Characterization of the Brazos River Estuary

by

Alex V. Miller, B.S.

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Alex V. Miller

APPROVED BY

____
George J. Guillen, Ph.D., Chair

____
Cindy Howard, Ph.D., Committee Member

____
Richard Puzdrowski, Ph.D., Committee Member

____
Dennis M. Casserly, Ph.D., Associate Dean

____
Zbigniew J. Czajkiewicz, Ph.D., Dean

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ABSTRACT

Characterization of the Brazos River Estuary

Alex V. Miller, M.S.

The University of Houston Clear Lake, 2013

Thesis Chair: Dr. George J. Guillen

Estuaries represent a continuum ranging from freshwater to marine water, influenced by the amount of freshwater inflow from tributary rivers. Freshwater inflow influences salinity, dissolved oxygen, nutrient transport, and sediment loading. Growing human populations have placed greater demands for freshwater for use in agricultural irrigation, industrial processes, and drinking water. When river water discharges are modified and reduced to meet these demands, this has an impact on the estuarine biota downstream as well as instream uses by riverine fauna. The impact of modified freshwater inflow on various aspects of estuarine ecology including salinity, nutrients, sediment, primary productivity and nekton communities have been studied in many estuaries around the world, including those in the Gulf of Mexico. Many of these are

classical lagoon or barrier island type estuaries; however, few studies have been conducted in "riverine" type estuaries. In the Northwestern Gulf of Mexico, there are only three riverine estuaries: the Brazos, lower Colorado River and lower Rio Grande.

Research was needed to determine if (1) water quality and nekton communities in the lower Brazos River have changed since last rigorously surveyed nearly 40 years ago; (2) how these subtropical communities have changed both temporally and spatially in terms of areas of the river utilized; and (3) how Brazos River communities were affected by alterations in freshwater inflow and associated water quality variables. This data is critically needed by resource managers to understand the impact that has been made on the riverine, estuarine and near shore marine ecosystem due to changes in freshwater inflow and water quality management.

Freshwater inflow from the current study on the Brazos River was compared to historical data compiled by the United States Geological Survey (USGS) and Texas Water Development Board (TWDB). The temperature, salinity and dissolved oxygen data from our current study period were compared to historical data collected by Texas Parks and Wildlife (TPWD) during the 1970's to determine how similar the water quality data was for each time period. Regression analysis was used to compare differences in biological responses (abundance, richness, and diversity) to gradients in temperature, salinity, turbidity and dissolved oxygen. Multivariate analyses were used to compare species assemblages, hydrology, and water quality between time periods and locations.

Research began on the Brazos River in January of 2012 and concluded in December of 2012. Based on this current data we determined that: 1) recent nekton assemblage at the mouth of the river exhibited 60% similarity with communities sampled at the same site during the 1970's; 2) these changes in the nekton community are mostly regulated by freshwater inflow; 3) diversity and richness was highest at the sites closest to the Gulf of Mexico; and 4) several mechanisms are likely responsible for these observed patterns including freshwater inflow directly affecting organisms via altered salinity regimes, and indirectly through modification in sediment transport and nutrients. The relative influence of freshwater inflow on overall nekton diversity and productivity during short and long time periods and the potential impacts on nearshore marine water productivity and utilization by estuarine and marine organisms are discussed.

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INTRODUCTION

Estuaries of the Gulf of Mexico (Gulf) are important because they support the early life stages of 70% of commercially and recreationally important fisheries species. On average, 66% of Penaeid Shrimp and 25% of Blue Crabs (*Calinectes sapidus*) harvested in the United States come from the Northern Gulf (Zimmerman et al. 2002). Many fish and invertebrate species composing nekton communities depend on estuaries to complete their life cycle. Estuaries are characterized by widely varying salinities and a mosaic of habitats including rivers, wetlands and bays caused by the merging of freshwater and saltwater ecosystems. The viability of these nekton species and unique characteristics of estuaries depends in part to freshwater inflow from rivers. Freshwater input alters aquatic spatial parameters, most notably salinity, along with the transportation of nutrients and sediment into these systems.

Many estuaries are threatened by degradation of water quality, loss of critical habitat, and reduction in freshwater inflow. One major change of particular importance is urbanization of the coastal zone (Minello 1999). Maintaining an essential fishery habitat for federally managed fish is required by law under the Magnuson-Stevens

Fishery Conservation and Management Reauthorization Act (Peterson 2003). Evidence of disturbed estuarine communities includes increases in abundance of tolerant species and decreased species diversity. Disturbed or polluted estuaries are also more susceptible to successful establishment of invasive species that can have a lasting detrimental impact on the ecosystem (Araujo et al. 2002). The distribution of many estuarine species is dependent on fluctuations of river inflow. Estuarine species must adapt to these changes in salinity in order to utilize the enhanced primary productivity provided by open bay habitat and sediment built deltaic wetlands. Adaptations include innate osmoregulatory functions and the ability to migrate into more favorable salinity zones. This ability to adapt in turn affects the distribution of both flora and fauna. Some nekton can tolerate widely varying salinities while others must migrate to more ideal conditions within the river-estuary interface (Bate et al. 2002).

Impact of Freshwater Inflow

Anthropogenic impacts on major rivers can be detrimental and irreversible (Chin et al. 2002; Graf 1999; Jonathan D. Phillips 2005). Artificial impoundments, otherwise known as reservoirs, grew rapidly in popularity over the past century, especially from the late 1950's to late 1970's, as a means of maintain a consistent supply of water for industrial, agricultural and human consumption (Graf 1999). The impact that impoundments have on freshwater and marine ecosystems is an area of ongoing research within the past few decades in the United States. Modern dams are large, artificial structures that influence ecosystems by fragmenting watersheds and/or withholding water from downstream rivers and marine environments. Their influence on the freshwater discharge is predicted to have a greater impact than global warming for the predicted near future (Graf 1999). This is because when dams hold water back from continuing downstream, they flood terraces upstream of the impoundment creating a reservoir and this vastly expands the surface area of the body of water. When the surface area to volume ratio increases, more water is exposed to the sun and evaporation increases. In the Northeast and Northwest where ground and surface water is more prevalent, dams are most commonly used to generate electricity. In other parts of the county however, water is stored for drinking water and irrigation in anticipation of the dry season. Some areas utilize dams and levees as a means of controlling flood events by holding back water from subsided areas that would fill up. The best example of this would be the city of New Orleans.

United States reservoir water storage has proliferated in the Great Plains, Rocky Mountains and Southwest where storage is up to 3.8 times the mean annual runoff. Relatively few dams hold the majority of this water. Across the U.S., the amount of stored water averages four acre feet per person each year. As of 1999, Texas had more dams than any other state in the union at 6,801. This is understandable when considering the magnitude of water required to support a population of over 25 million people. In Texas, major watersheds like the Rio Grande and Colorado flow through the state, but they are being increasingly tapped further upstream in other states, near their headwaters in the Rockies (Graf 1999).

When impoundments drastically reduce high flow events from surface runoff, the transport of sediment and nutrients downstream is affected; which greatly impacts the downstream riverine and estuarine ecosystems. High and low flows can cause spatial bottlenecks in communities (Poff and Ward 1989). Maintaining the natural flow regime is critical for the integrity of the biotic systems throughout the year. Drought and flooding periodicity is a natural process causing plants and animals to make behavioral and morphological adjustments over the species life history (Lytle and Poff 2004). Sediment, nutrients, and organic materials are transported downstream and into the adjacent riparian zone during heavy rainfall and subsequent flooding. Flooding increases biodiversity and often removes non-native vegetation (Baron et al. 2002). Non-natives are able to establish and outcompete native plants when hydrological conditions are altered to conditions more similar to that of the non-natives traditional habitat.

Water discharge downstream of an impoundment is generally less turbid, since turbidity as suspended sediments are deposited at the bottom of the reservoir instead of continuing downstream. Discharged dam water is generally colder and lower in dissolved oxygen. When sediment is retained behind the dam, water scours the land downstream of the impoundment as suspended sediment levels return back to saturation levels. The reduction in nutrients affects downstream plants in the riparian zone, phytoplankton and organismal life. Bacteria rely on these nutrients at the lowest level of trophic organization, which are then preyed upon by zooplankton and subsequently fishes which feed on zooplankton (Baron et al. 2002).

Altered freshwater inflow discharge from dams continues to have an impact on coastal environments. Organisms that utilize deltas, estuaries and lagoons depend on freshwater inflow to consistently shape the coastal landscape. Dams often cause channelization downstream of the impoundment resulting in increased velocities which often incises the habitat. The individual impact of dams is costly to study and difficult to manage (Sklar and Browder 1998). Since 1980, dam construction activity has slowed in the United States (Graf 1999). The removal of dams would help restore natural flows. When this is not an option, measures can still be taken to help maintain the integrity of the ecosystem by consistently regulating discharge based on the flow coming into the reservoir.

In the 80th Texas Legislature in 2007, the state passed Senate Bill 3 (SB3) in an effort to estimate and conserve water for environmental flows to meet ecological instream and freshwater inflow needs. The intent of SB3 was to determine a baseline requirement for freshwater inflow that could then be applied to all Texas rivers and streams. Evolving methodologies and lack of data have presented challenges for defining needed environmental flow (TCEQ 2013). The beneficial inflow needed in a riverine estuary is likely very different than a river that flows into an extensive bay system.

Biological Communities

Estuarine fishes and free swimming invertebrate assemblages, nekton, are important to study since many species support commercially important fisheries and their distribution and composition can serve as indicators of salinity regime, water quality and overall habitat suitability (Araujo et al. 2002). In order to understand the factors that influence the distribution of nekton the spatial and temporal distribution of salinity, habitat and water quality and their influence on estuarine nekton communities needs to be evaluated. Water resources in turn could be managed by monitoring the biological integrity of nekton communities. The biological integrity of a system is a term used to describe the aboriginal state of the community before being altered by anthropogenic activities. When declines in biological integrity occur, ecologists will recognize that there is a problem with the system (Karr 1991).

Species residing in dynamic habitats, like estuaries, must be able to adapt or migrate to more favorable conditions. The primary variables which influence estuarine organisms that are influenced by freshwater inflow include salinity, suspended sediment, dissolved oxygen and nutrients. Many studies have been conducted on aquatic communities around the world on the dynamics and influence of these variables (Akin et al. 2005; Akin et al. 2003; Araujo et al. 2002; Araujo and Williams 2000; Azevedo et al. 2007; Laegdsgaard and Johnson 2001; Maes et al. 1998; Serafy et al. 1997; Thorman 1986). However, none of the individual parameters are universally agreed upon as having the greatest impact on species abundance or diversity. Based on predicted climate change scenarios and past data, it is probable that tropical and warm temperate fishes will adapt by migrating north. Researchers have found that over two-thirds of the 16 European tidal estuarine fishes studied have migrated northward during a 30 year period (Nicolas et al. 2011). Authors concluded that winter warming in these estuaries most likely facilitated this migration.

It is often difficult to discern between the influence of temporal and spatial variation in variables on the response of aquatic communities. Studies in Southeastern Brazil (Araujo et al. 2002; Azevedo et al. 2007) and in the Mediterranean (Akin et al. 2005) found that fluctuations in estuarine fish communities may be influenced more by greater spatial variation versus temporal variation in environmental conditions. In contrast, Maes et al. (2004) determined that seasonal components could attribute up to 63.8% of population variance among estuarine fishes in Belgium estuaries. Spatial parameters were only minor indicators of fish abundance. However difficult, it is important to understand how fishes are impacted by their environment both seasonally and spatially before policies can be put in place to manage the resource.

The impact of freshwater inflow on nekton in the Gulf is well established (Browder 1998; Castellanos and Rozas 2001; Deegan 1990; Livingston et al. 1997;

Minello 1999; Peterson and Ross 1991; Sklar and Browder 1998; Tolan and Nelson 2009). Deegan (1990) exclusively looked at a common species in the Gulf, young-of-the-year Gulf Menhaden. She determined that winter temperatures and river discharge were the primary factors influencing their recruitment rates and development. Juvenile menhaden exposed to high discharges and cold temperatures resulted in higher mortality and smaller year classes. Tsou and Richard E. Matheson (2002), recognized a significant trend of higher evenness and less species diversity among nekton during the cold season in the Suwannee River estuary compared to the warm season. The intent of their research was to establish a baseline for understanding nekton assemblage shifts to freshwater input.

Little historical data is available on how nekton communities in the lower tidally influenced portions of the Brazos River are impacted by freshwater inflow. The Brazos Estuary is not incorporated in the State Texas Parks and Wildlife Department's (TPWD) routine sampling. Tolan and Nelson (2009) studied the health of Texas tidal streams by looking at the biological communities. They determined that these water bodies could support a high quality of life because the stream maintained a daily average dissolved oxygen value of at least four mg/L and never fell below three mg/L. They observed that the salinity gradients of the streams were structured primarily by freshwater inflow. Nekton community assemblages were affected by salinity values and seasonal variation of the communities was largely gear dependent (Tolan and Nelson 2009).

Parameters that exhibit significant spatial trends in estuarine systems include salinity, temperature, dissolved oxygen, turbidity, and depth. Biological communities are often impacted by more than just one variable. Outside of the United States, studies have found that salinity alone was not the primary determinant of fish distribution in freshwater deprived systems (Gutierrez-Estrada et al. 2008; Whitfield and Paterson 2003). A laboratory study found that some fishes are adapted to handle drastic changes in their environment such as flooding events (Serafy et al. 1997). These species were the ones most commonly found in the Biscayne Bay, Florida community. Species that could not tolerate rapid pulses of freshwater were unable to sustain residency in this bay system.

In Mississippi, Peterson and Ross (1991) researched the impact of a salinity gradient on nekton dynamics. They primarily captured juvenile species throughout the estuary. Their study area was divided into three habitats: tidal freshwater, oligohaline and mesohaline. They determined that nekton inhabiting tidal freshwater and oligohaline habitats exhibited greater diversity and evenness than mesohaline communities. A drought caused an increase in salinity and subsequent loss of species diversity in oligohaline and tidal freshwater communities. Peterson and Ross (1991) concluded that in tidal freshwater communities, temperature and salinity were the best predictors of nekton assemblage.

Additional environmental variables that could influence fish assemblages in tidal rivers included dissolved oxygen, pH, temperature, depth and turbidity. Juvenile fishes and crustaceans will migrate into turbid estuaries as a refuge from predators (Maes et al. 1998). However, elevated turbidity limits net primary productivity through increased shading that can reduce photosynthesis in submerged and suspended primary producers (Gutierrez-Estrada et al. 2008). In a similar study in Brazil, demersal fish populations were sampled using bottom trawling (Azevedo et al. 2007). They found that the greatest variation in species composition and abundance was related to water column depth. Another study concluded that temperature and dissolved oxygen were the most influential environmental variables influencing fish abundance in the Middle Thames Estuary in England (Araujo and Williams 2000). Maes et al. (2004) determined that spatial variation in other measured water quality variables were only minor contributors in explaining the distribution of fishes, while dissolved oxygen was the most important factor that influenced abundance.

Seasonal changes in communities are likely due in part to related changes predation pressure (Maes et al. 1998). When fishes are small, they are more likely to be preyed upon and they need to maintain concealment more than when they are larger. These young fishes and crustaceans sought refuge in the highly turbid portions of the Zeeschelde Estuary. Akin et al. (2003), concluded that fish community richness and abundance increased in the late spring, early summer of a Texas bay estuary.

When studying nekton communities, it is important to understand which species can cope with changing conditions and which migrate to a more suitable habitat. All species have physiological tolerances and critical limits that enable them to endure less than ideal conditions. This tolerance changes during their life cycle. In general, the early life stages of marine fishes are less tolerant of abnormal conditions (Miller and Kendall 2009). Fish assemblages do not remain constant throughout the year due to growth and ontogenetic shifts which are common in estuarine and marine organisms (Laegdsgaard and Johnson 2001).

Objectives

The primary objectives of our research are (1) to determine if nekton communities in the lower Brazos River have changed since last surveyed nearly 40 years earlier; (2) to characterize seasonal and longitudinal spatial changes in hydrology, water quality, and nekton community composition and abundance; and (3) to determine how these variables and communities are affected by alterations in freshwater inflow and associated water quality variables. This data is critically needed by resource managers to understand the impact that has been made on the riverine, estuarine and near shore marine ecosystem due to changes in freshwater inflow and associated water quality.

It is relatively unknown how nekton communities of the lower Brazos have changed since TPWD conducted their survey of the region in the mid 1970’s (Johnson 1977). In the proposed study, I will associate the responses of lower Brazos River fish and decapod crustacean communities' to changes in freshwater inflow and resulting salinity regime by comparing newly collected data with historical data collected at four previously monitored sites. Four sites monitored from February 1973 to January 1975 in the lower Brazos River by TPWD (Johnson 1977) will be compared to the collections from the same location in 2012. We will also compare our data with additional data collected in 1982 by Emmitte (1983).

METHODOLOGY

Study Area Description

One of the largest sources of freshwater inflow into the Gulf is the Brazos River. The Brazos River Basin is the largest watershed in Texas at 118,000 km^2 (Phillips 2006). The lower Brazos River discharges directly into the Gulf at Freeport, Texas (Figure 1). The river is heavily influenced by reservoir dams along its course and in tributaries that feed into the river (Anderson 2007; Dahm et al. 2005; Vogl and Lopes 2009). Thirty-nine reservoirs with capacities greater than 5,000 acre-feet are currently in operation in the Brazos River watershed. Dams within this basin hold back water and selected suspended constituents to control flooding and for industrial, agricultural and human ingestion. Upon installation of the Somerville Dam on a major Brazos tributary, a sharp reduction in sediment loading carrying capacity into the river was observed (Chin et al. 2002).

The headwaters of the Brazos River are located at the confluence of the Double Mountain and Salt Forks of the Brazos in North-Central Texas. The river flows through the state to Southeastern Texas transporting freshwater directly into the Gulf. This extensive watershed provides the highest sediment load to the Gulf of all Texas rivers

(Rodriguez et al. 2000). The mouth of the Brazos consists of an actively forming delta from alluvial deposits following major floods and wave action derived from the Gulf.

The lower Brazos River can be best classified as a riverine or deltaic type estuary that typically reaches oligohaline conditions several times throughout the year (Dyer 1997). Species have adapted to these conditions, but community assemblages may have changed since last thoroughly sampled by Texas Parks and Wildlife (TPWD) in 1973-5. Originally the river had one mouth located at the City of Surfside; however, dam construction and channel diversion was initiated in 1913 following a flood which silted in the original shipping docks. The position of the mouth and associated delta has changed due to diversion of the channel in 1929 from the historical location near Surfside to its present position (Rodriguez et al. 2000). Today, the Old Brazos River is disconnected from the main stem of the lower Brazos River by Brickyards Dam. The ecosystem of the lower Brazos River region is defined as a low coastal plain and is exposed to gradual subsidence. The current mouth of the river forms an active delta that began when the river was rerouted south (Phillips 2006). The benthic habitat on the Brazos is structured with a deep channel and muddy bottom with little vegetation. According to Beck et al. (2001), this type of habitat is utilized as a nursery area for estuarine fishes but this aquatic environment is not well researched.

From 1990 to 2010, the Texas Water Development Board studied the salinity of the Lower Brazos, GIWW, Freeport Channel and adjacent Chocolate Bay. The Brazos

River site located about 9.5 river kilometers (rkm) from the mouth, commonly recorded salinity values below 10 psu with infrequent readings as high as 35 psu. High salinity values at this location persisted when flows were low (Guthrie 2011). There is a need to understand the impact that the water quality is having on the biota in the river. Based on assessed water quality, the tidal section of the Brazos River (TCEQ segment 1201) is currently classified as an unimpaired water body with a high rating of aquatic use. In order to meet a high aquatic life use rating, the Texas Commission on Environmental Quality (TCEQ) standards require that the average levels of the following water quality variables not exceed the listed standard for an eight hour period: water temperature > 35°C; pH range of 6.5-9; or dissolved oxygen < 4.0 mg/L (Breitburg et al. 1997).

Based on limited historical data, the lower Brazos River most likely provides sediment, nutrients and habitat for many fishes and decapod crustaceans that selectively utilize the lower estuarine zone at different stages of their life cycle (DiMarco et al. 2012; Johnson 1977; Rodriguez et al. 2000). However, little detailed data has been collected on recent nekton communities of the lower Brazos River and how biota responds to varying freshwater inflows. The Coastal Fisheries and Inland Fisheries Divisions of TPWD do not conduct routine nekton monitoring within the Brazos River or adjacent water bodies.

We targeted our monitoring at historical index sites previously studied by TPWD in the mid-1970's to assess what changes, if any, occurred over the 40 year period. This will help them plan for the future as the demand for freshwater grows. The Brazos study sites were located at locations formerly sampled by Johnson (1977). The four Brazos River sample sites are located 0.6 rkm (B-0.6), 11.7 rkm (B-11.7), 21.5 rkm (B-21.5) and 42.4 rkm (B-42.4) from the point where the river meets the Gulf (Figure 1. **Brazos River sampling sites and the USGS Rosharon Gage in Southeast Texas.** Coordinates for the sampling locations are included in Appendix A. Photos of the sites are in

Appendix B-I. At the site 0.6 rkm upriver from the Gulf, the substrate is predominately non-vegetated sand. There is very little emergent vegetation and infrequent, large woody debris along the river bank. Tidal fluctuations are largely controlled by meteorological events with an average depth in the middle of the river of 4.65 meters. An abrupt sediment composition shift occurs once out of the prodelta from sand to a clay/mud aggregate. In contrast clay/mud aggregate is the dominant substrate at all Brazos River sampling sites upstream of B-0.6. The river depth gradually gets deeper upriver with a maximum average depth of 7.23 m recorded at B-42.4. Four National Pollution Discharge Elimination System permitted outfalls are located within the study site. The permit holders are the cities of Lake Jackson, West Columbia and Freeport;

there is also one for the Brazoria County Freshwater Control District 1 (Schoenbaechler et al. 2011).

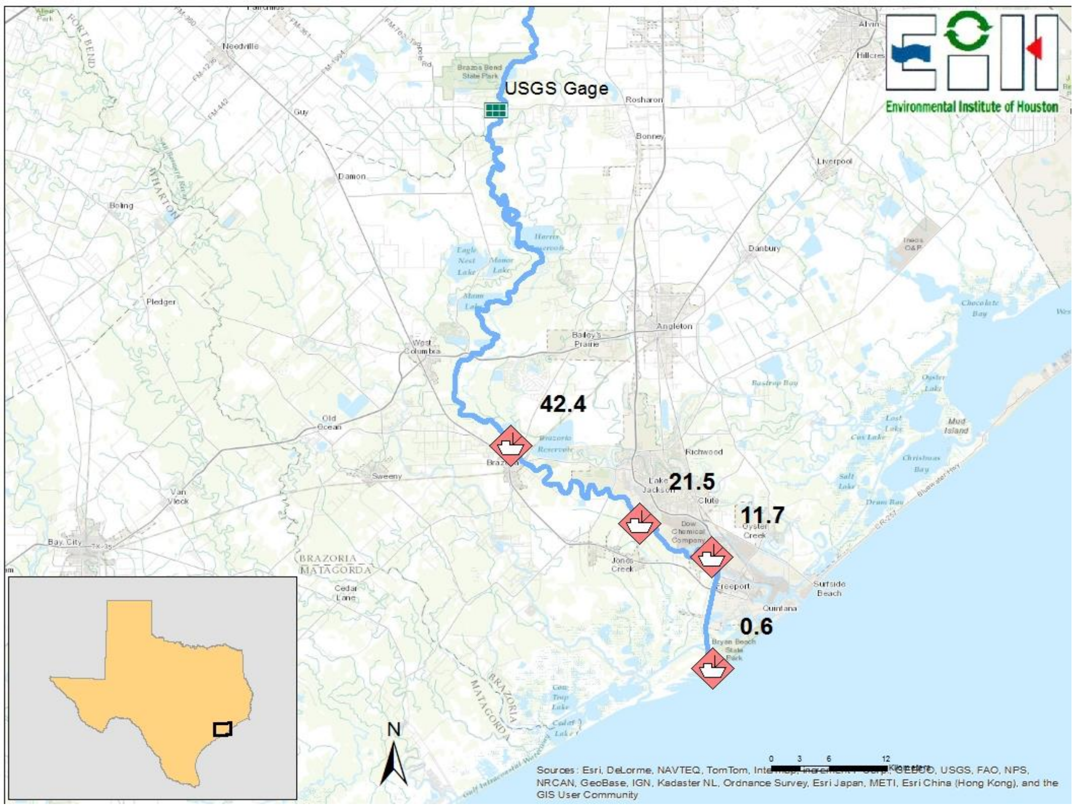

Figure 1. Brazos River sampling sites and the USGS Rosharon Gage in Southeast Texas. Sites are denoted B-## in the text, where ## is the river kilometer upstream from the mouth.

Field Collection Methods

During 2012, monthly nekton communities on the Brazos River were extensively sampled along with environmental data utilizing a variety of sampling techniques. This includes hydrology/meteorology, water quality and biological samples. Weather permitting, samples were collected the second week of every month. Field crews consisted of a boat captain and three research scientists. A fiberglass boat, generally a Twin Vee 22’ Bay Cat, with an outboard engine was used to collect samples.

Hydrology/Meteorology

Hydrology data for the current study was obtained from the United States Geological Society (USGS) Rosharon streamgaging station (08116650) located at N 29°20’58”, W 95°34’56”. This gage was about 50 rkm above sampling site B-42.4 and was the same gage used by the Texas Water Development Board during their Brazos River Estuary hydrology study (Schoenbaechler et al. 2011) (Figure 1). If discharge data, recorded in cubic feet/second (cfs), was not available during the sampling day, the gage height was used in reference to historical flows to generate a regression with 95% confidence interval of what the expected flows were for that sampling period. Precipitation data was obtained from the wunderground.com sponsored weather station at Plantation Village in Lake Jackson, Texas. This station was located less than one rkm from the Brazos River and just below B-42.4. Wind speed, wind direction, and ambient air temperature were collected with a Kestrel handheld meter at each site from the middle of the river while gathering water quality data.

Water Quality

Water quality parameters were measured at each site with a 600 XLM YSI multiprobe sonde. The sonde was calibrated prior to going to the site and checked for drift at the end of the sampling following TCEQ quality assurance standards (TCEQ 2011). The YSI meter was used to measure temperature, specific conductance, salinity, dissolved oxygen and pH in-situ at 0.3 meters below surface, half the total water depth and at 0.3 meters off the bottom to generate a profile of the water column. The vertical profile was taken in the middle of the river at each site on the Brazos Rivers. Turbidity was measured with a calibrated nephelometer from a surface grab sample at each site and recorded as nephelometric turbidity units (NTU). The sample was run three times and the average was recorded. A 120 cm transparency tube was also filled with in situ water at ~0.3m below the surface and drained until the symbol first appears to measure surface water transparency. This was recorded as Secchi disk turbidity.

Nekton Collection

In 2012, monthly nekton communities on the Brazos River were extensively sampled by utilizing a variety of sampling techniques. The collection methods utilized in this study were reviewed and approved by the University of Houston- Clear Lake Institutional Animal Care and Use Committee. All specimens were identified to species and the first 20 of each species were measured. Common and scientific names reported in this document were the most current nomenclature used by the American Fisheries Society (Page et al. 2013). Any species that could not be positively identified in the field were anesthetized in MS-222 and then preserved in 7% formalin for identification in lab using taxonomic keys. Organisms that were smaller than the net mesh of the sampling gear were documented as being present in the river but were not included in the final number of total collected because they were outside the parameters of the sampling equipment.

Similar to Johnson (1977), Emmitte (1983) also collected species with otter trawl. The otter trawl we used was identical to Johnson (1977) and consisted of 38.2mm stretched stretch mesh and was 3.1 meters wide. The 38.2mm stretched mesh was additionally equipped with an inside mesh of 6.1mm netting within the cod end. Three independent replicate trawl samples were taken at each site during each collection period. Each replicate sample consisted of a five minute tow at an average speed of two knots. A thirty meter tow line was used, with an additional tow line added when sampling depth exceeded seven meters. All trawls were towed upriver with speed adjustments depending on the current. Otter trawls were similar in design to those used by Gutierrez-Estrada et al. (2008). Their study determined this method to be an efficient sampling method for demersal fish populations. When the trawl got stuck on submerged structures, it was retrieved, emptied and redeployed above the hazard location to ensure independent sampling.

All fishes and invertebrates were identified to the lowest taxonomic level possible using regional guides and taxonomic keys (Galveston 2012; Hoese and Moore

1998; Kells and Carpenter 2011; Thomas et al. 2007). In most cases, specimens were identified to species level to facilitate comparisons between individual species abundances. This identification was also used for further calculation of number of taxa or species and community indices.

Literature Review- Historical Comparison

An extensive literature review was conducted on the distribution of fishes and decapods crustacean communities in riverine estuaries of the Texas Gulf Coast in relation to spatial and temporal trends during the design of this study. There have only been three previous nekton studies on the lower Brazos River. From 1973-75, Texas Parks and Wildlife conducted a study that included five sites on the lower Brazos River for nekton with 3.1 meter otter trawls (DiMarco et al. 2012; Emmitte 1983; Johnson 1977). The TPWD study included five sites from 0.6-42.4 rkm for 24 months with two trawls at each station. Then a follow-up study by the Texas Department of Water Resources for two months in 1977 (Kirkpatrick 1979). Due to the limited nature of this study, the results were not analyzed and only served as anecdotal discussion. Lastly in 1982, Dow Chemical Company inventoried the sites around their petrochemical plant on the Brazos River (Emmitte 1983). This research was only submitted as a company report. This study had four sites located from 4.8 – 15.3 rkm and used a 6.1 meter otter trawl quarterly for one year without replicate tows. Only limited summary data was available from this study and no raw data was available (Emmitte 1983).

Data Analysis

Preliminary Analyses

Several types of statistical analysis were conducted during this study that required pre-processing of physicochemical and fish community data and/or metrics. This included 1) univariate correlation analysis and 2) principal component analysis (PCA) to evaluate the role of physicochemical data and biological nekton community metrics, and 3) analysis of similarity of nekton communities between sites and collection periods using cluster analysis, followed by SIMPROF to identify significant groupings. These two statistical techniques used to describe and group collections based on the similarity of attributes (e.g. species) have been shown to complement each other in terms of providing a more holistic view of community structure. Physicochemical data was standardized to create equal weighting between variables prior to multivariate PCA.

Individual replicate data from each gear type for each collections was used to compute community metrics. Total abundance, Shannon-Wiener's Diversity (H') and Taxa Richness, were calculated for each replicate per gear type during each collection event (site X date combination) (Krebs 1999; Magurran 2007) The Shannon-Wiener Diversity index (H') is defined as is defined as - $\sum (P_i)(\ln P_i)$ where P_i is the proportion of each species in the sample. Richness or number of taxa is a count of the number of species or taxa present in a sample (Tuomisto 2010). I used Kruskal-Wallis multiple range test and plotted the non-overlapping confidence interval bars to the graphs. Kruskal-Wallis tested a one-way ANOVA on individual physicochemical variables based on ranks. Both aforementioned analysis tools were also used to evaluate nekton communities (Spurrier 2003).

Analysis of Spatial and Temporal Data – Current Study

Graphical comparisons consisting of boxplots and/or scatterplots were prepared to facilitate spatial (by site) and temporal (by month) comparisons of streamflow, temperature, salinity, specific conductance, dissolved oxygen, and biological community metrics including otter trawl total catch, richness and diversity. Dominant taxa for each collection were depicted using pooled replicate data and displayed on pie graphs. Correlation analysis and/or regression analysis was also conducted on physicochemical variables and biological community metrics, with a special focus on trawl based metrics. Correlation and regression analysis were conducted between the average biological metrics per collection and matching physicochemical variables. This analysis was used to determine the possible relationship between individual abiotic and biotic characteristics (variables) at each site. This was supplemented with PCA to characterize the environmental characteristics of each site and how these individual chemical and physical variables may be interrelated and combine into common “factors” or principal components that may influence the distribution of nekton community metrics (Peck and Devore 2010).

Multivariate analysis of physicochemical data consisted of cluster analysis and PCA. Prior to multivariate analysis physicochemical variables were standardized and rescaled to insure equal weighting between variables during clustering and ordination. Cluster analysis of physicochemical data was conducted by computing a Euclidean distance similarity matrix between sites and then constructing a dendrogram using the group average linkage method algorithm (Clarke and Gorley 2006). Significant groupings were identified using the SIMPROF test for variation in similarity. Principal coordinate analysis was the ordination technique used to evaluate the relationship of physicochemical variables and collections spatially. Since zero values in environmental data are typically rare, but are meaningful, PCoA was the ordination technique used to evaluate the relationship of physicochemical variables and collections spatially. This technique reduces the number of original variables into a smaller set of linear combination of these variables that can be used to predict interrelationships between variables and observations (Tabachnick and Fidell 2006). All cluster and PCoA analyses were performed with the PRIMER® 6.1 statistical software package (Clarke and Gorley 2006).

Nekton community multivariate analysis between collections consisted of cluster analysis and non-metric dimensional scaling. Cluster analysis consisted of computing a Bray Curtis similarity matrix between collection periods (e.g. sites X months or sites) based presence/absence transformed abundance of nekton species and then construction of cluster groupings using the group average, cluster analysis algorithm (Clarke and Gorley 2006). Significant groupings were identified using the SIMPROF test for variation in similarity. In addition to cluster analysis, principal coordinate analysis (PCoA) was used to evaluate the nekton community assemblages between collections. All PCoA analyses were performed with the PRIMER® 6.1 statistical software package (Clarke and Gorley 2006).

Pearson's correlation was used to compare the linear relationships between biological and physicochemical parameters. This analysis determines the direction and strength of the linear relationship between the two quantitative variables. The "r" value determines whether the relationship is positive or negative. The model assumes that no relationship exists between the two variable; this would result in r = 0 if this were to be the case. The analysis was run with Minitab 17® software.

Comparisons with Historical Studies

Data collected during the current study was compared to data from Johnson (1977) and Emmitte (1983). This included comparisons of hydrology, water quality and nekton collected using common gear, for example by otter trawls. Streamflow provided from USGS gage data and selected water quality variables were evaluated; this includes temperature, salinity/conductivity, and dissolved oxygen. Analysis of hydrology and water quality variables consisted of graphical comparisons (scatterplots and/or boxplots), and cluster analysis. Due to lack of complete information on sampling effort, comparisons of nekton collections were based on presence/absence only. In addition, comparisons were limited to each site and the study overall, but not temporally (i.e. months).

Prior to analysis physicochemical variables were standardized and rescaled to insure equal weighting between variables during clustering and ordination. Cluster analysis was used to attempt to group samples into discrete clusters. Cluster analysis of physicochemical data was conducted by computing a Euclidean distance similarity matrix between sites and then constructing a dendrogram using the group average linkage method algorithm (Clarke and Gorley 2006). Significant groupings were identified using the SIMPROF test for variation in similarity.

Nekton community analysis between historical and recent data consisted of graphical comparisons of cumulative number of taxa and multivariate cluster analysis. Cluster analysis consisted of computing a Bray-Curtis dissimilarity matrix between collection periods (e.g. sites X months or sites) based on presence/absence of nekton species and then construction of cluster groupings using the group average, cluster analysis algorithm (Clarke and Gorley 2006). Significant groupings were identified using the SIMPROF test for variation in similarity.

RESULTS

Current Study

Streamflow

Freshwater inflow was highest during the months of February, March and April on the Brazos River during the 12 month study period from January to December in 2012 (Figure 2). Over the rest of the year, the flows were greatly reduced with relatively little fluctuation. Discharge data was not available during the months of August, September and October, so we calculated flows based on a regression of streamflow versus gage height. The highest recorded flow was in March (25,100 cfs), while the lowest recorded flows were during the month of November (145 cfs). No major weather events occurred during the study period; however, this region was still in a drought period which started in 2011 (Figure 2).

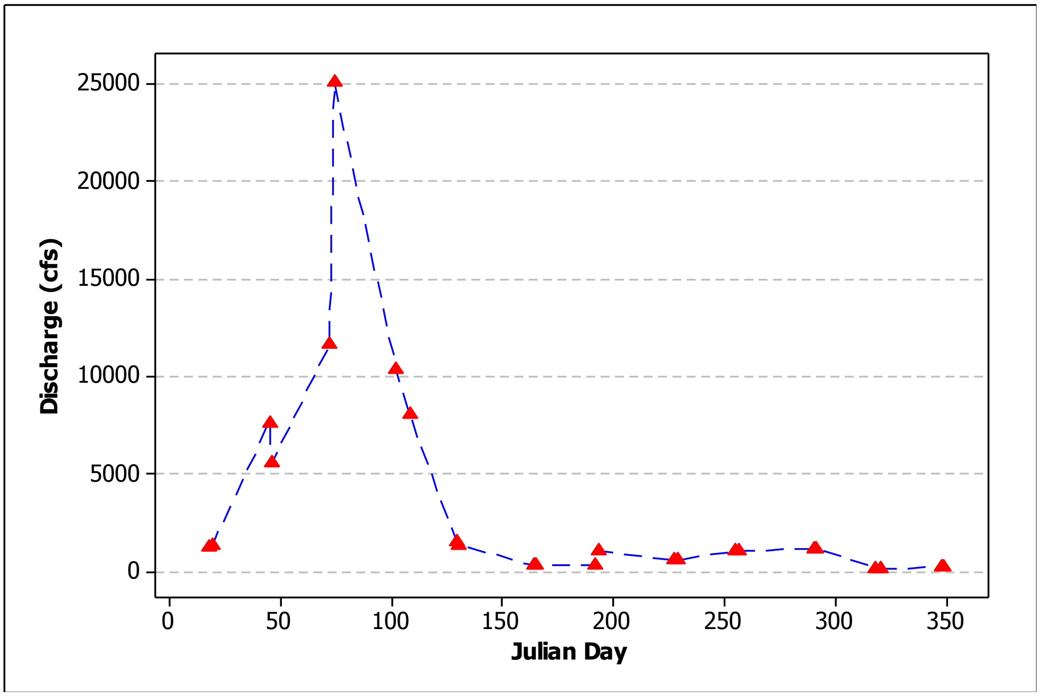

Figure 2. Scatterplots of Brazos River discharge data collected from Rosharon, TX gauging station (08116650) during collection events in 2012.

Water Quality

On average, the sampling site closest to the Gulf (B-0.6) exhibited the lowest temperature, highest salinity, lowest dissolved oxygen and lowest turbidity across all three levels in the water column (Table 1). Conversely, the uppermost site (B-42.4) displayed the lowest salinity and highest turbidity readings on average. On average, salinity steadily decreased upriver on the Brazos (Figure 3). The mouth of the river was slightly cooler on average compared to the other sites further from the Gulf. Bottom dissolved oxygen met standards suitable for fish communities most of the year (TCEQ 2013). Dissolved oxygen was highest at the mouth of the river (Figure 3). Mean dissolved oxygen values were generally high enough to support aquatic life; however no measurements were taken over a 24 hour period. The pH was always within TCEQ standards of 6.5-9.0 for Brazos River Tidal and was not statistically significant for any analysis (TCEQ 2013). Surface and middle water quality data was collected but not presented because our nekton communities were only collected on the bottom. The upper sites (B-21.5 and B-42.4), were generally deeper than the lower sites (B-0.6 and B-11.7) (Table 1). A complete table of water quality data collected during otter trawls by site is included in

Appendix J-N.

Table 1. Average water quality data collected on the Brazos River in 2012.

	Water Temp (C)	Salinity (psu)	D.O. (mg/L)	pH	Sample Depth (m)	Total Depth (m)	Turbidity (NTU)
Surface							
B-0.6	24.65	18.57	7.5	7.93	0.32	4.68	17.85

B-11.7	24.38	13.81	8	7.92	0.33	4.26	79.12
B-21.5	24.08	8.8	8.36	7.94	0.61	7.23	121.52
B-42.4	24.12	3.22	7.8	7.87	0.33	7.16	210.27
Middle							
B-0.6	24.09	22.91	7.12	7.88	2.33	4.68	-
B-11.7	24.82	19.63	6.51	7.71	2.14	4.27	-
B-21.5	24.81	17.47	5.01	7.55	3.7	7.23	-
B-42.4	24.54	7.58	5.68	7.63	3.6	7.16	-
Bottom							
B-0.6	23.9	27.78	6.89	7.9	4.33	4.68	-
B-11.7	25.32	23.96	5.82	7.49	3.9	4.27	-
B-21.5	25.04	21.89	4.84	7.48	6.94	7.23	-
B-42.4	24.78	10.37	5.5	7.5	6.79	7.19	-

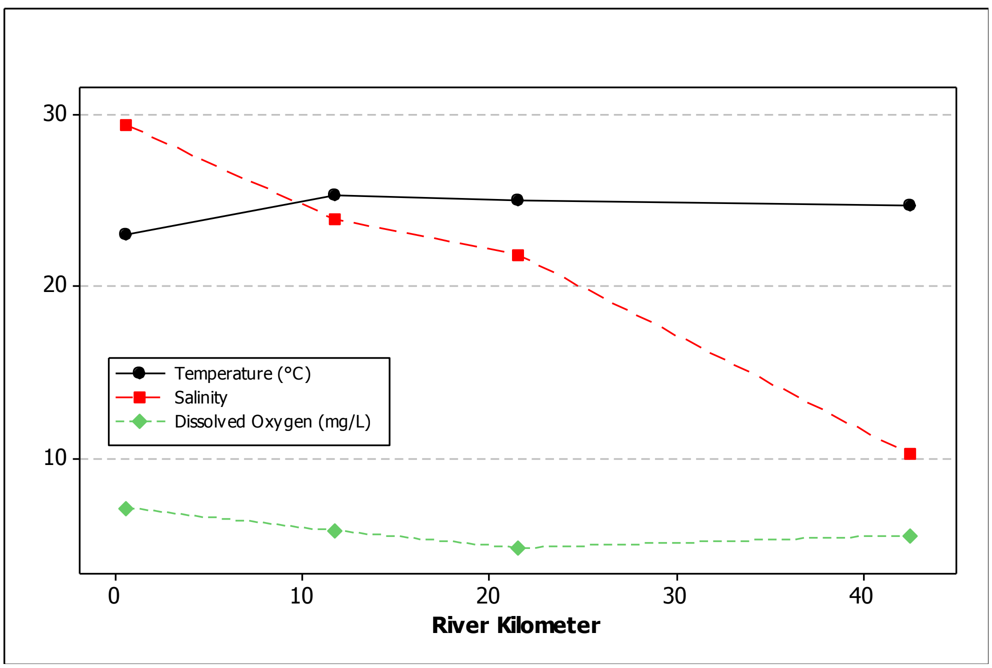

Figure 3. Scatterplot of average temperature, salinity and dissolved oxygen measurements taken 0.3m off the bottom of the Brazos River. River kilometer is the distance from the mouth of the river. (n=12)

Water Temperature

Bottom water temperature ranged from 14.5°C at B-0.6 in January up to 32.7°C at B-42.4 in August. Site B-21.5 exhibited the greatest variation and a lowest median value of

25.4°C. The results of the Kruskal-Wallis one-way analysis of variance test indicated there were no significant (CI = 86.761) differences between sites (Figure 4). More stable (less variable) temperatures were found at B-0.6 than the other sites upriver. Across all sites, bottom temperatures on the Brazos River increased from February to August before descending again (Figure 5). Lastly, site B-0.6 was generally cooler than the other sites on the Brazos River.

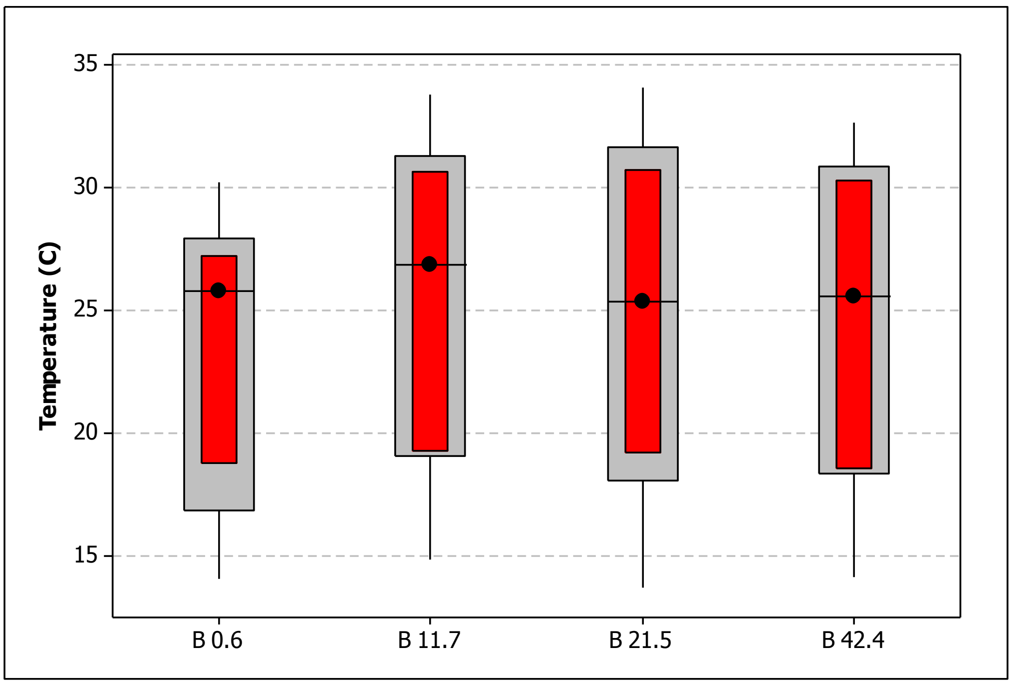

Figure 4. Boxplot of bottom temperature (°C) on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars were run using Kruskal-Wallis multiple range tests (CI = 87.761; ● = median; n = 12).

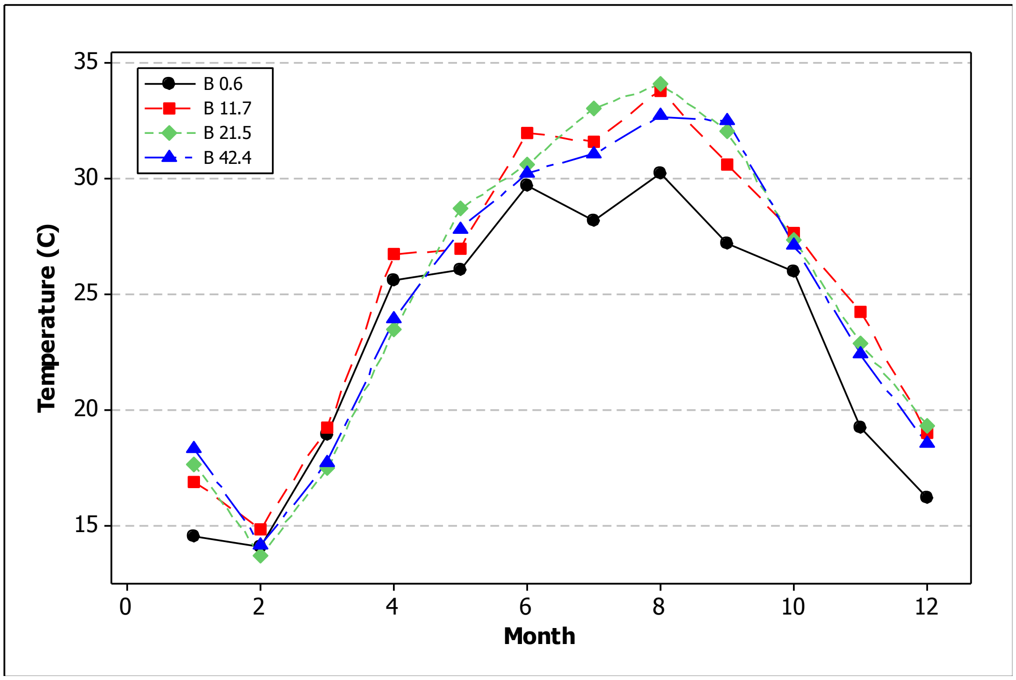

Figure 5. Scatterplot of bottom temperature recorded on the Brazos River in 2012 by site. (n=1)

Salinity

In 2012, there was a highly significant, negative correlation between distance from the Gulf and salinity (r = -0.559, p = 0.000) (

Appendix **o**). Bottom salinity was highest near the mouth of the river with a median salinity of 31.4 and lowest at B-42.4 with a median salinity of 11.3 (Figure 6). The smallest IQ range (10.2) was found at B-0.6 while the largest IQ range (26.2) was at B-21.5. Based on results of the Kruskal-Wallis test and post-hoc multiple comparison tests, the salinity values at the B-42.4 site was significantly lower than the other three sites on the Brazos River (Figure 6). During 2012 salinity fluctuated considerably between sampling periods (Figure 7). The salinity at the mouth of the river was mixoeuhaline (30-40 psu) during all months of the study except February through April. Whereas, sites B-21.5 and B-42.4 were fresh (<0.5 psu) February through April. Site B-42.4 was also fresh in January and May (Figure 7).

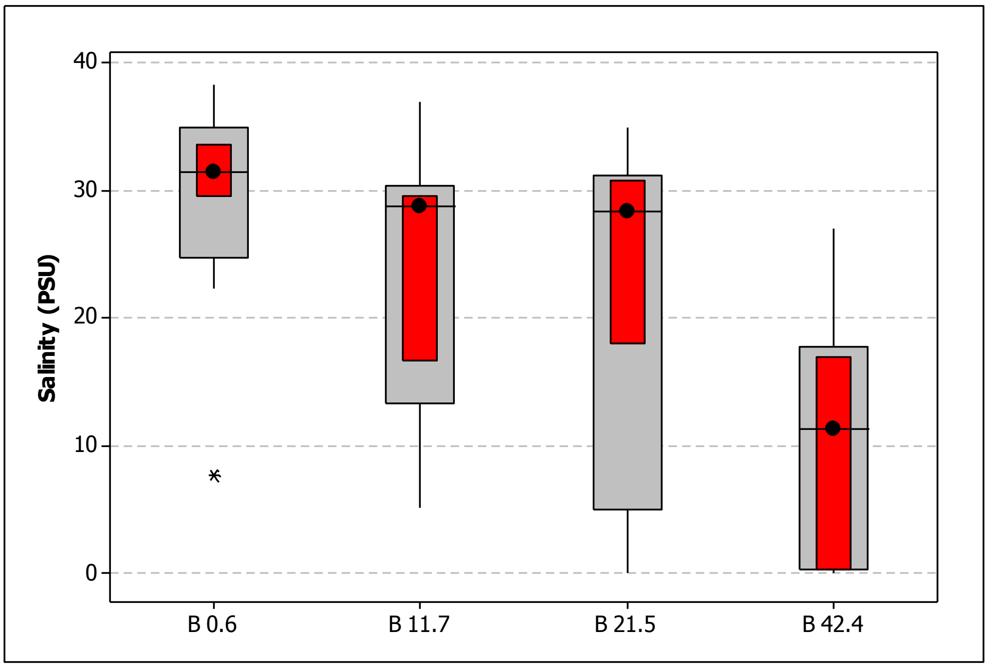

Figure 6. Boxplot of bottom salinity (PSU) on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars were run using Kruskal-Wallis multiple range test (CI = 87.761; ● = median; n = 12).

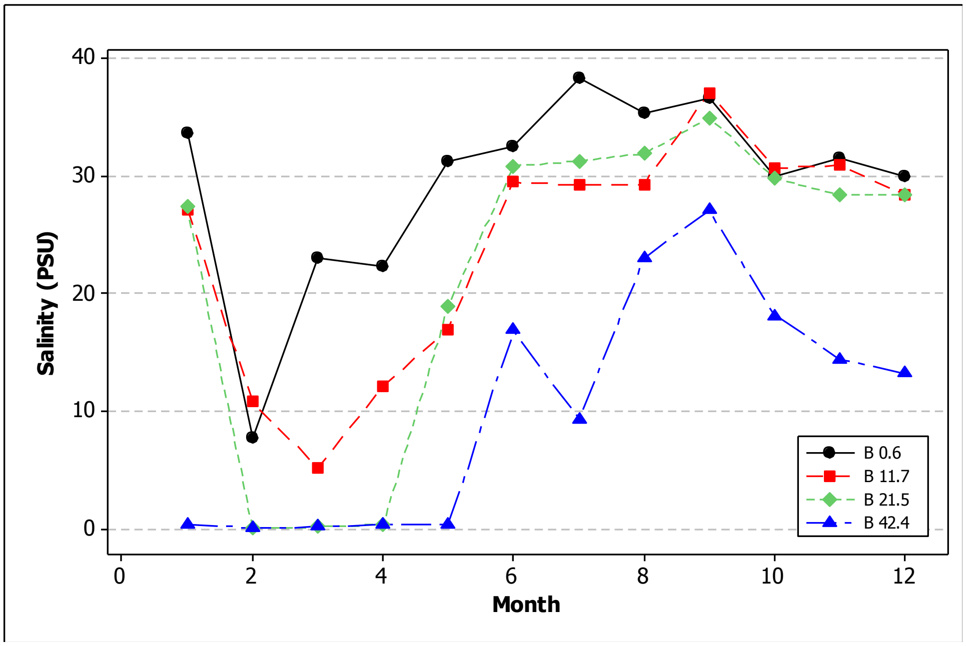

Figure 7. Scatterplot of bottom salinity recorded on the Brazos River in 2012 by site. (n=1)

Turbidity

Overall, ambient turbidity levels were low at each site (median < 11 NTU). The greatest variation was found at B-42.4, which exhibited median values of 931, 1415 and 608 NTU during three months and low values (< 100 NTU) during the remaining months. Kruskal-Wallis one-way analysis of variance and subsequent Dunn multiple range tests failed to detect any differences between Brazos River sites (Figure 8). Highest turbidity was observed in the lower Brazos River during the months of February, March and April (Figure 9). From June through December, the turbidity was relatively low across all sampling locations.

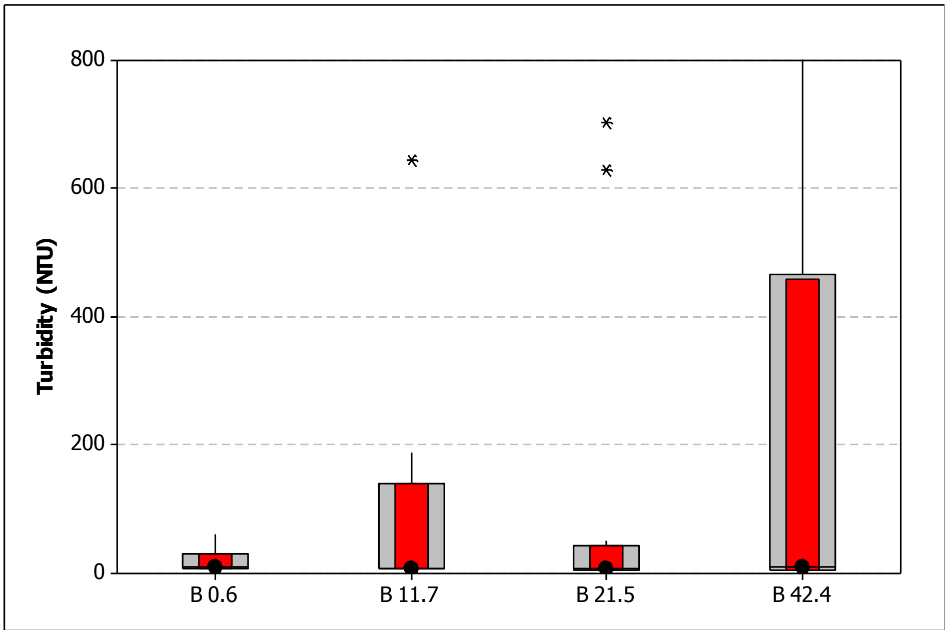

Figure 8. Boxplot of surface turbidity recorded on the Brazos River in 2012. Values of non-overlapping confidence interval bars were run using Kruskal-Wallis multiple range test (CI = 87.761; ● = median; n = 36). Note: Outlier for B-42.4 at 1,415 NTU's not represented in graph.

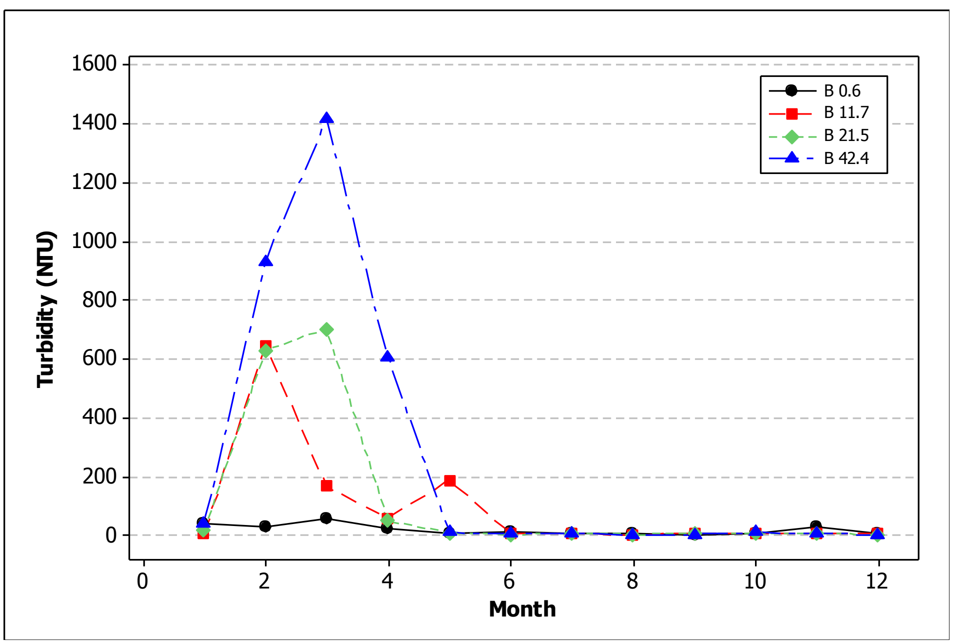

Figure 9. Scatterplot of surface turbidity on the Brazos River by site and month in 2012. (n=3)

Dissolved Oxygen

Overall, dissolved oxygen was highest during the winter months and lowest during the summer. Based on Kruskal-Wallis ANOVA and Dunn pairwise comparison for bottom dissolved oxygen, we were unable to reject the null hypothesis of no differences between sites (Figure 10). Hypoxic levels, defined as ambient dissolved oxygen below 2 mg/l, were not found at B-0.6 or B-11.7. Hypoxia was observed at the upper sites in August (Figure 11). Additionally, hypoxia was detected in May at B-21.5 (1.76 mg/l) and September at B-42.4 (1.81 mg/l). The sites closer to the Gulf generally exhibited higher levels of dissolved oxygen. The highest measured dissolved oxygen reading (11.48 mg/l) occurred at B-0.6 in November.

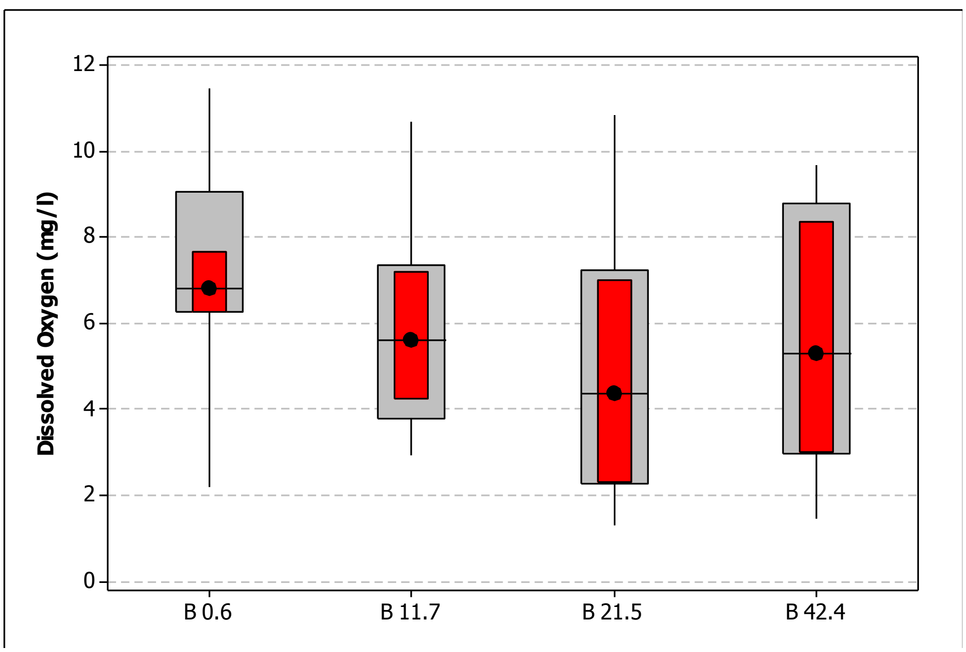

Figure 10. Boxplot of bottom dissolved oxygen (mg/l) on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars denote significant pair-wise differences detected by Kruskal-Wallis ANOVA and Dunn's multiple range test (CI = 87.761; ● = median; n = 12).

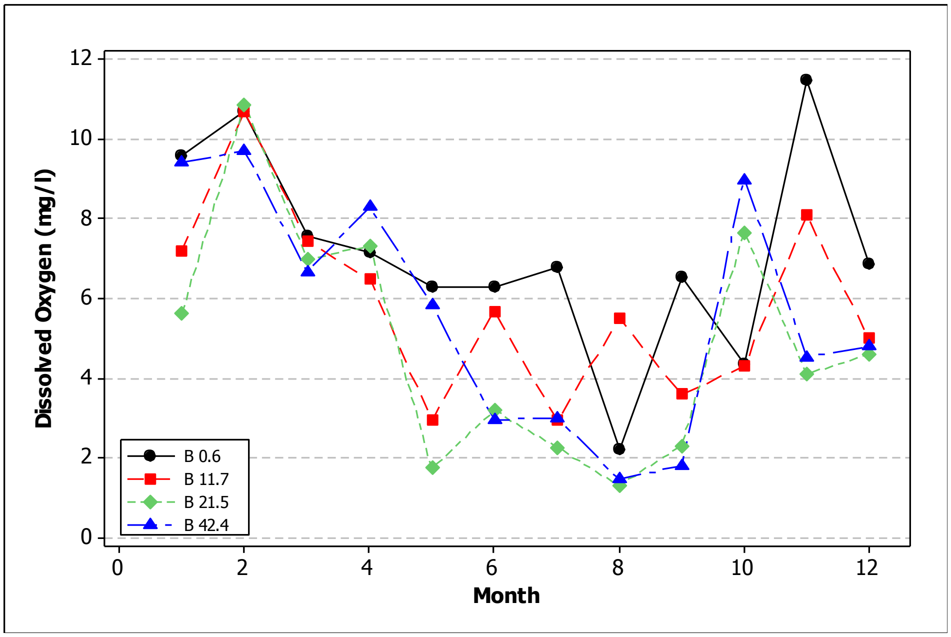

Figure 11. Scatterplot of bottom dissolved oxygen on the Brazos River by site and month in 2012 (n=1).

Biota

Overall Trends

During the course of the study, a total of 13,318 nekton representing 66 species were collected from 144 otter trawls on the Brazos River in 2012 (Table 2). A complete list of collected species is presented in

Appendix N.

The greatest number of taxa and abundance was found at the lower part of the estuary; the abundance and taxa decreased as distance of sampling sites increased from the Gulf. Out of the top ten most abundant taxa, Family Engraulidae (Anchovies), were the most abundant family; while four species from the Family Sciaenidae were in the top ten (Table 3). The Bay Anchovy (*Anchoa mitchilli*) and Atlantic Croaker (*Micropogonias undulatus*) were the most abundant fishes and the Brown Shrimp (*Farfantepenaeus aztecus*) was the most abundant macroinvertebrate collected with otter trawls at the four sites. While the Brazos Estuary was predominately structured by juvenile estuarine species, there were occurrences of marine species in the upper estuary and oligohaline species in the lower estuary. During high flows, oligohaline species such as Blue Catfish (*Ictalurus furcatus*), were collected at the mouth of the river. Lookdowns (*Selene vomer*), a marine fish species, were collected as high as B-21.5 during low flows.

Table 2. Overall collections of nekton with otter trawls on the Brazos River in 2012. (n=144)

	Site				
	B 0.6	B 11.7	B 21.5	B-42.4	Total
Abundance	5279	3538	2696	1805	13318
Taxa	48	45	21	20	66

Table 3. Most abundant species collected with otter trawls on the Brazos River in 2012. (n=144)

Rank	Common Name	Scientific name	Total Abundance
1	Bay Anchovy	*Anchoa mitchilli*	4828
2	Atlantic Croaker	*Micropogonias undulatus*	3437
3	Brown Shrimp	*Farfantepenaeus aztecus*	1271

4	White Shrimp	*Litopenaeus setiferus*	963
5	Sand Seatrout	*Cynoscion arenarius*	566
6	Gulf Menhaden	*Brevoortia Patronus*	328
7	Striped Anchovy	*Anchoa hepsetus*	268
8	Blue Catfish	*Ictalurus furcatus*	257
9	Silver Perch	*Bairdiella chrysoura*	222
10	Spot Croaker	*Leiostomus xanthurus*	205

Abundance

A positive correlation existed between Julian day and otter trawl abundance (r = 0.355, p = 0.013) (

Appendix **o**). Median nekton abundance declined at the sampling locations further from the Gulf (Figure 12). Data collected from Site B0.6 demonstrated the greatest IQ range (139), while the smallest range (13) was found at B-42.4. The furthest upstream site (B-42.4), exhibited significantly smaller abundances in comparison to the other three sites (Table 2). Little to no nekton were collected during the months of June to September at B-42.4. Highest median trawl abundance were collected during the month of July at sites B-0.6 (317 nekton) and B-11.7 (296 nekton). In November at site B-21.5, median abundance peaked at 483 nekton. The following month, B-42.4 exhibited the highest (462) median abundance (Figure 13).

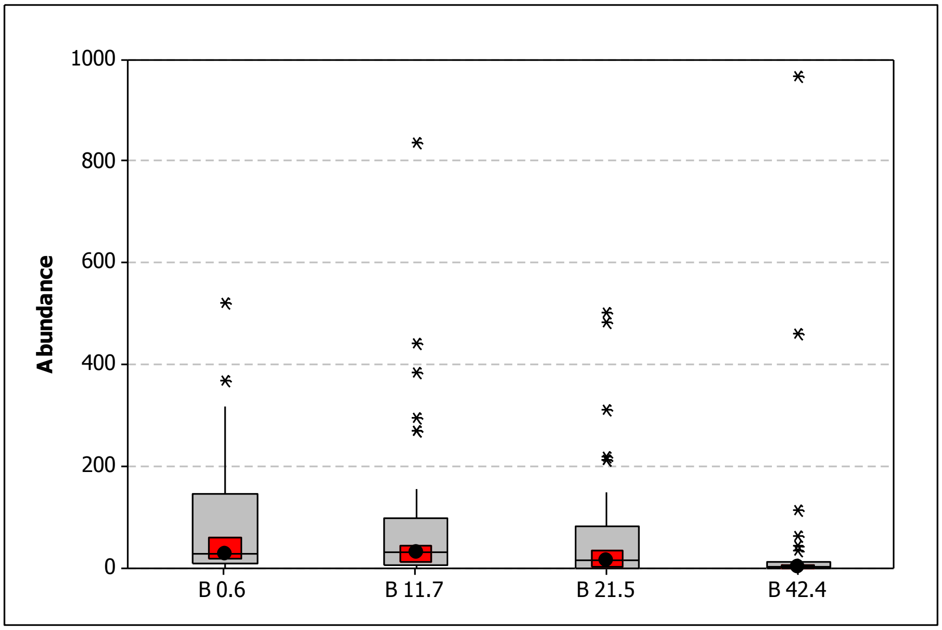

Figure 12. Boxplot of nekton abundance collected with otter trawls on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars were estimated using Kruskal-Wallis ANOVA and Dunn's multiple range test (CI = 87.761; ● = median; n = 36/site).

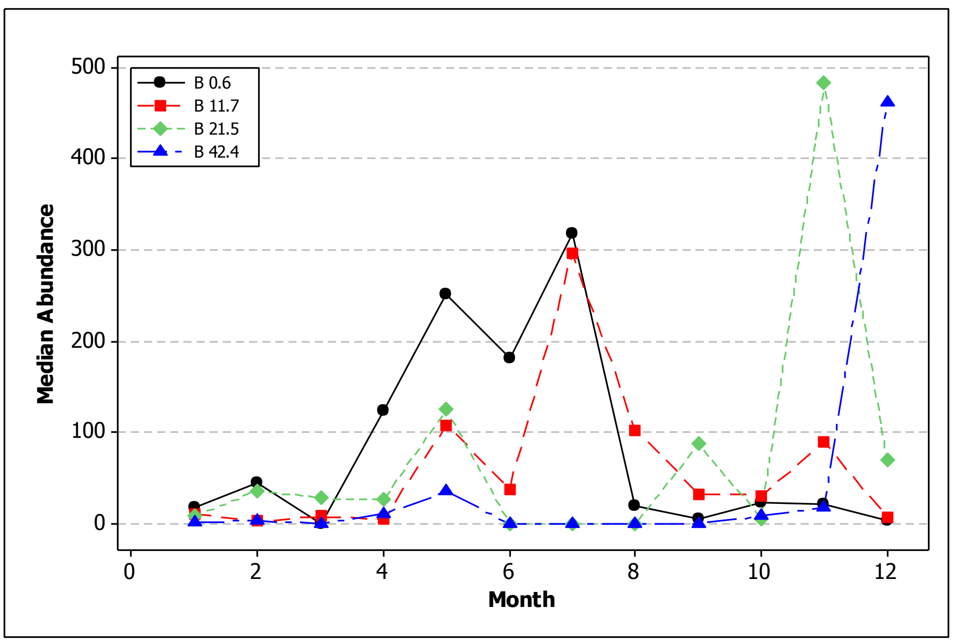

Figure 13. Scatterplot of median nekton abundance collected with otter trawls by site and month on the Brazos River in 2012 (n=3/site/month).

Taxa

A highly significant, negative correlation between distance from the Gulf and species richness (r = -0.548, p = 0.000) (

Appendix **O**) Overall, a higher median number of taxa was observed at sites B-0.6 (5.5) and B-11.7 (6) in comparison to B-21.5 (2) and B-42.4 (2) (Figure 14). The lower Brazos River sites exhibited significantly higher numbers of taxa in comparison to the upstream sites. The highest median taxa for the sampling period was observed in July at B-0.6 (13 taxa). During this same period, B-11.7 exhibited a median of only 9 species while B-21.5 and B-42.4 failed to yield any catch (Figure 15). Median number of taxa at the lower estuary site (B-0.6) was highest during May-July and October-November.

Ten species were collected at each site at least once throughout the year (

Appendix **N**). The most abundant of these species were the Bay Anchovy (*A. mitchilli*), White Shrimp (*Litopenaeus setiferus*), Atlantic Croaker (*Micropogonias undulates*) and Gulf Menhaden (*Brevoortia patronus*). At B-0.6, there were 15 species that were only collected at the mouth of the river. These were likely displaced marine migrants. The most common of these nekton were seven Atlantic Cutlassfish (*Trichiurus lepturus*). No species were unique to B-42.4. Nine species were only found at B-11.7 and three species were unique to B-21.5.

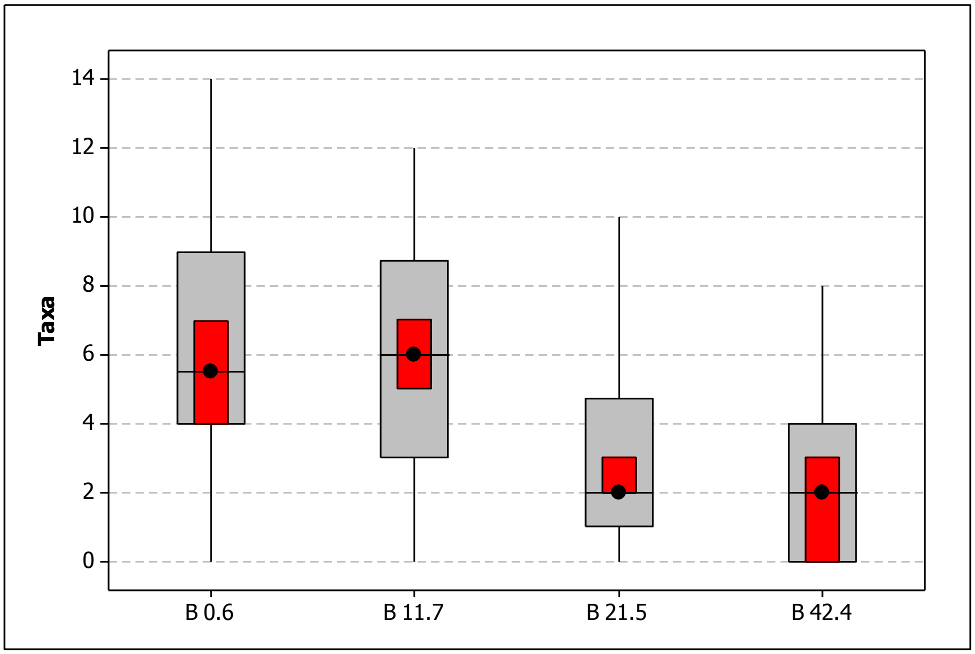

Figure 14. Boxplot of the number of nekton taxa collected with otter trawls on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars were run using Kruskal-Wallis multiple range tests (CI = 87.761; ● = median; n = 36/site). Note: non-real values were omitted from graph.

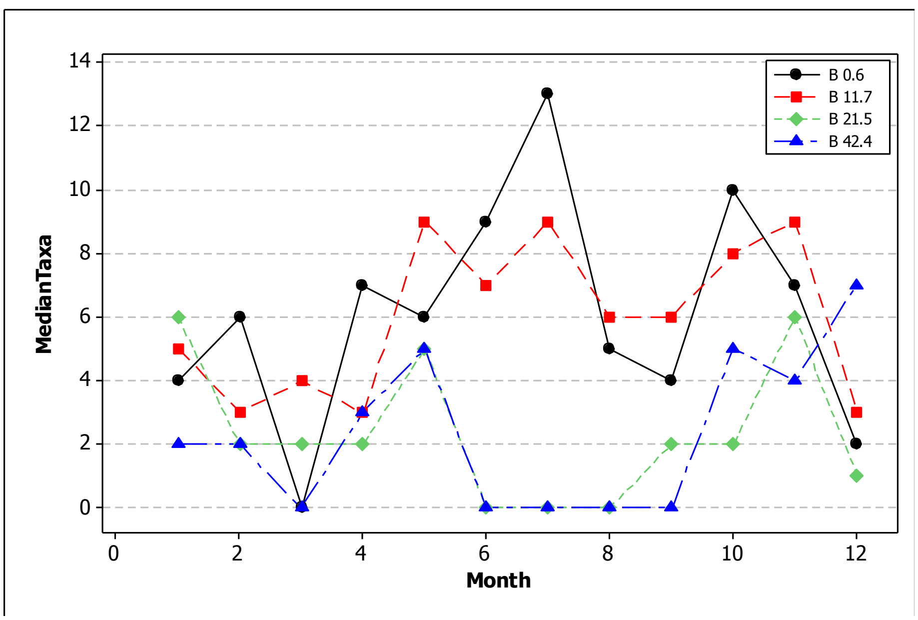

Figure 15. Scatterplot of average nekton taxa collected with otter trawls by site and month on the Brazos River in 2012 (n=3/site/month).

Shannons Diversity

Shannon Diversity (H') exhibited a significant, negative correlation between distance from the Gulf and Shannons diversity ($r = -0.342$, $p = 0.017$) (

Appendix **o**). Site B-11.7 exhibited the highest calculated median trawl nekton diversity (H' = 1.48). In contrast, the lowest calculated median diversity (H' = 0.36) was found at B-21.5. Based on a Kruskal-Wallis ANOVA and Dunn's pairwise comparison of H', both of the lower river sites exhibited significantly higher diversity in comparison to B-21.5 (CI=87.76%) (Figure 16). Additionally, B-11.7 was significantly different from B-42.4. Over the 12 months of the study, March displayed the lowest median diversity (H'=0.27) while highest diversity (H'=1.59) was in October. None of these months were significantly different (CI= 96.4%) (Figure 17). The two lower river sampling locations always exhibited H' > 1. In contrast, the two upriver locations showed months where H'=0. Site B-0.6 trawl diversity peaked during July through October whereas low H' values were common during March and November (Figure 18). The next site upriver, B-11.7, displayed peak H' in April to June and minimal during the months of August and September. Site B-21.5 exhibited the highest diversity in October but exhibited zero diversity for otter trawl catches from June to August. Lastly, the site furthest upstream on the Brazos River, B-42.4, exhibited its highest diversity during May and October and lowest diversity (H' =0) in March and July through September.

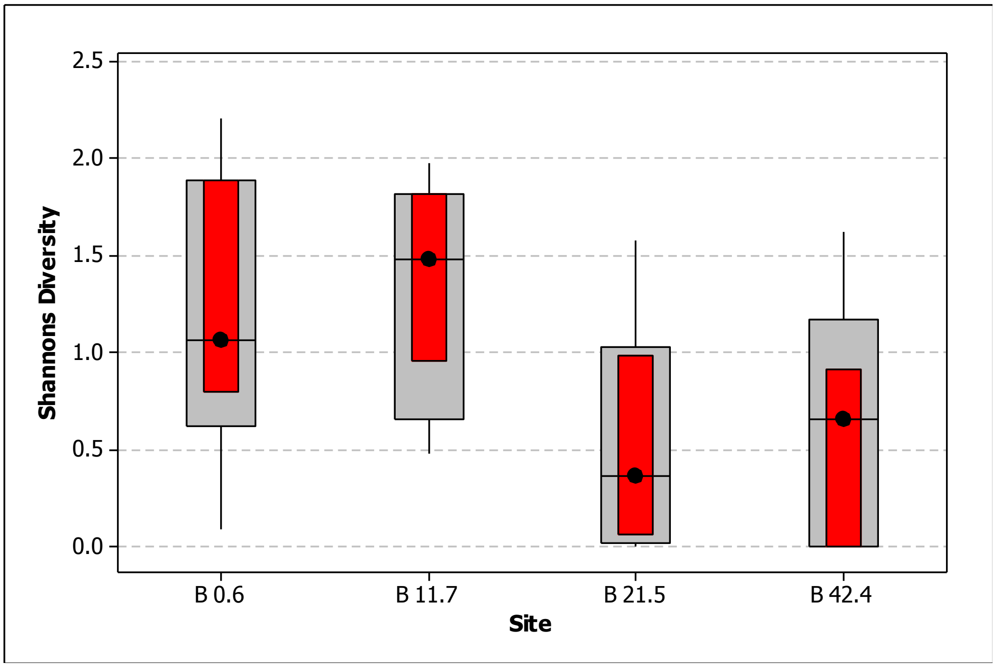

Figure 16. Boxplot of Shannons Diversity analysis of nekton collected with otter trawls on the Brazos River study sites in 2012. Values of non-overlapping confidence interval bars were run using Kruskal-Wallis multiple range tests (CI = 87.761; ● = median; n = 36/site).

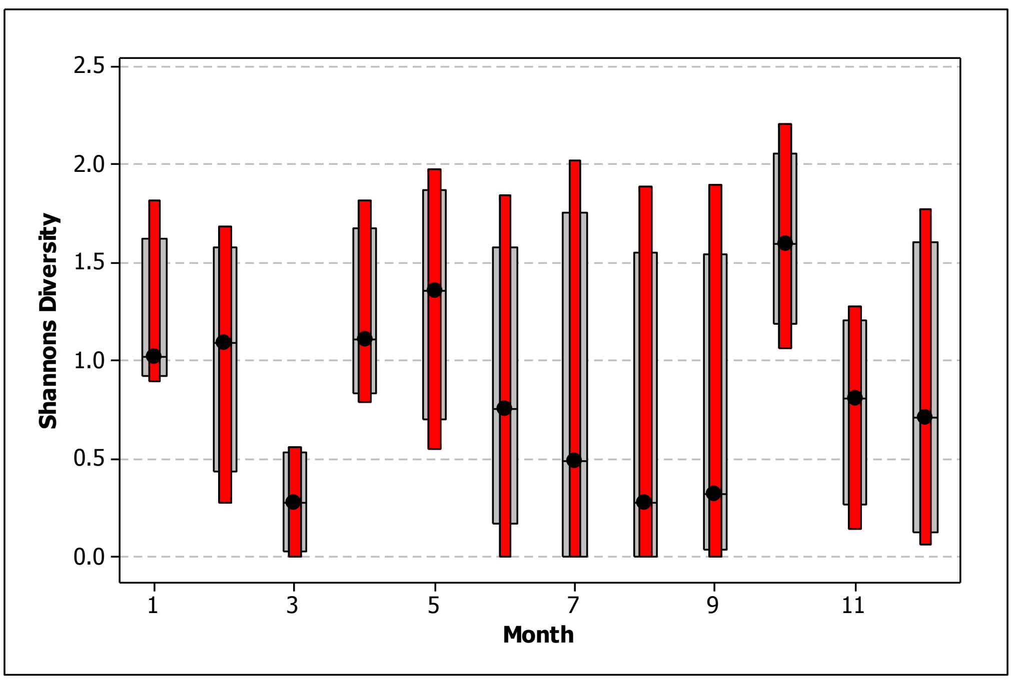

Figure 17. Boxplot of Shannons diversity on the Brazos River study sites in 2012 by month. Values of non-overlapping confidence interval bars were run using Dunns multiple range tests (CI = 96.395; ● = median; n = 12/month).

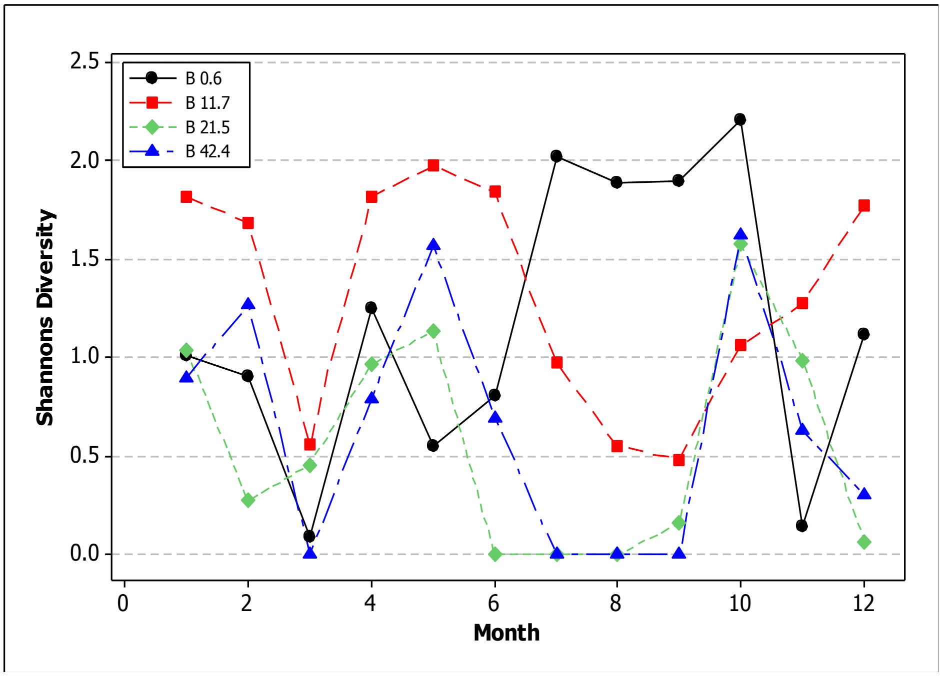

Figure 18. Scatterplot of average Shannons diversity from otter trawls in 2012 by site and month on the Brazos River in 2012 (n=3/site/month).

Parameter Relationships

All water physicochemical parameters (discharge, temperature, salinity, turbidity and dissolved oxygen) on the Brazos River in 2012 displayed a significant Pearson correlation with each other (

Appendix **o**). Negative correlations existed between temperature and DO, salinity and discharge, salinity and turbidity, temperature and turbidity, temperature and discharge, and salinity and DO. Positive correlations were amid turbidity and discharge, temperature and salinity, DO and turbidity, and DO and discharge (

Appendix **o**).

Scatterplots

No significant correlation (p >0.05) was detected between freshwater inflow and average abundances. There was a significant, negative Pearson correlation between discharge and otter trawl richness (r = -0.298, p = 0.04) (

Appendix **o**). Highest average abundance and richness occurred were recorded at flows less than 1,200 cfs. Average abundance plummeted at all sites once discharge reached over 5,000 cfs except during one sampling event at B-0.6 when an average of 140 nekton were collected (Figure 19). The highest cumulative richness after 3 trawls was 23 species at B-0.6 in July. There were two sampling events at B-42.4 where no nekton were collected (Figure 20).

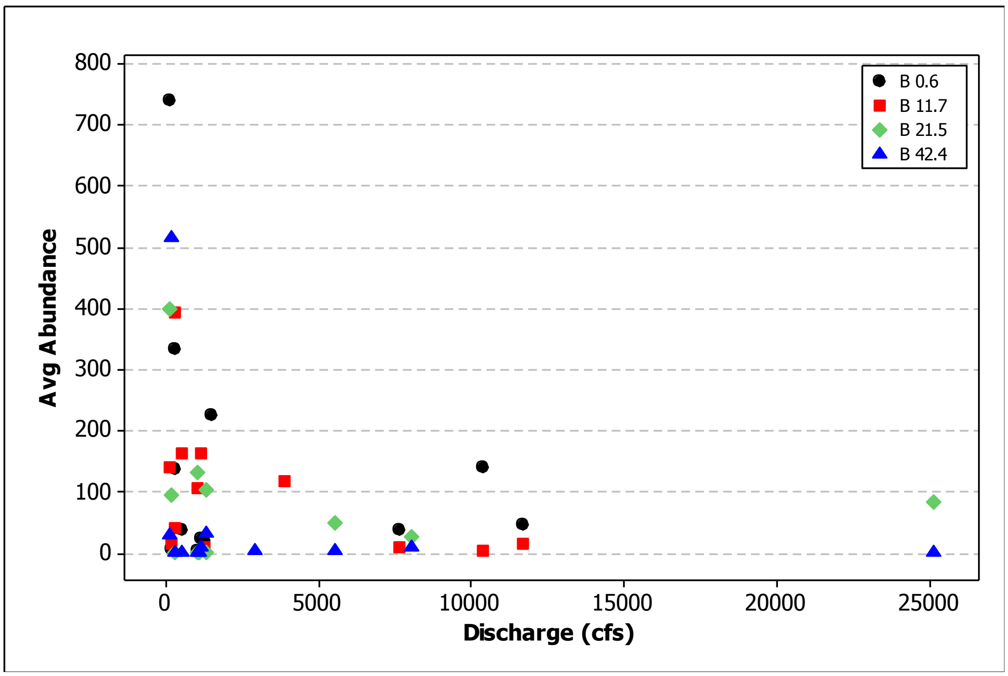

Figure 19. Scatterplot of average nekton abundance collected with otter trawls by site and bottom discharge on the Brazos River in 2012. (n=3/site/month)

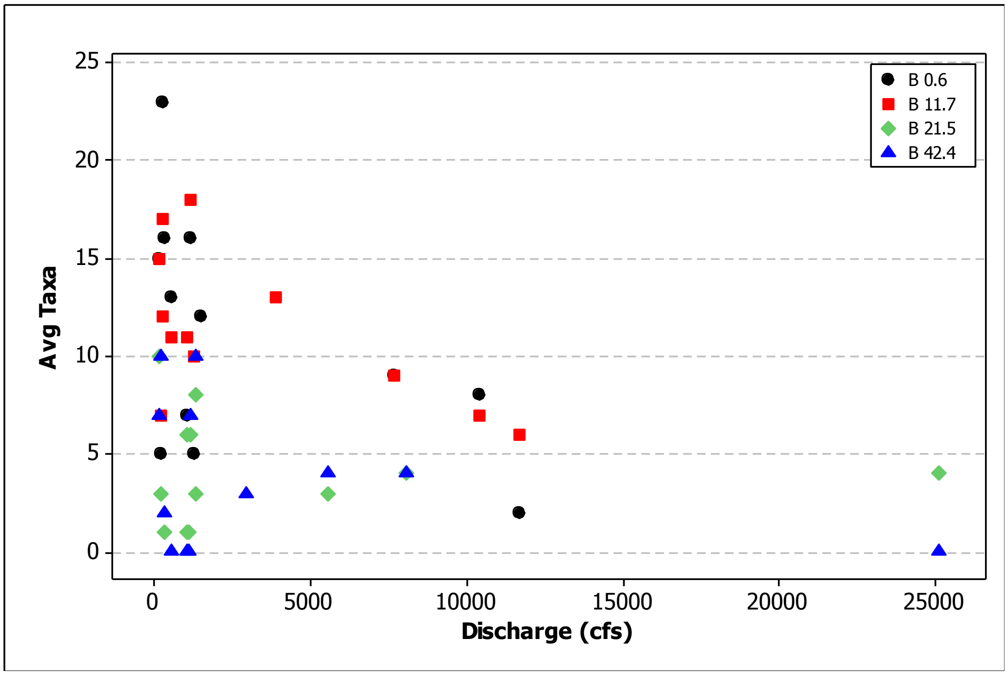

Figure 20. Scatterplot of average nekton abundance collected with otter trawls by site and bottom temperature on the Brazos River. (n=3/site/month).

Significant correlation between nekton abundance and bottom water temperature was lacking at any of the Brazos River sampling locations ($p > 0.05$) (Figure 21). Sites B-0.6 and B-42.4 exhibited the greatest average nekton abundance at water temperatures around 20°C. To a lesser extent, B-11.7 peaked at 31°C and B-21.5 at 24°C. There was a general trend for higher average number taxa with increased water temperature at B-0.6 and B-11.7 (Figure 22). Conversely, the upper sites demonstrated low average richness when bottom temperature exceeded 30 °C during the months of June through September (Figure 5).

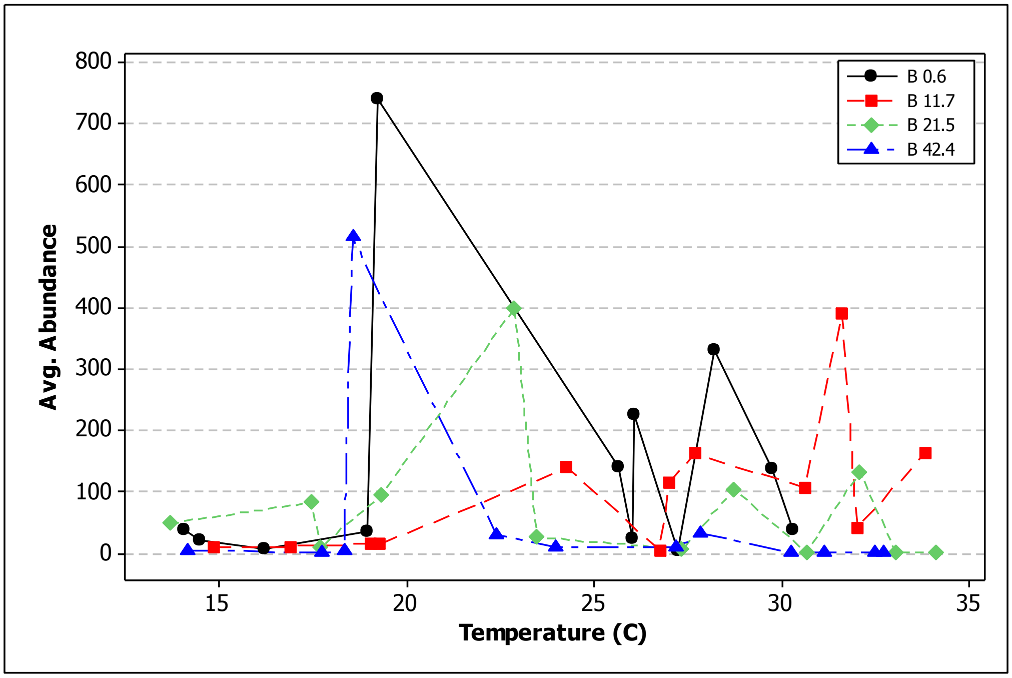

Figure 21. Scatterplot of average nekton abundance collected with otter trawls by site and bottom temperature on the Brazos River in 2012 (n=3/site/month).

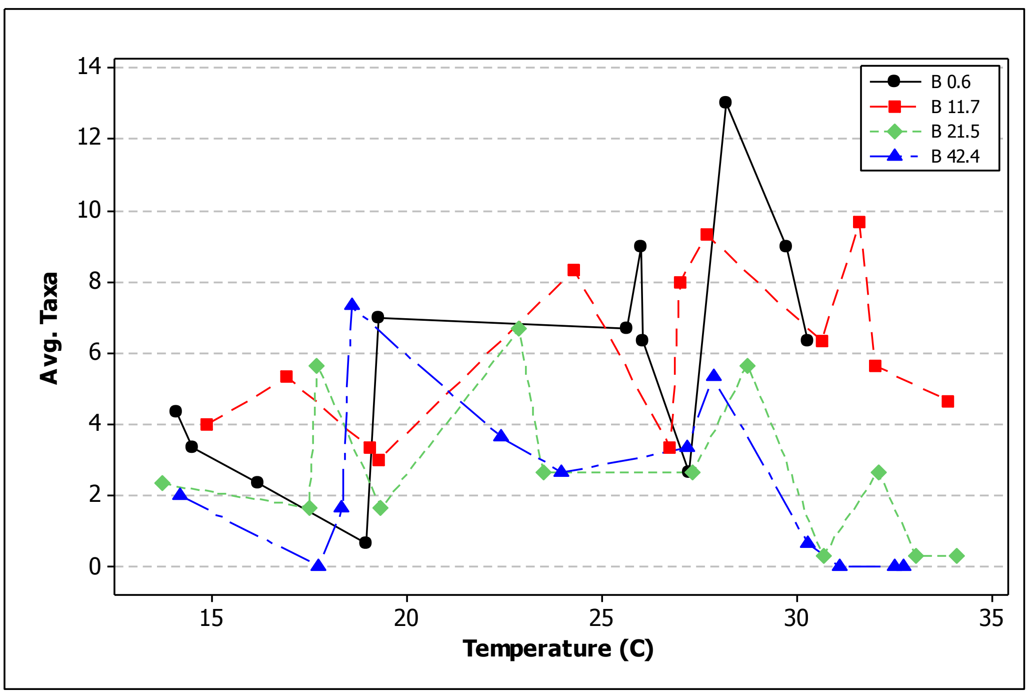

Figure 22. Scatterplot of average nekton taxa collected with otter trawls by site and bottom temperature on the Brazos River in 2012 (n=3/site/month).

Except for site B-42.4, average total nekton abundance was highest at all sites when salinity was around 30 psu (Figure 23). The site furthest upstream exhibited the highest average abundance when bottom salinity approached 13 psu (Figure 23). There was a significant, positive correlation (r= 0.395, p = 0.005) between average nekton taxa and bottom salinity (

Appendix **o**). The greatest average number of taxa (13 species) in the otter trawls was observed when the recorded bottom salinity was 38 psu (Figure 24).

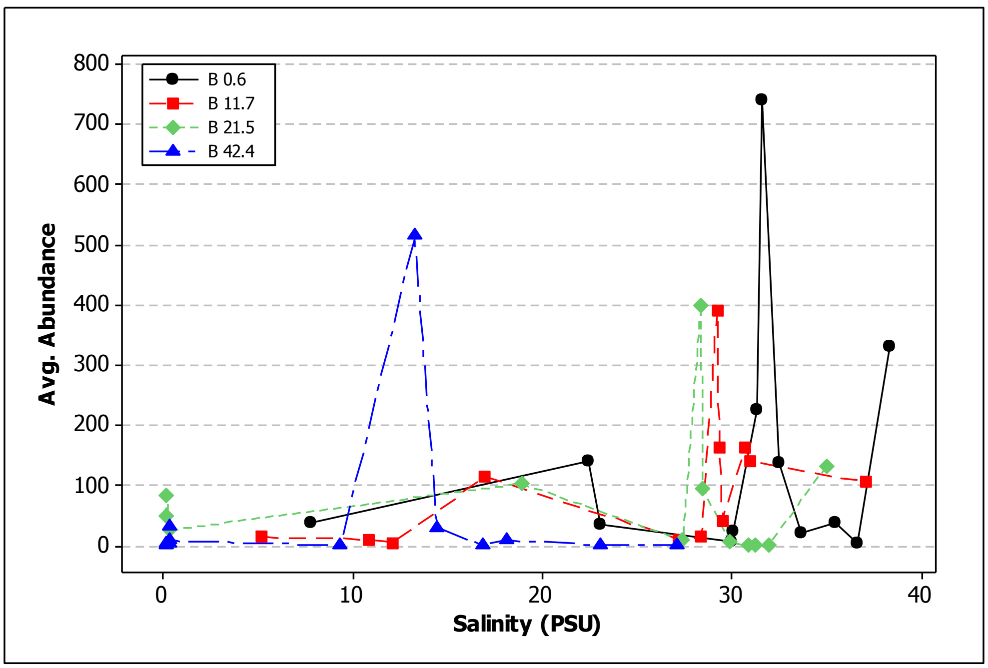

Figure 23. Scatterplot of average nekton abundance collected with otter trawls by site and bottom salinity on the Brazos River in 2012 (n=3/site/month).

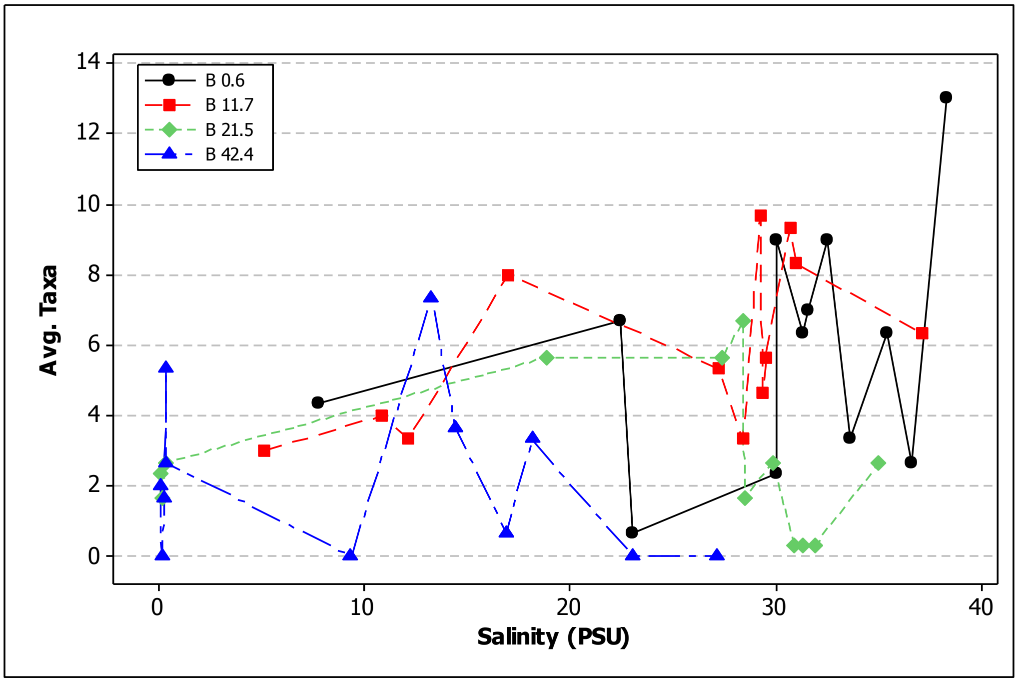

Figure 24. Scatterplot of average nekton taxa collected in otter trawls by site and bottom salinity on the Brazos River in 2012 (n=3/site/month).

No significant correlations existed between turbidity and nekton abundance or richness. The highest abundance occurred at B-0.6 with a turbidity reading of 30 NTU's and average abundance of 740 nekton per otter trawl haul (Figure 25). This sampling event is also when the highest richness occurred with an average of 13 species per haul (Figure 26). No otter trawl catches were collected at B-42.4 when turbidity was very low (7.5 NTU's) and when turbidity was highest (1415 NTU's) during the study. Unlike other physicochemical variables, turbidity did not appear to have an impact on the nekton communities of the Brazos Estuary.

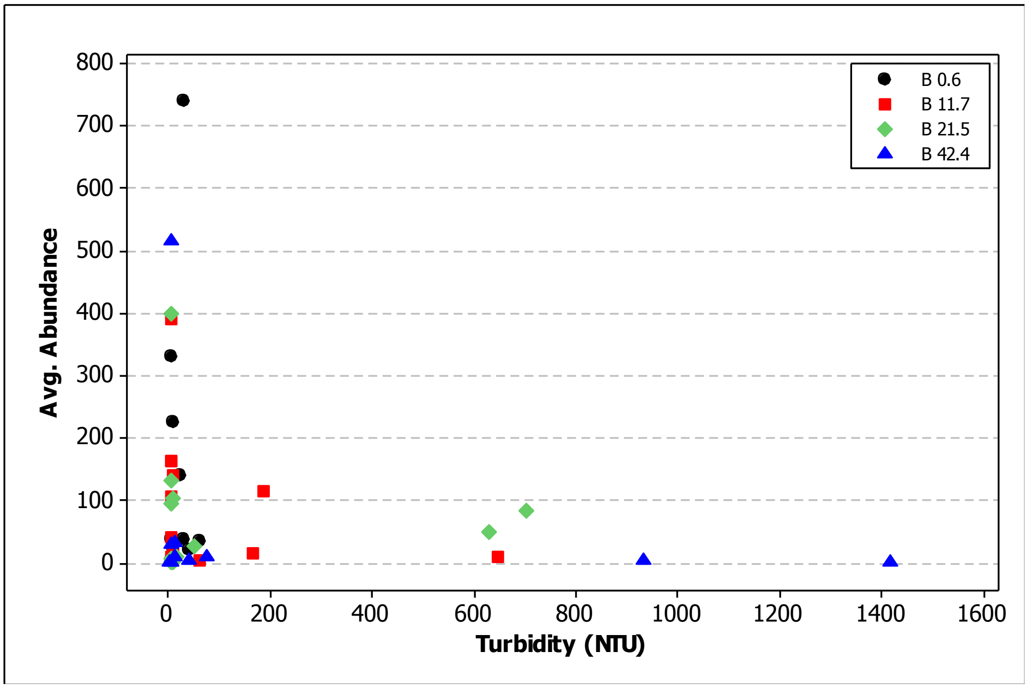

Figure 25. Scatterplot of average nekton abundance collected in otter trawls by site and surface turbidity on the Brazos River in 2012 (n=3/site/month).

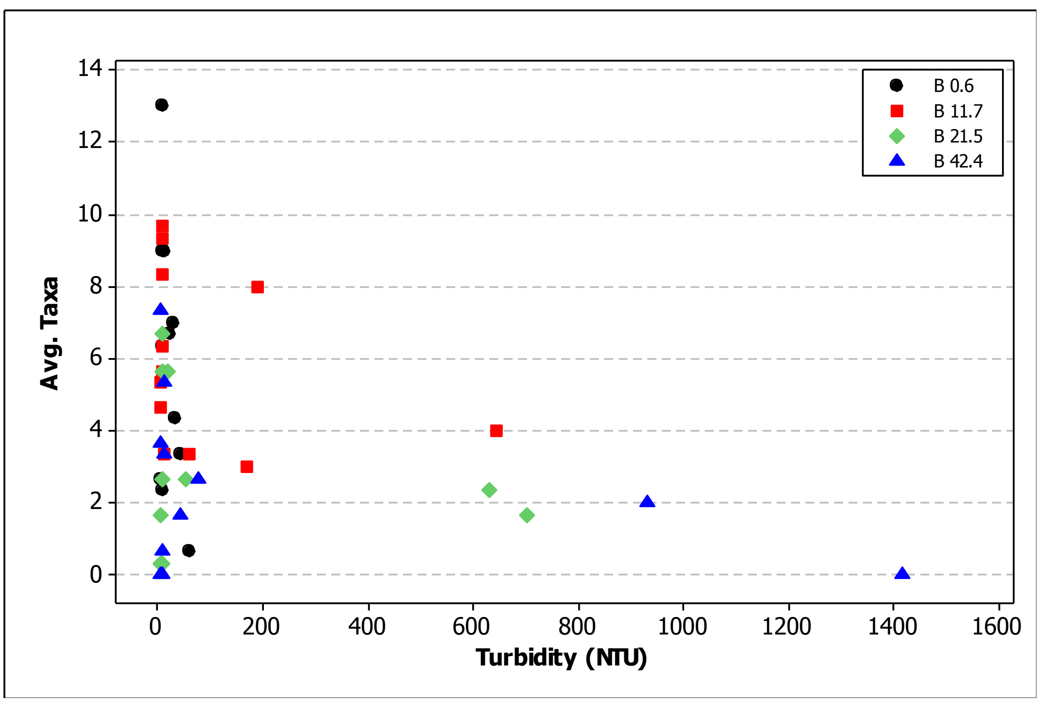

Figure 26. Scatterplot of average nekton abundance collected in otter trawls by site and surface turbidity on the Brazos River in 2012 (n=3/site/month).

During 2012, sites B-11.7, B-21.5 and B-42.4 exhibited the highest average abundances when dissolved oxygen ranged between 3 and 5 mg/l on the Brazos River (

Figure 27). The highest abundance of all sites occurred at 11 mg/L dissolved oxygen at site B-0.6. The lower Brazos River demonstrated the greatest richness from 4-8 mg/l (Figure 28).

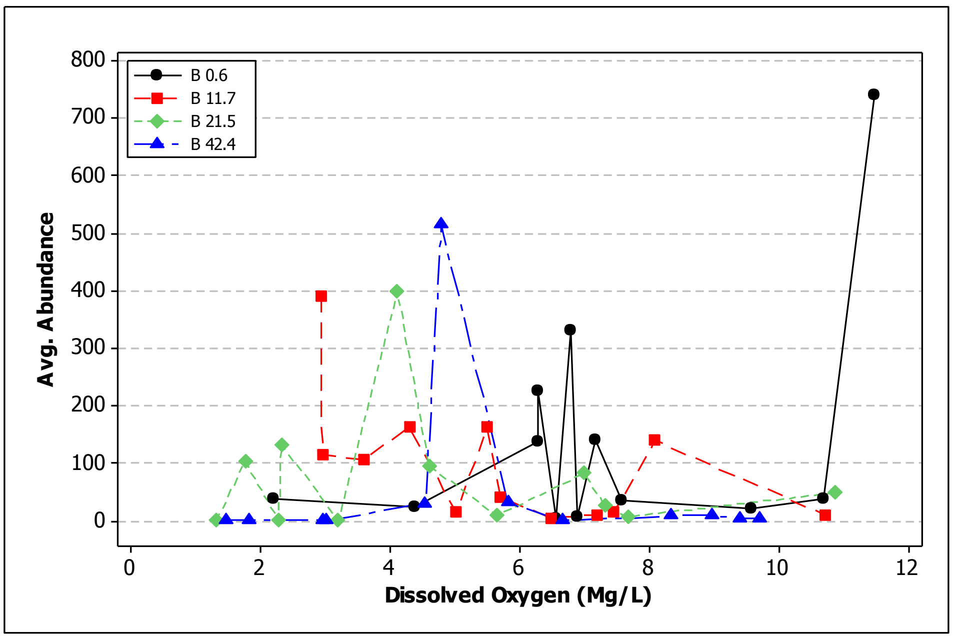

Figure 27. Scatterplot of average nekton abundance by site and bottom dissolved oxygen on the Brazos River in 2012 (n=3/site/month).

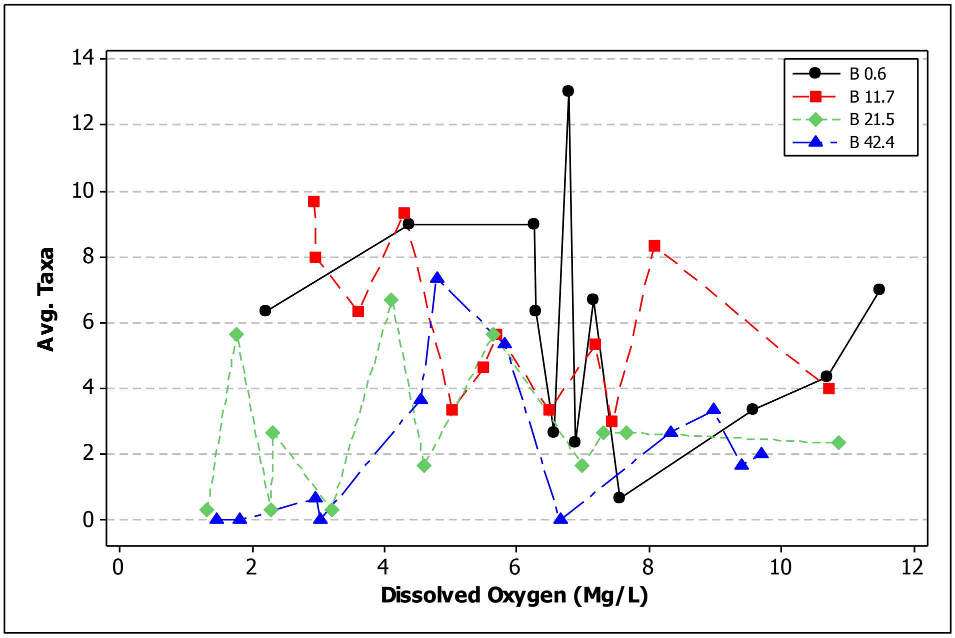

Figure 28. Scatterplot of average nekton taxa by site and bottom dissolved oxygen on the Brazos River in 2012 (n=3/site/month).

Multivariate Analysis

Classification of sites by cluster analysis using Euclidean distance measures and normalized physicochemical data is presented in a dendrogram (Figure 29). Based on physicochemical data, site B-0.6 was the most dissimilar and B-21.5 and B-42.4 were most similar to each other. A principal component analysis of the physicochemical data determined that 69.4% of the variation in the data is explained with increased dissolved oxygen and salinity in connection with decreased temperatures and total depth (Figure 30). Ordination of sites presented in a PCoA indicated that B-0.6 is best described as having higher dissolved oxygen and cooler temperatures. Site B-11.7 can best be described as having higher salinity and shallower total depths. Sites 21.5 and 42.4 are explained by increased water depth and decreased salinity. Turbidity was omitted from multivariate analysis because it exhibited strong correlations with discharge, temperature, salinity, and DO, however no correlation with biological data (

Appendix **o**).

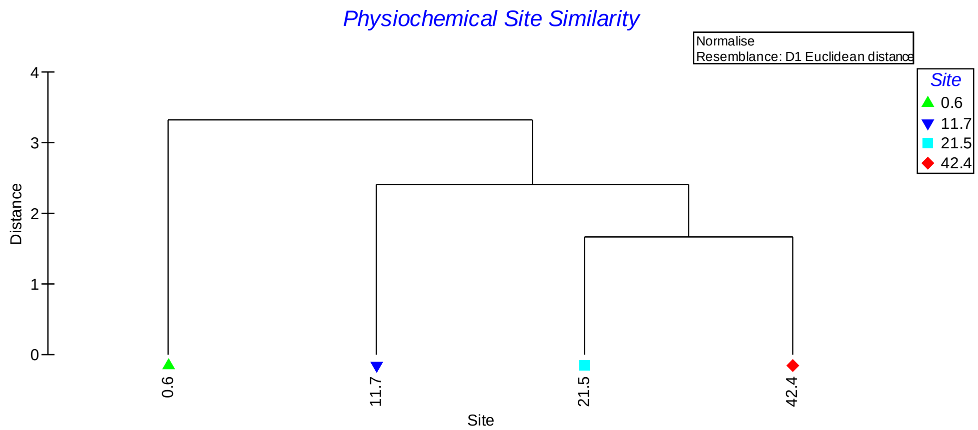

Figure 29. Dendrogram of Brazos River site resemblance based on normalized physicochemical data collected in 2012 (n=12).

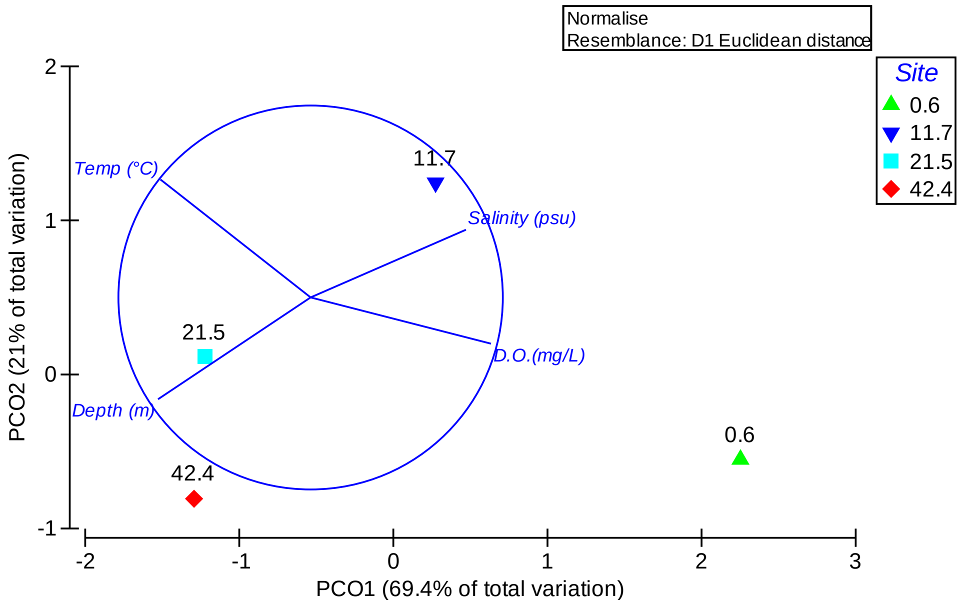

Figure 30. Principal coordinate analysis of normalized data according to temperature, salinity, dissolved oxygen and depth in 2012.

Additionally, we used the software package Primer v6 to analyze the physicochemical similarity during the study by each collection (site X month) event (Figure 31). The analysis classified collections into five main clusters. Cluster 1 is comprised of the 2 upstream collections in March and is most dissimilar from the other groupings. During this month, the Brazos River experienced the highest discharges. Cluster 2 includes 17 collections composed exclusively of the two upstream sites. Cluster 3 is composed primarily of collections from the downstream sites except samples obtained during February, March, and April. Clusters 2 and 3 are most similar to each other. Cluster 4 is a grouping of the upstream sites in February and April. Additionally, the January collection at B-42.4 is in this grouping. Group 5 is composed of the downstream sites sampled during February through April. Clusters 4 and 5 are more similar to each other in comparison to the other groupings.

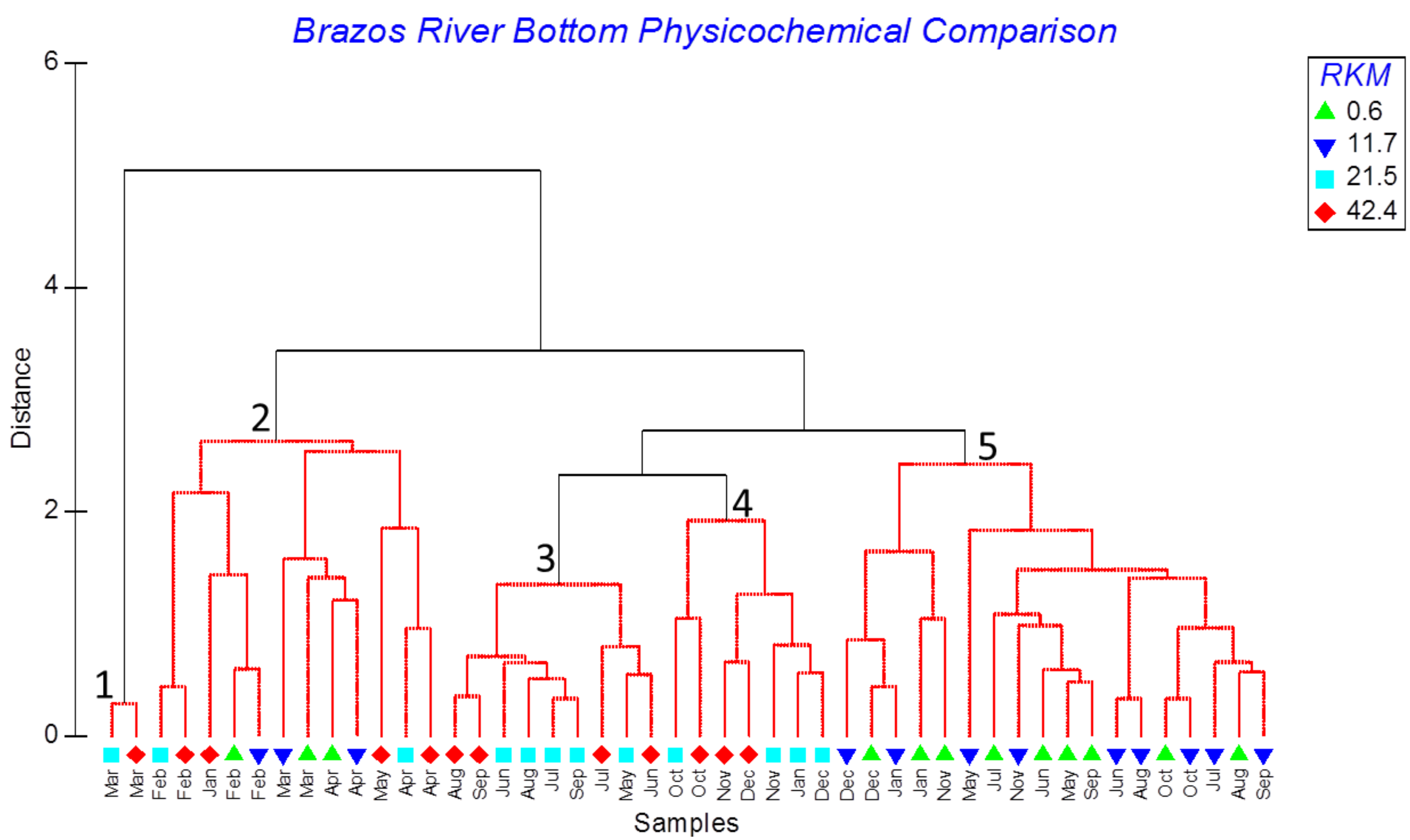

Figure 31. Dendrogram of Brazos River collection resemblance based on normalized water temperature, salinity, dissolved oxygen, depth, and discharge data in 2012 (n=1/collection). Note: RKM is river kilometer on the Brazos River from the Gulf of Mexico. The five groupings are significantly (p=0.00) different from each other based on the SIMPROF test.

Next, we ran a principal components analysis to determine how the Brazos River cluster groupings of collections may be structured by bottom physicochemical data. Almost half (49.1%) of the sample variation is explained by the first principal component (PC) (Figure 32. **Orthogonal transformation of bottom physicochemical observations at 4 sites (rkm)**). The coefficients of PC1 represent a linear combination of: + water temperate + salinity – dissolved oxygen – depth – discharge. We interpret principal component 1 as representing the influence of sample month or temporal/seasonal variation. Another 28.8% of the variation is explained by PC2 which is a linear combination of: – water temperature + salinity + dissolved oxygen – depth – discharge. We determine principal component 2 as representing spatial differences in physicochemical data between the lower and upper river locations.

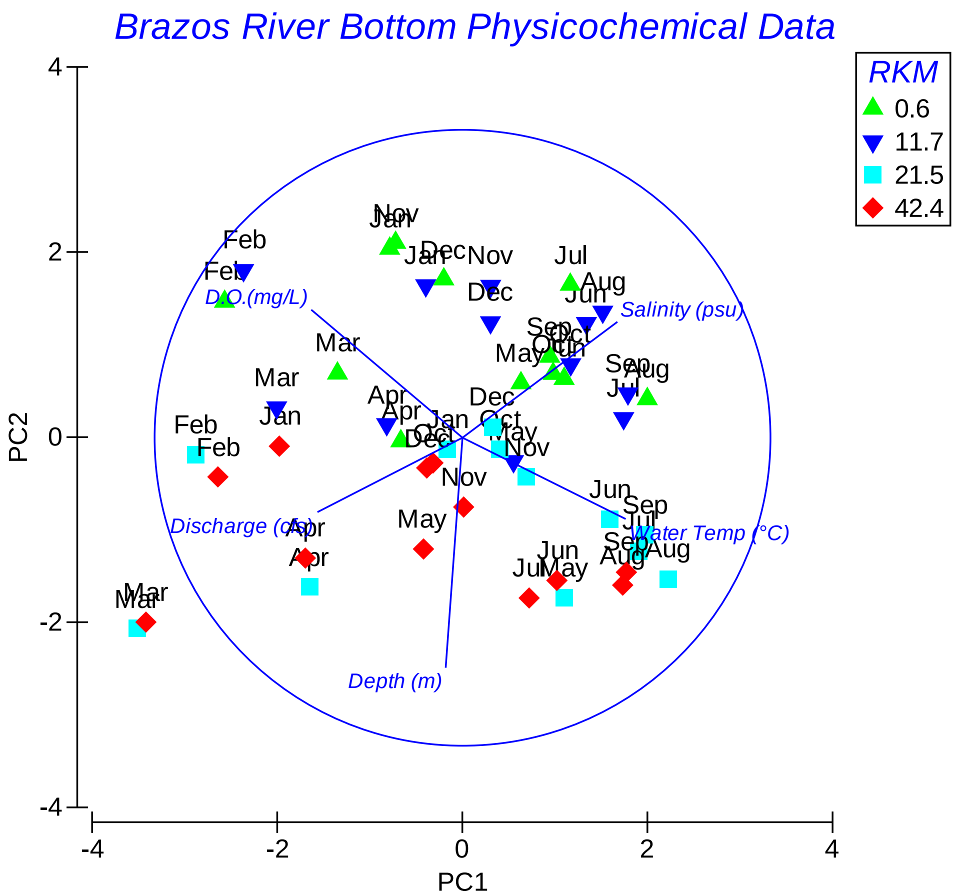

Figure 32. Orthogonal transformation of bottom physicochemical observations at 4 sites (rkm) of the Brazos River each month (n=1). Principal components 1 and 2 explain 49.1% and 28.8% variability, respectively. Note: RKM is river kilometer on the Brazos River from the Gulf of Mexico.

Next we conducted an analysis on nekton community structure based on presence/absence of the 10 most commonly collected species using Brays Curtis similarity for each sampling period on the Brazos River, using the average of all 3 replicates per collection. Cluster analysis identified cluster 1 which is a grouping of collections representing 5 dates where no nekton were collected (Figure 33). This only occurred at the upriver sites. Cluster 2 included collections from B-21.5 and B-42.4 during February through June. The 3rd cluster grouping was a singleton collection from

January at B-21.5. Cluster 4 is < 20% similar to cluster 5, 6, and 7 and was composed of collections from B-42.4 in January and B-21.5 in August. Clusters 5, 6, and 7 are >20% similar to each other and consist of all lower river collections and the remaining upriver samples. Cluster 5 is composed of collections from B-0.6 in July, October and November along with the July B-11.7 sample. Cluster 6 is the largest grouping of nekton collections with a variety of sites and dates. Site B-11.7 collections were common in cluster 6, by an exhibited 50% similar for the months of January, June, November, December, August, and September. Groups 5 and 6 are more similar to each other than the other major cluster groups. Cluster 7 is composed of collections from February and March for B-0.6 and B-11.7 as well as January B-0.6, April B-11.7, and, May B-42.4 (Figure 33).

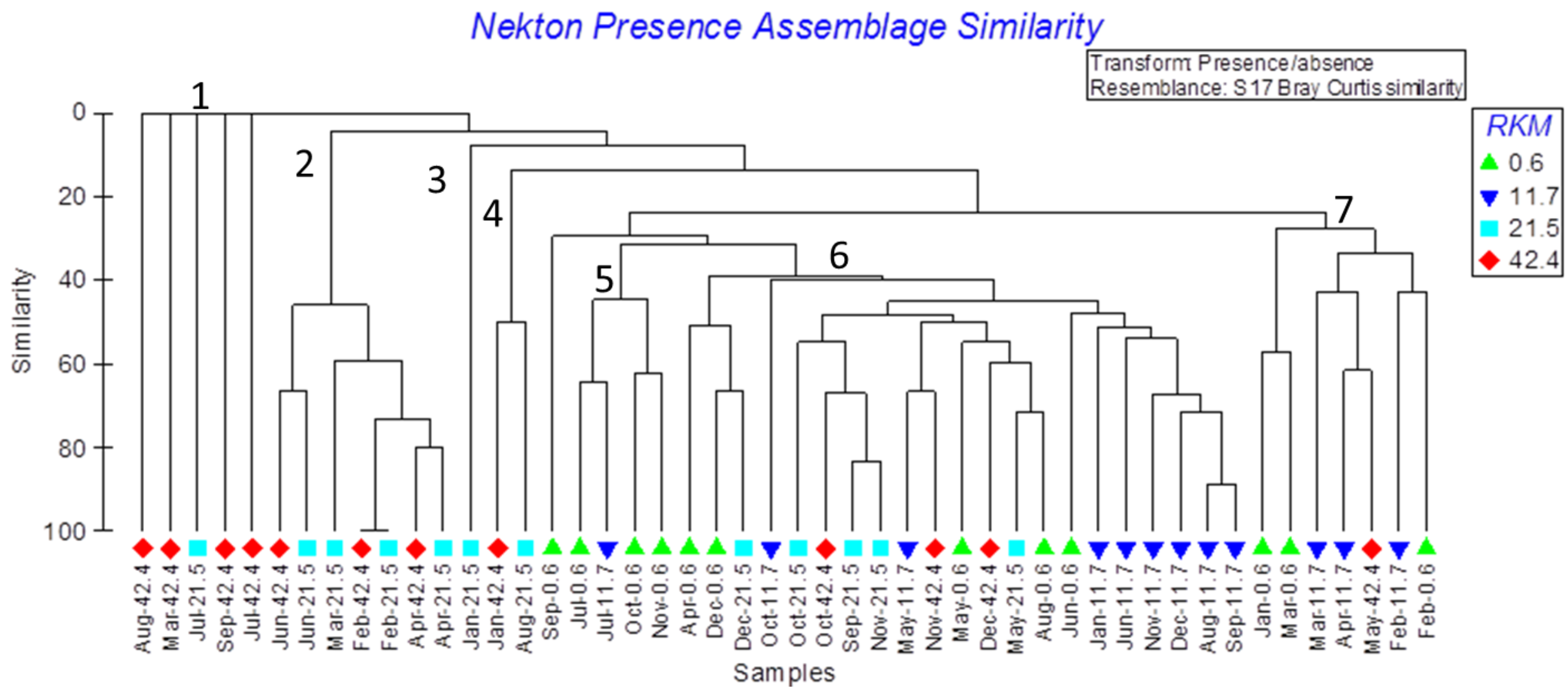

Figure 33. Cluster analysis of nekton presence from Brazos River otter trawls collections in 2012 (n=3 hauls/site/month). Note: RKM is the distance in river kilometers from the mouth of the river at the Gulf of Mexico to the sampling location.

Historical Comparison

Flow

High discharge surges did not occur during the current study in contrast to the Johnson (1977) study conducted during 1973-5 (Figure 34). In 1973, river discharges each month were always higher than the current study in 2012. In 1974, Johnson collected during a month where flows averaged 32,900 cfs. In contrast, the current study river discharges during November were only 150 cfs. The current study more closely resembled the flows that Emmitte (1983) observed in 1982. During the Emmitte study, streamflow peaked in February at 12,889 cfs before decreasing the following months and settling down to around 1000 cfs. Our studies highest average flow occurred in April at 1300 cfs and tapered off to between 1,670 and 148 cfs during the rest of the year. During his study Johnson (1977) found that freshwater inflow was also strongly correlated with turbidity.

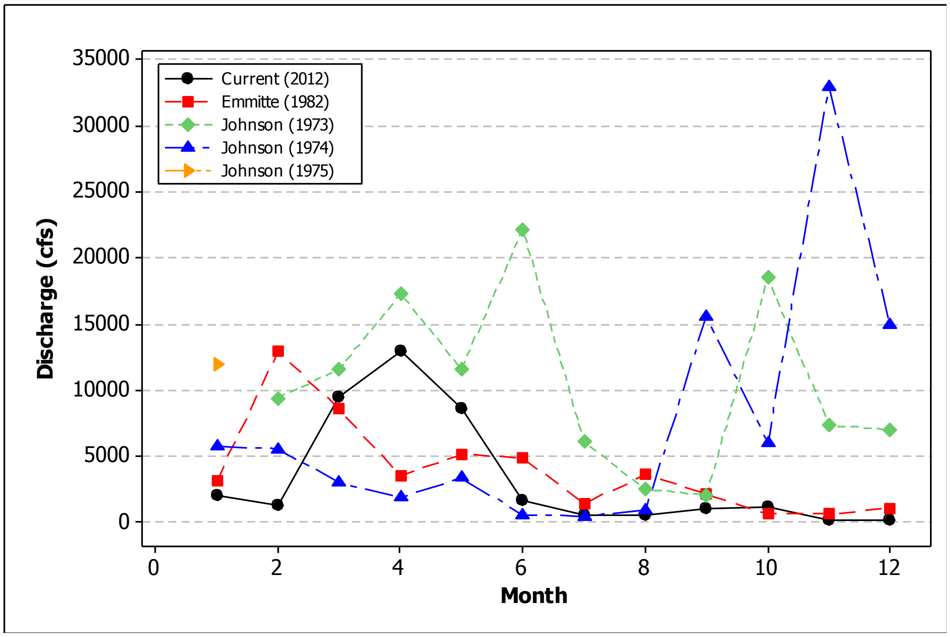

Figure 34. Scatterplot of average monthly river discharge during previous studies by Johnson (1977), Emmitte (1983), and the current study. Data was collected from The USGS Rosharon gaging station.

Water Quality

The average bottom water temperature measured by Johnson (1977) and our current study were similar at sites B-0.6 and B-11.7 (Figure 35). In both studies, the average temperature ranged between 22 to over 25°C. Further upriver, average water temperature decreased during Johnson's study, while dropping less than 1°C in the current study. During the Emmitte (1983) study, the temperature average remained around 22°C in 1982.

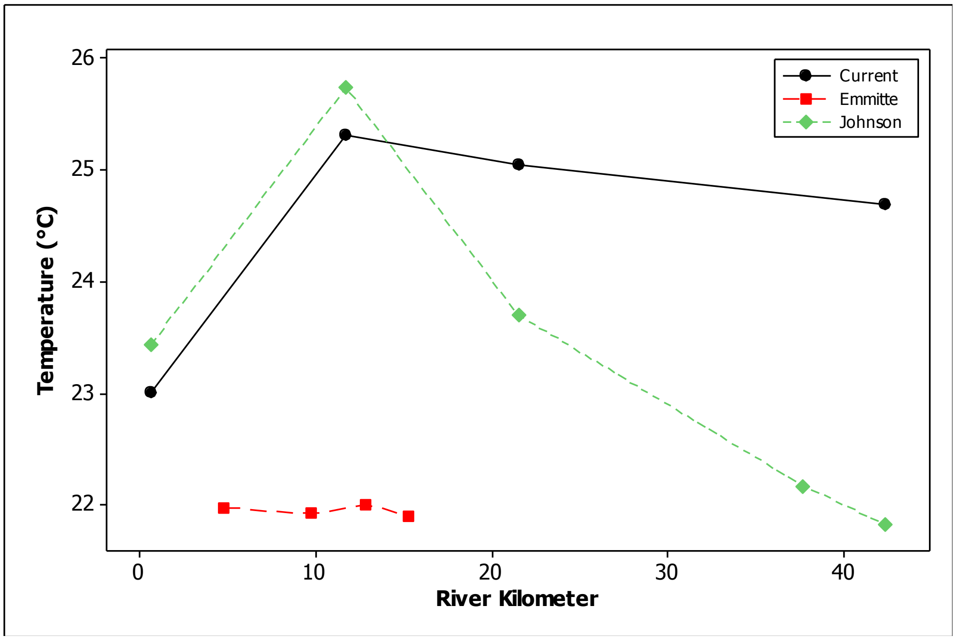

Figure 35. Scatterplot of average bottom water temperature by river kilometer for the Johnson (1977), Emmitte (1983), and current study on the Brazos River.

Average bottom salinity values steadily decreased on the Brazos River during the Emmitte and the current study (Figure 36). The Johnson study saw increased salinity from B-0.6 to B-11.7. Emmitte (1983) measured higher salinity values than the current and Johnson study. Johnson (1977) recorded higher salinity than the current study at B-21.5, but lower salinity at B-42.4.

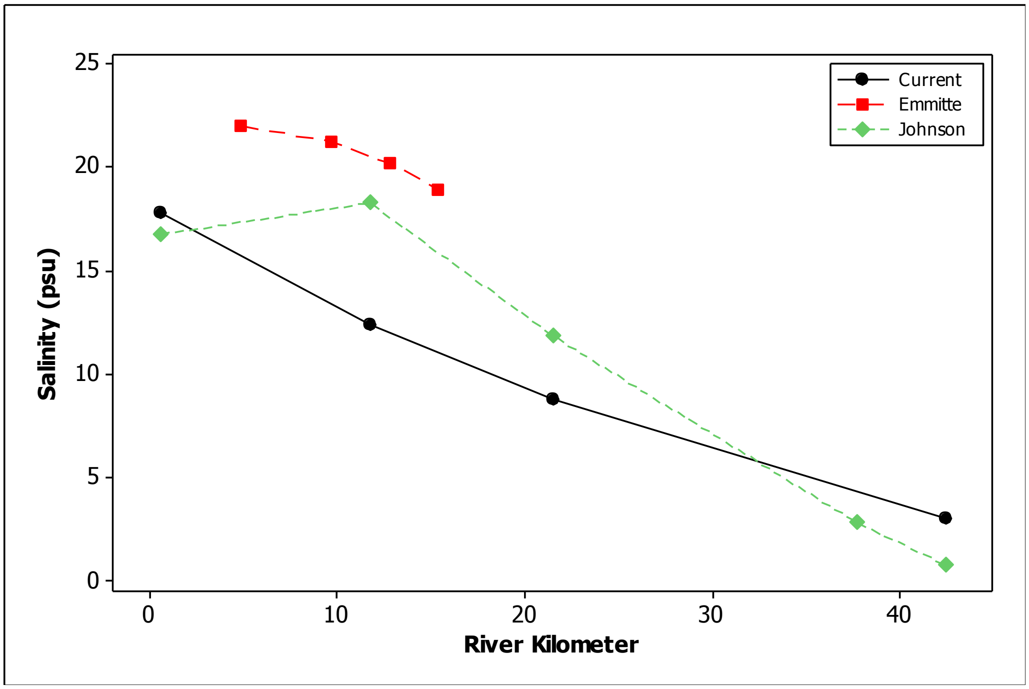

Figure 36. Scatterplot of average bottom salinity by river kilometer for the Johnson (1977), Emmitte (1983) and current studies conducted on the Brazos River.

With the exception of site B-42.4, average bottom dissolved oxygen was higher at all sites in past studies in comparison to the current investigation (Figure 37). During the Emmitte (1983) study, a large decline in dissolved oxygen was observed. He observed that at river kilometer 4.8 and 15.3 the dissolved oxygen averaged 7.3 mg/l and 3.9 mg/l respectively. The highest average dissolved oxygen (8.36 mg/L) was recorded during the current study at B-21.5. During the mid-1970's Johnson (1977) recorded the lowest dissolved oxygen (4.9 mg/l) at this site. During Johnson's study, the highest dissolved oxygen observed was 8.2 mg/l which occurred at 42.4 kilometers upstream of the mouth of the Brazos River.

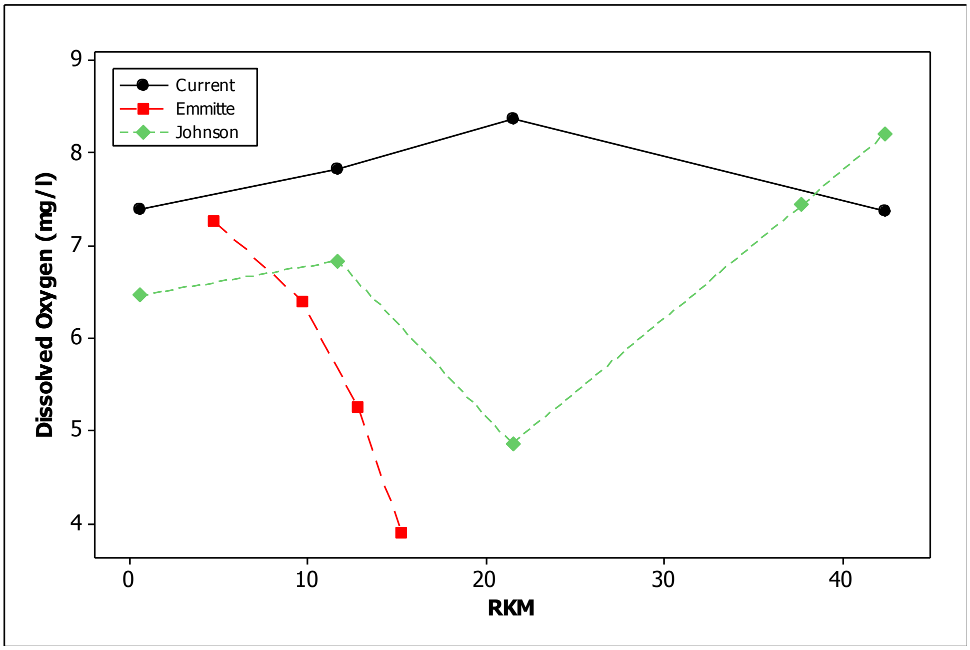

Figure 37. Scatterplot of average bottom dissolved oxygen by river kilometer for the Johnson (1977), Emmitte (1983), and current study on the Brazos River.

Biota

The frequency and otter trawl effort varied among the different studies (Appendix P). The highest average abundance over the study period was at B-0.6 of Johnson's study with 737.2 nekton per trawl in the mid-1970's (Figure 38). The highest average abundance observed during the current study occurred at the site closest to the Gulf, but was considerably less at 282.5 nekton per trawl. Emmitte (1983) found the highest average abundance per trawl at river kilometer 9.7 with an average haul of 249 nekton. During Johnsons' study, the lowest number of nekton collected occurred at site 11.7 with 6.5 nekton per haul. Catch size gradually increased with distance from the Gulf to 72.4 nekton/trawl at site B-42.4 (Johnson 1977). In contrast the average nekton abundance per trawl haul was lower during the current study (97.9 to 50.7 nekton/haul) at B-42.4 (Figure 38).

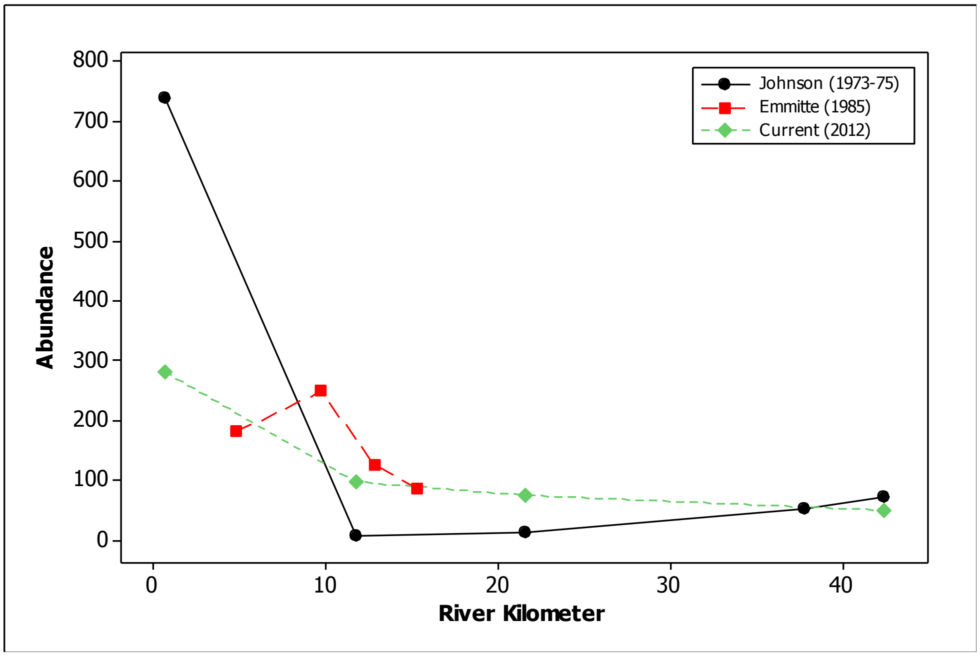

Figure 38. Scatterplot of average nekton abundance per trawl by river kilometer for the Johnson (1977), Emmitte (1983), and current study on the Brazos River.

In total, 70 fishes were collected by otter trawl in the Brazos Estuary by all studies combined. Of those species, only 19 were shared between each study. These were mostly from the fish families Sciaenidae and Clupeidae. Johnson (1977) collected eight species that were independent of the other studies and were predominately marine species. One of these species, the Florida Pompano (*T. carolinus*), was observed in the Brazos Estuary by the current study, but not captured by our otter trawls. Similarly, the Red Drum (*S. ocellatus*), was captured by other sampling means not reported in the current study but was one of the 5 unique species collected by Emmitte (1983). The current study found 23 distinct fishes including several from the families

Gobiidae and Gerreidae. See Appendix Q for a complete list of species present in all three studies by site.

Emmitte (1983) collected a higher average number of nekton species per trawl in the lower part of the river than Johnson (1977) and the current study (Figure 39). In comparison to past studies, the number of taxa reported by Johnson (1977) most closely matched the current study, with the exception of B-11.7. At B-11.7, the current study collected an average of 5.8 nekton species/trawl haul, while Johnson (1977) collected an average of 0.6 species/trawl haul. The fewest average number of nekton taxa that Emmitte collected was 8.3 nekton per haul at the site 15.3 rkm from the Gulf.

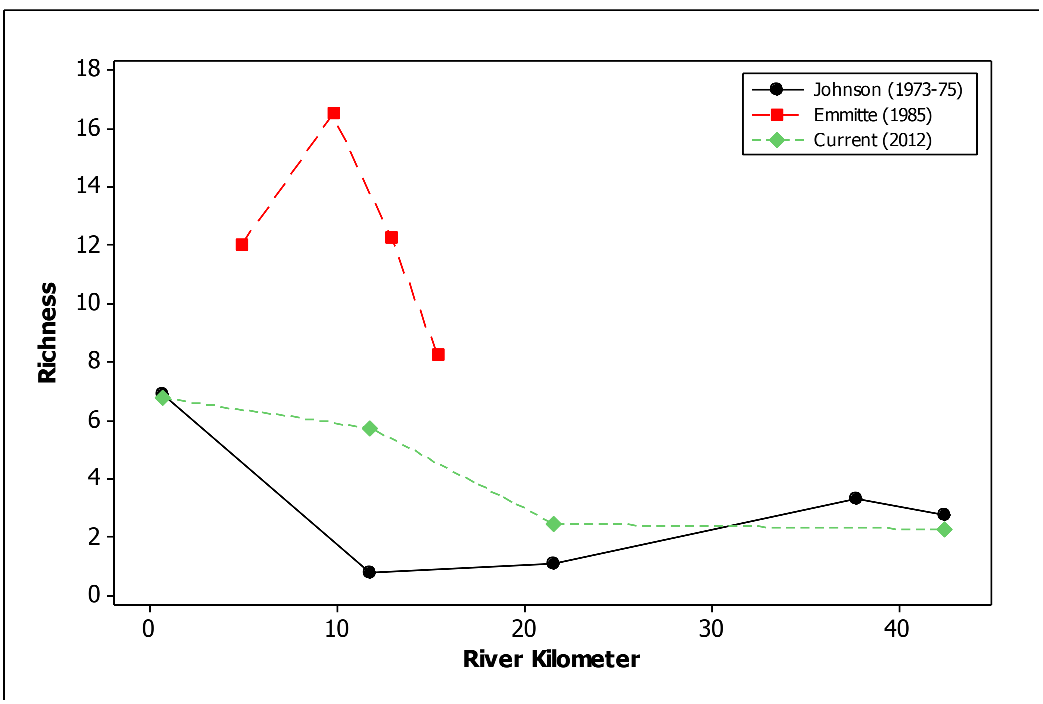

Figure 39. Scatterplot of nekton richness per trawl by river kilometer for the Johnson (1977), Emmitte (1983), and current study on the Brazos River in 2012.

Based on results of the cluster analysis of summary species assemblage data obtained from each study, it appeared that sites were grouped according to sampling period and not location (Figure 40). Cluster 1, exclusively Johnson's site at 11.7, was less than 10% similar to all other sampling communities. Cluster 2 contains three of Johnson's upper river locations and were at least 60% similar to each other. Cluster 3 was a grouping of sites B-21.5 and B-42.4 from this study. The fourth grouping consists of Emmitte's study sites in 1982. The fourth group was most similar to the current study's lower river sites and Johnson's 0.6 sampling site than any other cluster grouping. Johnsons 0.6 rkm nekton assemblage was slightly more similar to the currents studies B-11.7 than the B-0.6 assemblage. Emmitte's nekton assemblages collected at 12.8 and 15.3 were the most similar sites at 80% similarity (Figure 40).

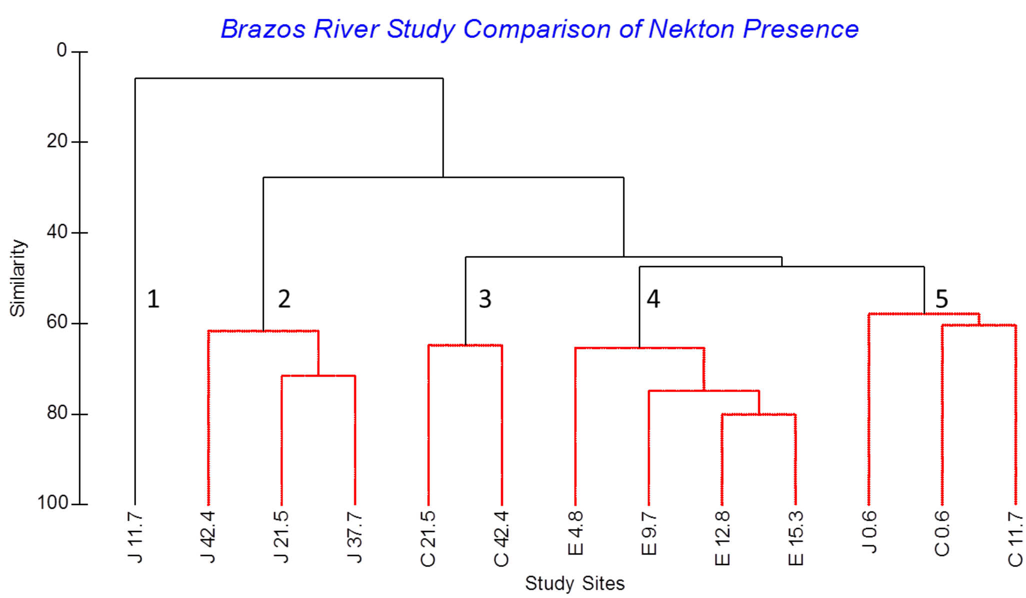

Figure 40. Cluster analysis of nekton presence on the Brazos River based on sampling location. (J = Johnson (1977), E = Emmitte (1983), and C = Current)

DISCUSSION

Current Study

Influence of Freshwater Inflow on Physicochemical Characteristics

The physicochemical structure of the lower Brazos River and estuary is predominately influenced by river discharge during high flows and wind and wave driven currents during low river discharge (Rodriguez et al. 2000). Freshwater inflow regimes in turn structure salinity, turbidity and dissolved oxygen in the lower Brazos River and estuary. Reduced flows, southeast winds and incoming tides can apparently carry the salt wedge up beyond the highest sampling location at 42.4 km upriver from the mouth. Stream discharge at Rosharon only exceeded 1,500 cfs during 3 months of the current sampling period. When a depositional river is consistently maintained at low flow levels, this will cause the rivers bank to degrade and channel down-cutting to occur (Arthington et al. 2006). We witnessed several exposed, eroding banks during all sampling events except in March. The lowest flows sampled occurred in November.

We did not find a significant overall difference in water temperature among sampling sites on the Brazos River. Median water temperatures were very similar between sites. This is likely due to the high amount of mixing and variability that is typically found in estuaries. Additionally, there was little average variability of temperature (< 1°C) vertically within the water column at all sampling locations (Table 1).

Human induced changes may also be contributing to the observed changes in water temperature. For example, the warmest site was B-11.7 in the month of August. This site was also located downstream of a permitted petrochemical process water outfall. This sampling location also experienced the largest temperature increase when flows sharply declined from May to June. In February, site B-21.5 exhibited the coldest temperature. In general, the upstream sites were cooler than the downstream sites. Site B-0.6 was generally cooler than the rest of the river sites, except during high flows. The nearby Gulf may have served as a thermal buffer during periods of low freshwater inflow. These trends in water temperature could be due to a combination of factors including the location of industrial discharges downstream, deeper water, closer proximity to warmer Gulf waters, and a lack of instream shading by riparian trees at downstream locations, and a larger riparian zone at upstream locations.

Salinity and discharge were not significantly correlated over the range of flow conditions observed during this study. This is likely due to the fact that predominant southeast winds and wave interactions when combined with upstream reductions in streamflow contributed to increased saline encroachment when compared to historical conditions. Waves derived from southerly winds would push the salt wedge upriver. Winds generally came from this direction during the study period months of May-

August. In November and December, salinity values were not as high as previous months, even though, discharge was the lowest in 2012. This is the result of winds primarily coming out of the North driving freshwater masses downstream while displacing more saline bottom water downstream and out into the Gulf.

In regards to salinity, only the furthest upstream site B-42.4, was significantly different from the other three sites. Unexpectedly, the median salinity of this site was still above 10 psu during many parts of the year. We anticipated this to be an oligohaline, not mesohaline, sampling location for much of the year. This high median salinity may be due to saline water intrusion during a period of low flows and southerly winds driving salt water from the Gulf upriver. This was most apparent when in September, bottom salinity reached 27.1 psu at B-42.4. It is clear that the Brazos Estuary expands upriver during low flows.

Another contributing factor that may be influencing salinity is the intrusion of upstream high conductivity hard water discharged from upstream areas in the watershed containing high concentrations of calcium ions (BBEST 2012). Though not significantly different, based on the Kruskal-Wallis multiple range test, B-0.6 displayed a higher reported median salinity value and lower variability. Similar to water temperature, intrusion of marine water from the Gulf mitigates drastic changes in salinity induced by other environmental factors such as lower levels of freshwater. The only low salinity value at B-0.6 occurred during high stream flows and could have prevented us from reaching the bottom water strata due to high velocities. There was little difference in median salinity between sites B-11.7 and B-21.5 even though they are nearly ten kilometers apart. It is likely that a salt wedge formed at B-21.5 and the water became stagnant.

Dissolved oxygen reached hypoxic levels twice in 2012 at the upstream sites. I did not collect water quality for extended periods of time, but it is highly probable that B-42.4 sustained hypoxic levels for longer than the 8 hour window the TCEQ permits for a water body to be deemed highly suitable for aquatic life. In August, the dissolved oxygen was 1.47 mg/l and 1.81 in September. The hypoxic water in May at B-21.5 is likely the result of high nutrient loading that has settled out from the high flows in previous months combined with the initiation of stratification via wave driven saline water from the Gulf. Sampling occurred during the middle of the day when levels are generally increasing due to phytoplankton and aquatic plant respiration. The higher dissolved oxygen at downstream sites near the Gulf is likely due to frequent mixing induced by wind and wave energy on shallow nearshore sand bars and shoreline.

Although we did not observe frequent hypoxia during this study, it is very likely that past hypoxic conditions in the Brazos River may have impacted nekton within the estuary and likely out into the Gulf. Nekton communities of the Northern Gulf are known to move out of hypoxic water (Rabalais et al. 2001). High flows in the Brazos have been linked to contributing to hypoxic events in the nearshore Gulf of Mexico

(DiMarco et al. 2012). The sharp decline in dissolved oxygen at B-0.6 in August was likely the result of a reported red tide. On August 13th, Texas Parks and Wildlife declared that an area of the upper Texas coast, including the area around the mouth of the Brazos River, was experiencing a red tide. We witnessed several thousands of adult dead fishes, mostly *Brevoortia spp.*, floating in the river washed up along the shoreline at B-0.6 on that sampling date (Appendix R. **Brevoortia spp. on bank at B-0.6 following a Texas Parks and Wildlife confirmed red tide event near the mouth of the Brazos River in August. (08/14/2012)**

).

As expected, there was a significant, negative correlation between dissolved oxygen and temperature. The physical properties of cold water allow more oxygen to be dissolved per unit of water. There were large fluctuations in turbidity at site B-42.4. These predominately occurred during high flow months of February, March and April. A large amount of the surface turbidity appeared to have settled out by the time it reached the lower sites as stream velocities declined. This is likely because the lower sites were below the site of the turbidity maxima. It is also interesting that the range of turbidity at B-11.7 was much greater than adjacent locations upriver and down river. This could be a result of the NPDES permitted discharge located near this site or a shifting of the estuarine turbidity maxima following the heavy stream discharge in the previous months. Relatively little fluctuation in turbidity occurred at B-0.6 and B-21.5. Turbidity was removed from further analysis because no significant correlations existed with biological data.

Physicochemical traits at sites B-0.6 and B-11.7 were more heavily influenced by salinity regime based on the magnitude of loadings of original variables in the principal components model. This is due to the closer proximity of these sites to the Gulf. When analyzed, the two upper sites were more closely related to each other than the two lower sites both seasonally and spatially in regards to salinity regime and associated parameters (Figure 29).

Freshwater inflow needs to be regulated on a “region by region basis” (Arthington et al. 2006). Similarly, (Freeman et al. 2001) recommended that adaptive management plans be used for regulated rivers. Methods for determining freshwater inflow needs for Texas bays and estuaries have already been developed and they continue to evolve as new information is collected by (Powell et al. 2002). These methods examine the boundaries of the system including saltwater intrusion, sediment constraints, nutrient inflow/outflow and fisheries constraints. Projected streamflow in Texas rivers are more difficult to predict than many western and eastern rivers because there is a lack of snow melt. In regions where snow melt is present, models can quantify runoff and predict timing. Texas water managers can only rely on rain events for runoff and these are much more difficult to predict. Additionally, the predominant sediment in the Brazos River is derived from the Pleistocene and Holocene eras and are relatively impermeable, therefore leading increased rapid changes in streamflow following rain events (i.e. flashiness) (Sylvia and Galloway 2006). Increased urbanization around watersheds has also contributed to a high percentage of impervious land and higher flows (Wissmar et al. 2004).

Direct and Indirect Influence of Freshwater Inflow on Biota

Freshwater inflow can directly influence nekton and other biota by physically flushing them from a riverine system during high flows. In addition, by decreasing salinity, increasing turbidity and sediment load and increasing nutrient loading, freshwater inflow can indirectly alter nekton communities. In addition, normal salinity gradients and seasonal periodicity in life history of individual species can strongly influence the community structure of nekton and benthos in estuaries (Day et al. 2013).

During the study, we found that nekton community structure in the Brazos River estuary was heavily influenced by interactions with marine biota from the Gulf. The highest abundance and most numerous taxa were collected at the river mouth sampling location. Site B-11.7 frequently exhibited higher nekton richness when compared to other sites in the estuary. The middle portions of estuaries often, on an annual basis, have a higher level of diversity due to the dynamic nature of this zone. During high salinity periods, marine organisms can intrude higher in the estuary, whereas during freshwater intrusions oligohaline species can migrate downstream. The slightly higher total richness at the mouth was due to infrequent marine migrants, such as the Lined Seahorse (*H. erectus*), during the months of May-September. These results contradict the findings of (Peterson and Ross 1991). They found diversity to be greater in tidal freshwater and oligohaline habitats than mesohaline. The nekton species collected in our study were primarily comprised of mesohaline species that maintained residency in the lower part of the estuary throughout most of the year. We collected 268 Broad-striped Anchovy (*A. hepsetus*) at B-11.7. This was the most abundant species unique to one site.

Surprisingly, no significant seasonal trends in community parameters were recognized although the median H’ fluctuated greatly between months and sites. Median abundance increased from April through July at the lower sites; these species were mostly Bay Anchovy, Atlantic Croaker and Brown Shrimp. Atlantic Croaker was the only species to be collected in otter trawls every month of the sampling period in 2012. Atlantic croaker are an estuarine species that has a high tolerance for variable salinity levels. Gulf Menhaden were typically collected in the lower estuary during the year until August when the red tide event occurred.

Nekton community abundance likely declined rapidly from July to August because of the red tide event. The upper sites demonstrated a sharp, staggered increase in November for B-21.5 and December at B-42.4 predominately of Bay Anchovy and Atlantic Croaker. Bay Anchovies were known to be the most dominant species in habitats similar to the Brazos estuary, that is shallow estuarine habitats with non-vegetated bottom, which are common in Texas and Louisiana (Minello 1999). In Galveston Bay, Bechtel and Copeland (Bechtel and Copeland) found Bay Anchovies to be the dominant species in highly stressed aquatic environments. Although water quality parameters collected in this study generally did not indicate a stressed environment, Bay Anchovies were collected with otter trawls every month except February and March. This is when freshwater inflow was highest and likely displaced them into the Gulf or up into tidal creek tributaries. In May, Bay Anchovies were collected at all four sampling locations of the Brazos Estuary.

Similar to Peterson and Ross (1991), we also found positive relationships among estuarine/marine species abundance with salinity and turbidity, though our findings were not statistically significant. We found that salinity, not dissolved oxygen, was the primary physicochemical factor influencing nekton community structure (Tolan and Nelson 2009). Several physicochemical scatterplots were wedge-shaped; this scatterplot shape is often indicative of other variables influencing the nekton communities other than the parameter (Justus et al. 2014). This study was not able to isolate a single driving force on nekton communities. Nekton communities are capable of adapting to variable salinity regimes as long as they do not experience rapid and extreme changes (Guenther and MacDonald 2012). Similar to Tsou and Richard E. Matheson (2002), our communities were likely impacted by a variety of seasonal and spatial fluctuations in the measured hydrological and water quality variables.

Low abundance of nekton occurred across a wide range of dissolved oxygen levels during our study. This is likely due to other variables impacting the community. In Northern Gulf estuaries, nekton communities were found to move out of hypoxic (< 2 mg/l) areas (Rabalais et al. 2001). Moving out of an area comes at a metabolic cost, however if there is no available prey, or the animal cannot tolerate hypoxic conditions, then it would have to relocate. Nekton communities are tolerant of shifts in temperature, salinity and dissolved oxygen as long as these variables stay within the organism's tolerance range. Therefore, nekton communities may not instantly react to higher salinity or lower dissolved oxygen but may attempt to adapt to changing conditions before choosing to migrate from an area.

Historical Comparisons

When comparing the current study to past investigations, it is important to remember that there were uncontrollable and designed differences. Emmitte's study can only be compared loosely to Johnson's study and more so to the current study because Emmitte sampled primarily at downstream river sampling locations, using slightly different gear and effort. The seasonal representation of nekton communities also varies among the studies. While these differences can have an impact on nekton collections because of the seasonal nature of nekton communities in estuaries, the combined effort of these two studies provides a snapshot of the condition of the river during the 1970's and 1980's.

Freshwater Inflow

Freshwater inflow was highly variable year to year and season to season. The only months consistently low between studies were July and August. Johnson (1977) experience the highest flows in August and lowest flows in February, while Kirkpatrick (1979) experienced the opposite flow regime. Johnson (1977) noted that river flows in 1973 were abnormally higher than normal for the river at the time. Kirkpatrick (1979), similar to Johnson (1977), concluded drought conditions resulted in at least 21 kilometers of benthic stream habitat loss. Loss of benthic habitat would have a detrimental impact on the fish populations. This was not observed during the current study at B-11.7. Emmitte's study more closely resembled our study, though our peak flow was a few months later and more sustained.

Water Quality

In the 1970's Johnson (1977) determined that the stretch of river from 9.8-21.1 rkm upriver from Gulf Intercoastal Waterway was polluted from Dow Chemical discharges. Later in that decade, Kirkpatrick (1979) determined that observed water quality problems were connected to permitted wastewater discharges. The Emmitte (1983) study in the early 1980's determined that the conditions of this same stretch of river were suitable for sustaining aquatic life and exhibited similar water quality to an adjacent minimally impacted river, the San Bernard River. The current study did not document any conditions associated with large scale organic during 2012.

Water temperature during the studies varied greatly across the different studies. The maximum temperature in the river was 35°C during the mid-1970s at B-0.6, B-11.7 and B-21.5 (Johnson 1977). Johnson (1977) attributed these high values to thermal discharges from industry. Neither Emmitte (1983), nor the current study found temperatures that high, though our study came close in August. At sites B-11.7 and B-21.5. Emmitte (1983) documented much lower water temperatures than the current study which could be the result of his limited data set. Upstream river sites sampled by Johnson (1977) were much colder than measured during the current study. This was most likely the result of high discharge from surface runoff during colder months of the year that occurred during the study period in the 1970's.

Unexpectedly, Johnson (1977) documented higher average salinity at B-11.7 than B-0.6. They determined that there was a high conductivity discharge from an industrial wastewater canal upstream of B-11.7. Similar to the current study results, the salt wedge reached above B-21.5 but did not get to B-42.4 during Johnson's study. Stagnation of that salt wedge occurred at B-21.5 (Johnson 1977). While Emmitte (1983) documented higher salinity around B-11.7 than Johnson (1977), we did not observe this condition. The current study documented a more gradual change in salinity between sites than Johnson (1977).

There were drastic differences with average dissolved oxygen readings between past investigations and our study. Johnson (1977) found that lowest average dissolved oxygen occurred at B-21.5, while this location displayed this highest average during our study. Johnson (1977) documented anoxic (0 mg/l) conditions at B-21.5 in August and was hypoxic during 46% of sampling events. If dissolved oxygen values are below 4 mg/l for over 8 hours than it is considered a violation of Texas Water Quality Standards (TCEQ 2013). Johnson attributed this to stagnation of the salt wedge, industrial cooling water discharge, municipal waste treatment outfall and warm temperatures from tidal surge which all contribute to less mixing of upper and lower water strata. All of these factors create a good environment for bacteria to deplete oxygen while anaerobic organisms increase by taking advantage of the large organic food supply (Johnson 1977).

Biota

Johnson (1977) on average collected over 400 more nekton at B-0.6 than the current study. This could be the result of high flows preventing upstream migration by estuarine nekton that were displaced by movement of freshwater nekton further downriver. Emmitte (1983) presented higher abundance and average richness than Johnson (1977) and the current study. This could be the result of an otter trawl that is twice the size of the one used by Johnson (1977) and the current study. Additionally, most of his sites were located in the lower river, which would bias his samples toward the areas containing peak diversity of taxa. The low average richness and dissolved oxygen at B-11.7 during the early 1970's was attributed to pollution and low dissolved oxygen (Johnson 1977). We did not observe this same pattern, suggesting water quality has improved.

There were 23 distinct species found in the current study and many of the species found in the other studies were observed in 2012, but not collected by otter trawl. This could be because the flow regime made the riverine estuary more accessible, the salt wedge was more established, dissolved oxygen was higher, there were less pollutants in the water, or because the average temperature in the river was higher making it more suitable for new species. Fishes are adjusting to climate change causing previously understood community zones to shift (Nicolas et al. 2011). This study recognized several species that were not collected in previous studies.

The dendrogram identified five major site assemblages, based on the presence/absence data of nekton from past and current studies. All sites within the groups showing 60% similarity represent fairly close community resemblance. All sites from Emmitte (1983) clustered together and revealed about a 50% resemblance to cluster 5 that included B-0.6 of Johnson (1977) and both lower sites in the current study. Assuming there has not been a major change in environmental conditions, I anticipated the sites to be linked according to their distance from the Gulf regardless of study period since salinity was identified as the major factor structuring site similarity. However there are a variety of aforementioned external factors that influenced these communities at the sampling sites to be less similar between studies. This primarily included different streamflow regimes, different pollutant loadings and the changes in dissolved oxygen regimes.

Data Gaps and Recommendations

We were not able to detect traditional seasonal changes in weather during 2012 along the upper Texas coast. In the humid subtropical region, drastic seasonal shifts in weather do not always exist during each year. We intended to delineate seasonal patterns based on ambient air and water temperature and precipitation but were unsuccessful in being able to delineate monthly patterns. The only rain event that occurred during the warm season was in July. Other studies in Texas have been able to document distinct seasonal patterns in temperature and salinity, and some have determined significant seasonal patterns in nekton communities (Akin et al. 2003; Minello 1999; Ostrand et al. 1999; Rozas and Minello 1998; Tolan and Nelson 2009).

For future studies, we recommend the following research be conducted to better understand the influence of hydrology and water quality on the nekton communities of the Brazos River estuary. The river should be sampled over multiple years to better capture the range of seasonal variability that exists in precipitation and streamflow. It is difficult to isolate seasonal and spatial variations from one year of sampling due to the variable nature of Texas weather and nekton periodicity. Additionally, we recommend that a flow meter be used to collect streamflow and velocity at each sample site during biological collections. During months the gage did not report data, we had to use a regression model with gage height as input to estimate streamflow. This approach is subject to errors that occur when attempting to extrapolate streamflow in a tidal river during low flow events. Lastly, we would deploy 24 hour data loggers at each of the sites to determine the length of time hypoxia was occurring in the river and to document long-term changes in temperature, salinity, turbidity and dissolved oxygen.

There were at least a few species that were observed but were not captured during the study in the otter trawl. *Acetus americanus* was likely collected and misidentified as a juvenile brown or white shrimp. During 2012, Texas game wardens also reported catches of Snook by hook and line anglers near our sample location at the Dow Chemical outfall near B-11.7. Additionally, a Flathead Catfish was caught by a field scientist on the river bottom with cut bait while sampling at B-42.4. The Flathead Catfish likely avoided the otter trawl because they prefer large woody debris habitat. Our trawl could not be pulled through these structures. Also of important note is the periodicity of displaced migrants. We collected the lined seahorse, and Sargassumfish (*H. histrio)*, among other species, that were likely more displaced into the river by incoming tides than an act of migration to use the estuary. Additional collection methods such as hook and line, overnight gill net set and high voltage electrofishing would allow us to better capture fishes that inhabit the large woody structure areas as opposed to muddy, unvegetated benthic habitat that we primarily sampled.

CONCLUSIONS

Infrequent heavy rains, multiple upstream dams and reservoirs and freshwater diversions for cities and agriculture , combined with impermeable clay soils has created a major management issue for environmental and conservation agencies and water rights holders who share responsibility for conserving the biological diversity and quality of the lower Brazos River Estuary. Limited historical data on aquatic communities make it difficult to determine baselines for water quality and native species composition and abundance. Based on the current findings, water quality conditions have greatly improved since the mid-1970's. During the 1970's hypoxia in the upper sites likely persisted long enough to affect aquatic life. We found mesohaline conditions in the bottom water column at our uppermost site 42.4 rkm from the mouth of the Brazos. Strong saline encroachment occurred in the riverine estuary when low flows persisted with persistent southeast, landward blowing winds. This physicochemical shift changed the lower Brazos River estuary from a system structured by freshwater inflow to a system primarily structured by wind and wave driven salt-wedge encroachment. This extended the estuarine zone upriver during the fall months well above our sampling location at B-42.4.

Based on the results of our study many economically important species such as brown and white shrimp, blue crab and Atlantic Croaker use the Brazos River estuary extensively, with some species occurring during every month of the year. We also found 23 fish species that had never been documented in the lower Brazos River and estuary. It is unclear whether these species were displaced opportunistic migrants or new residents in the community. We determined that 60% of the Johnson (1977) nekton community at the mouth of the river was similar to our B-0.6 and B-11.7 study sites in 2012. While the amount of freshwater inflow was the driving force, we were not able to isolate it as the exclusive factor that influences nekton communities. More extensive research is needed to understand the relationship of freshwater inflow, resulting water quality, and nekton communities of the Brazos Estuary.

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APPENDICES

Appendix A. Coordinates in UTM's of the Brazos River sampling locations in 2012.

Site	Latitude (N)	Longitude (W)
B-0.6	28.88083	-95.38117
B-11.7	28.97475	-95.38145
B-21.5	29.00254	-95.44878
B-42.4	29.06813	-95.56902

Appendix B. Photo at B-0.6 looking downstream to the mouth of the Brazos River where the river meets the Gulf of Mexico. (11/13/2012)

Appendix C. View from bank at B-0.6 looking upriver in November.

Appendix D. View of bank at B-11.7 looking downstream. (11/13/2012)

Appendix E. View of bank at B-11.7 looking upriver during low flow. (11/13/2013)

Appendix F. View looking upriver at Dow Chemical Plant from B-11.7 sampling location.

Appendix G. View looking downstream at B-21.5 during high flows in March. Notice the floating debris. (03/14/2012)

Appendix H. View of B-42.4 looking downstream in March during high flows. (03/15/2012)

Appendix I. View of B-42.4 looking upstream during low flows in November. (11/15/2012)

Appendix J. Complete water quality table from B-0.6 in 2012.

	Month	Water Temp. (°C)	Salinity (psu)	D.O. (mg/L)	pH	Total Depth (m)	Turbidity (NTU)	Discharge (cfs)
Surafce	Jan	14.54	33.64	9.57	8.02	4.66	41.20	1240
	Feb	14.27	3.76	10.59	7.89	4.36	31.10	7640
	Mar	18.51	1.97	8.25	7.86	4.85	61.00	11700
	Apr	25.09	2.54	7.6	7.81	5.67	22.80	10400
	May	28.5	13.89	8.27	8.03	5.38	9.24	1480
	Jun	30.28	25.94	6.71	8.03	5.15	12.51	272
	Jul	29.82	26.57	5.75	7.71	3.91	7.19	280
	Aug	31.91	26.77	6.29	8.02	4.56	7.01	550
	Sep	29.25	27.05	6.12	7.89	5.24	5.31	1048
	Oct	26.33	19.03	6.11	8.12	4.62	9.06	1150
	Nov	19.2	31.60	11.42	7.89	4.62	28.97	151
	Dec	17.4	29.55	6.12	7.87	4.57	8.20	180
Middle	Jan	14.52	33.64	9.59	8.02	4.66	-	1240
	Feb	13.92	5.14	10.6	7.84	4.36	-	7640
	Mar	18.12	2.01	8.24	7.85	4.85	-	11700
	Apr	24.84	3.20	8.09	7.90	5.67	-	10400
	May	26.41	30.67	6.49	7.93	5.38	-	1480
	Jun	30.29	29.01	5.96	7.89	5.15	-	272
	Jul	29.83	29.03	4.61	7.59	3.91	-	280
	Aug	30.41	34.86	5.89	7.98	4.56	-	550
	Sep	27.84	35.21	6.25	7.86	5.24	-	1048
	Oct	26.24	29.92	4.18	7.98	4.62	-	1150
	Nov	19.25	31.57	12.14	7.87	4.62	-	151
	Dec	16.65	29.89	6.39	7.88	4.57	-	180
Bottom	Jan	14.5	33.63	9.58	8.00	4.66	-	1240
	Feb	14.09	7.79	10.69	7.78	4.36	-	7640
	Mar	18.95	23.03	7.56	7.97	4.85	-	11700
	Apr	25.64	22.40	7.16	8.02	5.67	-	10400
	May	26.05	31.31	6.29	7.90	5.38	-	1480
	Jun	29.73	32.49	6.27	7.93	5.15	-	272
	Jul	28.18	38.33	6.78	7.84	3.91	-	280
	Aug	30.28	35.43	2.21	7.80	4.56	-	550
	Sep	27.23	36.62	6.55	7.84	5.24	-	1048
	Oct	26.01	30.03	4.37	7.99	4.62	-	1150
	Nov	19.25	31.57	11.48	7.85	4.62	-	151
	Dec	16.19	30.02	6.88	7.86	4.57	-	180

Appendix K. Complete water quality table from B-11.7 in 2012.

	Month	Water Temp. (°C)	Salinity (psu)	D.O. (mg/L)	pH	Total Depth (m)	Turbidity (NTU)	Discharge (cfs)
Surafce	Jan	16.4	13.69	9.35	7.91	4.16	6.23	1280
	Feb	13.82	0.55	10.7	8.11	3.59	645.00	7640
	Mar	18.38	0.30	9.14	7.83	4.43	168.00	11700
	Apr	24.83	0.56	7.53	7.79	4.46	60.43	10400
	May	24.77	1.13	5.39	7.74	4.85	189.67	3880
	Jun	31.41	11.96	10.88	8.54	3.51	7.05	272
	Jul	31.42	18.33	2.03	6.91	4.75	6.74	280
	Aug	33.04	18.15	8.05	8.14	3.30	4.88	550
	Sep	30.29	16.90	8.6	8.15	4.88	7.29	1048
	Oct	26.23	12.14	7.42	8.22	4.33	6.97	1150
	Nov	22.68	27.04	9.29	7.74	4.69	8.18	151
	Dec	19.39	27.54	5.49	7.74	4.31	10.76	180
Middle	Jan	16.33	25.75	8.33	7.97	4.16	-	1280
	Feb	14.14	4.65	11.05	7.92	3.59	-	7640
	Mar	18.6	1.92	7.96	7.68	4.43	-	11700
	Apr	25.06	3.74	7.44	7.71	4.46	-	10400
	May	24.92	3.33	5.22	7.69	4.85	-	3880
	Jun	32	24.57	6.89	7.88	3.51	-	272
	Jul	31.54	26.84	2.25	6.76	4.75	-	280
	Aug	33.34	20.82	7.29	8.05	3.30	-	550
	Sep	31	35.87	4.19	7.72	4.88	-	1048
	Oct	27.53	29.13	4.32	7.82	4.33	-	1150
	Nov	24.31	30.56	8	7.64	4.69	-	151
	Dec	19.02	28.33	5.14	7.71	4.31	-	180
Bottom	Jan	16.92	27.18	7.18	7.89	4.16	-	1280
	Feb	14.86	10.81	10.7	7.83	3.59	-	7640
	Mar	19.27	5.17	7.44	7.63	4.43	-	11700
	Apr	26.74	12.14	6.48	7.64	4.46	-	10400
	May	26.99	16.99	2.95	7.53	4.85	-	3880
	Jun	32	29.51	5.69	6.61	3.51	-	272
	Jul	31.6	29.22	2.94	6.74	4.75	-	280
	Aug	33.84	29.34	5.5	7.82	3.30	-	550
	Sep	30.62	37.07	3.6	7.05	4.88	-	1048
	Oct	27.67	30.69	4.3	7.80	4.33	-	1150
	Nov	24.27	30.96	8.08	7.60	4.69	-	151
	Dec	19.02	28.40	5.02	7.70	4.31	-	180

Appendix L. Complete water quality table from B-21.5 in 2012.

	Month	Water Temp. (°C)	Salinity (psu)	D.O. (mg/L)	pH	Total Depth (m)	Turbidity (NTU)	Discharge (cfs)
Surface	Jan	14.81	4.00	8.79	7.79	6.95	17.40	1320
	Feb	14.01	0.11	10.74	7.90	7.14	630.00	5560
	Mar	17.64	0.15	7.10	7.66	7.72	703.66	25100
	Apr	23.87	0.34	7.47	7.70	7.82	51.20	8060
	May	28.23	2.81	8.47	8.14	7.51	9.63	1320
	Jun	31.44	6.08	10.14	8.40	7.17	4.70	320
	Jul	28.58	12.30	7.60	8.13	7.29	9.47	1080
	Aug	32.94	15.99	6.65	7.94	7.56	5.15	550
	Sep	29.96	10.52	9.62	8.28	7.24	7.35	1048
	Oct	25.66	9.59	13.71	7.90	7.00	7.52	1150
	Nov	22.51	22.20	4.80	7.71	6.81	7.27	145
	Dec	19.28	21.52	5.26	7.69	6.58	4.91	182
Middle	Jan	16.85	24.32	6.60	7.65	6.95	-	1320
	Feb	13.94	0.11	10.76	7.90	7.14	-	5560
	Mar	17.51	0.15	7.03	7.65	7.72	-	25100
	Apr	23.52	0.34	7.16	7.68	7.82	-	8060
	May	28.27	14.71	3.65	7.48	7.51	-	1320
	Jun	30.77	28.42	2.86	7.21	7.17	-	320
	Jul	32.52	27.01	2.46	7.43	7.29	-	1080
	Aug	33.89	28.71	1.61	7.45	7.56	-	550
	Sep	32.45	34.99	2.32	7.54	7.24	-	1048
	Oct	26.67	25.26	7.48	7.39	7.00	-	1150
	Nov	22.11	23.07	3.72	7.60	6.81	-	145
	Dec	19.19	2.55	4.51	7.63	6.58	-	182
Bottom	Jan	17.68	27.41	5.65	7.46	6.95	-	1320
	Feb	13.71	0.11	10.85	7.67	7.14	-	5560
	Mar	17.48	0.15	6.99	7.64	7.72	-	25100
	Apr	23.47	0.36	7.31	7.68	7.82	-	8060
	May	28.72	18.90	1.76	7.28	7.51	-	1320
	Jun	30.66	30.87	3.20	7.19	7.17	-	320
	Jul	33.05	31.28	2.28	7.35	7.29	-	1080
	Aug	34.10	31.93	1.32	7.40	7.56	-	550
	Sep	32.07	34.99	2.32	7.54	7.24	-	1048
	Oct	27.33	29.87	7.66	7.34	7.00	-	1150
	Nov	22.87	28.37	4.11	7.63	6.81	-	145
	Dec	19.33	28.47	4.60	7.58	6.58	-	182

Appendix M. Complete water quality table from B-42.4 in 2012.

	Month	Water Temp. (°C)	Salinity (psu)	D.O. (mg/L)	pH	Total Depth (m)	Turbidity (NTU)	Discharge (cfs)
Surafce	Jan	18.34	0.31	9.20	7.90	6.51	42.30	2920
	Feb	14.30	0.10	9.83	7.98	6.95	931.00	5560
	Mar	17.78	0.16	6.72	7.61	8.10	1415.33	25100
	Apr	23.97	0.35	8.18	7.81	6.95	608.00	11800
	May	27.85	0.33	6.04	7.91	6.90	11.99	1320
	Jun	30.71	1.69	6.26	7.88	7.47	6.91	320
	Jul	29.36	4.66	7.09	7.96	7.38	7.50	1080
	Aug	32.52	8.54	7.27	7.88	7.35	3.98	550
	Sep	30.22	4.19	9.22	8.16	7.31	5.38	1048
	Oct	25.01	1.14	11.84	7.90	7.07	12.11	1150
	Nov	21.32	8.27	6.67	7.82	7.03	7.26	145
	Dec	18.13	8.39	6.75	7.74	6.69	5.00	182
Middle	Jan	18.34	0.31	9.14	7.89	6.51	-	2920
	Feb	14.18	0.10	7.71	7.98	6.95	-	5560
	Mar	17.75	0.16	6.57	7.59	8.10	-	25100
	Apr	23.95	0.35	8.22	7.81	6.95	-	11800
	May	27.85	0.33	5.74	7.84	6.90	-	1320
	Jun	30.55	11.57	3.19	7.32	7.47	-	320
	Jul	31.16	10.26	3.62	7.37	7.38	-	1080
	Aug	32.93	18.57	2.47	7.42	7.35	-	550
	Sep	32.30	24.60	2.04	7.33	7.31	-	1048
	Oct	25.15	2.57	10.01	7.81	7.07	-	1150
	Nov	21.82	11.01	5.05	7.69	7.03	-	145
	Dec	18.18	9.84	5.76	7.65	6.69	-	182
Bottom	Jan	18.33	0.31	9.40	7.90	4.66	-	2920
	Feb	14.15	0.10	9.70	7.98	6.95	-	5560
	Mar	17.73	0.16	6.65	7.55	8.10	-	25100
	Apr	23.95	0.35	8.32	7.81	6.95	-	11800
	May	27.85	0.33	5.82	7.84	6.90	-	1320
	Jun	30.27	16.88	2.96	7.18	7.47	-	320
	Jul	31.11	9.35	3.02	6.94	7.38	-	1080
	Aug	32.72	23.07	1.47	7.22	7.35	-	550
	Sep	32.50	27.10	1.81	7.33	7.31	-	1048
	Oct	27.17	18.14	8.96	7.26	7.07	-	1150
	Nov	22.40	14.43	4.54	7.64	7.03	-	145
	Dec	18.56	13.26	4.79	7.54	6.69	-	182

Appendix N. Table of pooled catch (n= 3 replicates) of nekton species collected on the Brazos River in 2012 by otter trawl.

Taxa			Site			
Family	Genus	Species	0.6	11.7	21.5	42.4
Dasyatidae	*Dasyatis*	*sabina*	0.3	0.0	0.0	0.0
Elopidae	*Elops*	*saurus*	0.0	0.7	0.3	0.0
Lepisosteidae	*Actractosteus*	*spatula*	0.0	0.3	0.3	0.7
Engraulidae	*Anchoa*	*mitchilli*	102.0	598.7	394.7	514.0
	Anchoa	*hepsetus*	0.0	89.3	0.0	0.0
Clupeidae	*Brevoortia*	*Patronus*	28.3	6.7	73.0	1.3
	Dorosoma	*cepedianum*	0.0	0.3	0.0	1.0
	Dorosoma	*pentenense*	0.3	0.0	0.0	1.3
	Harengula	*jaguana*	5.0	0.7	0.0	0.0
	Opisthonema	*oglinum*	1.3	0.3	0.0	0.0
	Clupeid	*spp.*	0.0	11.7	0.0	0.0
Aridae	*Arius*	*felis*	5.7	7.7	3.0	2.7
	Bagre	*marinus*	13.3	8.0	2.3	1.3
Ictaluridae	*Ictaluris*	*furcatus*	0.0	0.3	71.3	14.0
	Ictaluris	*punctatus*	0.0	0.7	9.3	3.0
Antennariidae	*Histrio*	*histrio*	0.3	0.0	0.0	0.0
Mugilidae	*Mugil*	*cephalus*	1.0	1.0	0.0	0.3
	Mugil	*curema*	0.0	1.0	0.0	0.0
Cyprinodontidae	*Cyprinodon*	*variegatus*	0.3	0.0	0.0	0.0
Syngnathidae	*Hippocampus*	*erectus*	0.3	0.0	0.0	0.0
	Sygnathus	*pelagicus*	0.3	0.0	0.0	0.0
Carangidae	*Caranx*	*hippos*	0.7	4.3	0.0	0.0
	Selene	*setapinnis*	0.3	0.7	0.0	0.0
	Selene	*vomer*	0.0	4.3	0.3	0.0
Lutjanidae	*Lutjanus*	*griseus*	0.3	0.7	0.0	0.0
Gerreidae	*Eucinostomus*	*argenteus*	0.3	1.0	0.0	0.0
	eucinostomus	*gula*	0.0	0.3	0.0	0.0
	Eucinostomus	*melanopterus*	0.0	4.3	0.0	0.0
Haemulidae	*Orthopristis*	*chrysoptera*	0.0	0.3	0.0	0.0
Sparidae	*Archosargus*	*probatocepha*	0.7	0.3	0.0	0.0
	Lagodon	*rhomboides*	0.3	1.0	0.0	0.0
Polynemidae	*Polydactylus*	*octonemus*	1.3	0.0	0.0	0.0
Scorpaenidae	*Scorpaena*	*plumieri*	0.3	0.0	0.0	0.0
Sciaenidae	*Bairdiella*	*chrysoura*	70.0	4.0	0.0	0.0
	Cynoscion	*arenarius*	9.0	15.3	158.3	6.0
	Cynoscion	*nebulosus*	0.0	2.7	0.0	0.0

	Larimus	*fasciatus*	1.7	0.3	0.0	0.0
	Leiostomus	*xanthurus*	1.7	43.3	12.0	11.3
	Menticirrhus	*americanus*	1.7	1.0	0.0	0.3
	Micropogonis	*undulatus*	962.3	120.7	42.3	20.3
	Pogonias	*cromis*	0.3	2.7	0.7	1.3
	Stellifer	*lanceolatus*	27.7	5.7	1.0	0.0
	Sciaenidae	*spp.*	9.7	0.0	0.7	0.3
	Eleotris	*amblyopsis*	0.0	0.3	0.0	0.0
Gobiidae	*Ctenogobius*	*boleosoma*	3.0	0.3	0.3	1.3
	Ctenogobius	*shufeldti*	0.3	0.0	0.0	0.0
	Gabionellus	*oceanicus*	0.0	0.0	0.3	0.0
	Gobiosoma	*bosc*	0.0	0.3	0.0	0.0
	Gobiidae	*spp.*	0.7	1.3	0.0	0.0
Ephippidae	*Chaetodipterus*	*faber*	1.3	0.0	0.0	0.0
Trichiuridae	*Trichiurus*	*lepturus*	2.3	0.0	0.0	0.0
Achiridae	*Achirus*	*lineatus*	0.3	0.0	0.0	0.0
	Gymnachirus	*texae*	0.0	0.0	0.3	0.0
Cynoglossidae	*Symphurus*	*piger*	0.0	0.0	0.3	0.0
Parachthyidae	*Citharichthys*	*spilopterus*	6.0	1.3	0.0	0.3
	Paralicthys	*lethostigma*	0.7	0.0	0.0	0.0
	Parachthyidae	*spp.*	12.0	0.3	0.0	0.0
Squillidae	*Squilla*	*empusa*	1.3	0.0	0.0	0.0
Penaeidae	*Farfantepenaeus*	*aztecus*	408.0	12.0	3.7	0.0
	Litopenaeus	*setiferus*	26.3	161.3	123.3	10.0
Palaemonidae	*Machrobrachium*	*ohione*	0.3	0.0	0.0	9.0
	Palaemonetes	*pugio*	2.7	0.3	0.0	0.0
Hippolytidae	*Lysmata*	*wurdemanni*	0.3	0.0	0.0	0.0
Alpheidae	*Alpheus*	*heterochaelis*	0.0	0.3	0.0	0.0
Epialtidae	*Libinia*	*dubia*	2.3	0.0	0.0	0.0
Portunidae	*Callinectes*	*sapidus*	17.7	3.3	0.7	1.7
	Callinectes	*similis*	19.0	1.3	0.0	0.0
Xanthidae	*Speocarcinus*	*lobatus*	0.3	0.0	0.0	0.0
Menippidae	*Menippe*	*adina*	0.7	0.3	0.0	0.0
Panopeidae	*Rhithropanopeus*	*harrisii*	0.0	0.0	0.0	0.0
Loliginidae	*Lolliguncula*	*brevis*	4.3	0.3	0.0	0.0
Fish	Unknown	Fish	2.0	0.0	0.0	0.0
Crab	Unknown	Crab	0.7	0.0	0.0	0.0
Shrimp	Unknown	Shrimp	0.0	55.7	0.0	0.0
Total Catch			5279	3538	2696	1805
Total Richness			48	45	21	20

Appendix O. Pearson correlation analysis of nekton community data and bottom physicochemical variables from otter trawls on the Brazos River in 2012. Only statistically significant relationships are shown.

Variable 1	Variable 2	Correlation	p-value
D.O.(mg/L)	D.O.(% sat)	0.930	0.000
Shannons Diversity	Shannons Evenness	0.857	0.000
Temperature (C)	D.O.(mg/L)	-0.736	0.000
Turbidity	Discharge (cfs)	0.723	0.000
Julian Day	Secchi (m)	0.707	0.000
Temperature (C)	Air Temperature (°C)	0.692	0.000
Secchi (m)	Discharge (cfs)	-0.614	0.000
Salinity (psu)	Discharge (cfs)	-0.608	0.000
D.O.(mg/L)	Air Temperature (°C)	-0.583	0.000
Abundance	Richness	0.567	0.000
RKM	Salinity (psu)	-0.559	0.000
Salinity (psu)	Turbidity	-0.555	0.000
Salinity (psu)	Secchi (m)	0.551	0.000
Richness	Shannons Diversity	0.551	0.000
RKM	Richness	-0.548	0.000
RKM	Wind Speed (km/h)	-0.545	0.000
D.O.(mg/L)	Secchi (m)	-0.540	0.000
Temperature (C)	pH	-0.525	0.000
Julian Day	Discharge (cfs)	-0.519	0.000
Julian Day	Salinity (psu)	0.516	0.000
D.O.(mg/L)	pH	0.512	0.000
Temperature (C)	D.O.(% sat)	-0.508	0.000
Turbidity	Secchi (m)	-0.501	0.000
Temperature (C)	Turbidity	-0.466	0.001
D.O.(% sat)	Air Temperature (°C)	-0.461	0.001
D.O.(% sat)	pH	0.459	0.001
Temperature (C)	Salinity (psu)	0.451	0.001
Julian Day	Turbidity	-0.417	0.003
Temperature (C)	Secchi (m)	0.416	0.003
D.O.(% sat)	Wind Speed (km/h)	0.400	0.005
Temperature (C)	Discharge (cfs)	-0.399	0.005
Temperature (C)	Wind Speed (km/h)	-0.398	0.005
Salinity (psu)	Richness	0.395	0.005
pH	Wind Speed (km/h)	0.394	0.006

D.O.(% sat)	Secchi (m)	-0.394	0.006
Julian Day	D.O.(mg/L)	-0.389	0.006
Salinity (psu)	D.O.(mg/L)	-0.376	0.008
D.O.(% sat)	Shannons Evenness	0.368	0.010
pH	Air Temperature (°C)	-0.368	0.010
Julian Day	Temperature (C)	0.364	0.011
Julian Day	Abundance	0.355	0.013
D.O.(% sat)	Shannons Diversity	0.354	0.013
Air Temperature (°C)	Wind Speed (km/h)	-0.351	0.014
D.O.(mg/L)	Wind Speed (km/h)	0.348	0.015
RKM	pH	-0.348	0.015
RKM	D.O.(% sat)	-0.343	0.017
D.O.(mg/L)	Turbidity	0.342	0.017
RKM	Shannons Diversity	-0.342	0.017
D.O.(mg/L)	Shannons Evenness	0.341	0.018
D.O.(mg/L)	Discharge (cfs)	0.319	0.027
Secchi (m)	Air Temperature (°C)	0.317	0.028
Discharge (cfs)	Richness	-0.298	0.040
Salinity (psu)	Wind Speed (km/h)	0.295	0.042
Wind Speed (km/h)	Richness	0.290	0.045
pH	Secchi (m)	-0.288	0.047

Appendix P. Table of study duration, effort, nekton and fish collected by otter trawl on the Brazos River (Johnson 1977; Emmitte 1983; Current study).

	Johnson (1973-75)					**Emmitte (1982)**				**Current (2012)**			
	0.6	11.7	21.5	37.7	42.4	4.8	9.7	12.8	15.3	0.6	11.7	21.5	42.4
Duration (Months)	24	24	24	24	24	12	12	12	12	12	12	12	12
Tows	48	48	48	48	48	4	4	4	4	36	36	36	36
Avg. No. Nekton	6.9	0.8	1.1	3.3	2.8	12.0	16.5	12.3	8.3	6.8	5.8	2.5	2.3
Avg No. Fish Taxa/Trawl	4.6	0.2	0.9	2.4	1.7	8.8	13.3	9.3	5.8	4.5	4.6	2.0	1.9
Avg. No. Nekton	737.2	6.5	12.9	52.7	72.4	181.5	249.0	125.8	87.0	282.5	97.9	75.4	50.7
Avg. No. Fish Per Trawl	488.0	0.8	10.5	23.2	46.3	111.8	193.8	105.3	65.5	201.9	77.4	64.4	48.9
Cumulative No. Nekton	41	7	8	12	9	20	31	26	19	47	44	24	21
Cumulative No. Fish	31	2	7	7	6	17	27	23	17	36	36	21	18

Appendix Q. Comparison of nekton presence by study site: Johnson (1977) Emmitte (1983) and Current. Note: 1 = present, 0 = absent.

	Johnson 1973-5					Emmitte 1982				Current 2012			
Species	0.6	11.7	21.5	37.7	42.4	4.8	9.7	12.8	15.3	0.6	11.7	21.5	42.4
Dasyatis sabina	0	0	0	0	0	0	0	0	0	1	0	0	0
Elops saurus	1	0	0	0	0	0	0	0	0	0	1	0	0
Actractosteus spatula	0	0	0	0	0	0	0	0	0	0	1	1	1
Anchoa mitchilli	1	0	1	0	1	1	1	1	1	1	1	1	1
Anchoa hepsetus	0	0	0	0	0	0	0	0	0	0	1	0	0
Brevoortia patronus	1	0	1	1	0	1	1	1	1	1	1	1	1
Dorosoma cepedianum	0	0	0	1	0	1	1	1	1	0	1	1	1
Dorosoma petenense	0	0	0	0	0	1	1	1	1	1	0	0	1
Harengula pensacolae	1	0	0	0	0	1	0	1	0	0	0	0	0
Harengula jaguana	0	0	0	0	0	0	0	0	0	1	0	0	0
Opisthonema oglinum	0	0	0	0	0	0	0	0	0	1	1	0	0
Hyobopis aestivalis	0	0	1	1	1	0	0	0	0	0	0	0	0
Arisu felis	1	0	0	0	0	1	1	1	0	1	1	1	0
Ictalurus fucatus	1	0	1	1	1	0	0	1	0	0	1	1	1
Ictalurus punctatus	0	0	1	1	1	1	1	1	1	0	1	1	1
Bagre marinus	1	0	0	0	0	1	0	0	0	1	1	0	0
Porichthys plectrodon	0	0	0	0	0	1	1	1	1	0	0	0	0
Histrio histrio	0	0	0	0	0	0	0	0	0	1	0	0	0
Mugil cephalus	1	0	0	0	1	1	1	1	1	1	1	1	1
Mugil curema	0	0	0	0	0	0	0	0	0	0	1	0	0
Menidia sp.	0	0	0	0	0	0	1	0	0	0	0	0	1
Cyprinodon variegatus	0	0	0	0	0	0	0	0	0	1	0	0	0
Hippocampus erectus	0	0	0	0	0	0	0	0	0	1	0	0	0
Sygnathus pelagicus	0	0	0	0	0	0	0	0	0	1	0	0	0
Centropomus undecim	0	0	0	0	0	0	1	1	1	0	0	0	0
Caranx hippos	1	0	0	0	0	0	1	0	0	1	1	0	0
Chloroscombrus chrysu	1	0	0	0	0	0	1	1	1	0	0	0	0
Selene vomer	1	0	0	0	0	0	1	0	0	0	1	1	0
Selene setapinnis	0	0	0	0	0	0	0	0	0	1	1	0	0
Trachinotus carolinus	1	0	0	0	0	0	0	0	0	0	0	0	0
Lutjanus griseus	0	0	0	0	0	0	0	1	1	1	1	0	0
Eucinostomus gula	0	0	0	0	0	0	0	0	0	0	1	0	0
Eucinostomus argenteu	0	0	0	0	0	0	0	0	0	1	0	0	0
Eucinostomus melanop	0	0	0	0	0	0	0	0	0	0	1	0	0
Orthopristis chrysopter	0	0	0	0	0	0	1	1	0	0	1	0	0
Archosargus probatoce	0	0	0	0	0	0	1	1	1	1	1	1	0

Lagodon rhomboides	1	1	0	0	0	1	1	1	0	1	1	0	0
Polydactylus octonemu	1	0	0	0	0	1	1	1	1	1	0	0	0
Aplodinotus grunniens	0	0	0	1	1	0	0	0	0	0	0	0	0
Bairdiella chrysura	1	0	0	0	0	1	1	1	1	1	1	0	0
Cynoscion arenarius	1	0	0	0	0	0	1	1	0	1	1	1	1
Cynoscion nebulosus	0	0	0	0	0	0	0	0	0	0	1	0	0
Larimus faciatus	1	0	0	0	0	0	1	1	1	1	1	0	0
Leiostomus xanthurus	1	0	1	0	0	1	1	1	1	1	1	1	0
Menticirrhus american	1	0	0	0	0	0	0	0	0	1	1	0	1
Micropogonias undulat	1	0	1	1	0	0	1	1	0	1	1	1	1
Pogonias cromis	0	0	0	0	0	0	1	0	0	1	1	1	1
Sciaenops ocellatus	0	0	0	0	0	1	1	0	1	0	0	0	0
Stellifer lanceolatus	1	0	0	0	0	0	1	1	1	1	1	1	0
Chaetodipterus faber	1	0	0	0	0	0	0	0	0	1	0	0	0
Scomberomorus macuc	0	0	0	0	0	1	1	0	0	0	0	0	0
Astroscopus y-graecum	1	0	0	0	0	0	0	0	0	0	0	0	0
Eleotris amblyopsis	0	0	0	0	0	0	0	0	0	0	1	0	0
Ctenogobius boleosom	1	0	0	0	0	0	0	0	0	1	1	1	1
Gobionellus hastatus	1	0	0	0	0	0	0	0	0	0	0	0	0
Ctenogobius shufeldti	0	0	0	0	0	0	0	0	0	1	0	0	0
Gabionellus oceanicus	0	0	0	0	0	0	0	0	0	0	0	1	0
Gobiosoma bosc	0	0	0	0	0	0	0	0	0	0	1	0	0
Chaetodipterus faber	0	0	0	0	0	0	0	0	0	1	0	0	0
Trichiurus lepturus	1	0	0	0	0	0	0	0	0	1	0	0	0
Peprilus alepidotus	1	0	0	0	0	0	0	0	0	0	0	0	0
Peprilus triacanthus	0	0	0	0	0	1	1	0	0	0	0	0	0
Prionotus tribulus	1	0	0	0	0	0	0	0	0	0	0	0	0
Achirus lineatus	0	0	0	0	0	0	0	0	0	1	0	0	0
Gymnachirus texae	0	0	0	0	0	0	0	0	0	0	0	1	0
Symphurus piger	0	0	0	0	0	0	0	0	0	0	0	1	0
Citharichthys spilopteru	1	1	0	0	0	0	0	0	0	1	1	0	1
Paralichthys lethostigm	1	0	0	0	0	1	1	0	0	1	0	0	0
Pleuronectiformes	0	0	0	0	0	0	0	0	0	1	1	0	0
Sphoeroides parvus	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix R. Brevoortia spp. on bank at B-0.6 following a Texas Parks and Wildlife confirmed red tide event near the mouth of the Brazos River in August. (08/14/2012)