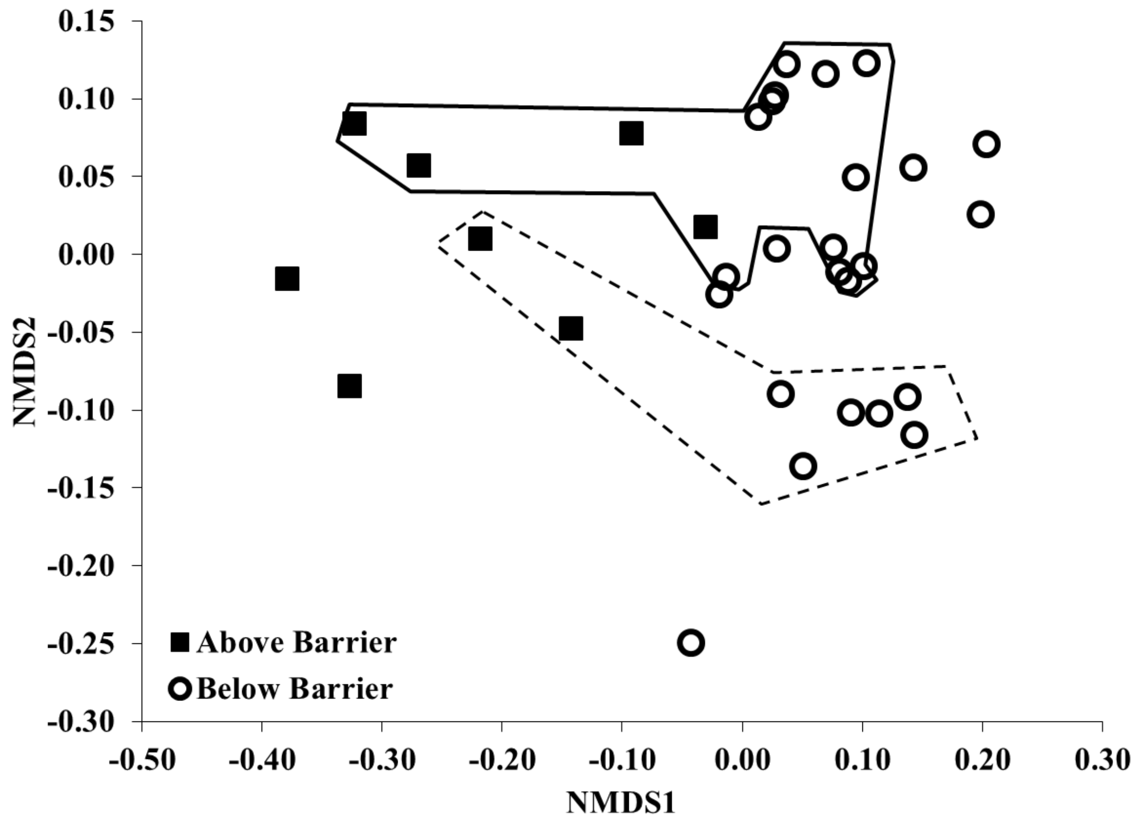

Figure 13. NMDS ordination plot of seine samples classified by location relative to the saltwater barrier (above or below). The solid line encloses samples taken during months when the barrier was closed, dashed line encloses samples taken during May 2012, and unenclosed samples were taken during July 2012.

CPUE and relative percent abundance data reveal that only four of the thirty-eight species obtained in gillnet surveys during summer 2012 were exclusive to sites above the barrier, whereas twenty one were exclusive to sites below the barrier; all other species showed no clear distribution patterns based on sampling location. Certain species, such as *Aphredoderus sayanus*, *Cyprinella venusta*, *Cyprinus carpio,* and *Pylodictis olivaris,* were only captured at sites above the barrier, whereas others, including *Archosargus probatocephalus*, *Atractosteus spatula*, *Sciaenops ocellatus*, *Ictalurus punctatus,* and *Morone* spp., were only captured below the barrier. Eight species were exclusive to samples taken when the barrier was open (obtained during May or July), and six species were exclusive to samples taken when the barrier was closed (obtained during June or August); all other species showed no clear pattern based on sample location or time period. *Brevoortia patronus* had highest relative abundance during May and August (23% and 31% of total individuals were caught during those two months, respectively). *Brevoortia patronus* was unevenly distributed among sites; this species was abundant at site 8 during May and distributed throughout sites 2-8 during August. Collectively, *Lepisosteus osseus* and *Lepisosteus oculatus* had highest relative abundances in June and July (32% and 35%, respectively), the second highest relative abundance in May (13%), and were distributed throughout most sites (*L. osseus* was not found at site 5 during summer 2012). The two outlier samples in the far left of the NMDS ordination (“1” and “2” in Figure 12b) had only 1 species each. *Aplodinotus grunniens* was the only species obtained at site 1, and *Lepomis macrochirus* was the only species obtained from site 7; each of these species were only obtained from one other site within the periods when they were recorded.

NMDS analysis of seine data revealed a clear difference in assemblage structure of samples taken above and below the barrier, regardless of whether the barrier was open or closed. Samples from above and below the barrier had no overlap in location in NMDS ordination space. Assemblage structure of samples taken during May (enclosed by the dashed line in Figure 13) was distinct from other samples; May samples taken below the barrier were more similar to each other than May samples from above the barrier. Samples taken when the barrier was closed (enclosed by the solid line in Figure 13) had different assemblage structures than samples taken when the barrier was open. When the barrier was closed, samples taken below the barrier were more similar to each other than to samples taken above the barrier.

CPUE and relative abundance data reveal that ten species were exclusive to seine sites above the barrier, whereas fourteen species were exclusive to sites below the barrier, regardless of whether the barrier was open or closed. Nine species were exclusive to May, seven species were exclusive to samples obtained while the barrier was open, and no species were exclusive to samples obtained while the barrier was open (two species exclusive to June consisted of less than 0.1% relative abundance). Six species, including *B. patronus, Ctenogobius boleosoma, I. punctatus,* and *Lepomis microlophus*, were only found above the barrier during May (these species were found at sites below the barrier during other months). Several species, including *Cynoscion arenarius, Cyprinella lutrensis, Macrhybopsis hyostoma,* and *Notropis sabinae,* were only captured during May. *Dorosoma cepedianum* and *Pimephales vigilax* were only found at sites below the barrier during periods when the barrier was open. Marine and brackish species, such as *Micropogonias undulatus* and *Syngnathus scovelli,* were abundant at sites below the barrier. *Trinectes maculatus* also was most common below the barrier, however, it was found above the barrier during months the barrier was open. Samples from site 3 (outlier in the lower central area of the NMDS ordination, Figure 13) contained species that tended to have greater abundance upstream of the barrier (e.g., *Labidesthes sicculus* and *Notropis texanus*) as well as species more common below the barrier (e.g., *B. patronus* and *Citharichthys spilopterus).* Site 3 also lacked several species common upstream of the barrier (e.g., *D. cepedianum* and *Lythrurus fumeus*) and downstream of the barrier (e.g., *M. undulatus* and *Mugil cephalus*).

Canonical correspondence analysis (CCA) performed with species CPUE data and seven environmental variables yielded stronger ordinations for seine samples than gillnet samples (Tables 3 and 4). For May gillnet samples, axis 1 contrasted sites based on salinity, conductivity, and temperature; sites 5 and 8 had strong associations with these variables and were dominated by *B. patronus, M. cephalus,* and *Sciaenops ocellatus*. The second axis contrasted sites based on DO levels; sites with high negative scores on axis 2 were dominated by *Pomoxis annularis* and *Lepisosteus occulatus*. The first axis of the CCA for June was strongly correlated with salinity and conductivity; sites 5 and 8 were strongly associated with these environmental variables and were dominated by *Leiostomus xanthurus, B. patronus,* and *S. ocellatus*. The second axis was strongly correlated with DO; sites with higher DO were most associated with the species

Alosa chrysochloris, *Dorosoma petenense*, and *L. osseus*. Axis 1 for July samples most strongly contrasted sites based on salinity and temperature; sites associated with low salinities (all sites except 5 and 8) were dominated by *L. ossesus*, *L. oculatus*, and *I. bubalus*. Conductivity and pH were correlated with the second axis. Site 5 had a relatively high conductivity level and low pH, and was dominated by *Lepomis megalotis* and *Lepomis microlophus*. None of the water quality parameters scored highly on the first axis for August samples; site 1 and *Aplodinotus grunniens* were positively correlated with axis 1. Axis 2 contrasted sites with higher DO, temperature, and depth with sites having higher pH, salinity, and conductivity. Sites with higher pH, salinity, and conductivity were dominated by *A. grunniens* and *M. cephalus*, whereas sites with greater DO, temperature, and depth were dominated by *B. patronus* and *Ictalurus furcatus* (Figures 14 and 15, Appendices 5-8).

		Eigenvalue	Percent Variance Explained	Pearson Correlation Species-Environment
May	Axis 1	0.78	28.4%	1.0
	Axis 2	0.53	19.1%	1.0
June	Axis 1	0.48	34.6%	1.0
	Axis 2	0.30	21.8%	1.0
July	Axis 1	0.76	27.0%	1.0
	Axis 2	0.70	24.9%	1.0
August	Axis 1	0.75	25.1%	1.0
	Axis 2	0.70	23.2%	1.0

Table 3. Axis summary statistics for the first two axes from CCA analysis performed on fish gillnet data.

		Eigenvalue	Percent Variance Explained	Pearson Correlation Species-Environment
May	Axis 1	0.55	53.2%	1.0
	Axis 2	0.20	19.3%	1.0
June	Axis 1	0.57	47.7%	1.0
	Axis 2	0.36	30.4%	1.0
July	Axis 1	0.70	43.0%	1.0
	Axis 2	0.36	21.9%	1.0
August	Axis 1	0.61	61.2%	1.0
	Axis 2	0.12	11.8%	1.0

Table 4. Axis summary statistics for the first two axes from CCA analysis performed on fish seine net data.

For May seine samples, the first axis contrasted sites based on salinity and temperature; sites most associated with larger values for these variables were dominated by *A. mitchilli, M. beryllina,* and *D. petenense*. The second axis contrasted sites with higher DO with sites having higher pH and conductivity. Sites associated with higher DO were dominated by *B. patronus,* whereas *C. arenarius, M. undulatus,* and *C. spilopterus* were more common at sites with higher pH and conductivity. For CCA axis 1 pH most strongly differentiated sites during June, and the site with the lowest pH level (site 3) was dominated by *B. patronus*. The second axis contrasted sites with higher DO with sites having higher salinity, conductivity, and temperature. Sites with higher DO tended to have more *P. vigilax*, *C. venusta*, and *O. emiliae*, whereas sites associated with higher temperature, salinity, and conductivity were dominated by *A. mitchilli, M. beryllina,* and *M. undulatus*. During July, CCA axis 1 was most strongly correlated with DO; sites 1 and 2 had higher DO levels and had many *P. vigilax, Notropis volucellus,* and *Fundulus notatus*. Axis 2 was most strongly correlated with salinity; higher salinities were associated with *M. beryllina, M. undulatus,* and *C. spilopterus*. Both CCA axes in August contrasted sites with higher salinity and conductivity with sites having higher DO. Sites with higher DO were dominated by *C. venusta, Notropis texanus,* and *P. vigilax,* whereas sites with higher salinity levels were associated with *A. mitchilli* and *M. beryllina* (Figure 16 and 17, Appendices 9-12).

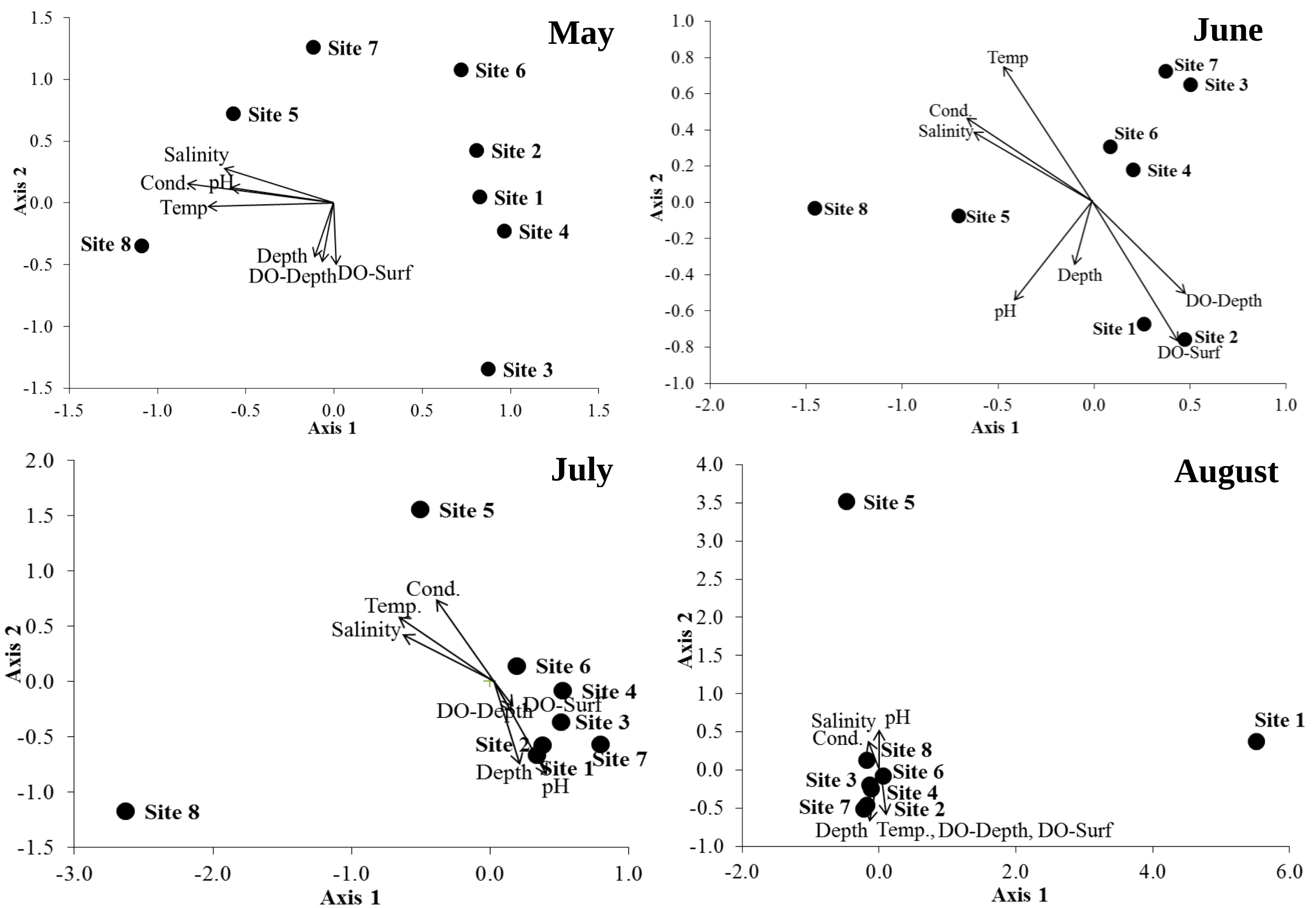

Figure 14. Canonical Correspondence Analysis (CCA) of fish CPUE from gillnet surveys and seven physiochemical variables measured at eight sites each month during summer 2012. Dissolved oxygen at a depth of 10 feet = DO-Depth, dissolved oxygen measured just below the surface = DO-Surf, Temperature = Temp, and Conductivity = Cond.

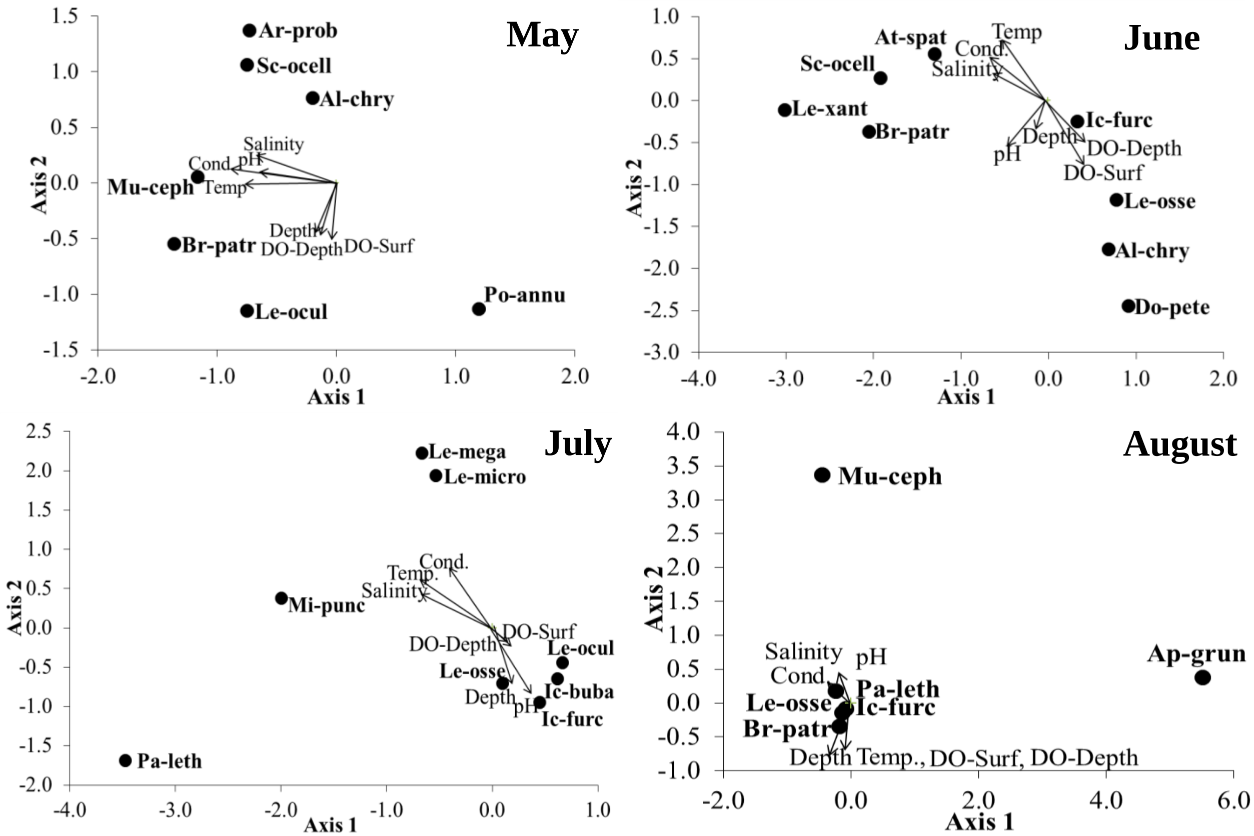

Figure 15. Canonical Correspondence Analysis (CCA) of fish CPUE from gillnet surveys and seven physiochemical variables measured at eight sites each month during summer 2012. Codes for physiochemical variables are defined in Figure 14. Al-chry = *Alosa chrysochlorus*, Ap-grun = *Aplodinotus grunniens*, Ar-prob = *Archosargus probatocephalus*, At-spat = *Atractosteus spatula*, Br-patr = *Brevoortia patronus*, Do-pete = *Dorosoma petenense*, Ic-buba = *Ictiobus bubalus*, Ic-furc = *Ictalurus furcatus*, Le-mega = *Lepomis megalotis*, Le-micro = *Lepomis microlophus*, Le-ocul = *Lepisosteus oculatus*, Le-osse = *Lepisosteus osseus*, Le-xant = *Leiostomus xanthurus*, Mi-punc = *Micropterus punctulatus*, Mu-ceph = *Mugil cephalus*, Pa-leth = *Paralichthys lethostigma*, Po-annu = *Pomoxis annularis*, Sc-ocell = *Sciaenops ocellatus.*

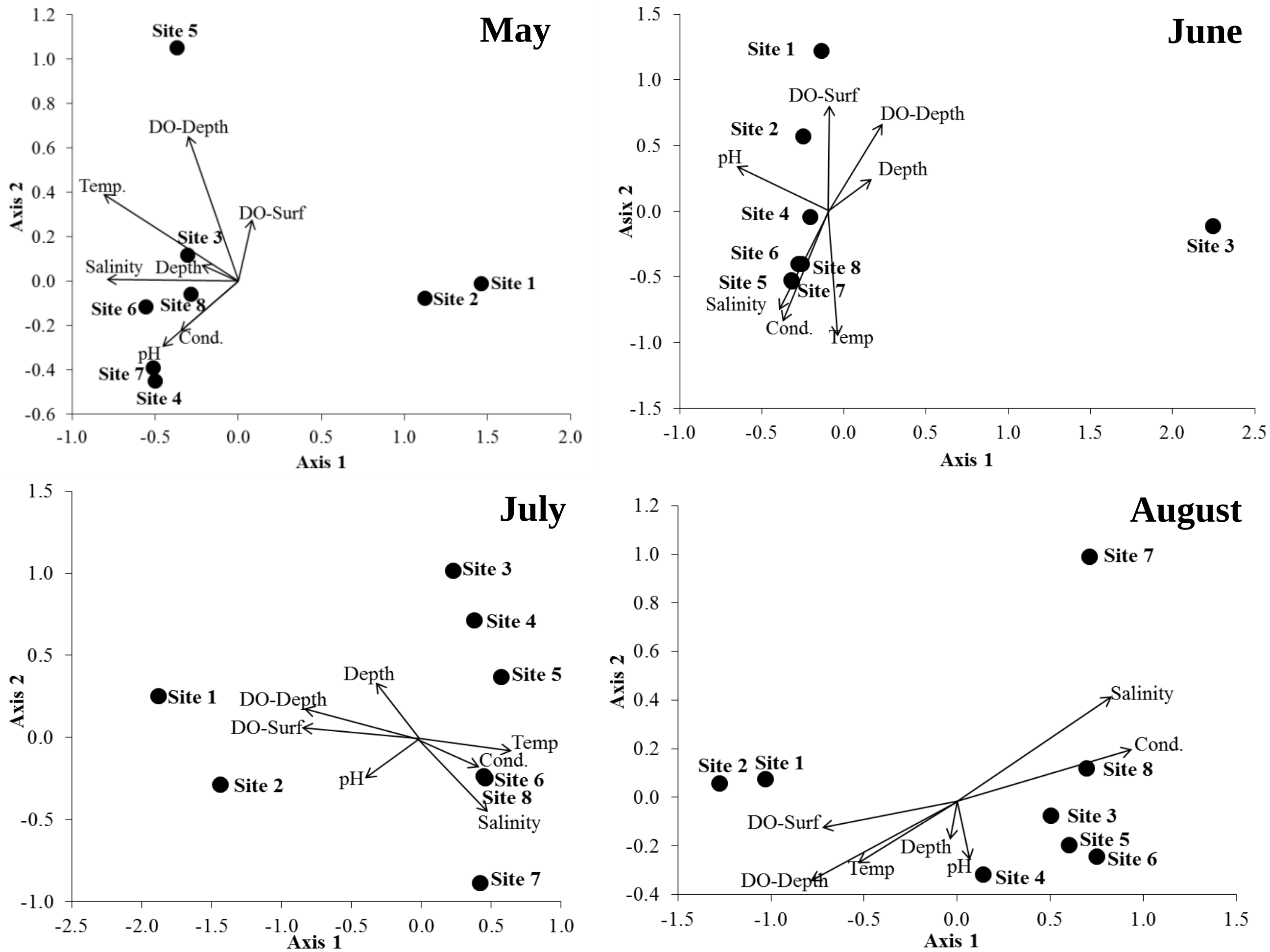

Figure 16. Canonical Correspondence Analysis (CCA) of fish CPUE from seine surveys and seven physiochemical variables measured at eight sites each month during summer 2012. Dissolved oxygen at a depth of 10 feet = DO-Depth, dissolved oxygen measured just below the surface = DO-Surf, Temperature = Temp, and Conductivity = Cond.

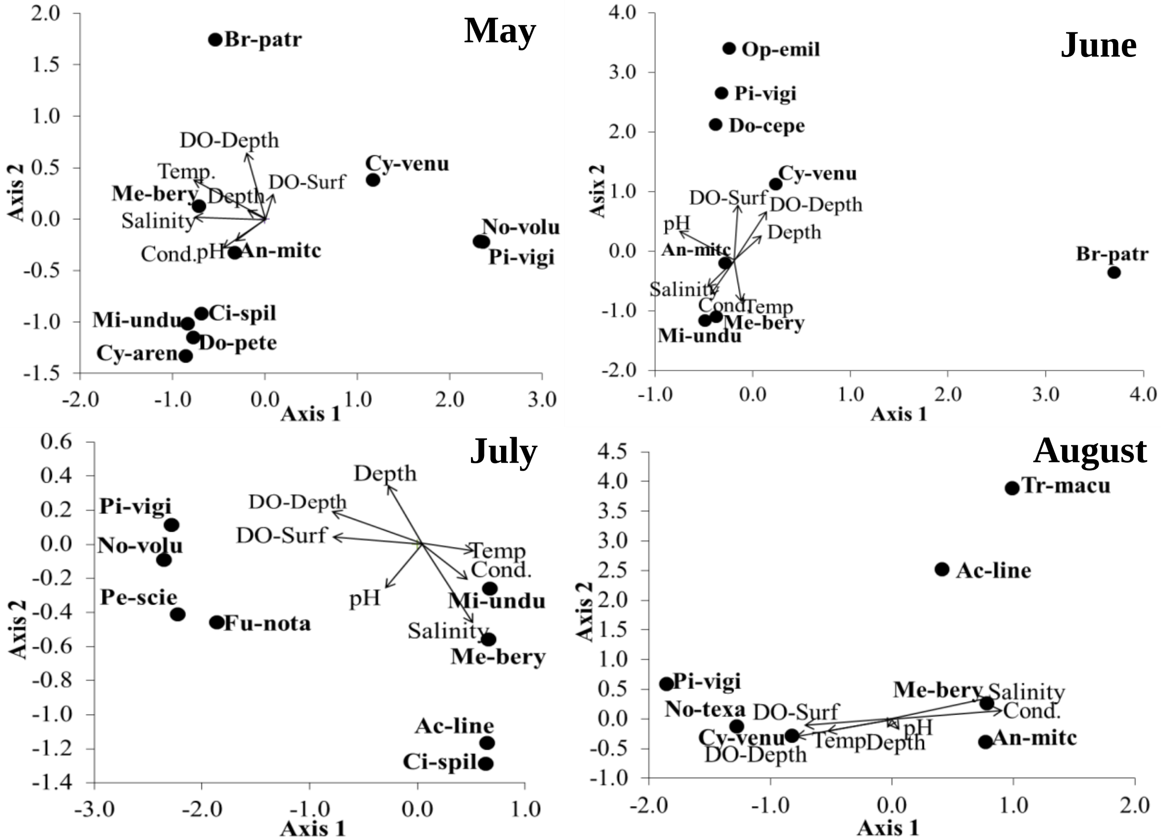

Figure 17. Canonical Correspondence Analysis (CCA) of fish CPUE from seine surveys and seven physiochemical variables measured at eight sites each month during summer 2012. Codes for physiochemical variables are defined in Figure 16. Ac-line = *Achirus lineatus*, An-mitc = *Anchoa mitchilli*, Br-patr = *Brevoortia patronus,* Ci-spil = *Citharichthys spilopterus,* Cy-aren = *Cynoscion arenarius,* Cy-venu = *Cyprinella venusta*, Do-cepe = *Dorosoma cepedianum,* Do-pete = *Dorosoma petenense,* Fu-nota = *Fundulus notatus,* Me-bery = *Menidia beryllina*, Mi-undu = *Micropterus undulatus,* No-texa = *Notropis texanus,* No-volu = *Notropis volucellus*, Op-emil = *Opsopoeodus emiliae*, Pe-scie = *Percina sciera,* Pi-vigi = *Pimephales vigilax*, Tr-macu = *Trinectes maculatus.*

4. DISCUSSION

4.1 Drought in 2011

Drought conditions lasting from October 2010 through September 2011 resulted in the driest 12-month period in Texas' recorded history, with a statewide average precipitation total of approximately 11.4 inches, surpassing the drought of 1956 by 2.4 inches (Nielsen-Gammon 2012). This lack of precipitation was reflected in the flow patterns of the Lower Neches, which exhibited a low, mostly consistent flow until larger and more frequent rainfall events occurred at the end of 2011. Physiochemical measurements taken during this drought period revealed that water quality in the lower Neches River below the saltwater barrier deteriorates during extended periods of low flow. Differences in water quality measurements taken directly above and directly below the saltwater barrier indicated a clear separation between these two segments of the river during extreme low-flow periods when the barrier was closed. Seine samples obtained during October and November 2011 consisted of species tolerant to low DO and enrichment with dissolved organic compounds (DOC) as well as brackish and saline conditions (Linam and Kleinsasser 1998). Further, samples lacked cyprinid species as well as a number of other freshwater species common to seine samples obtained during summer 2012. Although conditions improved below the barrier in December 2011, following the return of periodic rain events, the river lacked the spatial salinity gradient characteristic of coastal streams (Rakocinski et al. 1992, Jaureguizar et al. 2003, Martino and Able 2003, Albaret et al. 2004). Further, the lowest DO measurement was taken just below the barrier during November indicating that, while the barrier was closed, it is possible that tidal flux dominated downstream reaches, thereby allowing for greater saltwater intrusion and minimal flushing of paper mill effluent downstream to Sabine Lake (Harrel and Smith 2002). This lack of dilution of the paper mill effluent probably increased BOD and COD, thereby reducing DO levels (Lima Neto et al. 2007).

4.2 Post-Drought Conditions

In December 2011 and summer 2012, gillnet samples revealed evidence of a recovering system following drought. Species obtained during drought conditions included a marine species (*Cynoscion* spp.) and two freshwater species (*L. osseus* and *D. cepedianum*); these freshwater species have been identified as tolerant to degraded water quality and low DO (Linam and Kleinsasser 1998). When water quality improved during December 2011, fish assemblages showed signs of recovery; there was an increase in species richness and abundance and an increase in the proportion of freshwater species. Further, only one tolerant species (*Aplodinotus grunniens*) was obtained, and all others were species found to be intermediately tolerant. Fish are highly mobile organisms, thus it is not uncommon to see rapid recovery in species richness and assemblage composition as environmental conditions improve (Sheldon and Meffe 1995, Lonzarich et al. 1998, Stevens et al. 2006). However, the rate of restoration between systems is highly variable, and species composition may deviate from the original assemblage if some species are lost from ecosystems that have undergone long-term changes or experienced repeated or chronic harsh conditions (Larimore et al. 1959, Yount and Niemi 1990, Sheldon and Meffe 1995, Lake 2003). Even though species richness from gillnet surveys conducted during May, July, and August 2012 were similar to species richness during October 2011, the 2012 samples showed evidence of further recovery and included a variety of intermediately tolerant freshwater and marine species.

During summer 2012, species richness was similar for May, July, and August, but was highest in June; however, all months included a mix of intolerant and tolerant fish species. June was the only month to include a species identified as intolerant to low DO and high DOC (the sand seatrout, *C. arenarius*, which is a marine species). Contrary to results from my analysis of seine data, analyses of gillnet samples revealed weak patterns in assemblage structure based on location relative to the barrier and sampling period. Assemblages of larger-bodied fishes captured in gillnets consisted of a mix of larger predatory species (*L. osseus*, *L. occulatus*, *Ictalurus furcatus*, *I. punctatus*, *Micropterus salmoides*, and *M. punctulatus*). Most of these species are tolerant to low DO and high concentrations of DOC as well as to brackish water (Linam and Kleinsasser 1998, Roach and Winemiller 2011). A possible explanation for low variation among gillnet samples is that these larger species are capable of moving greater distances over short time periods (Lonzarich et al. 1998, Hubert et al. 2012). Larger fishes typically have larger home ranges (the area used over a period of days by the organism) presumably due to their higher energy demands that require foraging over larger areas (Gerking 1953, Lonzarich et al. 1998, Kramer and Chapman 1999). Further, larger fishes are less susceptible to predation than smaller fishes, so that larger fishes can venture farther from structurally complex habitats that provide smaller fishes with refuge from predators (Mittelbach 1981, Schlosser 1987, Chick and Mlvor 1997). Gillnet samples from sites 5 and 8 showed the strongest correlations with physiochemical variables; site 8 was in closest proximity to Sabine Lake and site 5 was located within a bayou that had relatively high salinity and low DO.

On average, seine samples taken while the barrier was open had significantly higher species richness than samples taken while the barrier was closed. Further, samples taken above the barrier were significantly richer in species than samples taken below the barrier, regardless of sampling period. Species assemblage patterns observed among sites and sampling periods during summer 2012 were generally consistent with results seen in previous studies along the same stretch of river. Harrel (1975) analyzed water quality and assemblages of benthic macroinvertebrates of the Neches above and below the barriers (prior to the construction of the permanent saltwater barrier in 2003, a pair of temporary installments were used for a similar purpose to the permanent barrier used now) and found lower water quality and species richness below the barrier as compared to sites above the barrier. Harrel and Smith (2002) conducted a similar study in the following decades after imposition of new regulations and improved water treatment. They documented improvement in water quality and species richness at sites below the barrier, except for two sites in closest proximity to the paper mill effluent discharge that continued to show evidence of high DOC and low DO (Harrel and Smith 2002). Similar results were observed in my seine samples during summer 2012; across all months (except June), regardless of whether the barrier was open or closed, species richness was lowest in sites closest to the location of the paper mill effluent discharge pipe. Although there seems to be some improvement in water quality between Harrel and Smith's study and the current study, there remains evidence of impact on species assemblages at sites near the effluent discharge pipe, especially during times of low flow.

4.3 Saltwater Intrusion in the Lower Neches

During summer 2012, freshwater fish were observed in higher abundance and diversity at sites above the barrier and during the month of May, when flows were relatively high, whereas lower sites (closer to Sabine Lake) revealed greater dominance of marine and estuarine species. Certain freshwater species, such as *L. microlophus* and *P. annularis,* were only collected during May, and other species, such as *C. lutrensis* and *M. salmoides*, had wider distributions across sites during May than any other month. Although salinity levels also were low during July, species distributions may have been restricted due to DO levels below the barrier having declined to suboptimal levels for most fishes (McKinsey and Chapman 1998, Kramer and Chapman 1999, Stevens et al. 2006).

Distributions of many freshwater fishes were confined to upstream sites, whereas marine and estuarine species increased in abundance downstream. Certain freshwater species, such as *Percina sciera, A. grunniens,* and *N. volucellus*, were confined to sites above the barrier during all months, and other species were primarily found at sites above the barrier when the barrier was closed and were collected below the barrier when it was open. Multivariate analysis revealed distinct assemblage patterns at sites above the barriers across all months. It appears that the saltwater barrier may block dispersal by certain species of fishes regardless of whether it is open or closed.

Relationships between salinity gradients and fish assemblages, such as those observed in the Lower Neches, have been observed in estuarine ecosystems around the world (Keup and Bayless 1964, Garcia et al. 2003b, Martino and Able 2003, Whitfield et al. 2006). Strong variation in precipitation and runoff can shift longitudinal spatial patterns of salinity gradients and fish assemblages (Garcia et al. 2003a, Love et al. 2008, Vivier et al. 2010, Zampatti et al. 2010). Coastal streams and estuaries play important roles in recruitment of marine species that depend on estuarine gradients and access to oligohaline habitats (Rogers et al. 1984, Akin et al. 2003), and chronic high salinities may have detrimental effects on these marine populations (Roessig et al. 2004, Dolbeth et al. 2008). Zampatti et al. (2010) observed a large decline in recruitment of estuarine-dependent marine species in an Australian estuary as freshwater flow from the contributing river decreased over a three-year period. Saltwater intrusion, in addition to closure of the saltwater barrier, in the Lower Neches may have significant impacts on estuarine-dependent species of this region, such as *S. ocellatus, B. patronus,* and *C. spilopterus*. These fishes depend on oligohaline coastal ecosystems for optimal juvenile growth and survival, as well as production of crustacean populations that are important food resources (Deegan 1990, Reichert and van der Veer 1991, Raynie and Shaw 1994, Craig et al. 1995, Roessig et al. 2004).

Along with analyzing relationships between spatiotemporal variation in fish assemblages and physiochemical environmental parameters, this project monitored water quality parameters in order to determine how drought and low flows may affect the broader ecosystem of the Lower Cypress Tract. The 2011 drought lasted over 12 months with record-low precipitation (Nielsen-Gammon 2012), and by November salinity levels below the saltwater barrier had exceeded tolerance levels for the dominant tree species (bald cypress and water tupelo) of the bottomland hardwood forest (Krauss et al. 2009, Hoeppner and Rose 2011). During 2012, stress and mortality was observed among trees near the Neches riverbanks below the saltwater barrier. Such occurrences were not observed above the barrier (author's personal observations). Bald cypress is reported to be the most saline-tolerant floodplain hardwood species of Gulf coast bottomland forests. Nonetheless, adult trees are only able to withstand chronic salinity exposure up to approximately 3 – 4 ppt on average before they are adversely affected (Krauss et al. 2007). It is important to note that salinity tolerances vary between populations (Conner and Inabinette 2005, Krauss et al. 2007). For example, Krauss et al. (2009) observed that basal area growth decreased approximately 50% over a four year study period for adults in sites with salinities of 1.3 ppt and greater. For seedlings, experiments have revealed 100% mortality after two weeks at 10 ppt, 73% mortality after three months at 8 ppt, and detrimental effects to growth at salinities over 2 ppt (Conner et al. 1997, Krauss et al. 2007). Further, as Hackney et al. (2007) revealed, low flows resulting in saltwater intrusion also can lead to conversion of freshwater marsh within this area into brackish or saltwater marsh at salinity levels around 2 ppt, and this change may occur in as little as 4 months.

5. CONCLUSIONS

Strong relationships between the structure of fish assemblages and environmental variables have been observed in coastal streams and estuaries throughout the world. These areas of transition between freshwater and marine ecosystems typically exhibit steep environmental gradients, particularly in salinity, that have been observed to shape local fish assemblages in fairly predictable ways (Peterson and Ross 1991, Akin et al. 2003, Zampatti et al. 2010). Previous studies have observed shifting dominance of freshwater, estuarine, and marine fish species along these gradients, and have revealed that rising salinities in estuaries and the lower reaches of coastal streams may have detrimental effects on species richness and recruitment for important estuarine-dependent species (Garcia et al. 2003b, Zampatti et al. 2010). Analysis of the Neches River during 2011-2012 revealed that water quality deteriorates during low-flow periods. During 2011, a period of extended severe drought when salinity levels increased substantially below the Lower Neches saltwater barrier, DOC from the MeadWestvaco paper mill effluent became concentrated in this region of the river. Degradation in this reach also was apparent during July 2012 when flows were low. Freshwater flows during drought conditions appear to be insufficient to maintain the current riparian vegetation community of the Lower Cypress Tract, a reserve within the federal Big Thicket Preserve. There is cause for even greater concern given that the current Texas state water plan proposes to meet the increasing water demands of a growing population with additional diversions from streams and rivers, which will only further reduce freshwater instream flows. Should this occur, impacts documented here for water quality and fish assemblages in the Lower Neches River during the recent drought could occur in other regions of the Texas Gulf coast in the future. Further, a reduction of available freshwater inflows could allow for a drought of lower intensity to result in impacts just as severe as those observed during the record drought of 2011.

As Texas strives to satisfy the water needs of a growing population and economy, it will become increasingly difficult to allow for sufficient freshwater for river and stream ecosystems. One means of addressing this challenge would be a campaign to educate the public regarding these tradeoffs and the need for water conservation, even in southeastern Texas, the most water-rich region of the state. Ensuring that the proper knowledge and tools for more efficient water use are widely available would reduce the demand and waste of water while reducing the need for additional water diversions from streams and rivers. With regard to the lack of downstream flushing of paper mill effluent in the Lower Neches during times of drought, it may be necessary to revise the current permit of allowable daily discharge from the MeadWestVaco paper mill to account for impacts during periods of low instream flows. Currently, the permit allows for a single value for daily discharge. In terms of protecting environmental quality, biodiversity, and ecosystem services, it clearly would be beneficial to examine options for setting reduced discharges during periods of drought.

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APPENDIX

Appendix 1. Percent composition of species obtained from gillnet surveys each month during fall 2011. Dashes indicate no individuals of that species were obtained during that month.

Family	**Species**	**October**	**November**	**December**
Lepisosteidae	Longnose gar, *Lepisosteus osseus*	100.0%	-	-
Clupeidae	Gizzard shad, *Dorosoma cepedianum*	-	50.0%	-
	Gulf menhaden, *Dorosoma petenense*	-	-	13.3%
Catostomidae	Smallmouth buffalo, *Ictiobus bubalus*	-	-	20.0%
Ictaluridae	Channel catfish, *Ictalurus puncatus*	-	-	40.0%
Mugilidae	Striped mullet, *Mugil Cephalus*	-	-	6.7%
Moronidae	Striped bass, *Morone saxatilis*	-	-	3.3%
	Yellow Bass, *Morone mississippiensis*	-	-	3.3%
Centrarchidae	*Micropterus* spp.	-	-	3.3%
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	-	-	6.7%
	Red drum, *Sciaenops occelatus*	-	-	3.3%
	Unidentified Sciaenidae	-	50.0%	-
	Total Number of Fish	1	2	30

Appendix 2. Abundance catch-per-unit-effort (CPUE) of each species (the number of individuals collected per 10-m of gillnet per h of deployment) obtained from gillnet sampling during summer 2012. Dashes indicate no individuals of the species were obtained during that month from that site.

Family	**Species**	**Month**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Lepisosteidae	Alligator gar, *Atractosteus spatula*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	0.010	0.019	0.010	0.027
		July	-	-	-	0.020	0.011	-	-	-
		August	-	-	-	-	-	-	-	0.010
	Spotted gar, *Lepisosteus oculatus*	May	-	-	0.009	-	-	-	-	0.026
		June	0.009	0.060	0.057	0.034	0.010	0.065	0.086	0.018
		July	0.005	0.017	0.019	0.040	-	0.010	0.020	-
		August	-	-	0.010	0.009	-	0.020	-	-
	Longnose gar, *Lepisosteus osseus*	May	0.009	0.029	0.009	0.019	-	0.009	-	-
		June	0.009	0.119	0.010	0.017	-	0.028	0.010	-
		July	0.005	0.050	0.019	-	-	0.021	-	0.009
		August	-	0.010	0.019	0.009	-	-	-	0.021
Elopidae	Ladyfish, *Elops saurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	0.010	-	-	-	-	-
Clupeidae	Skipjack shad, *Alosa chrysochloris*	May	-	0.010	-	0.009	0.009	-	0.019	0.018
		June	0.018	0.017	-	0.008	-	-	-	-
		July	-	0.006	-	-	-	-	-	-
		August	-	-	0.048	0.009	-	-	-	0.010
	Gulf menhaden, *Brevoortia patronus*	May	-	-	-	-	0.009	-	-	0.176
		June	0.009	0.009	-	-	0.010	0.009	-	0.081
		July	-	-	-	-	-	-	-	-
		August	-	0.181	0.107	0.009	-	0.010	-	0.084

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Clupeidae	Gizzard shad, *Dorosoma cepedianum*	May	0.027	-	-	0.009	-	-	-	0.009
		June	0.027	0.034	0.019	0.008	0.010	0.019	-	0.036
		July	-	0.006	-	-	-	-	-	-
		August	-	0.029	0.029	0.009	-	-	-	0.010
	Threadfin shad, *Dorosoma petenense*	May	-	-	0.009	-	-	-	-	-
		June	0.009	0.051	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	0.143	-	-	-	-	-	-
Cyprinidae	Blacktail shiner, *Cyprinella venusta*	May	-	-	-	-	-	-	-	-
		June	0.009	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Common carp, *Cyrpinus carpio*	May	-	-	-	-	-	-	-	-
		June	-	0.009	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Catostomidae	Smallmouth buffalo, *Ictiobus bubalus*	May	-	-	-	-	0.009	0.009	0.037	0.009
		June	0.009	0.026	0.019	0.008	-	0.019	0.029	-
		July	-	0.011	0.028	-	-	-	-	-
		August	-	-	0.058	0.009	-	-	-	0.021
Ictaluridae	Blue catfish, *Ictalurus furcatus*	May	0.018	0.019	0.009	0.019	-	-	-	-
		June	0.018	0.051	0.038	0.008	0.019	0.019	0.010	0.009
		July	-	0.011	-	-	-	-	-	-
		August	-	-	0.048	0.018	-	0.010	-	0.031

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Ictaluridae	Channel catfish, *Ictalurus punctatus*	May	-	-	-	0.009	-	0.018	-	-
		June	-	-	0.010	-	-	0.009	0.010	0.009
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	0.010	-	-	-
	Flathead catfish, *Pylodictis olivaris*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.006	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Ariidae	Gafftopsail catfish, *Bagre marinus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	0.009	-	-	-	-
Aphredoderidae	Pirate perch, *Aphredoderus sayanus*	May	-	0.010	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	0.010	-	-	-	-	-	-
Mugilidae	Striped mullet, *Mugil cephalus*	May	-	-	-	-	0.009	-	-	0.018
		June	-	0.009	-	0.008	0.010	-	-	0.018
		July	-	-	0.037	0.020	0.011	-	-	-
		August	-	-	0.010	-	0.040	-	-	0.010
Moronidae	White bass, *Morone chrysops*	May	-	-	0.009	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	0.009
		August	-	-	-	-	-	-	-	-

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Moronidae	Yellow bass, *Morone missisippiensis*	May	-	-	-	-	-	-	-	0.009
		June	-	-	0.010	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Striped bass, *Morone saxatilis*	May	-	-	-	-	-	-	-	0.009
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Centrarchidae	Flier, *Centrarchus macropterus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	0.009	0.010	-	-	-	-
		August	-	-	-	-	0.010	-	-	0.010
	Warmouth, *Lepomis gulosus*	May	-	-	-	0.009	-	-	-	-
		June	-	-	-	-	-	-	0.010	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Bluegill, *Lepomis macrochirus*	May	0.009	0.010	-	-	-	-	0.009	-
		June	-	-	0.019	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	0.018	-	-	0.010	-
	Longear sunfish, *Lepomis megalotis*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	0.010	-
		July	-	-	-	-	0.032	-	-	-
		August	-	-	-	-	-	-	-	-

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Centrarchidae	Redear sunfish, *Lepomis microlophus*	May	-	-	0.009	0.009	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.063	0.010	-	-
		August	-	-	-	-	-	-	-	-
	Spotted bass, *Micropterus punctulatus*	May	-	-	0.009	-	-	-	-	-
		June	-	-	-	0.008	0.010	-	-	0.018
		July	-	-	-	-	0.011	-	-	0.009
		August	-	-	-	-	-	-	-	-
	Largemouth bass, *Micropterus salmoides*	May	-	0.010	-	-	-	-	-	-
		June	-	-	0.038	0.017	-	0.019	-	-
		July	-	-	-	-	0.011	0.021	-	-
		August	-	-	-	-	-	-	-	-
	White crappie, *Pomoxis annularis*	May	-	-	0.009	0.019	-	-	-	-
		June	0.009	-	0.010	-	-	-	-	-
		July	-	-	0.009	0.020	-	0.010	-	-
		August	-	0.019	-	-	-	-	-	-
Sparidae	Sheepshead, *Archosargus probatocephalus*	May	-	-	-	-	0.009	-	-	-
		June	-	-	-	0.008	-	-	0.010	0.009
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	May	-	0.019	0.009	-	0.009	-	0.009	-
		June	0.009	0.009	0.010	0.008	-	0.009	0.019	-
		July	-	0.011	-	0.010	-	0.031	-	-
		August	0.029	-	0.010	-	-	-	-	-

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Sciaenidae	Sand seatrout, *Cynoscion arenarius*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	0.009	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Spot croaker, *Leiostomus xanthurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	0.036
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Atlantic croaker, *Micropogonias undulatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	0.010	-	0.010
	Red drum, *Sciaenops ocellatus*	May	-	-	-	-	0.009	-	0.009	0.009
		June	-	-	-	-	-	0.009	-	0.018
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	0.010
Eleotridae	Fat sleeper, *Dormitator maculatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.010	-
		August	-	-	-	-	-	-	-	-
Paralichthyidae	Bay whiff, *Citharichthys spilopterus*	May	-	-	0.009	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-

Appendix 2 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Paralichthyidae	Southern flounder, *Paralichthys lethostigma*	May	-	-	-	-	-	-	-	-
		June	-	-	-	0.008	-	-	-	-
		July	-	-	-	-	-	-	-	0.028
		August	-	-	-	-	-	-	-	0.042
Achiridae	Hogchoker, *Trinectes maculatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	0.009	-	-	-	-	-
		August	-	-	-	-	-	-	-	-

Appendix 3. Percent composition of species obtained from seine surveys during fall 2011 by month and site. Dashes indicate no individuals of that species were obtained in that sample.

Family	**Species**	**October Seine 1**	**October Seine 2**	**October Seine 3**	**November Seine 1**
Engraulidae	Bay anchovy, *Anchoa mitchilli*	16.00%	-	-	25.00%
Clupeidae	Gulf menhaden, *Brevoortia patronus*	10.00%	-	-	-
Mugilidae	Striped mullet, *Mugil cephalus*	1.00%	-	-	-
Atherinopsidae	Inland silverside, *Menidia beryllina*	72.00%	22.60%	6.10%	64.20%
Fundulidae	Bayou killifish, *Fundulus pulvereus*	-	3.80%	1.20%	-
	Fundulus spp.	-	-	-	0.90%
	Gulf killifish, *Fundulus grandis*	-	-	-	3.00%
	Rainwater killifish, *Lucania parva*	-	-	2.90%	3.00%
Cyprinodontidae	Sheepshead minnow, *Cyprinodon variegatus*	-	62.70%	6.50%	-
Poeciliidae	Sailfin molly, *Poecilia latipinna*	-	9.40%	72.20%	-
	Western mosquitofish, *Gambusia affinis*	1.00%	1.40%	10.60%	-
Centrarchidae	*Lepomis* spp.	-	-	0.40%	-
Sciaenidae	Spot croaker, *Leiostomus xanthurus*	-	-	-	3.00%
	Unidentified Sciaenidae	-	-	-	0.40%
Gobiidae	*Ctenogobius* spp.	-	-	-	0.40%
	Total Number of Fish	100	212	245	232

Appendix 4. Abundance (CPUE) of each species (the number of individuals collected per 10-m of habitat seined) obtained from seine sampling during summer 2012. Dashes indicate no individuals of the species were obtained during that month from that site.

Family	**Species**	**Month**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Elopidae	Ladyfish, *Elops saurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	0.025	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Engrualidae	Bay anchovy, *Anchoa mitchilli*	May	2.363	10.458	15.500	108.850	10.600	11.667	70.771	69.050
		June	3.517	8.000	0.750	3.150	1.950	27.978	5.860	13.900
		July	0.029	-	25.467	13.500	21.325	2.067	3.644	4.100
		August	0.429	0.033	5.578	20.200	27.400	3.450	2.667	4.833
Cyprinidae	Red shiner, *Cyprinella lutrensis*	May	0.163	-	-	-	0.025	-	-	0.050
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	0.111	-	-	-	-	-
	Blacktail shiner, *Cyprinella venusta*	May	10.775	4.000	0.333	0.200	1.300	0.022	0.171	3.000
		June	0.700	0.458	0.275	0.475	0.075	0.044	0.060	0.050
		July	0.114	0.375	-	-	0.025	-	0.200	1.600
		August	4.171	2.400	-	2.560	0.775	0.025	0.156	0.133
	Ribbon shiner, *Lythrurus fumeus*	May	0.075	0.417	0.033	-	-	-	-	-
		June	-	0.042	-	-	-	0.044	-	-
		July	0.057	0.083	0.467	-	-	-	0.067	0.400
		August	0.029	0.367	-	-	-	-	-	-
	Shoal chub, *Macrhybopsis hyostoma*	May	0.013	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Golden shiner, *Notemigonus crysoleucas*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Cyprinidae	Golden shiner, *Notemigonus crysoleucas*	July	-	-	-	-	-	-	-	0.033
		August	-	-	-	-	-	-	-	-
	Sabine shiner, *Notropis sabinae*	May	0.025	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Weed shiner, *Notropis texanus*	May	0.625	0.208	-	-	-	-	-	-
		June	0.300	-	0.075	-	-	-	-	-
		July	0.543	0.208	0.667	0.075	-	-	-	-
		August	1.857	1.733	0.244	0.680	-	-	-	-
	Mimic shiner, *Notropis volucellus*	May	2.963	3.042	-	-	-	-	-	-
		June	0.050	-	-	-	-	-	-	-
		July	1.200	1.417	-	-	-	-	-	-
		August	0.029	0.067	-	-	-	-	-	-
	Pugnose minnow, *Opsopoeodus emiliae*	May	-	-	-	-	-	-	-	-
		June	0.217	-	-	-	-	-	-	-
		July	0.029	-	-	0.025	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Bullhead minnow, *Pimephales vigilax*	May	3.213	3.333	0.033	-	-	-	-	-
		June	1.250	0.750	-	-	-	-	-	-
		July	3.229	2.375	0.067	0.050	-	-	-	-
		August	2.571	1.600	-	-	-	-	-	-
Catostomidae	Smallmouth buffalo, *Ictiobus bubalus*	May	0.013	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Ictaluridae	Blue catfish, *Ictalurus furcatus*	May	0.013	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Ictaluridae	Blue catfish, *Ictalurus furcatus*	July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Ictaluridae	Channel catfish, *Ictalurus punctatus*	May	0.013	-	-	0.025	0.050	0.067	0.171	0.050
		June	-	-	-	-	0.025	-	-	-
		July	-	-	-	-	-	-	0.067	-
		August	-	-	-	-	-	-	-	-
Mugilidae	Striped mullet, *Mugil cephalus*	May	0.013	-	0.033	0.025	0.350	-	-	-
		June	-	-	-	-	-	0.022	-	-
		July	-	-	-	0.025	-	-	-	0.033
		August	-	-	-	-	-	-	0.222	0.200
Atherinopsidae	Brook silverside, *Labidesthes sicculus*	May	-	-	-	-	-	-	-	-
		June	0.017	-	0.025	-	-	-	-	-
		July	-	0.083	-	-	0.025	-	-	-
		August	0.029	-	-	-	0.025	-	-	-
	Inland silverside, *Menidia beryllina*	May	-	0.083	0.300	1.475	1.925	0.978	2.029	3.800
		June	0.050	0.083	0.125	0.300	0.975	1.489	2.620	0.900
		July	-	0.042	-	0.100	3.800	4.911	2.267	6.267
		August	0.143	0.033	0.222	0.400	3.450	0.175	0.689	0.133
Belonidae	Atlantic needlefish, *Strongylura marina*	May	-	-	-	0.025	-	-	-	-
		June	-	0.042	-	-	-	0.022	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Fundulidae	Gulf killifish, *Fundulus grandis*	May	-	-	-	-	0.575	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.075	-	-	-
		August	-	-	-	-	-	-	-	-
	Blackstripe topminnow, *Fundulus notatus*	May	0.013	0.042	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Fundulidae	Blackstripe topminnow, *Fundulus notatus*	July	0.057	0.417	-	0.025	-	0.022	-	-
		August	0.229	0.133	0.156	-	-	-	-	-
	Rainwater killifish, *Lucania parva*	May	-	-	-	-	0.025	0.044	0.029	-
		June	-	-	-	-	-	-	-	0.025
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Cyprinodontidae	Sheepshead minnow, *Cyprinodon variegatus*	May	-	-	-	-	0.025	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.100	-	0.022	-
		August	-	-	-	-	-	-	-	-
Poeciliidae	Western Mosquitofish, *Gambusia affinis*	May	-	0.208	0.133	0.025	-	0.089	0.314	0.850
		June	-	0.042	0.050	-	-	-	-	0.025
		July	-	0.250	-	0.025	-	0.089	9.267	0.800
		August	-	0.033	-	-	-	-	-	-
	Least killifish, *Heterandria formosa*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.067	-
		August	-	-	-	-	-	-	-	-
	Sailfin molly, *Poecilia latipinna*	May	-	-	-	-	-	0.022	-	0.050
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.356	-
		August	-	-	-	-	-	-	-	-
Syngnathidae	Opossum pipefish, *Microphis brachyurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.042	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Gulf pipefish, *Syngnathus scovelli*	May	-	-	-	0.025	-	-	0.029	-
		June	-	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Syngnathidae	Gulf pipefish, *Syngnathus scovelli*	July	-	-	-	-	-	0.022	0.067	-
		August	-	-	-	-	-	-	-	-
Moronidae	White bass, *Morone chrysops*	May	-	-	0.033	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Centrarchidae	Flier, *Centrarchus macropterus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.042	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Green sunfish, *Lepomis cyanellus*	May	-	-	-	-	0.025	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Warmouth, *Lepomis gulosus*	May	-	0.042	0.067	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	0.067	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Bluegill, *Lepomis macrochirus*	May	0.050	0.208	0.033	-	-	-	-	-
		June	0.050	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	0.033	0.044	-	-	-	0.022	0.033
	Longear sunfish, *Lepomis megalotis*	May	-	1.167	0.033	0.050	-	-	-	-
		June	0.033	0.042	0.025	0.025	-	-	-	-
		July	0.057	1.083	-	-	-	0.333	0.556	-
		August	0.057	0.167	-	0.240	-	-	-	0.033
	Redear sunfish, *Lepomis microlophus*	May	0.013	-	0.067	0.050	-	0.022	-	-
		June	-	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Centrarchidae	Redear sunfish, *Lepomis microlophus*	July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Redspotted sunfish, *Lepomis miniatus*	May	-	-	0.067	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Lepomis spp. (Juvenile sunfish)	May	-	-	-	-	-	-	-	-
		June	0.050	0.042	-	-	-	-	-	-
		July	-	-	0.133	-	-	-	-	0.033
		August	-	-	-	-	-	-	-	0.033
	Spotted bass, *Micropterus punctulatus*	May	0.025	0.708	0.100	-	-	-	-	-
		June	0.033	0.208	-	-	-	-	-	-
		July	0.057	0.083	0.133	-	-	0.067	-	-
		August	0.029	-	-	-	-	-	0.067	-
	Largemouth bass, *Micropterus salmoides*	May	0.083	-	0.167	0.150	0.050	0.022	-	-
		June	0.017	-	-	-	-	-	0.020	-
		July	-	-	-	-	0.025	0.044	-	0.033
		August	-	-	0.022	-	-	-	-	0.033
	White crappie, *Pomoxis annularis*	May	-	0.042	-	0.025	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Percidae	Bluntnose darter, *Etheostoma chlorosomum*	May	0.013	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	0.042	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Dusky darter, *Percina sciera*	May	0.100	0.042	-	-	-	-	-	-
		June	0.017	-	-	-	-	-	-	-

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Percidae	Dusky darter, *Percina sciera*	July	0.029	0.083	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	May	0.088	0.042	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.167	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Sand seatrout, *Cynoscion arenarius*	May	0.025	-	-	0.125	-	0.444	0.371	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Spot croaker, *Leiostomus xanthurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	0.067	0.050	-
		July	-	-	-	-	-	-	-	-
		August	-	-	-	-	-	-	-	-
	Atlantic croaker, *Micropogonias undulatus*	May	-	-	-	0.650	0.175	0.289	1.343	0.500
		June	-	-	-	0.025	0.200	0.511	0.020	0.375
		July	-	-	-	0.125	0.325	0.800	0.178	0.033
		August	-	-	-	-	-	-	0.089	-
Clupeidae	Gulf menhaden, *Brevoortia patronus*	May	0.063	0.792	3.433	0.825	51.175	3.489	0.829	2.850
		June	-	-	4.475	-	-	0.067	-	0.050
		July	-	-	-	-	-	0.111	-	-
		August	-	-	-	-	-	-	0.022	-
	Gizzard shad, *Dorosoma cepedianum*	May	0.050	-	-	-	-	-	-	-
		June	0.083	0.208	-	-	-	-	-	-
		July	0.057	0.083	0.133	0.025	0.025	-	-	-
		August	0.029	-	-	-	-	-	-	-
	Threadfin shad, *Dorosoma petenense*	May	0.038	0.167	1.500	22.950	0.200	3.978	2.743	1.300
		June	0.050	0.833	0.025	0.125	0.075	0.444	-	0.200

Appendix 4 continued

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Clupeidae	Threadfin shad, *Dorosoma petenense*	July	0.029	0.500	-	0.475	0.150	0.422	0.133	-
		August	0.029	-	0.067	-	-	0.025	0.044	-
Gobiidae	Darter goby, *Ctenogobius boleosoma*	May	0.013	-	-	-	-	0.022	0.086	0.100
		June	-	-	-	-	-	0.022	-	-
		July	-	-	-	-	-	0.178	0.111	-
		August	-	-	-	-	-	0.025	0.022	-
	Freshwater goby, *Ctenogobius shufeldti*	May	-	-	-	-	-	-	0.057	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	0.022	-	-
		August	-	-	-	-	-	-	-	-
	Naked goby, *Gobiosoma bosc*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.022	-
		August	-	-	-	-	-	-	-	-
Paralichthyidae	Bay whiff, *Citharichthys spilopterus*	May	-	-	0.033	0.025	-	0.022	0.400	0.700
		June	-	-	-	-	-	-	-	0.075
		July	-	-	-	-	-	0.244	0.133	0.033
		August	-	-	-	-	-	-	0.022	-
Achiridae	Lined sole, *Achirus lineatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.025	0.022	0.089	0.100
		August	0.029	-	0.067	-	-	-	0.044	-
	Hogchoker, *Trinectes maculatus*	May	0.013	0.042	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	0.029	-	0.067	0.025	0.025	0.044	0.033	-
		August	-	-	0.044	-	-	-	0.044	-

Appendix 5. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for gillnet samples from May 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Alosa chrysochloris	-0.20	0.76	Depth	0.10	-3.03
Aphredoderus sayanus	1.03	0.81	pH	0.61	-2.46
Aplodinotus grunniens	0.46	0.59	Salinity	0.04	8.15
Archosargus probatocephalus	-0.73	1.37	DO-Surface	0.23	4.99
Brevoortia patronus	-1.36	-0.55	DO-Depth	-0.61	0.11
Citharichtys spilopterus	1.12	-2.55	Conductivity	-1.44	0.10
Dorosoma cepedianum	0.61	-0.17	Temperature	0.00	-4.69
Dorosoma petenense	1.12	-2.55	**Site**		
Ictalurus furcatus	1.11	-0.22	Site 1	0.82	0.05
Ictalurus punctatus	1.03	1.20	Site 2	0.81	0.43
Ictiobus bubalus	-0.26	1.77	Site 3	0.87	-1.35
Lepisosteus oculatus	-0.75	-1.15	Site 4	0.97	-0.23
Lepisosteus osseus	1.08	0.15	Site 5	-0.57	0.72
Lepomis gulosus	1.23	-0.43	Site 6	0.72	1.08
Lepomis macrochirus	0.65	1.10	Site 7	-0.12	1.26
Lepomis microlophus	1.18	-1.48	Site 8	-1.09	-0.35
Micropterus punctatus	1.12	-2.55			
Micropterus salmoides	1.03	0.81			
Morone chrysops	1.12	-2.55			
Morone mississippiensis	-1.39	-0.66			
Morone saxatilis	-1.39	-0.66			
Mugil cephalus	-1.16	0.05			
Pomoxis annularis	1.20	-1.13			
Sciaenops ocellatus	-0.75	1.06			

Appendix 6. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for gillnet samples from June 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Alosa chrysochloris	0.69	-1.77	Depth	-0.09	-0.38
Aplodinotus grunniens	0.67	0.62	pH	-0.42	-0.58
Archosargus probatocephalus	-0.60	0.99	Salinity	-0.63	0.40
Atractosteus spatula	-1.30	0.56	DO-Surface	0.47	-0.81
Brevoortia patronus	-2.05	-0.37	DO-Depth	0.50	-0.53
Cynoscion arenarius	0.17	1.01	Conductivity	-0.67	0.48
Cyprinella venusta	0.54	-2.22	Temperature	-0.47	0.77
Cyprinus carpio	0.98	-2.49	**Site**		
Dorosoma cepedianum	-0.32	-0.56	Site 1	0.26	-0.67
Dorosoma petenense	0.91	-2.45	Site 2	0.47	-0.76
Ictalurus furcatus	0.33	-0.25	Site 3	0.50	0.65
Ictalurus punctatus	-0.22	1.38	Site 4	0.20	0.18
Ictiobus bubalus	0.72	0.45	Site 5	-0.71	-0.08
Leiostomus xanthurus	-3.01	-0.11	Site 6	0.08	0.31
Lepisosteus oculatus	0.43	0.70	Site 7	0.37	0.72
Lepisosteus osseus	0.78	-1.18	Site 8	-1.45	-0.03
Lepomis gulosus	0.77	2.38			
Lepomis macrochirus	1.04	2.14			
Lepomis megalotis	0.77	2.38			
Micropterus punctulatus	-1.79	0.01			
Micropterus salmoides	0.68	1.50			
Morone mississippiensis	1.04	2.14			
Mugil cephalus	-1.26	-0.46			
Paralichthys lethostigma	0.42	0.59			
Pomoxis annularis	0.80	0.04			
Sciaenops ocellatus	-1.92	0.27			

Appendix 7. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for gillnet samples from July 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Alosa chrysochloris	0.45	-0.95	Depth	-0.11	-0.49
Aplodinotus grunniens	0.38	-0.11	pH	-0.60	0.12
Atractosteus spatula	0.22	0.69	Salinity	-0.65	0.27
Citharichthys spilopterus	0.69	-0.32	DO-Surface	0.02	-0.55
Dormitator maculatus	1.05	-0.81	DO-Depth	-0.08	-0.52
Dorosoma cepedianum	0.45	-0.95	Conductivity	-0.86	0.16
Ictalurus furcatus	0.45	-0.95	Temperature	-0.74	-0.03
Ictiobus bubalus	0.62	-0.65	**Site**		
Lepisosteus oculatus	0.67	-0.44	Site 1	0.38	-0.57
Lepisosteus osseus	0.10	-0.71	Site 2	0.34	-0.66
Lepomis megalotis	-0.67	2.23	Site 3	0.52	-0.37
Lepomis microlophus	-0.53	1.94	Site 4	0.52	-0.09
Micropterus punctulatus	-1.99	0.38	Site 5	-0.50	1.55
Micropterus salmoides	-0.06	0.89	Site 6	0.19	0.14
Morone chrysops	-3.48	-1.69	Site 7	0.80	-0.57
Mugil cephalus	0.47	0.02	Site 8	-2.63	-1.18
Paralichthys lethostigma	-3.48	-1.69			
Pomoxis annularis	0.58	-0.13			
Pylodictis olivaris	0.45	-0.95			
Trinectes maculatus	0.68	-0.52			

Appendix 8. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for gillnet samples from August 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Alosa chrysochloris	0.00	-0.10	Depth	-0.14	-0.62
Aphredoderus sayanus	-0.30	-0.73	pH	0.00	0.58
Aplodinotus grunniens	5.51	0.37	Salinity	-0.17	0.47
Atractosteus spatula	-0.23	0.18	DO-Surface	0.11	-0.66
Bagre marinus	-0.15	-0.35	DO-Depth	0.09	-0.60
Brevoortia patronus	-0.18	-0.34	Conductivity	-0.17	0.45
Citharichthys spilopterus	-0.43	2.57	Temperature	0.12	-0.52
Dorosoma cepedianum	-0.13	-0.33	**Site**		
Dorosoma petenense	-0.30	-0.73	Site 1	5.51	0.37
Elops saurus	0.08	-0.11	Site 2	-0.23	-0.51
Ictalurus furcatus	-0.07	-0.08	Site 3	0.06	-0.08
Ictalurus punctatus	-0.63	5.07	Site 4	-0.11	-0.24
Ictiobus bubalus	-0.02	-0.07	Site 5	-0.48	3.52
Lepisosteus oculatus	-0.11	-0.26	Site 6	-0.13	-0.20
Lepisosteus osseus	-0.13	-0.15	Site 7	-0.18	-0.46
Lepomis macrochirus	-0.18	-0.46	Site 8	-0.17	0.13
Micropogonias undulatus	-0.21	-0.04			
Mugil cephalus	-0.45	3.36			
Paralichthys lethostigma	-0.23	0.18			
Pomoxis annularis	-0.30	-0.73			
Sciaenops ocellatus	-0.23	0.18			

Appendix 9. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for seine samples from May 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Anchoa mitchilli	-0.32	-0.33	Depth	-0.25	0.09
Aplodinotus grunniens	2.47	-0.16	pH	-0.49	-0.32
Brevoortia patronus	-0.54	1.75	Salinity	-0.82	0.01
Citharichthys spilopterus	-0.69	-0.91	DO-Surface	0.09	0.30
Ctenogobius boleosoma	-0.54	-0.96	DO-Depth	-0.21	0.71
Ctenogobius shufeldti	-0.93	-1.96	Conductivity	-0.38	-0.25
Cynoscion arenarius	-0.86	-1.33	Temperature	-0.84	0.41
Cyprinella lutrensis	1.61	0.48	**Site**		
Cyprinella venusta	1.17	0.38	Site 1	1.46	-0.01
Cyprinodon variegatus	-0.67	5.28	Site 2	1.13	-0.08
Dorosoma cepedianum	2.67	-0.05	Site 3	-0.31	0.12
Dorosoma petenense	-0.78	-1.15	Site 4	-0.50	-0.45
Etheostoma chlorosomum	2.67	-0.05	Site 5	-0.37	1.05
Fundulus grandis	-0.67	5.28	Site 6	-0.56	-0.11
Fundulus notatus	2.20	-0.31	Site 7	-0.51	-0.39
Gambusia affinis	-0.28	-0.63	Site 8	-0.28	-0.06
Ictalurus punctatus	-0.73	-0.45			
Ictiobus bubalus	2.67	-0.05			
Lepomis cyanellus	-0.67	5.28			
Lepomis gulosus	0.45	0.21			
Lepomis macrochirus	1.85	-0.21			
Lepomis megalotis	1.78	-0.46			
Lepomis microlophus	-0.47	-0.58			
Lepomis miniatus	-0.56	0.59			
Lucania parva	-0.90	0.52			
Lythrurus fumeus	1.96	-0.26			
Macrhybopsis hyostoma	2.67	-0.05			
Menidia beryllina	-0.72	0.13			
Micropogonias undulatus	-0.84	-1.02			
Micropterus punctulatus	1.70	-0.23			
Micropterus salmoides	-0.12	0.04			
Morone chrysops	-0.56	0.59			
Mugil cephalus	-0.56	4.18			
Notropis sabinae	2.67	-0.05			
Notropis texanus	2.50	-0.15			

Appendix 9 continued

Species	Axis 1	Axis 2
Notropis volucellus	2.36	-0.22
Percina sciera	2.48	-0.15
Pimephales vigilax	2.33	-0.21
Poecilia latipinna	-0.67	-0.38
Pomoxis annularis	0.93	-1.09
Strongylura marina	-0.91	-2.26
Syngnathus scovelli	-0.92	-2.10
Trinectes maculatus	2.20	-0.31

Appendix 10. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for seine samples from June 2012.

Species	**Axis 1**	**Axis 2**
Anchoa mitchilli	-0.28	-0.20
Brevoortia patronus	3.70	-0.36
Citharichthys spilopterus	-0.46	-1.11
Ctenogobius boleosoma	-0.49	-1.11
Cyprinella venusta	0.24	1.12
Dorosoma cepedianum	-0.38	2.12
Dorosoma petenense	-0.37	0.27
Elops saurus	-0.36	-0.12
Gambusia affinis	1.44	0.19
Ictalurus punctatus	-0.57	-1.46
Labidesthes sicculus	2.29	1.18
Leiostomus xanthurus	-0.52	-1.27
Lepomis macrochirus	-0.24	3.40
Lepomis megalotis	0.52	1.34
Lepomis spp (juvenile)	-0.33	2.57
Lucania parva	-0.46	-1.11
Lythrurus fumeus	-0.46	0.19
Menidia beryllina	-0.38	-1.10
Micropogonias undulatus	-0.49	-1.16
Micropterus punctulatus	-0.41	1.85
Micropterus salmoides	-0.41	0.73
Mugil cephalus	-0.49	-1.11
Notropis texanus	0.67	2.60
Notropis volucellus	-0.24	3.40
Opsopoeodus emiliae	-0.24	3.40
Percina sciera	-0.24	3.40
Pimephales vigilax	-0.32	2.66
Strongylura marina	-0.46	0.64

Physiochemical Variables	**Axis 1**	**Axis 2**
Depth	0.24	0.31
pH	-0.64	0.40
Salinity	-0.37	-0.74
DO-Surface	-0.03	0.87
DO-Depth	0.28	0.73
Conductivity	-0.35	-0.83
Temperature	0.01	-0.94
Site		
Site 1	-0.14	1.22
Site 2	-0.25	0.57
Site 3	2.25	-0.11
Site 4	-0.20	-0.04
Site 5	-0.32	-0.52
Site 6	-0.28	-0.40
Site 7	-0.32	-0.54
Site 8	-0.26	-0.40

Appendix 11. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for seine samples from July 2012.

Species	Axis 1	Axis 2
Achirus lineatus	0.64	-1.17
Anchoa mitchilli	0.57	0.92
Aplodinotus grunniens	-2.06	-0.80
Brevoortia patronus	0.65	-0.69
Centrarchus macropterus	-2.06	-0.80
Citharichthys spilopterus	0.63	-1.29
Ctenogobius boleosoma	0.63	-1.40
Ctenogobius shufeldti	0.65	-0.69
Cyprinella venusta	-0.13	-0.78
Cyprinodon variegatus	0.78	0.38
Dorosoma cepedianum	-0.77	1.31
Dorosoma petenense	-0.19	0.04
Etheostoma chlorosomum	-2.69	0.70
Fundulus grandis	0.82	1.04
Fundulus notatus	-1.86	-0.46
Gambusia affinis	0.43	-1.96
Gobiosoma bosc	0.60	-2.49
Heterandria formosa	0.60	-2.49
Ictalurus punctatus	0.60	-2.49
Labidesthes sicculus	-1.38	-0.37
Lepomis gulosus	0.33	2.85
Lepomis megalotis	-0.79	-1.22
Lepomis spp (juvenile)	0.39	2.12
Lythrurus fumeus	0.07	0.74
Menidia beryllina	0.66	-0.56
Microphis brachyurus	-2.06	-0.80
Micropogonias undulatus	0.67	-0.26
Micropterus punctulatus	-0.71	0.88
Micropterus salmoides	0.69	-0.26
Mugil cephalus	0.60	0.48
Notemigonus crysoleucas	0.64	-0.67
Notropis texanus	-1.12	1.45
Notropis volucellus	-2.35	-0.09
Opsopoeodus emiliae	-1.18	1.31
Percina sciera	-2.22	-0.41

Physiochemical Variables	Axis 1	Axis 2
Depth	-0.32	0.37
pH	-0.42	-0.27
Salinity	0.52	-0.47
DO-Surface	-0.88	0.06
DO-Depth	-0.86	0.19
Conductivity	0.47	-0.20
Temperature	0.70	-0.07

Site	Axis 1	Axis 2
Site 1	-1.88	0.25
Site 2	-1.44	-0.29
Site 3	0.23	1.01
Site 4	0.38	0.71
Site 5	0.57	0.37
Site 6	0.46	-0.25
Site 7	0.42	-0.89
Site 8	0.44	-0.24

Appendix 11 continued

Species	Axis 1	Axis 2
Pimephales vigilax	-2.28	0.11
Poecilia latipinna	0.60	-2.49
Syngnathus scovelli	0.61	-2.03
Trinectes maculatus	0.12	0.76

Appendix 12. Species, site, and environmental variable eigenvalues associated with the first two CCA axes for seine samples from August 2012.

Species	Axis 1	Axis 2	Physiochemical Variables	Axis 1	Axis 2
Achirus lineatus	0.41	2.52	Depth	-0.05	-0.18
Anchoa mitchilli	0.77	-0.38	pH	0.07	-0.26
Brevoortia patronus	1.16	8.41	Salinity	0.84	0.38
Citharichthys spilopterus	1.16	8.41	DO-Surface	-0.76	-0.11
Ctenogobius boleosoma	1.19	2.86	DO-Depth	-0.81	-0.32
Cyprinella lutrensis	0.82	-0.63	Conductivity	0.97	0.13
Cyprinella venusta	-0.82	-0.28	Temperature	-0.56	-0.26
Dorosoma cepedianum	-1.68	0.65	**Site**		
Dorosoma petenense	0.54	1.81	Site 1	-1.03	0.08
Fundulus notatus	-1.03	0.22	Site 2	-1.28	0.06
Gambusia affinis	-2.08	0.50	Site 3	0.50	-0.07
Labidesthes sicculus	-0.44	-0.43	Site 4	0.14	-0.32
Lepomis macrochirus	0.23	1.58	Site 5	0.60	-0.20
Lepomis megalotis	-0.72	-0.94	Site 6	0.75	-0.24
Lepomis spp (juvenile)	1.13	1.01	Site 7	0.71	0.99
Lythrurus fumeus	-2.05	0.51	Site 8	0.69	0.12
Menidia beryllina	0.78	0.26			
Micropogonias undulatus	1.16	8.41			
Micropterus punctulatus	0.30	6.05			
Micropterus salmoides	1.01	0.35			
Mugil cephalus	1.15	4.89			
Notropis texanus	-1.28	-0.12			
Notropis volucellus	-1.96	0.54			
Pimephales vigilax	-1.85	0.58			
Trinectes maculatus	0.99	3.89			