FINAL REPORT

EFFECT OF FRESHWATER INFLOW ON MACROBENTHOS PRODUCTIVITY IN MINOR BAY AND RIVER-DOMINATED ESTUARIES - SYNTHESIS

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ABSTRACT

This final report is a synthesis of a five-year study to determine the importance of freshwater inflow on benthic community composition in minor bays and river-dominated estuaries along the Texas coast. Minor bays are small lagoonal bays with no direct freshwater inflow source, instead receiving most water from indirect sources, *e.g.*, runoff. Thus, salinity is used as an indicator of inflow because flow is not measured directly. River estuaries encompass the section of a river influenced by tidal exchange with the Gulf of Mexico. The data have been compiled to examine how these unique ecosystems differ, both temporally and spatially, and how they might differ from major open water bays that have been previously studied (Lavaca and Matagorda Bays). The data set was large and complex, therefore three different approaches were used to assess freshwater inflow requirements; 1) coast-wide approach to determine broad trends among estuaries, 2) within-system approach to determine how climate affected the individual systems, and 3) hypothesis-driven approach to test eight specific null hypotheses. Three river estuaries (Rio Grande, San Bernard River, and Brazos River) and four minor bays (Christmas Bay, Cedar Lakes, East Matagorda Bay and South Bay Coastal Preserve) were sampled between September 2000 and July 2005.

River-dominated estuaries have lower average salinities than minor bays. Temperatures are warmer in the two most southern systems, the Rio Grande and South Bay, even though Rio Grande has the lowest salinity and South Bay has the highest salinity. Coast-wide, Texas coastal ecosystems act as sources for ammonium and silicate, but as sinks for nitrate plus nitrite, and phosphate. Chlorophyll a is highest in the river systems, but lowest in minor bays. Typically, freshwater inflow causes declining salinities, but increasing nutrient (nitrogen and phosphorous) levels and increasing chlorophyll levels.

In terms of benthic productivity as evidenced by abundance and biomass, the estuaries sampled are divided into three groups: San Bernard River and Brazos River have the lowest (about 5,000 individuals m^{-2} and 1 g m^{-2}), the Rio Grande and Cedar Lakes are mid-range (about 8,000 individuals m^{-2} and 3 g m^{-2}), and South Bay, Christmas Bay, and East Matagorda Bay have the highest (about 20,000 individuals m^{-2} and 10 g m^{-2}). Lavaca Bay is in the low group and Matagorda Bay is in the mid group. The high group is unique because of the presence of seagrass beds. Diversity is low in estuaries with salinities between 1 and 17 ppt, but increases with salinities of up to 30 ppt. Diversity decreases again in hypersaline conditions however.

Macrofaunal community structure could be divided into two groups coast-wide with at least 40 % similarity among systems within each group. The first group represented polyhaline communities and contained East Matagorda, Matagorda, Christmas and South Bays. In this first group, there was at least a 58 % similarity in macrofaunal communities among East Matagorda, Matagorda and Christmas Bays. The second group represented oligo-mesohaline community characteristics and contained Lavaca Bay, San Bernard River, Brazos River, Cedar Lakes and the Rio Grande.

The implications of these results for managing freshwater flows is that each system has a characteristic community that is strongly influenced by hydrology of the systems. There appears to be a tipping point at about 17 - 22 ppt where coastal systems change from oligo-mesohaline to polyhaline community characteristics.

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INTRODUCTION

From the early 1970's to 2000, Texas Water Development Board (TWDB) freshwater inflow studies focused on the major bay systems of the Texas coast. These bay systems, which are influenced primarily by river inflow, are now considered to be well understood. In particular, Texas researchers have completed several studies on the effect of freshwater inflow on macrobenthos productivity in these open bay systems (Montagna 1989; 1999; 2000; Kalke and Montagna 1991; Montagna and Yoon 1991; Montagna and Kalke 1992; 1995; Montagna and Li 1996). These studies have demonstrated that regional scale processes and long-term hydrological cycles regulate benthic abundance, productivity, diversity and community structure. Thus, there are three major causes of changes in estuarine productivity in Texas related to freshwater inflow: 1) year-to-year climatic variability in rain, temperature, and wind, which affects precipitation and evaporation, 2) a latitudinal climatic gradient of decreasing precipitation superimposed on a soil's gradient of increasing sand content, which results in reduced inflow from northeast to southwest, and 3) the salinity gradients within estuaries from rivers to the Gulf of Mexico. The overall intended result of these studies is to demonstrate the need for minimum inflow requirements on an estuary-scale or a watershed-level basis.

Attention is now focused on minimum inflows required by minor bays and river-dominated estuaries. Freshwater inflow into minor bays is generally dominated by non-point source runoff or an indirect source via circulation from adjacent systems. The river-dominated estuaries drain directly into the Gulf of Mexico rather than into a bay. These drowned-river valley ecosystems are thus uniquely different from the typical bar-built estuaries of Texas that are characterized by large open bays. Because the minor bay and river-dominated estuaries are different from typical Texas estuaries, new studies are required to elucidate how inflow affects benthic productivity in those systems. Texas state agencies will be required to complete freshwater inflow assessments on seven minor bays and river estuaries in the near future. Until the current series of reports, there was very little information available on the biotic response to inflow in these two types of ecosystems. The first, second and third reports (Montagna 2001; 2002; 2003) focused on East Matagorda Bay, South Bay Coastal Preserve and Christmas Bay Coastal Preserve respectively. The fourth and fifth reports focused on Cedar Lakes and San Bernard River estuary, which were studied for three years (Montagna 2004; 2005), and the long-term monitoring of the Rio Grande and Brazos River estuaries, which were sampled from October 2000 to July 2005. The current report is a synthetic analysis of the hydrographic and benthic community data among all minor bays and river estuaries described in the previous five reports.

Historical studies have stressed the importance of freshwater inflow to estuarine systems, and determined that inflow is a major factor driving estuary functioning and health (Chapman 1966; Kalke 1981). Inflows serve a variety of important functions in estuaries, including the creation and preservation of low-salinity nurseries, sediment and nutrient transport, allochthonous (outside) organic matter inputs, and movement and timing of critical estuarine species (Longley 1994). Benthic macrofauna (body length > 0.5 mm) are especially sensitive to changes in inflow, and can be useful in determining its effects on estuarine systems over time (Kalke and Montagna 1989, Montagna 2000).

Benthos are excellent indicators of environmental effects of a variety of stressors because they are abundant, diverse, sessile, and long-lived relative to plankton. Therefore, benthos integrate temporal changes in ecosystem factors over long time scales and large spatial scales. Benthic abundance, biomass, and diversity were measured to assess inflow effects on ecosystem productivity. In addition, relevant water quality and sediment variables (*i.e.*, salinity, temperature, dissolved oxygen, nutrients, chlorophyll, grain size and carbon and nitrogen content) were measured during each sampling period to assess inflow effects on the overlying water column and sediments that make up benthic habitat.

METHODS

Study Area and Sampling Design

The objective of this study was to determine the relationship between temporal and spatial variability of benthic productivity variables and freshwater inflow in minor bays and river-dominated estuaries. Three river estuaries (Rio Grande, San Bernard River, and Brazos River) and four minor bays (Christmas Bay, Cedar Lakes, East Matagorda Bay and South Bay Coastal Preserve) were sampled between September 2000 and July 2005 (Table 1). Not all minor bays and river estuaries were sampled each year due to funding availability. The sites can be divided into northern and southern systems: the northern systems include the Brazos River, San Bernard River, Christmas Bay, Cedar Lakes, and East Matagorda Bayand the southern systems include the Rio Grande and South Bay Coastal Preserve. The Brazos River and Rio Grande represent river estuaries in Texas having the highest and lowest inflow respectively, so long-term comparison of these systems was also desirable.

Station locations in all bays were chosen based on previous sampling experience, sediment type, depth found on National Oceanic and Atmospheric Administration navigation charts, and constraints of sampling logistics. In addition to this, stations within each bay or river were chosen to represent both the salinity gradient within the estuary, and a broad spatial coverage. The locations of stations were recorded and relocated using GPS (Table 2).

Three stations on the lower Rio Grande were chosen between the confluence with the Gulf of Mexico and Brownsville (Figure 1). Station A, B and C were 12.6 km (7.8 mi), 11.3 km (7.0 mi) and 5.5 km (3.4mi) from the Gulf of Mexico respectively. In April 2002, it was discovered that station C was not on the main channel of the river, but in a secondary meander channel that was situated north of the main channel. A new station (D) was established in the main channel, approximately 100 meters from station C. Sampling at station D began in July 2002 and conituned until the end of the study period in July 2005. After being missed in July 2002, sampling resumed at Station C in October 2002. A new station (E) located 1.8 km (1.1 mi) downstream of station D and 5.1 km (3.2 mi) from the mouth was added in October 2002.

Two stations in South Bay were chosen to represent the variability within the bay (Figure 1). Because of accessibility limitations associated with the shallowness of the bay, the station locations are only 1.5 km (0.95 mi) apart. South Bay is connected to the Gulf of Mexico via the Brownsville Ship Channel. Station B is closer to the Brownsville ship channel (and therefore closer to the Gulf of Mexico) than Station A. Neither station in South Bay is directly influenced by freshwater inflow.

Three stations (A, B, and C) were sampled in a transect along the length of East Matagorda Bay (Figure 2). The most likely source of freshwater to East Matagorda Bay is the Gulf Intracoastal Water Way (GIWW), which is connected to many small tributaries and the much larger Brazos River.

Two stations were sampled in Cedar Lakes minor bays (Figures 2 and 3). The Cedar Lakes is a cluster of coastal lagoons linked to the GIWW. It was assumed that inflow would be provided by San Bernard River water flowing west, thus stations were chosen to represent distances from the San Bernard River. Both stations were southeast of the GIWW and south of the San Bernard River. Station A was closest to the San Bernard River and Station B was farther south and furthest from the Gulf of Mexico.

Two stations were sampled in the San Bernard River estuary (Figures 2 and 3). Station A is northwest of the GIWW and also the most upriver of the two stations. Station B was south-southeast of the GIWW, and closest of the two stations to the Gulf of Mexico.

Three Brazos River stations (A, B and C) were chosen along the estuary gradient (Figure 2 and 3). Stations A, B and C were 5.9 km (3.7 mi), 3.4 km (2.1 mi) and 1.1 km (0.7 mi) from the Gulf of Mexico respectively. Stations A and B were north of, and station C south of the GIWW.

Three stations were sampled in Christmas Bay Coastal Preserve (Figures 2 and 3). Christmas Bay is in the western part of the Trinity-San Jacinto Estuary. Christmas Bay is also situated between the GIWW to the northwest and the Gulf of Mexico to the southeast.

In previous benthic studies (Montagna and Li 1996; Montagna 2000), quarterly sampling has been demonstrated to be effective in capturing temporal benthic dynamics, while economizing on temporal replication. Quarterly sampling occurred every October, January, April, and July between October 2000 and July 2005. The timing of the sampling captured the major seasonal inflow events and temperature changes in Texas estuaries. Each quarter, three replicate benthic samples were collected per station.

During each sampling period ancillary environmental data were also collected. Water quality characteristics were determined by measuring salinity, nutrient concentrations, and chlorophyll concentrations in the water column. Sediment characteristics, *e.g.*, grain size, porosity, and elemental content were measured annually.

Hydrographic Measurements

Salinity, conductivity, temperature, pH, percent dissolved oxygen, and dissolved oxygen (mg l^{-1}) were measured at each station during each sampling trip using multiprobe water quality meters. A YSI 6920 multiprobe sonde was used to measure these parameters, except for in South Bay and the Rio Grande. The accuracy of each reading was as follows: DO % saturation ± 2 %, DO ± 0.2 mg l^{-1}, conductivity greater of ± 0.5 % of reading or ± 0.001 mS/cm, temperature ± 0.15°C, pH ± 0.2 units, depth ± 0.02 m, and salinity greater of ± 1 % of reading or ± 0.1 ppt. Salinity levels are automatically corrected to 25°C. In addition, a surface refractometer was used to verify the YSI meter salinity readings. Measurements were made at both 0.1 m deep and 0.1 to 0.2 m above the bottom. Depth was measured to the nearest 0.1 meter with a weighted measuring tape.

South Bay and Rio Grande hydrographic measurements were made using a Hydrolab Surveyor 4 (by University of Texas - Pan American staff). The following parameters were measured (accuracy and units): temperature (± 0.15 EC), pH (± 0.1 units), dissolved oxygen (mg l^{-1} ± 0.2), specific conductivity (± 0.015 - 1.5 mmhos/cm depending on range), and salinity (greater of ± 1 % of reading or ± 0.01 ppt), automatically corrected to 25°C. Depth was measured with a marked PVC pole to the nearest centimeter.

Chlorophyll and Nutrient Measurements

Water samples were collected at the surface by hand and at the bottom using a horizontal mounted Van Dorn bottle. Bottom water was collected approximately 20 cm from the sediment-water interface. Water for chlorophyll analysis was filtered onto Whatman GF/F 25 mm glass fiber filters and placed on ice (< 4.0 ˚C). Nutrient samples were filtered to remove biological activity (0.45 µm polycarbonate filters) and also placed on ice (< 4.0 ˚C). Chlorophyll was extracted overnight and read on a Turner Model 10-AU fluorometer using a non-acidification technique (USEPA 1997; Welschmeyer 1994). Nutrient analysis was conducted using a LaChat QC 8000 ion analyzer with computer controlled sample selection and peak processing. Nutrients measured were (concentration ranges; Quikchem method) nitrate+nitrate (0.03 - 5.0 µM; 31-107-04-1-A), silicate (0.03 - 5.0 µM; 31-114-27-1-B), ammonium (0.07 - 3.57 µM; 31-107-06-5-A) and phosphate (0.03 - 2.0 µM; 31-115-01-3-A).

Sediment Measurements

Sediment grain size analysis was also performed. At each site, a 6.7-cm diameter sediment core sample was taken by diver or coring pole and sectioned at 0 - 3 cm and 3 - 10 cm depth intervals. Analysis followed standard geologic procedures (Folk, 1964; E.W. Behrens, personal communication). A 20 cm^3 sediment sample was mixed with 50 ml of hydrogen peroxide and 75 ml of deionized water to digest organic material in the sample. The sample was wet sieved through a 62 µm mesh stainless steel screen using a vacuum pump and a Millipore Hydrosol SST filter holder to separate rubble and sand from silt and clay. After drying, the rubble and sand were separated on a 125 µm screen. The silt and clay fractions were measured using pipette analysis. Percent contribution by weight was measured for four components: rubble (e.g. shell hash), sand, silt, and clay.

The proportion of organic and inorganic carbon and nitrogen content in the sediment was also measured. In addition to this, carbon and nitrogen isotopes $\delta^{13}C$ and $\delta^{15}N$ were measured. Samples were measured using a Finnigan Delta Plus mass spectrometer linked to a CE instrument NC2500 elemental analyzer. The system uses a Dumas type combustion chemistry to convert nitrogen and carbon in solid samples to nitrogen and carbon dioxide gases. These gases are purified by chemical methods and separated by gas chromatography. The stable isotopic composition of the separated gases is determined by a mass spectrometer designed for use with the NC2500 elemental analyzer. Standard material of known isotopic composition was run every tenth sample to monitor the system and ensure the quality of the analyses.

Biological Measurements

The macrobenthos was sampled with core tubes held by divers or with a coring pole. The macrofauna were sampled with a 6.7 cm diameter tube (35.26 cm^{-2} area), and sectioned at depth intervals of 0 - 3 cm and 3 - 10 cm. Three replicates were taken within a 2 m radius. Samples were preserved in the field with 5 % buffered formalin. In the laboratory, samples were sieved on 0.5 mm mesh screens, sorted, identified to the lowest taxonomic level possible, and counted.

Each macrofauna sample was also used to measure dry weight biomass. Individuals were combined into higher taxa categories, e.g., Crustacea, Mollusca, Polychaeta, before being dried for 24 hours at 55°C, and weighed. The carbonate shells of molluscs were dissolved using 1 N HCl, and rinsed with fresh water before drying.

Analytical Approach

The goal of this study is to provide information for determining the minimum freshwater inflow requirements for minor bay and river-dominated estuaries. Minor bays and river-dominated estuaries located along the Texas coast were studied for five years. The data have been compiled to examine how these unique ecosystems differ, both temporally and spatially, and how they might differ from major open water bays that have been previously studied.

Control sites are needed in research studies to compare reference conditions to experimental conditions. Lavaca Bay and Matagorda Bay comprise the Lavaca-Colorado estuary, a major bay system that has been studied for many years (Montagna 2000). Lavaca Bay, a secondary bay, represents an area with more freshwater influence while Matagorda Bay, a primary bay, represents an area of greater marine influence. Data from these bays have been previously collected for other projects, therefore information is available to be applied to the current project to represent major open bay system control sites. These particular bays were chosen based on their close proximity to most of the systems studied in the current project.

The data set from the current study was large and complex, therefore it was necessary to use three different approaches to assess freshwater inflow requirements in minor bays and river-dominated estuaries. The approaches differed in terms of spatial and temporal scales, but similarly use the large coast-wide climatic gradient and year-to-year inflow difference to assess the effect of different inflow regimes on the estuaries.

1) The coast-wide approach aggregated data over all samples to determine broad trends and relationships among estuaries. In this approach, every estuary sampled is represented by a point on a graph. This approach removes temporal variability so that only spatial variability is determined.

2) The within-system approach compared wet versus dry months to determine how climate affected the river-dominated systems. This approach . was used to assess temporal trends within the Rio Grande and Brazos River estuary systems.

Wet and dry month thresholds were determined using freshwater inflow data from hydrological stations close to the sampling stations in both the Brazos River and the Rio Grande. The data from the Rio Grande were obtained from the Rio Grande Near Brownsville hydrological station, which is managed by the International Boundary and Water Comission (http://www.ibwc.state.gov/Water_Data/histflo1.htm). Inflow data for the Brazos River were obtained from the United States Geological Survey Brazos River near Rosharon hydrological station (http://waterdata.usgs.gov/nwis/sw).

Daily flow was smoothed by averaging the 30 days prior to and including each daily flow value. This 30-day criterion was used to account for the lag in benthic response after a freshwater event (Kinsey, 2006). The total mean of the 30-day daily flow means was calculated using the twenty year period from 1985 to 2005. Data before 1985 was discarded because of large decreases in inflows before 1985 in the lower Rio Grande. Macrofauna sample dates were deemed to be in 'dry' weather conditions if the date sampled had a lower than average 30-day daily flow mean and in 'wet' weather conditions if the date sampled had a higher than average 30-day daily flow mean.

3) The hypothesis-driven approach involved partitioning the data set to test specific null hypotheses, which are described below.

The sampling program is complex and unbalanced, therefore, the data set was subdivided to derive balanced data sets needed to test hypotheses. Table 3 details the groups of data that were used to test each hypothesis given below.

> Ho_1: There are no differences in hydrology, sediment, and macrofaunal communities in East Matagorda Bay, a minor bay, versus Lavaca Bay and Matagorda Bay, two major bays.

East Matagorda Bay, a minor bay, was sampled only one year, therefore, to determine differences from this minor bay samples were compared to Lavaca Bay and Matagorda Bay, two major bays that constitute the Lavaca-Colorado estuary, that were sampled in the same year. A two-way analysis of variance (ANOVA) was run using bays and dates as main effects.

> Ho_2: There are no differences in hydrology, sediment, and macrofaunal communities among all minor bays sampled.

Minor bays were not all sampled in the same year, however, it is useful to try and identify some similarities and differences among all minor bays sampled, using an incomplete block design.

> Ho_3: There are no differences in hydrology, sediment, and macrofaunal communities between South Bay, a southern minor bay, and the Rio Grande, a southern river-dominated estuary.

South Bay is located in the southern-most part of the study area, unfortunately no reference site samples were taken around this minor bay. In hindsight, samples should have been collected in the Laguna Madre to allow for comparison. For this study, South Bay was compared to the Rio Grande using a two-way ANOVA with bays and dates as main effects.

> Ho_4: There are no differences in hydrology, sediment, and macrofaunal communities between northern systems: Cedar Lakes and Christmas Bay (minor bays) and San Bernard River and Brazos River (river-dominated estuaries) were compared to Lavaca Bay and Matagorda Bay (major bay systems).

Christmas Bay is a minor bay located in the northern-most area of the study site. Differences in hydrology, sediment, and macrofaunal communities were tested among the central coastline systems with attention on Christmas Bay. A two-way ANOVA was run using bays and dates as main effects.

> Ho_5: There are no differences in hydrology, sediment, and macrofaunal communities between Brazos River, a northern river-dominated estuary, versus the Rio Grande, a southern river-dominated estuary.

Brazos River and Rio Grande represent the two largest river-dominated estuaries that empty into the Gulf of Mexico. Brazos River is located in the northern central area of Texas and has a much higher rate of precipitation than the southern part of Texas where the Rio Grande is located. This hypothesis tests for differences in river-dominated estuaries between two different climatic zones. A two-way ANOVA was run using bays and dates as main effects.

> Ho_6: There are no differences in hydrology, sediment, and macrofaunal communities between sampling dates in Cedar Lakes, San Bernard River, Brazos River, Lavaca Bay and Matagorda Bay.

The greatest concentration of minor bays and river-dominated estuaries is located in the central coastline of Texas. Cedar Lakes, San Bernard River, and Brazos River are minor bays and river-dominated estuaries that are located in close proximity to one another. These systems were sampled for three years and compared to Lavaca Bay and Matagorda Bay, major estuary systems, to identify differences along the central coastline of Texas. This is the test with most samples, hence highest power to detect change. A two-way ANOVA was run using bays and dates as main effects.

> Ho_7: There are no differences in hydrology, sediment, and macrofaunal communities between all river-dominated estuaries; Rio Grande, San Bernard River and Brazos River.

River-dominated estuaries sampled varied between location and climate regions. The Rio Grande, San Bernard River and Brazos River were tested for differences between northern and southern river-dominated estuaries along the Texas coastline. A two-way ANOVA was run using bays and dates as main effects.

> Ho_8: There are no differences in hydrology, sediment, and macrofaunal communities between Brazos River and Christmas Bay, northern systems, and Rio Grande and South Bay, southern systems.

Brazos River, a river-dominated estuary and Christmas Bay, a minor bay, are located in the northern part of the study area and were compared to the Rio Grande, a river-dominated estuary, and South Bay, a minor bay, located in the southern-most part of the study area. Differences were identified between the two types of systems as well as between two climate areas. A two-way ANOVA was run using bays and dates as main effects, partially hierarchical in design.

Statistical Methods

Statistical analyses were performed using SAS software (SAS 1991). All data, except species diversity data, were log-transformed prior to analysis. Two-way analysis of variance (ANOVA) tests were run on water column, abundance and biomass data to test for differences between stations within bays, dates within bays and between bays. The generic sources of the 2-way ANOVAs were space and time.

Multivariate analyses were used to analyze species distributions and assess how environmental variables affect distributions. The water column structure and sediment structure were each analyzed using Principal Component Analysis (PCA). PCA reduces multiple environmental variables into component scores, which describe the variance in the data set to discover the underlying structure in a data set. In this study, only the first two principal components were used. Correlations between principal component scores were determined to examine the relationship between sediment and water column data.

Macrofaunal community structure was analyzed using non-metric Multi-Dimensional Scaling (MDS). The MDS procedure uses a Bray-Curtis similarity matrix among stations or station-date combinations to create a MDS plot. The MDS plot shows the macrofaunal community relationship among stations spatially so that the distances among stations are directly related to the similarities in macrofaunal species compositions among those same stations (Clarke and Warwick 2001). Relationships within each MDS were highlighted using a Cluster Analysis using the group average method. The Cluster Analysis is also based on Bray-Curtis similarity matrices. Cluster Analysis was displayed as similarity contours on the MDS plots and as dendrograms, both using percentage similarity among factors. Significant differences between each cluster were tested using the SIMPROF permutation procedure using a significance level of 0.05. Data were log(x+1) transformed prior to any analysis in Primer in order to improve performance of the test (Clarke and Gorley 2001). Both PCA and MDS were calculated using Primer v6 software.

RESULTS

During the first week of February, 2001, a sand bar formed and closed the mouth of the Rio Grande, stopping exchange with the Gulf of Mexico (Figure 4). The mouth was artificially opened with a backhoe on 18 July 2001 by the International Boundary and Water Commission (U.S. State Department), however, it closed again in November 2001. The mouth of the Rio Grande was manually opened again on 9 October 2002 at Boca Chica Beach, but closed on 15 October 2002. On 2 November 2002, a large rain storm event occurred near the river mouth, east of Brownsville, which caused enough pressure to breach the berm, restoring exchange between the river and the sea. The Rio Grande mouth has remained open since that date (Randy Blankenship, personal communication, 20 May 2003). The mouth was open when the Rio Grande was sampled in late November 2002. Based on available reports, the river mouth was not blocked during the sampling period (October

2002 to July 2003), in fact heavy rain occurred in October to November 2002 that delayed sampling of stations C and E for a month.

Coast-wide Approach

Physical characteristics

Water quality parameters for each site were merged using Principal Component Analysis (PCA; Figure 5). The first and second principal components (PC1 and PC2) explained 39.7 % and 21.7 % of the variation within the data set respectively (total 61.4 %). Salinity was negatively related to phosphate, chlorophyll-*a*, dissolved inorganic nitrogen and silicate along PC1 (Figure 5B). Nitrogen to phosphorus ratios, water temperatures and dissolved inorganic nitrogen all correlated with positive PC2 values. Depth, dissolved oxygen and pH did not explain much variation within the first two principal components. The three river-estuaries (Rio Grande, Brazos River and San Bernard River) were separated from the other estuaries along the PC1 axis (Figure 5A). The river-estuaries had higher mean dissolved inorganic nitrate, phosphate and chlorophyll-*a* (chl-*a*) concentrations and lower mean salinities than any other estuary.

Mean salinities in river-dominated estuaries were lower than for minor bays (Figure 6). Mean salinities ranged from 4.2 ppt in the Rio Grande to 36.6 ppt in South Bay. Variation in salinity was smallest in the Rio Grande, South Bay and Christmas Bay. Mean temperatures were higher in the Rio Grande and South Bay (25.1 and 25.0 °C respectively) than all other estuaries (21.2 to 23.5 °C; Figure 6). The coldest mean water temperatures were found at Christmas and Lavaca Bays (21.2 and 21.9 °C respectively). The greatest variability in temperatures was found within East Matagorda Bay and Cedar Lakes. There was no correlation between temperature and salinity (Figure 6A). Ammonium levels were the lowest in Lavaca, Matagorda, East Matagorda, and Christmas Bays, 1.0 to 1.5 µM compared with 4.8 to 7.6 µM at other ecosystems (Figure 6B). These bays also had the most consistent ammonium concentrations i.e., lowest variance. The river-dominated estuaries had the highest concentrations of ammonium (5.8 to 7.6 µM). Ammonium was negatively correlated with salinity among estuaries with the exception South Bay, which had both high salinity and ammonium levels.

Phosphate and silicate concentrations were both inversely proportional to salinity (Figures 6 and 7). The Rio Grande had the highest concentration of phosphate and second highest concentration of silicate (5.7 µM and 163.1 µM respectively) while South Bay and Christmas Bay had the lowest concentrations (0.2 to 0.4 µM and 9.3 to 48.2 µM). Cedar Lakes and Matagorda Bay had silicate concentrations of at least 40 µM lower than Lavaca Bay and East Matagorda Bay despite similar salinities. River-dominated estuaries had the highest concentrations of nitrate plus nitrite, ranging from 16.83 µM in the San Bernard River to 40.40 µM in the Brazos River (Figure 7). Other estuaries examined along the Texas coast had much lower nitrate plus nitrite concentrations (0.8 to 5.9 µM). The Rio Grande had the highest mean chl-*a* concentration (20.80 µM), while South Bay had the lowest (2.69 µM; Figure 7). Mean chl-*a* concentrations in the other estuaries ranged from 5.0 to 11.1 µM.

The first and second principal components (PC1 and PC2) for sediment content along the Texas coast explained 54.1 % and 17.8 % of the variation within the data set (total 71.9 %; Figure 8). East

Matagorda Bay had the highest rubble content (4.2 %) while Cedar Lakes had the lowest (0.8 %). Sand content was highest in South Bay (69.2 %), Cedar Lakes (59.9 %) and the Rio Grande (54.3 %), and lowest in the San Bernard River (12.5 %) and Matagorda Bay (19.9 %). The Rio Grande and South Bay had the lowest sediment porosity (34.1 and 37.1 % respectively) while Matagorda Bay and the San Bernard River had the highest (63.9 and 61.7 % respectively). Clay content was highest in Matagorda Bay (45.3 %) and lowest in Cedar Lakes(7.8 %). $\delta^{15}N$ ranged from 4.1 ‰ in South Bay to 8.4 ‰ in East Matagorda Bay. The nitrogen content varied slightly along the coast, from 0.05 % in Cedar Lakes to 0.12 % in San Bernard River. $\delta^{13}C$ ranged from -17.1 ‰ in San Bernard to -7.1 ‰ in the Rio Grande. East Matagorda Bay, South Bay, Christmas Bay Cedar Lakes, Matagorda Bay and the Rio Grande had the lowest silt contents (21.3 to 33.2 %), whereas the San Bernard and Brazos Rivers had the highest (58.3 to 61.5 %).

In a third PCA, both sediment and water quality parameters were combined to compare all estuaries (Figure 9). PC1 and PC2 accounted for 34.6 % and 22.1 % of variation within the data set respectively. PC1 represented mostly sediment variables. Positive PC1 values were indicative of high silt, nitrogen and total organ carbon (TOC) within the sediment in addition to sediment porosity and bottom depth. Negative PC1 values were indicative of high sand and $\delta^{13}C$ concentrations in addition to high water pH values. Positive PC2 values correlated with high phosphate, silicate, dissolved inorganic nitrogen and chl-*a* concentrations, while negative PC2 values correlated with high salinity. Along PC1, differences in mostly sediment characteristics were most extreme in the San Bernard River, which had the highest mean silt, TOC and nitrogen concentrations in its sediment, and the Rio Grande, which had the highest mean pH and mean sediment $\delta^{13}C$ concentration. The most extreme differences in water quality were between South Bay, which had a high mean salinity and low nutrient concentrations, and the geographically adjacent Rio Grande, which had a low mean salinity and high nutrient concentrations.

Macrofauna

Macrofaunal abundance was positively correlated with biomass (Figure 10). The estuaries in this current study were divided into three groups based on abundance and biomass. The first group consisted of San Bernard River, Brazos River and Lavaca Bay. This first group had both the lowest biomass (0.5 to 0.8 g m^{-2}) and abundance (3,800 to 5,200 n m^{-2}) of all the groups. The second group included Matagorda Bay, Cedar Lakes and the Rio Grande. This second group had intermediate biomass (2.3 to 3.7 g m^{-2}) and abundances (7,700 to 10,300 n m^{-2}) relative to the other groups. The third group, which included South Bay, Christmas Bay and East Matagorda Bay, had the highest biomass (6.9 to 10.9 g m^{-2}) and abundances (14,700 to26,200 n m^{-2}). There was a negative correlation between abundance and biomass for this group of three systems. Individually, East Matagorda had the highest biomass (10.9 g m^{-2}) and South Bay had the highest abundance (26,200 n m^{-2}). The standard error of both abundance and biomass increased with the mean across all groups.

Macrofaunal diversity increased with increasing salinity, however only where salinity values were above 20 ppt (Figure 11). Mean diversity at the lower salinity estuaries , which included all of the river estuaries as well as Lavaca Bay and Cedar Lakes, only ranged from 2.3 to 2.6 species per 35 cm^{-2}, whereas mean macrofaunal diversities for Matagorda Bay and East Matagorda Bay (moderate salinities) were 4.2 and 5.1 species 35-cm^{-2} respectively. Mean macrofaunal diversities for the highest salinity systems, South Bay and Christmas Bay, were 6.8 and 8.2 species 35-cm^{-2} respectively.

Standard errors for salinity were smallest at South Bay, Christmas Bay and the Rio Grande stations. (0.3 ppt) compared to the other systems (0.7 to 1.7 ppt).

Multidimensional scaling (MDS) analysis on species abundances divided macrofaunal communities into two significantly different groups ($p < 0.001$ %) with at least 40 % similarity among stations within each group (Figure 12). The two groups were 75 % different from (25 % similar to) each other. MDS group one contained Lavaca Bay, San Bernard River, Brazos River, Cedar Lakes and the Rio Grande. Within MDS group one, the macrofaunal communities of Lavaca Bay, San Bernard River, Brazos River and Cedar Lakes were at least 50 % similar to each other. MDS group two contained East Matagorda, Matagorda, Christmas and South Bays. Within MDS group two, there was at least a 58 % similarity in macrofaunal communities among East Matagorda, Matagorda and Christmas Bays.

Estuaries within MDS group two contained a larger mean density of polychaete worms (6 000 to 18 200 m^{-2}) than estuaries within MDS group one (3 200 to 5 300 m^{-2}). On a higher taxa level, the two groups were quite different. Two phyla, Phoronida (made up of solely *Phoronis architecta*) and Echinodermata (made up solely of the ophiuroid *Amphiodia atra*) were found at all estuaries in MDS group two but no estuaries in MDS group one. Unidentified Anthozoa species occurred in average densities of 11 to 18 m^{-2} in group two, but were absent in group one except for in the Brazos River and Lavaca Bay, where densities were low (3 to 5 m^{-2}). Unidentified Turbellaria species occurred in MDS group two estuaries at average densities of 6 to 55 m^{-2}, however of the MDS group one estuaries was only found in the Brazos River (2 m^{-2}).

There were many species that were unique to MDS group two, but no such species occur uniquely in MDS group one. Individual species that were found exclusively to and universally throughout MDS group two included polychaetes *Cirrophorus lyra*, *Aricidea catharinae* (60 to 981 m^{-2}), *Branchioasychis americana* (35 to 347 m^{-2}), *Axiothella* sp. A (20 to 134 m^{-2}), *Euclymene* sp. B (1 to 118 m^{-2}), *Melinna maculata* (8 to 71 m^{-2}), *Glycera americana* (11 to 35 m^{-2}), *Ceratonereis irritabilis* (2 to 30 m^{-2}), *Malmgreniella* sp. (6 to 60 m^{-2}), *Drilonereis magna* (1 to 20 m^{-2}), cumacean *Oxyurostylis* sp. (5 to35 m^{-2}), pea crab *Pinnixa* sp. (6 to 14 m^{-2}), gastropod *Turbonilla* sp.(6 to 55 m^{-2}), phoronid *Phoronis architecta* (1 to 142 m^{-2}) and ophiuroid *Amphiodia atra* (12 to 197 m^{-2}, Table 4). Chironomid larvae were absent from group two except for in Matagorda Bay (5 m^{-2}). In MDS group one, chironomid larvae were present in low average abundances (2 to 75 m^{-2}) except for at the Rio Grande, where abundances were on average 3 500 m^{-2}. In all MDS group one estuaries except for the San Bernard River, both unidentified ostracods (2 to 11 m^{-2}) and the polychaete *Laeonereis culveri* (2 to 165 m^{-2}) were present.

Comparing physical characteristics to macrofauna

Apart from at low salinity systems, biomass and abundance increased with increasing salinity (Figure 11). Mean macrofaunal abundance was lowest when mean salinities were between 10 and 16 ppt and increased as salinities increased or decreased from this salinity range (Figure 11A). The macrofaunal biomass minima was at 10 ppt at the San Bernard River, which again increased with both increasing and decreasing salinities. However, above mean salinities of 24 ppt (as at East Matagorda Bay), biomass decreased again. N1 Diversity was consistently low (2.4 to 2.6) in estuaries with mean salinities below 16 ppt. Diversity increased with an increase in mean estuary salinity where mean bay salinities were above 22 ppt.

PC1 from principal components analysis on water quality data was significantly and negatively correlated with both macrofaunal abundance ($r = -0.75$, $p \leq 0.02$) and N1 diversity($r = -0.77$, $p \leq 0.02$; Table 5). A positive PC1 value (in Figure 5) indicates high concentrations of dissolved inorganic nitrogen, phosphate, silicate and chl-*a* and low salinity values. Therefore the negative correlations between PC1 and both diversity and abundance means that as salinity increases and selected nutrients decrease, macrofaunal abundance and diversity increase.

System-wide Approach

Seven out of the total twenty dates sampled for macrofauna were considered to be in dry weather conditions in the Rio Grande (Figure 4). Similarly, eight out of the twenty dates sampled for macrofauna were considered to be in dry weather conditions in the Brazos River. Six of the twenty samples taken in the Rio Grande were taken when connection with the Gulf of Mexico was closed.

Comparing water quality in the Brazos River and Rio Grande in wet and dry years, PC1 and PC2 represented 37.9 % and 16.9 % of the variability in the data set, respectively (total 54.8 %, Figure 13). PC1 approximated water nutrient characteristics and depth, while PC2 approximated seasonal effects with dissolved oxygen opposing temperature. Rio Grande stations separated from those in the Brazos River along PC1, grouping to the left side of the plot and indicating higher chlorophyll-a and PO_4 levels regardless of wet or dry year. Within the Rio Grande there was no strong separation between wet and dry years as a function of season along PC2. Wet and dry years in the Brazos River showed some separation along PC2, with wet years tending to cluster in the upper right portion of the plot.

Multidimensional scaling analysis of the Brazos and Rio Grandes in wet and dry months indicated that there were more differences in macrofauna community composition between the Brazos River and the Rio Grande than between wet and dry months within each of these rivers. There were only small differences in macrofaunal communities found in dry conditions compared to wet conditions in both the Rio Grande and Brazos River (Figure 14).

In the Rio Grande, the polychaete *Boccardia* sp. was found in four of thirteen samples taken in wet conditions, but no samples in taken in dry conditions. *Boccardia* sp was found in the last four sampling periods however (October 2004 to August 2005). In the Rio Grande, crustaceans are found in all seven sampling periods that are considered to be in dry weather conditions. However crustaceans were only found in five out of thirteen macrofauna samples taken in wet weather conditions. Mean total abundance was higher in dry weather conditions (22 381 m^{-2}) than wet weather conditions (6 048 m^{-2}). Mean abundance for each phyla found in the Rio Grande (Insecta, Nemertea, Mollusca, Annelida and Crustacea) were all much higher (2 to 31 times) in dry conditions than wet conditions.

Although mean abundance in the Brazos River is also greater in dry conditions (5 586 m^{-2}) than wet conditions (4903 m^{-2}), the difference in individual phyla abundance between wet and dry conditions was small. Except for insects, individual phyla abundances were similar between wet and dry conditions. Insects were found in five out of twelve months with wet conditions but were absent in dry conditions. Crab megalops and the polychaete *Paraprionospio pinnata* were found in three of the eight months with dry conditions, but were absent in wet conditions. The polychaete *Polydora ligni* and chironomid larvae were found in three and four sampling months respectively that were in wet conditions, but were absent in dry conditions.

Hypothesis-driven Approach

Ho$_1$: East Matagorda Bay versus Lavaca-Colorado Estuary

Mean macrofaunal abundance and biomass were significantly higher in Matagorda (25,900 m^{-2} and 12.8 g m^{-2}) and East Matagorda (14,700 m^{-2} and 10.9 g m^{-2}) Bays than in Lavaca Bay (5,800 m^{-2} and 1.0 g m^{-2}; Table 6). N1 diversity was significantly different among all three bay systems. Matagorda Bay had the highest N1 diversity (6.7 species 35 cm^{-2}), followed by East Matagorda Bay (5.1 species 35 cm^{-2}) and Lavaca Bay (3.1 species 35 cm^{-2}). Biomass and abundance were significantly different between all sampling months over all bay systems, whereas diversity was not significantly different between months. There were also no significant bay-month interactions.

There were eleven species that were common to all bays in the 2001 fiscal year. Polychaete *Mediomastus ambiseta* was the most abundant species at all bays. Mean densities of *M. ambiseta* were3 300 m^{-2} in Lavaca Bay, 8 200 m^{-2} in Matagorda Bay and 7 400 m^{-2} in East Matagorda Bay. The polychaete *Cirrophorus lyra* was absent in Lavaca Bay samples and more than ten times more abundant in East Matagorda Bay (1 500 m^{-2}) than Matagorda Bay (120 m^{-2}). Numerically dominant species (species with total mean abundance of $\geq$ 100 m^{-2}) were mollusc *Mulinia lateralis*, polychaetes *Cossura delta*, *Streblospio benedicti*, *Paraprionospio pinnata*, *Gyptis vittata*, amphipod *Ampelisca abdita* and unidentified nemerteans.

Despite some similarities, macrofauna communities were significantly different among all three bays (Figure 15). Lavaca Bay was most different out of all three bays. The macrofauna community in Lavaca Bay was only 30 % similar to Matagorda and East Matagorda Bays. Macrofauna communities in Matagorda and East Matagorda Bays were 49 % similar to each other. Part of this difference in macrofauna community structure among the three bays was due to differences in diversity. Only twenty-three species were found in Lavaca Bay, compared with fifty-one in East Matagorda Bay and seventy in Matagorda Bay. Eight of the twenty-three species found in Lavaca Bay were not found in the other two bays. These species are molluscs *Macoma mitchelli*, *Eulimostoma* sp., *Rictaxis punctostriatus*, *Lyonsia hyalina floridana*, crustaceans *Edotea montosa*, *Mysidopsis* sp. unidentified Ostracoda and polychaete *Parandalia ocularis*. None of these species were found in more than two of the four months sampled. Lavaca Bay was the only bay that had no species from the classes Ophiuroidea, Turbellaria or Oligochaeta found in any samples from the 2001 fiscal year. In addition to this, no organisms from the polychaete families Maldanidae, Paraonidae and Lumbrineridae and bivalve family Lasaeidae were found in Lavaca Bay, yet organisms from these families were found in every month sampled at both Matagorda and East Matagorda Bays. Twenty-five species were found in both Matagorda Bay and East Matagorda Bay but not Lavaca Bay. The most abundant of these include polychaetes *Cirrophorus lyra*, *Aricidea catharinae*, *Polydora caulleryi*, *Lumbrineris parvapedata*, *Branchioasychis americana*, *Tharyx setigera*, *Axiothella* sp. A. and ophiuroid *Amphiodia atra*.

As determined by cluster analysis, Matagorda Bay and East Matagorda Bay were significantly different from each other ($p \leq 0.001$). Macrofauna from the Phoronida phylum was present in all sampling months at East Matagorda Bay and was not present at all in Matagorda Bay. Macrofauna from the Sipuncula and Echiuridea, Ostracoda and Hemichordata taxa were present in one or two sampling months in Matagorda Bay but were never present in East Matagorda Bay. Numerically dominant species (species with mean abundance > 100 m^{-2}) in Matagorda Bay were tanaidacean Apseudes sp. A (8 400 m^{-2}), bivalves Corbula contracta (1 000 m^{-2}), Nuculana acuta (330 m^{-2}), Lepton sp (180 m^{-2}), and polychaete Minuspio cirrifera (370 m^{-2}). No numerically dominant species were exclusive to East Matagorda Bay.

The first two principal components (PCs) from principal component analysis (PCA) of water quality explains 65.7 % of the variation in the data set (Figure 16C). PC1 explains 44.8 % of the variation and PC2 explains 21.0 % of the total variation. Chl-*a* was not included in PCA analysis because it was not measured in October 2000. Positive PC1 values correspond with high dissolved oxygen, dissolved inorganic nitrogen (DIN), nitrogen to phosphorus ratios, whereas negative values correspond with high temperatures and phosphate concentrations. Positive PC2 values correspond with high silicate concentrations whereas negative PC2 values correspond with higher salinity.

Water quality among samples varies more by date than by sampling station or bay (Figures 16A and B). The highest temperatures were measured in July 2001. Samples in July also had higher phosphate concentrations and lower dissolved oxygen concentrations then most other samples. The lowest DIN concentrations and nitrogen to phosphorus ratios occurred in October 2000 and July 2001. Water quality in all bays showed a cyclical pattern with starting dates in October 2000 being similar to the last month sampled in July 2001 (Figures 16A and B). The largest difference between sampling months was between October 2000 and January 2001. This difference is largely attributable to a large temperature drop. Samples taken in January had the lowest temperatures and among the lowest dissolved oxygen concentrations. The Lavaca Bay stations had the highest PC2 scores relative to other stations within each month sampled. The high PC2 scores at Lavaca Bay stations because the highest silicate concentrations and among the lowest salinity values occurred at Lavaca Bay stations for all months sampled.

Salinity was similar in East Matagorda stations C and F to Lavaca Bay stations A and B in January (18.3 to 22.7 ppt in Lavaca Bay and 17.1 to 22.4 ppt in East Matagorda Bay) and April (13.9 to 14.1 ppt in Lavaca Bay and 13.7 to 14.1 ppt in East Matagorda Bay). The salinities of Matagorda Bay stations C and D were higher than both Lavaca and East Matagorda Bays in both January and April (21.8 to 26.5 ppt). In July, salinity was lower in Lavaca Bay (16.8 to 19.4 ppt) than both East Matagorda Bay (22.1 to 23.3 ppt) and Matagorda Bay (25.1 to 28.4 ppt). Hypersaline conditions occurred in East Matagorda Bay stations B and C in October 2000 (38.3 to 39.6 ppt). Salinities were also high in Matagorda Bay (236.0 to 36.4 ppt) and Lavaca Bay (32.7 to 33.8 ppt) and east Matagorda Bay station F (32.6 ppt) relative to other months sampled.

PC1 and PC2 from PCA of sediment quality explains 57.1 and 24.5 % of the variation within the data set respectively (total 81.6 %, Figure 17). Positive PC1 values represent high $\delta^{13}C$, $\delta^{15}N$, rubble and total inorganic carbon (TIC) concentrations, whereas negative PC1 values represent high clay concentrations. High PC2 values represent high porosity, total organic carbon (TOC) and nitrogen concentrations. The Lavaca Bay stations are separated from the Matagorda and East Matagorda Bay stations along PC1 (Figure 17A). The Lavaca Bay stations have lower $\delta^{13}C$ (-14.7 to -14.6 ‰), $\delta^{15}N$ (6.4 -7.1 ‰), TIC (0.4 - 0.6 %) and rubble (0.7 %) than Matagorda (-11.7 to -10.8 ‰ $\delta^{13}C$, 7.3 to 7.6 ‰ $\delta^{15}N$, 0.7 to 1.1 % TIC) and East Matagorda Bays (-9.4 to -7.8 ‰ $\delta^{13}C$, 8.4 ‰ $\delta^{15}N$, 0.8 to 1.1 % TIC). Lavaca Bay stations also had higher clay concentrations (55.9 to 56.0 %) compared with East Matagorda (29.0 to 46.0 %) and Matagorda Bays (40.9 to 42.2 %). Stations were separated into three groups along PC2. The first group contained Lavaca Bay station B and Matagorda Bay stations C and D. These three stations had the highest porosity (58.9 % to 64.7 %), TOC (0.7 to 0.8 %) and nitrogen (0.10 to 0.11 %) concentrations of all the stations sampled. The second group contained Lavaca Bay station A and East Matagorda Bay stations B and F. These three stations had the lowest nitrogen concentrations (0.06 to 0.07 %) and porosity values (45.4 to 51.2 %) of all the stations. The third group contained only East Matagorda Bay station C, which had moderate porosity (56.0 %) nitrogen (0.08 %) and TOC concentrations (0.6 %).

PC1 and PC2 from the sediment PCA were positively correlated with macrofauna abundance, biomass and N1 diversity (Table 5). However, the only significant correlation was between PC1 and macrofauna biomass ($r = 0.78$, $p \leq 0.04$). PC1 from the water quality PCA was significantly and positively correlated with macrofaunal abundance ($r = 0.38$, $p \leq 0.05$). Correlations between PC1 and PC2 from the water quality PCA and macrofauna abundance, biomass and N1 diversity were all weak and not statistically significant.

Ho_2: Comparison of all Minor Bay and River-dominated Estuaries

The macrofaunal communities were split into two significantly different groups with only 22 % similarity between them (Figure 18). The first group contained Cedar Lakes and Lavaca Bay, which were not significantly different from each other. The second group contained Christmas, South, Matagorda and East Matagorda Bays. The estuaries in the second group were all significantly different to each other. Within the second group, South Bay was only 31 % similar to the other bays. East Matagorda and Christmas Bays were more similar to each other than with any other estuary. Cedar Lakes and Lavaca Bay had significantly lower macrofaunal biomass and N1 diversity than any other estuary (Table 7). The lowest mean macrofaunal abundances existed at Cedar Lakes and Lavaca Bay, but only Lavaca Bay had significantly lower abundance than all estuaries in the second macrofaunal community group. No universally dominant species existed in Cedar Lakes and Lavaca Bay that did not occur in the other minor bay estuaries. Bivalve *Macoma mitchelli*, polychaete *Laeonereis culveri* and chironomid larvae all occurred exclusively in Lavaca Bay and Cedar Lakes but were only present in a maximum of 25 % of date-estuary combinations (Table 4). The five most abundant species found exclusively in the second macrofaunal community group included polychaetes *Cirrophorus lyra*, *Aricidea catharinae*, *Lumbrineris parvapedata* and *Polydora caulleryi* in addition to oligochaete *Amphiodia atra*.

South Bay, Christmas Bay and East Matagorda Bay had significantly higher abundance than Cedar Lakes, Matagorda Bay and Lavaca Bay (Table 7). Macrofaunal biomass was greater in East Matagorda and Christmas bays than all other estuaries and significantly greater than all except for South Bay. N1 diversity was significantly higher in Christmas Bay than all other estuaries. Other than Christmas Bay,macrofaunal diversity was significantly higher than all other estuaries.

The first two PCs (PC1 and PC2) from the PCA of water quality added to 48.5 % (Figure 19). Positive PC1 scores corresponded with high phosphate, silicate, chlorophyll-*a* and dissolved inorganic nitrogen (DIN) concentrations, but low salinity values. Positive PC2 scores corresponded with high nitrogen to phosphorus ratios and DIN concentrations, but shallow depths. South Bay had consistently the lowest PC1 scores and always positive PC2 scores. South Bay had high salinities (32.2 to 38.9 ppt) and nitrogen to phosphorous rations (1.6 to 142.7) but low chlorophyll-*a* (1.7 to 3.5 mg l^{-1}) and silicate (0.8 to 28.6 μmol l^{-1}) concentrations. The range of PC1 and PC2 scores in each estuary overlapped with each others. Cedar Lakes date-station combinations consistently had positive PC2 scores whereas Christmas Bay had mid to low PC2 scores.

The first two PCs (PC1 and PC2) from the PCA of sediment quality added to 64.6 % (Figure 20). Positive PC1 scores indicated high total organic Carbon (TOC), nitrogen, porosity and clay concentrations but low sand concentrations in the sediment. Positive PC2 scores indicated high rubble, total inorganic carbon and δ^{13}C concentrations. PC1 and PC2 scores were negative for almost all station-year combinations in Christmas Bay and Cedar Lakes. These two estuaries had relatively high sand concentrations (35.3 to 76.7 %). Lavaca and Matagorda Bays had similar sediment quality to each other that varied slightly over time. In general, these two major bays had high clay (10.2 to 69.4 %), nitrogen (0.08 to 0.14 %) and TOC (0.4 to 1.1 %) content and porosity (46 to 70 %).

PC1 from the water quality PCA was significantly and negatively correlated with macrofaunal abundance, biomass and diversity (Table 5). The correlation between diversity and PC1 was the strongest of all these relationships (r = -0.5). PC2 from the water quality PCA was significantly correlated with macrofaunal abundance, however the r-values was only 0.2. The first two PCs from the sediment PCA were both significantly correlated with macrofaunal abundance, biomass and diversity. The three macrofaunal variables were negatively correlated with PC1 and positively correlated with PC2. All correlations had r-values between -0.4 and 0.4 except for the correlation between macrofaunal abundance and PC2, which had an r-value of 0.5.

Ho_3: Southern Minor Bay and River-dominated Estuary Systems

Macrofaunal communities in the Rio Grande stations were at least 80 % different from communities in South Bay (Figure 21). There was at least 41 % similarity among the mean macrofauna communities for each sampling date in South Bay compared with at least 44 % similarity among the mean macrofauna communities for each sampling date in the Rio Grande. Except for one sampling date in July 2002, the Rio Grande had a similarity of at least 63 % between mean macrofauna communities averaged by date. A total of 124 species were found in South Bay and a total of 28 species were found in the Rio Grande. Eleven of the species found were common to both estuaries. Abundant species that were common in at least seven out of eight samples taken in South Bay included polychaetes *Tharyx setigera*, *Prionospio pinnata*, *Sphaerosyllis* sp. A, *Cossura delta*, *Polydora caulleryi*, *Cirrophorus lyra*, *Schistomeringos* sp. A and *Aricidea catharinae*. Abundant species in the Rio Grande that were not found in South Bay include Chironomid larvae and the gastropod *Neritina virginea*. Macrofaunal abundance, diversity and biomass were all significantly higher at South Bay than in the Rio Grande (Table 8).

The first two principal components (PC1 and PC2) of water quality data for South Bay and Rio Grande explained 68.1 % of the variation in the data set (Figure 22). PC1 explained 51.6 % of the variation and PC2 explained 16.6 % of the total variation. Positive PC1 values were indicative of high silicate, phosphate and chlorophyll-*a* concentrations, while negative PC1 values were indicative of high salinity, depth and nitrogen to phosphorus ratios. Positive PC2 values were indicative of high dissolved inorganic nitrogen (DIN) concentrations, whereas negative PC2 values were indicative of high water temperatures. Water samples taken in the Rio Grande were clearly separated along PC1 from samples taken in South Bay (Figure 22A). Rio Grande samples all had positive PC1 values, whereas South Bay samples all had negative PC1 values. The Rio Grande was characterized by having high water column silicate (110 to 140 µmol l^{-1}), phosphate (5.4 to 10.3 µmol l^{-1}), and chlorophyll-*a* (16 to 42 mg l^{-1}), high sediment $\delta^{15}N$ (6.8 to 9.2 ppt), but also having low salinity (3 to 5 ppt), nitrogen to phosphorus ratios (1.1 to 2.7), and shallower depth (0.4 to 0.8 m). South Bay had low silicate (5 to14 µmol l^{-1}), phosphate (0.1 to 0.3 µmol l^{-1}), and chlorophyll-*a* (2 to 4 mg l^{-1}), $\delta^{15}N$ (3.3 to 4.6 ppt), but also had high salinity (35 to 38 ppt), nitrogen to phosphorus ratios (20.1 to 55.9), and greater depth (0.7 to 1.2 m). Differences among stations along PC2 were attributable to seasonal differences, which were similar between the two estuaries (Figure 22B).

PC1 and PC2 from the PCA of sediment data explained 49.8 and 26.2 % of the variation within the dataset (total 76.0 %, Figure 23). Positive PC1 values were indicative of high porosity and total organic carbon (TOC), silt and nitrogen concentrations. Negative PC1 values were indicative of high sand concentrations. Positive PC2 values were indicative of high clay concentrations and low $\delta^{13}C$ and $\delta^{15}N$ concentrations. The Rio Grande station C had higher PC1 values than the rest of the stations, regardless of the bay that they were in. All stations had similarly negative PC2 values in the 2002 fiscal year but in 2001, PC2 values, and hence clay, $\delta^{13}C$ and $\delta^{15}N$ concentrations, were more varied among stations. There were no clear differences between sediment properties between the Rio Grande and South Bay.

Five of the eight samples in this sub-study were taken when the Rio Grande was closed to the Gulf of Mexico (April and July 2001, January, April and July 2002 Figures 4 and 21). Macrofauna communities in four out of the five sampling dates when the Rio Grande was closed (July 2001 and January to July 2002) were in different clusters than the communities in other dates (Figure 21B). Salinities were higher in January 2001 when the Rio Grande was open, then in 2002 when the Rio Grande was closed (Figure 4). However flow was much lower in January 2001 than January 2002. Overall, the scores for the first two PCs of water quality samples taken with the Rio Grande closed were all similar top the range of scores for water quality samples taken when the Rio Grande was open.

Correlations between PCs from the sediment and water quality PCAs were generally low and insignificant (Table 5). However, there was a significant relationship between N1 diversity and PC1 from the water quality PCA. This relationship was negative, indicating that high macrobenthic diversity is related to high salinity and depth, and low phosphate, silicate and chl-*a* concentrations (Figure 22).

Ho_4: Northern Estuary System Comparisons

The macrofauna communities in the northern estuary systems were divided into two significantly different groups (Figure 24). The first group was constituted of macrofaunal community groups in Matagorda and Christmas Bays. Within this group, Matagorda Bay Station D was significantly different from Matagorda Bay Station C and all stations in Christmas Bay (Stations A, B and C). The second group contained macrofauna communities from Cedar Lakes, San Bernard River, Brazos River and Lavaca Bay. Within this second group, macrofauna communities in Lavaca Bay were significantly different from communities in the San Bernard River, Brazos River and Cedar Lakes. Four species made up over 98 % of total abundance in the second group. Of these four species, polychaetes *Mediomastus ambiseta*, *Streblospio benedicti*, and unidentified Nemerteans were ubiquitous throughout all estuaries in the hypothesis four sub-study. Unidentified Oligochaetes were found in both MDS groups but not at either Lavaca Bay station or Matagorda Bay station C.

Macrofauna communities at Christmas Bay had significantly higher total abundance, biomass and N1 diversity than all other northern bays or rivers (Table 9). Matagorda Bay macrofauna communities had significantly greater abundance, biomass and N1 diversity than all other northern systems apart from Christmas Bay. Cedar Lakes, Lavaca Bay, the San Bernard River and Brazos River were not significantly different from each other in terms of macrofauna abundance, biomass and diversity. There were significant differences in biomass and abundance among months and bay-month interactions. There were no significant differences in N1 diversity among months and bay- month interactions however.

The first component (PC1) of the water quality PCA accounted for 34.2 % of variation of the dataset, while the second component (PC2) accounted for 23.8 % (Total 57.9 %; Figure 25). Positive PC1 values are indicative of high silicate and phosphorus concentrations and low salinities. Positive PC2 values are indicative of high nitrogen to phosphorus ratios and low pH values. There was no clear separation of the water quality of any single estuary among the different estuaries (Figure 25A). The Brazos River was different to most other station-date combinations along PC2. Water quality in the Brazos River was at times similar to that of the San Bernard River and Lavaca Bay, but was different to Christmas Bay, Matagorda Bay and Cedar Lakes in all dates sampled. Lavaca Bay station B was very different to the other station-date combinations in July 2003, with the highest phosphate and DIN concentrations, the second highest silicate concentrations and the second highest nitrogen to phosphorus ratios in the data set. Water quality in Matagorda Bay and Christmas Bay was generally similar.

In the PCA of sediment variables, PC1 and PC2 accounted for 52.1 and 23.6 % of the variation within the data set (75.7 %, Figure 26). Positive PC1 values are indicative of high porosity, in addition to high nitrogen, silt and TOC concentrations. Negative PC1 values indicate high sand and rubble concentrations. High PC2 values indicate high δ^{13}C and δ^{15}N concentrations. With respect to sediment qualities, the estuaries were separated into three groups along PC1. Bay stations A and C, as well as Matagorda Bay station C and had the lowest PC1 scores and hence the highest sand concentrations (42.9 to 67.6 %) and among the highest rubble concentrations (1.2 to 10.2 %) among all stations. Brazos River stations A and B, San Bernard stations A and B and Lavaca Bay Station B had the highest PC1 scores. This second group had the highest silt concentrations (59.6 to 80.5 %) and among the highest porosity (54.9 to 66.8 %) and nitrogen (0.09 to 0.11 %)and TOC concentrations (0.84 to 1.08 %). Cedar Lakes Stations A and B, Christmas Bay station B, Lavaca Bay station A, Matagorda Bay station D and Brazos River station C had intermediate PC1 scores. The stations also could be split three ways along PC2. Cedar Lakes stations (A and B) had the highest PC2 scores. Cedar Lakes Stations had the highest δ^{15}N concentrations (8.1 to 9.4 ‰) and among the highest δ^{13}C concentrations (-11.8 to -10.0 ‰) among all stations. Matagorda Bay Station C, Brazos

River station C and San Bernard station A had the lowest PC2 scores and hence the lowest δ^{15}N concentrations (-2.8 to 1.6 ‰) and among the lowest δ^{13}C concentrations (-20.9 to -16.1 ‰) among all stations.

Macrofauna biomass, abundance and N1 diversity were negatively correlated with PC1 and PC2 from the water quality PCA and PC1 from the sediment PCA (Table 5). All of these relationships were significant except for the water quality PC2 relationships with abundance and biomass. In general this means that water with high salinity and low silicate and phosphate correlates with benthic macrofauna communities with high biomass, abundance and diversity. It also means that water with high pH values and low nitrogen to phosphorus ratios correlate with high macrofaunal diversity. On the sediment side of things, coarser sediment with lower nitrogen and TOC contents correlate with higher macrofaunal abundance, biomass and diversity.

Ho$_5$: River-dominated Estuaries in Two Different Climatic Zones

The macrofauna communities in the Rio Grande were significantly different than the communities in the Brazos River (Figure 27). One estuary-sampling period combination, the Brazos River in October 2000, was less than 35 % similar to all other estuary-sampling period combinations. Ignoring this Brazos River-October 2000 sample mean, the macrofaunal communities in each river estuary were at least 56 % different from each other. The benthic community in July 2002 in Rio Grande was only 47 % similar with the communities sampled in other time periods in the Rio Grande. Macrofauna communities were at least 52 % similar to each other over time in the Brazos River and at least 54 % similar to each other in the Rio Grande. The only abundant species found throughout the Rio Grande but not the Brazos River was the gastropod *Neritina virginea*. Chironomid and Ceratopogonid larvae, the polychaete *Laeonereis culveri* and bivalve *Mulinia lateralis* were all common in the Rio Grande but were not found in more than two station-date combinations in the Brazos River. The only abundant species that was exclusively in the Brazos River was polychaete *Parandalia ocularis*. The Rio Grande had significantly higher total abundance, biomass and diversity than the Brazos River (Table 10). The mean abundance in the Rio Grande was over double that found in the Brazos River (12,000 n m^{-2} compared with 5,000 n m^{-2}). The mean biomass in the Rio Grande was over triple that found in the Brazos River (2.8 g m^{-2} compared with 0.8 g m^{-2}).

PC1 and PC2 represented 37.9 % and 16.9 % of the variability in the water quality data set of the Rio Grande and Brazos River, respectively (total 54.8 %, Figure 13). PC1 approximated water nutrient characteristics and depth, while PC2 approximated seasonal effects with dissolved oxygen opposing temperature. Rio Grande stations separated from those in the Brazos River along PC1. Most of the Rio Grande samples had negative PC1 scores, indicating higher chlorophyll-*a* and PO_4 levels. All Brazos River samples had positive PC1 scores, indicating high DIN concentrations, nitrogen to phosphorus ratios and depths than the Rio Grande samples. Samples from both rivers were scattered along the PC2 axis. Most January and April samples had high PC2 scores, while most July and October samples had negative PC2 scores. Samples with high PC2 scores generally had high dissolved oxygen concentrations and low temperatures, whereas samples with low PC2 scores had the opposite.

PC1 and PC2 accounted for 46.7 and 22.0 % of the sediment quality data set respectively (total 68.6 %, Figure 28). Positive PC1 scores indicated high silt, nitrogen and TOC concentrations, high porosity and low sand content. Negative PC1 scores indicated the opposite of positive PC1 scores. High PC2 scores indicated high TIC, $\delta^{13}C$ and $\delta^{15}N$ concentrations. Both estuaries exhibited similar ranges of PC1 scores. Within the Brazos River, station C tended to have lower PC1 scores than stations A and B. Within the Rio Grande, stations D and E always had negative PC1 scores, however stations A, B and C had a wide range of PC1 scores. Station-date combinations from the Brazos River generally had lower PC2 scores than station-date combinations from the Rio Grande however. One station-date combination, the Brazos River station C in October 2002, had a PC2 score much lower than any other station-date combination. In October 2002, the Brazos River station C had TIC, $\delta^{13}C$ and $\delta^{15}N$ concentrations of 0.4 %, -2.8 ‰, and -20.9 ‰ respectively, compared with ranges of 0.5 to 2.8 %, 1.7 to 9.3 ‰, -16.0 to -4.5 ‰ respectively at all other station-date combinations.

Macrofauna biomass, abundance and N1 diversity were significantly correlated with both PC1s from the sediment and water quality PCAs (Table 5). All of these relationships were negative correlations. PC2 from the water quality PCA was also both significantly and negatively correlated with macrofaunal abundance. The relationship between abundance and the water quality PC2 was weak however ($r = -0.22$). The water quality PC1 correlation means that high pH values and phosphate concentrations, and low nitrogen to phosphate ratios, water depths and DIN concentrations correspond with high macrofaunal abundance, biomass and diversity. The water quality PC2 correlation means that high temperatures and low dissolved oxygen concentrations correlate with high macrofaunal abundances. The correlation between macrofaunal community characteristics and the sediment PC1 signifies that high sand content and low nitrogen, TOC, silt and pore water contents correlates with high macrofauna abundance, biomass and diversity.

Ho_6: Temporal Central Coast Comparison

The macrofauna communities in the central coast were divided into two significantly different groups which were about 25% similar to one another (Figure 29). The first group consisted of macrofaunal community groups from the Brazos and San Bernard Rivers, Cedar Lakes and Lavaca Bay that were at least 40% similar to one another. Within this group, Lavaca Bay macrofauna from two sampling periods in 2003 and one sampling period in 2005 were at least 55% similar to one another. A second grouping of Cedar Lakes sampling periods was also 55% similar to one another, clustering to the lower left portion of the MDS plot. There was no other clear separation of systems or sampling periods within this group. Within the second group, Matagorda Bay macrofaunal communities were 50% similar to one another and significantly different from macrofaunal communities in all other central coast systems. There were significant differences in macrofaunal abundance, biomass and diversity among bays and months, as well as significant bay-month interactions (Table 11). Macrofaunal abundance and biomass was highest in Matagorda Bay (abundance 6,693, biomass 3.58) and Cedar Lakes (abundance 7,654, biomass 2.28). Matagorda Bay stations also had significantly higher N1 diversity (4.99) than any other system.

Many species occur in Matagorda Bay but no other estuary in this hypothesis. These include polychaetes *Cirrophorus lyra*, *Lumbrineris parvapedata*, *Aricidea bryani*, *Minuspio cirrifera*, tanaid *Apseudes* sp. A and ophiuroid *Amphiodia atra* (for five year species list see Table 4). *Cossura delta* was also abundant throughout Matagorda Bay over time but also occurred in Lavaca Bay.

PC1 of the water quality PCA accounted for 32.1 % of the variation in the data set, while the PC2 accounted for 19.4 % (Total 51.5 %, Figure 30). Positive PC1 scores were indicative of high nitrogen to phosphorus ratios and high DIN, silicate and phosphate concentrations. Negative PC2 scores corresponded to high salinity and pH values. Positive PC2 scores corresponded to high dissolved oxygen concentrations and low temperatures. All estuaries were represented in a wide range of PC2 scores, however some differences in PC1 scores could be teased out between estuaries. Station-date combinations from the Brazos River always had positive PC1 scores. All Matagorda Bay station-date combinations except for one had negative PC1 scores. Lavaca Bay, Cedar Lakes and the San Bernard River were represented over a wide range of PC1 scores.

The first two PCs from the sediment PCA accounted for 68.7 % of the variation within the data set of sediment variables (Figure 31). PC1 accounted for 46.6 % and PC2 accounted for 22.1 % of this variation. Positive PC1 values corresponded with high clay, nitrogen, TOC and pore water contents. Negative PC1 scores indicated high sand contents in the sediments. Positive PC2 scores correspond to high $\delta^{13}C$ and $\delta^{15}N$ and low silt concentrations. No estuaries are completely different to each other with respect to overall sediment quality. Cedar Lakes station-date combinations have consistently negative PC1 scores and positive PC2 scores. San Bernard station-date combinations have PC1 scores equal to or above zero and PC2 scores of less than or equal to 0.1. Matagorda Bay stations E and F, which were only sampled once in this study period (for Ho_6) had the highest PC1 and PC2 scores.

Both of the first principal components from the sediment and water quality PCAs were negatively correlated with macrofaunal abundance, biomass and diversity (Table 5). The water quality PC1 was only significantly correlated with abundance and diversity, while the sediment PC1 was only significantly correlated with macrofaunal abundance.

Ho_7: Comparison of River-dominated Estuaries along the Texas Coastline

Macrofauna communities in the Rio Grande between October 2002 and July 2005 were significantly different from any community in the Brazos and San Bernard River for the same time period (Figure 32). Communities in the Rio Grande were at most 45 % similar to communities in either the San Bernard or Brazos Rivers. There was no clear difference between communities from the Brazos and San Bernard Rivers, which were at least 50 % similar to each other. Mean abundance was significantly different between all three rivers (Table 12). Abundance was highest in the Rio Grande (7,900 n m^{-2}), followed by the Brazos River (4,900 n m^{-2}) and the San Bernard River (4,100 n m^{-2}). Biomass was significantly greater in the Rio Grande (2.0 g m^{-2}) than the Brazos (0.7 g m^{-2}) and San Bernard (0.5 g m^{-2}) Rivers, while the Brazos and San Bernard Rivers were not significantly different from each other. There was no significant difference in N1 diversity between the three rivers.

Although there were no significant differences between rivers estuaries in species diversity, there were differences in individual species occurrences. The gastropod *Neritina virginea* was common in most sampling dates in the Rio Grande but absent in the Brazos and San Bernard Rivers. Ceratopogonid larvae, and the polychaete *Laeonereis culveri* were also very common in the Rio Grande and but were found in only two separate months in the Brazos River and were absent in the San Bernard River. Chironomid larvae were found in all sampling months in the Rio Grande but only in five (out of twenty-four) sampling month-bay combinations in the San Bernard and Brazos Rivers in much lower abundances. Polychaetes *Parandalia ocularis*, and *Capitella capitata* each occurred in approximately half of the months sampled in the Brazos and San Bernard Rivers but were not found in the Rio Grande.

PCA was used to analyze sediment variables on station-fiscal year means for each of the Rio Grande, Brazos and San Bernard Rivers. PC1 and PC2 accounted for 29.9 % and 20.7 % of the variance within the water quality data set respectively (total 50.6 %; Figure 33). Positive PC1 scores correspond to station-date combinations with high nitrogen to phosphorus ratios, DIN concentrations and depths. Negative PC1 scores also corresponded to high temperatures and phosphate concentrations. Positive PC2 scores indicate high pH, chl-*a* concentrations and dissolved oxygen concentrations. The water quality of the Brazos and San Bernard Rivers were much more similar to each other than with the Rio Grande. Most of the station-date combinations from the Brazos and San Bernard Rivers occupied the same space on the PCA graph, whereas station-date combinations from the Rio Grande did not. Station date combinations from the Brazos and San Bernard Rivers generally had mid-high PC1 scores and mid-low PC2 scores relative to the Rio Grande. Station-date combinations from the Brazos and San Bernard Rivers tended to have high PC1 scores and PC2 scores close to zero in January and April months, but negative PC2 scores and PC1 scores close to zero in October. The Rio Grande did not have a monthly trend like that of the Brazos and San Bernard Rivers.

PC1 and PC2 from the sediment PCA accounted for 53.2 and 19.9 % of the variation with the data set of sediment variables (total 73.1 %, Figure 34). Positive PC1 scores corresponded to station-year combinations with high pore water, TOC, nitrogen, silt and clay contents but low sand content. Positive PC2 scores corresponded to high TIC, $\delta^{13}C$ and $\delta^{15}N$ concentrations. Stations in the San Bernard River consistently had positive PC1 scores, whereas station-year combinations from the Brazos and San Bernard Rivers had a large range of PC1 scores. Station C contained a higher sand content than all other stations (A and B) within the Brazos River. This is indicated by the low PC1 scores for Brazos River Station C samples. The Rio Grande had the highest PC2 scores, followed by the Brazos River. PC2 scores in San Bernard Rivers were the most variable.

Both of the first principal components from PCA of sediment and water quality were negatively correlated with macrofaunal abundance, biomass and diversity (Table 5). Of these correlations, all were significant except between the sediment PC1 and N1 diversity. The correlations imply that macrofaunal abundance, biomass and diversity is positively correlated with phosphate concentrations and temperature, but negatively correlated with nitrogen to phosphorus ratios, DIN and depth. These correlations also imply that abundance and biomass is positively correlated with sand content, but negatively correlated with pore water, TOC, nitrogen, silt and clay contents.

Ho_8: River-dominated Estuary and Minor Bay in Northern Region Compared to Southern Region

Macrofaunal communities in Christmas Bay and South Bay in 2001 and 2002 were significantly different from those in the Brazos and Rio Grande for the same time period (Figure 35). Communities in Christmas Bay were at most 30% similar to those in South Bay, whereas communities within either Christmas Bay or South Bay were at least 60% or 50% similar to one another, respectively. Within the second group, macrofaunal communities from the Rio Grande were, with the exception of one sampling date, at least 50% similar to those in the Brazos River.

Abundant species often found in South and Christmas Bays but not in either of the rivers include polychaetes *Cirrophorus lyra*, *Tharyx setigera* , *Aricidea catharinae*, *Polydora caulleryi*, *Cossura delta*. The only dominant organism found in the two rivers and not the two bays was Chironomid larvae. Chironomid larvae were largely absent from the Brazos River however. There were two abundant species that were in South Bay and not Christmas Bay. These were *Capitella capitata* and *Prionospio heterobranchia*. Similarly, the polychaete *Lumbrinereis parvepedata* and bivalve *Periploma* cf. *orbiculare* were abundant species that were commonly found in Christmas Bay but were absent from South Bay. There were only two species that were present in at least half of the station-date combinations in the Rio Grande and absent in the Brazos River. These were Ceratopogonid larvae and the polychaete *Laeonereis culveri*. No species that were present in at least half of the Brazos River station-date combinations of were absent in the Rio Grande.

There were significant differences in macrofaunal abundance, biomass and diversity among estuaries and months, as well as significant estuary-month interactions (Table 13). Mean macrofaunal abundance in the Brazos River (6,177 n m^{-2})was significantly lower than in Christmas Bay (16,300 n m^{-2}), South Bay (20,500 n m^{-2}) and the Rio Grande (22,500 n m^{-2};). Christmas Bay and South Bay had similarly high macrofaunal biomass (8.80 and 8.10) and N1 diversity (7.93 and 7.06)compared to the Rio Grande (biomass 3.36, diversity 2.47) or Brazos River (biomass 0.94, diversity 2.42).

PC1 and PC2 accounted for 34.6 and 26.0 % of the variation respectively in the water quality data set (total 60.7 %, Figure 36). Dissolved oxygen and pH were erroneously not measured in January 2002 at South Bay, therefore causing South Bay January data to be omitted from this PCA. Positive PC1 scores correspond to high phosphate, silicate and DIN concentrations but low salinities. Positive PC2 scores correspond to high depth and nitrogen to phosphorus ratios, but low pH values. Each system was separated fairly well from each other. Brazos River and the Rio Grande station-date combinations all had positive PC1 scores but differed from each other in that station-date combinations from the Brazos River all had positive PC2 values, whereas station-date combinations from the Rio Grande all had negative PC2 scores. Christmas Bay was more similar in water quality to South Bay then the Brazos River was to the Rio Grande. All station-date combinations from Christmas and South Bays had negative PC1 scores and moderate PC2 scores (-0.7 to 0.2), except for South Bay station B in July 2002, which had a PC2 score of 1.2. Christmas Bay PC1 station-date scores were similar to South Bay station PC1 scores from July 2002

PC1 and PC2 accounted for 39.1 and 26.0 % of the variation within the sediment data set, respectively (total 65.1 %; Figure 37). Positive PC1 scores corresponded to high silt, nitrogen, pore water and clay contents, but low sand content. Positive PC2 scores corresponded to high TIC and $\delta^{13}C$ concentrations. Both South Bay stations (A and B), Rio Grande stations A and B and Christmas Bay station C had negative PC1 scores, while all Brazos River stations (A, B, and C), Christmas Bay stations A and B and Rio Grande station C had positive PC1 scores. Christmas Bay stations B and C had low PC2 scores (-1.7 to 2.0), while all other stations from all estuaries had moderate PC2 scores (-0.4 to 0.9).

PC1 from the water quality PCA was significantly and negatively correlated with both macrofaunal biomass and N1 diversity (Table 5). PC2 from the water quality PCA was significantly correlated with macrofaunal abundance. PC1 from the sediment PCA was negatively and significantly correlated with macrofaunal abundance. PC1 from the sediment PCA was also negatively and almost significantly correlated with macrofaunal biomass.

DISCUSSION

Coast-wide Approach

The coast-wide approach aggregated data over all samples to determine broad trends and relationships among estuaries along the Texas coast. Temperature ranges were similar for the northern systems while the two southern systems had slightly higher temperature ranges (Figure 6). This is expected because Rio Grande and South Bay, located in the southern portion of the Texas coast, are in a different climate zone than the other estuaries studied. Other differences in overall water quality between the northern and southern climate zones were not observed (Figure 5).

Although differences between northern and southern estuaries were not observed, strong coast-wide correlations occurred between salinity and other physical variables (Figures 5, 6 and 7). As salinity increased phosphate, silicate, nitrate and chlorophyll *a* concentrations decreased. River-dominated estuaries such as the Rio Grande, Brazos River, and San Bernard River had lower salinity ranges and tended to have higher concentrations of nutrients. In contrast, minor bays such as South Bay, Christmas Bay and East Matagorda Bay had higher salinities and lower nutrient concentrations. The negative correlations between salinity and nutrient concentrations are likely to be due to nutrient loading by freshwater inflows. While not studied here, it is thought that agricultural and urban areas are sources of nutrients in the watersheds. The reference sites, Lavaca Bay and Matagorda Bay were relatively neutral (i.e., had PC 1 values near zero) when compared to most rivers and minor bays in this study (Figure 5). This neutrality demonstrates the difference between these two major bays compared to the two types of ecosystems (river and minor bay estuaries).

At low salinities, macrofaunal densities increased with increasing salinity (Figure 11). Biomass and abundance were lower for river-dominated estuaries (low salinities) and high for minor bays (high salinities, Figure 11). Cedar Lakes was the only minor bay that had low biomass and abundance, which can be attributed to lower salinity in this estuary. Palmer et al. (2002) studied the Nueces Delta marsh and determined low biomass and abundance in upper estuary areas can be due to high flow velocities and lack of salinity tolerant species. Flow velocities that are too high can prohibit organic matter from depositing in the sediments which would stimulate benthic productivity. However flow velocities can not be the only factor in causing decreased macrofaunal biomass and abundance because flow velocities in Cedar Lakes are relatively low. Salt tolerance also plays a major role in estuarine systems; organisms can be killed if there is too much or too little inflow (Palmer et al. 2002).

Species diversity in estuaries along the Texas coast increased with increasing salinity (Figure 11). Diversity in river-dominated estuaries was lower than minor bays, again except for Cedar Lakes. These results support findings from previous studies showing that species diversity increases from nearly freshwater to seawater (Montagna and Kalke 1992; Mannino and Montagna 1997; Palmer et al. 2002; Ysebaert et al. 2003). The current diversity versus salinity plot did not follow the Remane curve, whereby diversity maxima occur at both high and low salinities (Paavola et al. 2005, Remane and Schlieper 1971, Remane 1934). One possibility for reduced diversity at low salinities in this current study is that insect taxa (chironomid larvae, diptera sp.) may have been many species and therefore we underestimated diversity at low salinities because of a lack of taxonomic resolution. It is also possible that the lowest average salinities in this study, which occurred at the Rio Grande, were possibly not low enough to yield a diverse number of oligohaline species.

The significant and negative correlation between macrofaunal metrics (macrofaunal abundance and diversity) and the water quality PC1 implies a negative correlation between estuarine dominance by inflows and high macrofaunal productivity (Figure 5 and Table 5). A positive PC1 score correlates with estuaries with high nutrient concentrations and low salinities. Therefore PC1 approximates freshwater inflow dominance in an estuary. The lack of any significant correlation between other sediment or water quality PCs suggests that on a coast-wide basis, inflow is the most important factor influencing macrofaunal communities.

Macrofaunal community structure was divided into two major types (Figure 12). The first type contained communities found in the Rio Grande, Brazos River, San Bernard River, Lavaca Bay and Cedar Lakes. The estuaries in this first group all had mean salinities below 16 ppt, and hence represented oligohaline (0.5 to 5 ppt) and mesohaline (5 to 18 ppt) conditions (Venice Classification system; Anonymous 1958). The second macrofaunal community grouping contained Matagorda, East Matagorda, Christmas and South Bays. The estuaries in this second group had mean salinities of above 22 ppt and hence represented a more polyhaline (18 to 30 ppt) community (Venice Classification system; Anonymous 1958). The estuaries of the first type are subject to a greater range of flows and water quality-related fluctuations because of the strong influence that rivers have on them (Figures 6 and 7). The estuaries of the second type have relatively stable nutrient concentrations and salinities.

The oligo-mesohaline community type had the lowest mean diversity and biomass values in this study (Figure 11). The only common organism in this group that was rare in the polyhaline group was Chironomid larvae (Table 4). Chironomid larvae have been shown to be more common in oligohaline conditions in many estuaries (Grenon 1982, Fuentes et al. 2005, Brammer et al. 2007, Dimitriadis and Cranston 2007), however, certain species of chiromonids also exist at higher salinities elsewhere (Carew et al. 2007, Dimitriadis and Cranston 2007, Keats and Osher 2007). Chironomid larvae were more abundant in the upper reaches of the Rincon Bayou, Texas, rather than downstream (Palmer et al. 2002). However in that study, the high relative abundance was attributed to the broader salinity range that occurred upstream in the Rincon Bayou.

Many species were found in the polyhaline estuaries in addition to species found in the oligo-mesohaline estuaries. Species that were found exclusively in and universally throughout the polyhaline estuaries included polychaetes *Cirrophorus lyra*, *Aricidea catharinae*, *Branchioasychis americana*, *Axiothella* sp. A, *Euclymene* sp. B, *Melinna maculata*, *Glycera americana*, *Ceratonereis irritabilis*, *Malmgreniella* sp., *Drilonereis magna*, cumacean *Oxyurostylis* sp., pea crab *Pinnixa* sp., gastropod *Turbonilla* sp., phoronid *Phoronis architecta* and ophiuroid *Amphiodia atra*. The increase in the number of species found in the polyhaline estuaries is due to an increased number of marine species (Remane and Schlieper 1971). There appears to be a tipping point at about 17 to 21 ppt where coastal systems change from oligo-mesohaline to polyhaline community characteristics.

System-wide Approach

The only two estuaries with enough sampling dates to sufficiently assess temporal variability as a result of change in inflow were the Brazos River and Rio Grande. Quarterly samples were taken for five years in both of these river-estuaries. Although these estuaries were both river dominated, there was a greater difference in macrofaunal communities between estuaries than between wet and dry months within estuaries. This may be because overall sediment and water quality was different between the two estuaries (Figures 13 and 28). Even though flows were almost always greater in the Brazos River than the Rio Grande, the salinity of the Brazos River stations was usually higher than the Rio Grande stations (Figure 4). This is likely to be the result of a combination of factors. One possible factor is that when the Rio Grande was closed to the Gulf of Mexico, the tidal salt wedge was restricted from reaching the Rio Grande stations and hence didn't increase salinities even when inflow was low. Another likely reason is that the Brazos River stations could have been situated further in the zone influenced by the salt wedge than the stations in the Rio Grande.

Mean macrofaunal abundance was over three times greater in dry periods in the Rio Grande (22 000 m^{-2}) than wet periods (6 000 m^{-2}) . The greater number of organisms present in wet months was not a result of an increase in any individual taxa, but rather an increase in all five major taxa found (Insecta, Nemertea, Mollusca, Annelida and Crustacea). Abundance was only fourteen percent greater in dry conditions in the Brazos River (5 600 m^{-2}) than in wet conditions (4 900 m^{-2}). There were some taxa differences in that insects were only found in wet months and sipunculid worms were only found in dry months. However, these two taxa made up less than one percent of the total abundance within each classification (wet or dry).

Hypothesis-driven Approach

Although Matagorda and East Matagorda Bays are very near one another, but the eastern arm of Matagorda Bay has inflow from the Colorado River diversion, whereas East Matagorda has inflow from the Brazos River and Caney Creek via the Gulf Intracoastal Water Way (GIWW). Thus this makes an interesting comparison in the context of inflow effects. Matagorda and East Matagorda had similar average salinities (~23 ppt) while the average salinity in Lavaca Bay was lower (15 ppt). Abundance, biomass and diversity were similar in Matagorda Bay and East Matagorda Bay, but both were significantly different from Lavaca Bay (Table 6). Abundance, biomass and diversity decreased as salinity decreased in both systems. Overall, Matagorda Bay and East Matagorda Bay were similar.

Christmas and South Bays had the highest macrofaunal abundance and diversity out of all minor bays in this study (Table 7). In contrast, Cedar Lakes had significantly lower macrofaunal abundance, biomass and diversity than all other minor bays. Macrofaunal abundance and biomass was higher in East Matagorda Bay, Christmas Bay than both major bays, Matagorda Bay and Lavaca Bay. In part, this probably a result of the relative environmental stability of these minor bays.

The macrofaunal community structures of the minor bays were separated by mean salinity (Figures 11 and 18). Cedar Lakes had the lowest salinities and was significantly different to all other bays.

Macrofaunal communities in South Bay were the next most different from all other minor bays. South Bay also experienced the highest salinities. It was difficult to tease out differences in sediment and water qualities among the bays (Figures 19 and 20). The negative correlation between the water quality PC1, a proxy for freshwater inflow, and the three univariate macrofaunal descriptors (abundance, biomass and diversity) proved that freshwater inflow was correlated with macrofaunal productivity (Table 5). There were significant correlations between the first two PCs from the sediment PCA and all of the three univariate macrofaunal descriptors, showing that sediment has a role in determining macrofaunal communities among minor bays. All correlations between sediment and macrofaunal characteristics were significant but weak, meaning that sediment plays a smaller role than water quality in structuring macrofaunal communities among minor bays.

The two southernmost systems are a river, the Rio Grande, and a minor bay, South Bay, so this makes another point of comparison for inflow effects. Although the temperature is similar in these two systems, they are dramatically different because the Rio Grande was virtually a lake when it was closed from exchange with the Gulf of Mexico. Consequently, the Rio Grande had the lowest average salinity and South Bay had the highest average salinity in this entire study. In general, South Bay had higher abundance, biomass, and diversity than the Rio Grande (Table 8), and the community structure was dramatically different (Figure 21).

The four northernmost systems (Christmas Bay, Cedar Lakes, San Bernard River, and Brazos River) were all studied in 2003 and that allows an interesting synoptic comparison between two minor bays and two rivers in the same region. Christmas Bay receives little or no direct freshwater inflow which makes this bay a typical minor bay in Texas. It does have an indirect connection with the Gulf of Mexico via Cold and San Luis Passes. Christmas Bay also has some exchange with the GIWW. Previous studies have identified four characteristics which make this bay unique: 1) diversity is highest in summer, 2) diversity is dominated by Mollusca, 3) *Streblospio benedicti* (a polychaete) is not common, let alone the dominant species, and 4) the community structure represents a climax community (Montagna 2003). The reasons for these unique characteristics may be due to a small data set (only 2 years) - with a larger data set the trends may disappear - or Christmas Bay habitats may be truly unique, rich and relatively pristine. The latter explanation is likely true because Christmas Bay is a preserve and has a typical climax community with the highest abundance, biomass, and diversity of all systems studied (Table 9). The Christmas Bay community was most similar to the Matagorda Bay Community, but significantly different from Cedar Lakes (Figure 24). In fact, the community in Cedar Lakes had more in common with the San Bernard and Brazos River communities. The macrofaunal communities in the San Bernard River, Brazos River and Cedar Lakes were more similar to each other than communities in Lavaca Bay and very different to communities in Matagorda and Christmas Bays. Water quality at Christmas and Matagorda Bays was generally very similar to each other but not totally dissimilar to Lavaca Bay, the San Bernard River and Cedar Lakes. The water quality in the Brazos River was distinctly different than that of Christmas and Matagorda Bays.

The Rio Grande and Brazos Rivers are two large rivers in different parts of Texas that were sampled for a total of 5 years. Analysis indicates that the Brazos and Rio Grandes are quite different in water quality (Figure 13), sediment type (Figure 28) and in macrofauna communities (Figure 27). The Rio Grande has undergone severe changes because of reduced inflow to the system. In February 2001, a sand bar forming at the mouth of the river blocked exchange with the Gulf of Mexico and led to a transformation of the estuary into a lake. This lake-like effect was evidenced by the decreasing salinities over the course of the study period in the Rio Grande when the mouth was closed, even though inflow was low (Figure 4). The Rio Grande was re-opened in 2001 and 2002 and consequently salinities returned to estuary conditions. The largest difference in water quality between the two systems is in the nutrient-chlorophyll dynamics. The Brazos River has much higher dissolved inorganic nitrogen concentrations yet lower chlorophyll-*a* and phosphate concentrations. It is expected that the Brazos River would have higher chlorophyll-*a* and phosphate concentrations because the Brazos catchment receives more rainfall. The unexpected nutrient concentrations in the Brazos River relative to the Rio Grande is likely to be because the Brazos River has a good connection with the Gulf of Mexico.

The macrobenthic communities were found to be quite different between the Rio Grande and the Brazos River. Abundance, biomass and diversity was significantly higher in the Rio Grande than the Brazos River (Table 10). The macrofaunal community structure was also significantly different (Figure 14). The Rio Grande was dominated by insects and polychaetes while the Brazos River was dominated solely by polychaetes (Table 4). Molluscs are also abundant in the Rio Grande but are virtually absent from the Brazos River. Previous studies have concluded that molluscan dominance indicates the fauna is dominated by species responsive to freshwater inflow. Certain bivalve species, particularly *Macoma mitchelli* and *Rangia flexuosa*, are indicator species that are responsive to inflow (Montagna and Kalke 1995, Montagna et al. 2002). During sampling it was noted that the Rio Grande has a large amount of cyanobacteria and filamentous green algae, which likely adds to the high productivity of the system (Montagna 2005).

Overall, the two river systems work quite differently, *i.e.*, the Rio Grande appears to be more influenced by freshwater inflow than the Brazos River. The confounding factor with difference in inflow is the connection with the Gulf of Mexico. The lack of strong exchange with the Gulf of Mexico in 2001 caused the Rio Grande to change from an estuarine ecosystem to a freshwater ecosystem, but from late 2002 through 2004 the system returned to brackish conditions. It will take several years of data collection to gain a better understanding of typical conditions that occur in the river estuaries when the connection with the Gulf is maintained.

The central part of the Texas coast has the greatest concentration of rivers and minor bays, which includes the San Bernard River, Brazos River, and Cedar Lakes (Figure 2). This is a good area to test for regional-scale differences in inflow (Table 11). All of the systems fit into the mesohaline salinity category (Figure 6), but the Brazos River and San Bernard River have lower mean salinities and higher nutrient regimes than the Cedar Lakes (Figures 6, 7 and 30). Interestingly, the benthic community structure and diversity in the three systems were very similar (Figure 29). Total biomass and abundance, however was significantly greater in Cedar Lakes than in the San Bernard and Brazos Rivers (Table 11). Overall, the more saline conditions in Cedar Lakes was related to higher productivity, which is indicated by higher biomass and abundance, but the community structure of the three systems was similar.

Three rivers were included in the study, but they were sampled simultaneously for only three years (2003 to 2005). However, this is a good way to compare the similarities of riverine estuaries within Texas. The Rio Grande was more fresh than the San Bernard and Brazos Rivers (Figure 6) even though the Rio Grande’s connection with the Gulf of Mexico was open for 11 out of 12 sampling months (Figure 4). Although diversity was similar in the three rivers, the Rio Grande had nearly twice the abundance of the other two, and nearly three times the biomass (Table 12). The Rio Grande also had a completely different community structure, which was uniquely co-dominated by Chironomid larvae and polychaete *Mediomastus ambiseta* (Figure 32, Table 4). Overall, the Brazos River and San Bernard River were similar hydrologically and biologically.

On a coast-wide basis, it is interesting to ask if latitudinal location is an important factor compared with whether a system is a minor bay or river. A balanced design exists to test this question based on pairing the Rio Grande and South Bay in the south Texas coast to the Brazos River and Christmas Bay of the central Texas coast (Table 13). Here, it is clear that minor bays have more in common with one another than they do with a nearby river system. Abundance, biomass, and diversity was higher and more similar in Christmas Bay and South Bay, than in the Rio Grande and Brazos River, which were similar (Table 13). Community structure was similar in Christmas Bay and South Bay, and different from the Rio Grande and Brazos River, which were similar (Figure 35). The differences are related to the hydrology, because the rivers have much lower salinities and higher nutrient and chlorophyll levels than the minor bays (Figures 6, 7 and 36).

From the results of the current study, it appears that river estuaries have more in common with one another than they do with minor bays, even when the minor bays are adjacent and within the same climatic subregion. It is also apparent that rivers and minor bays each share some similarities with major bays. For example Lavaca Bay, which is a secondary bay that receives freshwater flows from the Lavaca River has similar values of salinity and some nutrients (phosphate, nitrite and nitrate) with Cedar Lakes, which is the freshest minor bay. Lavaca Bay and Cedar Lakes also share some similarity in benthic characteristics with the rivers because all of them have relatively low macrofaunal abundance (4,000 to 12,000 n m^{-2}), biomass (1 to 3 g m^{-2}), and diversity (N1 about 2.5). In contrast, the other minor bays are more saline and have lower nutrients and chlorophyll concentrations. The other minor bays share some similarity in benthic characteristics, which are much greater than that found in the rivers because macrofaunal abundance ranges from 15,000 to 27,000 n m^{-2}, biomass ranges from 7 to 11 g m^{-2}, and N1 diversity ranges from 5 to 8. Interestingly, Matagorda Bay, which is a primary bay of the Lavaca-Colorado Estuary, has similar abundance and biomass to the rivers, but similar diversity to the minor bays. The high diversity in Matagorda Bay is likely due to the proximity and close connection to exchange with the Gulf of Mexico, which allows marine species to move freely into and out of the bay. The rivers and minor bays have very different community structures; Lavaca Bay resembles the rivers, whereas Matagorda Bay resembles the minor bays.

In the current study of minor bays and rivers along the Texas Coast several key points arise that are pertinent to the management of environmental flows to the coast. On one hand, there is a degree of uniqueness among the systems. This is common in estuarine ecology and has been termed the “estuarine signature” of the system. Whereas all estuaries will have some differences from one another, it is striking that along the Texas coast, rivers share similarities with one another and minor bays share similarities among one another as well. Another striking finding is that the rivers resemble at least one major secondary bay, and the minor bays resemble at least one major primary bay. This indicates that much of the research performed on the major bays is of value in assessing the rivers and minor bays.

Hydrology affects water quality, meaning that the volume of fresh water flowing into a bay is related to declines in salinity and increased concentrations of nitrate, nitrite, and phosphate, and Texas estuaries are sinks for these nutrients. In addition, Texas estuaries appear to be a source of ammonium, which is likely resulting from the microbial decay of organic matter flowing into the estuary and produced within the estuary. The implications of these results for managing freshwater flows is that each system has a characteristic community that is strongly influenced by hydrology of the systems, and there appears to be a tipping point at about 17 to 21 ppt where the characteristics of the coastal systems change from oligohaline to brackish communities.

REFERENCES

Adams, J.B., W.T. Knoop, and G.C. Bate. 1992. The distribution of estuarine macrophytes in relation to freshwater. *Botanica Marina.* 35: 215-226.

Anonymous. 1958. The Venice System for the classification of marine waters according to salinity. *Limnology and Oceanography*. 3: 346–347.

Brammer AJ, Z.R. Rodriguez del Rey, E.A. Spalding and M.A. Poirrier. 2007. Effects of the 1997 Bonnet Carre Spillway opening on infaunal macroinvertebrates in Lake Pontchartrain, Louisiana. *Journal of Coastal Research* 23: 1292-1303.

Carew, M.E., V. Pettigrove, R.L. Cox, and A.A. Hoffmann. 2007. The response of Chironomidae to sediment pollution and other environmental characteristics in urban wetlands. *Freshwater Biology*. 52: 2444-2462.

Chapman, E.R. 1996. The Texas basins project. In: R.F. Smith, A.H. Swartz, and W.H. Massmann (eds.), A symposium on estuarine fisheries. *American Fisheries Society* 95:83-92. Special Publ. No. 3., 154 pp.

Clarke, K.R. and R.N. Gorley. 2001. Primer v5: User Manual / Tutorial. Primer-E: Plymouth, United Kingdom.

Clarke, K.R. and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. Primer-E: Plymouth, United Kingdom.

Dimitriadis, S. and Cranston, P.S., 2007. From the mountains to the sea: assemblage structure and dynamics in Chironomidae (Insecta : Diptera) in the Clyde River estuarine gradient, New South Wales, south-eastern Australia. *Australian Journal of Entomology*. 46: 188-197.

Folk, R.L. 1964. Petrology of sedimentary rocks. Hemphill's Press. Austin, TX. 155pp.

Fuentes, C., A.J. Green, J. Orr, and J.S. Olafsson. 2005. Seasonal variation in species composition and larval size of the benthic chironomid communities in brackish wetlands in southern Alicante, Spain. *Wetlands*. 25: 289-296.

Grenon, J.-F., 1982. The macrobenthic fauna of the Eastmain Estuary (James Bay, Quebec), before the diversion. *Naturaliste Canadien*. 109(4): 793-802.

Kalke, R.D. 1981. The effects of freshwater inflow on salinity and zooplankton populations at four stations in the Nueces-Corpus Christi and Copano-Aransas Bay systems, TX from October 1977-May 1975. *In:* Cross, R.D. and D.L. Williams (eds.), Proceeding of the International Symposium on Freshwater Inflow to Estuaries. Washington, D.C: U.S. Dept. Int. Fish & Wildlife, pp. 454-471.

Kalke, R.D. and P.A. Montagna. 1989. A Review: The effect of freshwater inflow on the benthos of three Texas estuaries, pp. 185-218. *In:* Montagna, P.A. Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. University of Texas Technical Report No. TR/89-011. 370 pp.

Kalke, R.D. and P.A. Montagna. 1991. The effect of freshwater inflow on macrobenthos in the Lavaca River Delta and Upper Lavaca Bay, Texas. *Contributions in Marine Science*. 32:49-71.

Keats, R.A. and L.J. Osher. 2007. The macroinvertebrates of Ruppia (widgeon grass) beds in a small Maine estuary. *Northeastern Naturalist*. 14: 481-491.

Kinsey, J.W. 2006. Response of benthic macrofauna to freshwater inflow in the Lavaca-Colorado Estuary, Texas, USA. Unpublished Master of Science Thesis. University of Texas at Austin.

Longley, W.L. (ed.). 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.

Mannino, A. and P.A. Montagna. 1997. Small-scale spatial variation of macrobenthic community structure. *Estuaries*. 20(1): 159-173.

Montagna, P.A. 1989. Nitrogen Process Studies (NIPS): the effect of freshwater inflow on benthos communities and dynamics. Technical Report No. TR/89-011, Marine Science Institute, The University of Texas, Port Aransas, TX. 370 pp.

Montagna, P.A. 1999. Predicting long-term effects of freshwater inflow on macrobenthos and nitrogen losses in the Lavaca-Colorado and Guadalupe Estuaries. Final Report to Texas Water Development Board. Technical Report No. TR/99-001, Marine Science Institute, The University of Texas, Port Aransas, TX. 68 pp.

Montagna, P.A. 2000. Effect of freshwater inflow on macrobenthos productivity and nitrogen losses in Texas estuaries. Final report to Texas Water Development Board, Contract No. 2000-483-323, University of Texas Marine Science Institute Technical Report Number TR/00-03, Port Aransas, TX. 78 pp.

Montagna, P.A. 2001. Effect of freshwater inflow on macrobenthos productivity in minor bay and river-dominated estuaries - FY01. Final Report to Texas Water Development Board, Contract No. 2001-483-362, University of Texas Marine Science Institute Technical Report Number TR/01-002. 32 pp.

Montagna, P.A. 2002. Effect of freshwater inflow on macrobenthos productivity in minor bay and river-dominated estuaries - FY02. Final Report to Texas Water Development Board, Contract No. 2002-483-414, University of Texas Marine Science Institute Technical Report Number TR/02-002. 38 pp.

Montagna, P.A. 2003. Effect of freshwater inflow on macrobenthos productivity in minor bay and river-dominated estuaries - FY03. Final Report to Texas Water Development Board, Contract No. 2003-483-471, University of Texas Marine Science Institute Technical Report Number TR/03-03. 56 pp.

Montagna, P.A. 2004. Effect of freshwater inflow on macrobenthos productivity in minor bay and river-dominated estuaries - FY04. Final Report to Texas Water Development Board, Contract No. 2004-483-012, University of Texas Marine Science Institute Technical Report Number TR/04-01. 23 pp.

Montagna, P.A. 2005. Effect of freshwater inflow on macrobenthos productivity in minor bay and river-dominated estuaries - FY05. Final Report to Texas Water Development Board, Contract No. 2005-483-541, University of Texas Marine Science Institute Technical Report Number TR/05-005. 27 pp.

Montagna P.A. and R. D. Kalke. 1992. The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces Estuaries, Texas. *Estuaries*. 15: 307-326.

Montagna P.A. and R. D. Kalke. 1995. Ecology of infauna mollusca in south Texas estuaries. *American Malacological Bulletin*. 11: 163-175.

Montagna, P.A., R.D. Kalke, and C. Ritter. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. *Estuaries* 25:1436-1447.

Montagna, P.A., and J. Li. 1996. Modeling and monitoring long-term change in macrobenthos in Texas estuaries. Final Report to the Texas Water Development Board. University of Texas at Austin, Marine Science Institute, Technical Report No. TR/96-001, Port Aransas, Texas. 149 pp.

Montagna, P.A. and W.B. Yoon. 1991. The effect of freshwater inflow on meiofaunal consumption of sediment bacteria and micophytobenthos in San Antonio Bay, Texas, USA. *Estuarine and Coastal Shelf Science*. 33: 529-547.

Palmer, T.A., P.A. Montagna, and R.D. Kalke. 2002. Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. *Estuaries*. 25: 1448-1456.

Remane, A., 1934. Die Brackwasserfauna. *Verhandlungen der Deutschen Zoologischen Gesellschaft*, 36: 34-74.

Remane, A. and Schlieper, C., 1971. Biology of Brackish Water. John Wiley and Sons, 372 pp.

SAS Institute, Incorporated. 1991. SAS/STAT® User's Guide, Version 6, 4th ed., Volume 2.. SAS Institute Inc., Cary, NC. 378pp.

Tenore, K.R., R.N. Zajac, J. Terwin, F. Andrade, J. Blanton, W. Boynton. 2006. Characterizing the role benthos plays in larger coastal seas and estuaries: a modular approach. *Journal of Experimental Biology and Marine Ecology.* 330: 392-402.

USEPA. 1997. Method 445.0, *In vitro* determination of chlorophyll *a* and pheophytin *a* in marine and freshwater algae by fluorescence. USEPA, National Exposure Research Laboratory, Cincinnati, OH.

Welschmeyer, N.A. 1994. Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. *Limnology and Oceanography*. 39: 1985-1992.

Ysebaert, T., P.M.J. Herman, P. Meire, J. Craeymeersch, H. Verbeek, and C.H.R. Heip. 2003. Large-scale spatial patterns in estuaries: estuarine macrobenthic communities in the Schelde estuary, NW Europe. *Estuarine Coastal and Shelf Science*. 57: 335-355.

Table 1: Long-term schedule for sampling minor bay (MB), river-dominated estuaries (RD) and major estuary (ME) systems. Number of stations sampled at each location and year (with the total number of samples collected in parentheses). Fiscal year runs from October of the previous year to July of the recorded year.

		Fiscal Year				
Bay	Type	2001	2002	2003	2004	2005
East Matagorda Bay	MB	3 (36)				
South Bay Coastal Preserve	MB	2 (24)	2 (24)			
Rio Grande Estuary	RD	3 (36)	3 (36)	5 (60)	5 (60)	5 (60)
Christmas Bay Coastal Preserve	MB		3 (36)	3(36)		
Cedar Lakes	MB			2 (24)	2 (24)	2 (24)
San Bernard River Estuary	RD			2 (24)	2 (24)	2 (24)
Brazos River Estuary	RD	3 (36)	3 (36)	3 (36)	3 (36)	3 (36)
Lavaca-Colorado Estuary						
Lavaca Bay (secondary)	ME	2 (24)	2 (24)	2 (24)	2 (24)	2 (24)
Matagorda Bay (primary)	ME	3 (36)	3 (36)	3 (36)	3 (36)	3 (36)
TOTAL Stations (samples)		16 (192)	16 (192)	20 (240)	17 (204)	17 (204)

Table 2: Station location coordinates. Locations are given in degrees and decimal seconds format. Readings were made with a GPS unit using differential signal reception.

Estuary	Station	Latitude (N)	Longitude (W)
Brazos River	A	28˚ 55.670'	95˚ 23.050'
	B	28˚ 54.322'	95˚ 23.176'
	C	28˚ 53.103'	95˚ 22.923'
San Bernard	A	28˚ 52.946'	95˚ 28.429'
	B	28˚ 51.713'	95˚ 26.274'
Cedar Lakes	A	28˚ 51.493'	95˚ 27.672'
	B	28˚ 50.895'	95˚ 29.599'
Christmas Bay	A	29˚ 02.717'	95˚ 12.500'
	B	29˚ 02.833'	95˚ 11.000'
	C	29˚ 04.000'	95˚ 11.000'
East Matagorda Bay	A	28˚ 39.000'	95˚ 56.000'
	B	28˚ 41.250'	95˚ 52.000'
	C	28˚ 42.667'	95˚ 49.000'
	D	28˚ 43.667'	95˚47.500'
	E	28˚ 44.583'	95˚ 46.283'
	F	28˚ 44.000'	95˚ 43.500'
South Bay	A	26˚ 01.639'	97˚ 10.546'
	B	26˚ 02.351'	97˚ 10.992'
Rio Grande	A	25˚ 57.584'	97˚ 13.662'
	B	25˚ 57.796'	97˚ 12.668'
	C	25˚ 57.720'	97˚ 11.105'
	D	25˚ 57.610'	97˚ 11.089'
	E	25˚ 57.953'	97˚ 10.420'

Table 3: Subsets of data in terms of systems and sampling years used to test the eight null hypotheses.

Test	Data Sets	Sampling Years (Fiscal Years)
Ho_1	Minor Bay versus two reference major bays: East Matagorda Bay, Lavaca Bay, and Matagorda Bay	2001
Ho_2	All minor bays: East Matagorda Bay, South Bay, Christmas Bay, Cedar Lakes, Lavaca Bay, and Matagorda Bay	2001-2005
Ho_3	Southern systems: South Bay and Rio Grande	2001-2002
Ho_4	Northern systems: Cedar Lakes, Christmas Bay, San Bernard River, Brazos River, Lavaca Bay and Matagorda Bay	2003
Ho_5	River dominated systems in two climatic zones: Brazos River and Rio Grande	2001-2005
Ho_6	Central coastline systems: Cedar Lakes, San Bernard River, Brazos River, Lavaca Bay and Matagorda Bay	2003-2005
Ho_7	All river estuaries: Rio Grande, San Bernard River and Brazos River	2003-2005
Ho_8	North and south river-dominated systems: Brazos River, Rio Grande, Christmas Bay, South Bay	2002

Table 4. Mean species abundance list of all estuaries. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay. Taxa Groups: C = crustacean, CL = Chironomid Larvae, CN = cnidaria, M = mollusc, N = nemertean, O = other, OL = oligochaete, OP = ophiuroid, P = polychaete, S = sipunculid.

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Mediomastus ambiseta	P	2036	4463	3475	7359	2333	3891	3101	1127	1525	3257	29.8	29.8
Streblospio benedicti	P	2335	327	1422	496	518	574	1311	2340	4775	1567	14.3	44.1
Oligochaetes (unidentified)	O	183	126	2013	16	2	572	831	248	6370	1151	10.5	54.6
Cirrophorus lyra	P	0	3892	0	1544	0	116	0	0	231	643	5.9	60.5
Tharyx setigera	P	0	1466	0	32	2	67	0	0	2996	507	4.6	65.1
Chironomid larvae	C	17	0	75	0	2	5	3533	28	0	407	3.7	68.9
Polydora caulleryi	P	13	1009	0	158	0	122	0	4	1058	263	2.4	71.3
Aricidea catharinae	P	0	981	0	827	0	60	0	0	166	226	2.1	73.3
Prionospio heterobranchia	P	0	0	0	0	0	0	0	0	2033	226	2.1	75.4
Capitella capitata	P	47	0	142	0	31	0	1	28	1743	221	2.0	77.4
Cossura delta	P	8	307	0	426	206	383	0	0	449	198	1.8	79.2
Nemertea (unidentified)	N	166	327	63	173	73	182	243	118	248	177	1.6	80.8
Lumbrineris parvapedata	P	0	717	0	559	0	76	0	0	0	150	1.4	82.2
Mulinia lateralis	M	3	63	8	741	310	15	46	24	12	136	1.2	83.4
Apseudes sp. A	C	0	0	0	0	0	1171	0	0	0	130	1.2	84.6
Sphaerosyllis sp. A	P	0	47	0	0	0	11	0	0	875	104	1.0	85.6
Gyptis vittata	P	3	378	0	229	10	128	0	12	6	85	0.8	86.4
Branchioasychis americana	P	0	225	0	347	0	36	0	0	142	83	0.8	87.1
Periploma orbiculare	M	0	646	0	0	0	37	0	0	0	76	0.7	87.8
Mysella planulata	M	0	370	0	87	0	30	0	4	0	55	0.5	88.3
Ampelisca abdita	C	0	47	122	32	104	34	0	0	112	50	0.5	88.8
Paraprionospio pinnata	P	8	67	4	244	12	106	0	8	0	50	0.5	89.2
Amphiodia atra	O	0	118	0	197	0	101	0	0	12	48	0.4	89.7

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Clymenella torquata	P	0	284	0	126	0	7	0	0	0	46	0.4	90.1
Exogone sp.	P	0	0	0	0	0	0	3	0	396	44	0.4	90.5
Abra aequalis	M	0	20	0	0	0	0	1	0	313	37	0.3	90.8
Schistomeringos sp. A	P	0	95	0	0	0	8	0	0	207	34	0.3	91.1
Glycinde solitaria	P	0	99	8	102	24	36	0	12	12	32	0.3	91.4
Polydora ligni	P	16	0	51	0	2	5	210	4	0	32	0.3	91.7
Haploscoloplos fragilis	P	2	0	0	16	10	6	0	0	248	31	0.3	92.0
Schizocardium sp.	O	2	162	0	0	0	69	0	20	12	29	0.3	92.3
Periploma margaritaceum	M	0	205	0	0	0	46	0	0	0	28	0.3	92.5
Phoronis architecta	O	0	8	0	95	0	1	0	0	142	27	0.3	92.8
Euclymene sp. B	P	0	99	0	24	0	1	0	0	118	27	0.3	93.0
Aligena texasiana	M	0	102	0	126	0	5	0	0	0	26	0.2	93.3
Polydora socialis	P	181	0	0	0	0	6	2	0	30	24	0.2	93.5
Parandalia ocularis	P	65	8	75	0	14	1	0	43	0	23	0.2	93.7
Axiothella sp. A	P	0	28	0	134	0	20	0	0	24	23	0.2	93.9
Laeonereis culveri	P	3	0	24	0	2	0	164	0	0	22	0.2	94.1
Melinna maculata	P	0	71	0	71	0	8	0	0	36	21	0.2	94.3
Corophium louisianum	C	2	4	8	0	0	0	170	0	0	20	0.2	94.5
Caprellidae sp.	C	0	0	0	0	0	1	0	0	154	17	0.2	94.6
Neritina virginea	M	0	0	0	0	0	0	150	0	0	17	0.2	94.8
Ceratopogonid larvae	C	2	4	0	0	0	0	143	0	0	17	0.2	94.9
Macoma mitchelli	M	0	0	0	0	66	5	70	4	0	16	0.2	95.1
Mediomastus californiensis	P	0	4	0	0	0	0	0	0	136	16	0.1	95.2
Pomatoceros americanus	P	0	0	0	0	0	0	0	0	136	15	0.1	95.4
Caecum johnsoni	M	0	63	0	55	2	0	0	0	0	13	0.1	95.5
Turbonilla sp.	M	0	47	0	55	0	11	0	0	6	13	0.1	95.6
Corbula contracta	M	0	4	0	0	0	109	0	0	0	13	0.1	95.7
Microphthalmus	P	0	20	36	0	0	0	0	0	53	12	0.1	95.8

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
abberrans													
Aricidea bryani	P	0	16	0	0	0	92	0	0	0	12	0.1	95.9
Leucon sp.	C	0	47	0	47	7	5	0	0	0	12	0.1	96.1
Syllis cornuta	P	0	0	0	0	0	0	0	0	106	12	0.1	96.2
Glycera americana	P	0	36	0	32	0	11	0	0	24	11	0.1	96.3
Minuspio cirrifera	P	0	8	0	0	0	86	0	0	0	11	0.1	96.4
Nuculana acuta	M	0	47	0	0	0	46	0	0	0	10	0.1	96.5
Malmgreniella taylori	P	0	59	0	8	0	25	0	0	0	10	0.1	96.5
Sphaerosyllis cf. sublaevis	P	0	91	0	0	0	0	0	0	0	10	0.1	96.6
Naineris sp. A	P	0	0	0	0	0	11	0	0	77	10	0.1	96.7
Turbellaria (unidentified)	O	2	8	0	55	0	13	0	0	6	9	0.1	96.8
Edotea montosa	C	3	0	8	0	2	5	0	0	59	9	0.1	96.9
Grubeulepis cf. mexicana	P	0	0	0	0	0	0	0	0	77	9	0.1	97.0
Ceratonereis irritabilis	P	0	28	0	16	0	2	0	0	30	8	0.1	97.0
Brania furcelligera	P	0	0	0	0	0	0	0	0	71	8	0.1	97.1
Molgula manhattensis	O	0	67	0	0	0	1	0	0	0	8	0.1	97.2
Anthozoa (unidentified)	C	3	16	0	16	5	11	0	0	18	8	0.1	97.3
Boccardia sp.	P	0	0	0	0	0	0	68	0	0	8	0.1	97.3
Potamanthidae (unidentified)	C	0	0	0	0	0	0	67	0	0	8	0.1	97.4
Cymadusa compta	C	0	0	0	0	0	0	0	0	65	7	0.1	97.5
Acteocina canaliculata	M	0	12	0	32	14	0	0	0	6	7	0.1	97.5
Listriella barnardi	C	0	32	0	8	0	24	0	0	0	7	0.1	97.6
Notomastus latericeus	P	0	47	0	0	0	11	0	0	0	6	0.1	97.6
Nereidae (unidentified)	P	8	12	16	8	0	6	2	0	6	6	0.1	97.7
Oxyurostylis sp.	C	0	8	0	8	0	5	0	0	36	6	0.1	97.8
Heteromastus filiformis	P	0	0	24	0	0	0	2	0	30	6	0.1	97.8
Capitellidae	P	0	0	0	0	0	0	2	0	53	6	0.1	97.9

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
(unidentified)													
Brachidontes exustus	M	0	0	0	0	0	0	54	0	0	6	0.1	97.9
Xenanthura brevitelson	C	0	0	0	0	0	0	0	0	53	6	0.1	98.0
Chone sp.	P	0	4	0	0	0	0	0	0	47	6	0.1	98.0
Microprotopus sp.	C	3	28	0	8	2	4	0	0	6	6	0.1	98.1
Lyonsia hyalina floridana	M	0	39	0	0	2	1	0	0	6	5	0.1	98.1
Grandidierella bonnieroides	C	2	0	4	0	0	0	1	0	41	5	0.1	98.2
Pinnixa sp.	C	0	12	0	8	0	14	0	0	6	4	0.0	98.2
Spiochaetopterus costarum	P	0	4	0	32	0	4	0	0	0	4	0.0	98.3
Eudorella sp.	C	0	24	0	0	5	8	0	0	0	4	0.0	98.3
Tellina texana	M	3	0	4	0	0	0	0	0	30	4	0.0	98.3
Bivalvia (unidentified)	M	0	0	12	0	2	7	10	4	0	4	0.0	98.4
Leptochelia rapax	C	0	0	0	0	0	0	0	0	36	4	0.0	98.4
Paleanotus heteroseta	P	0	4	0	0	0	7	0	0	24	4	0.0	98.4
Drilonereis magna	P	0	20	0	8	0	1	0	0	6	4	0.0	98.5
Hobsonia florida	P	2	0	12	0	2	14	0	4	0	4	0.0	98.5
Maldanidae (unidentified)	P	0	16	0	0	0	5	0	0	12	4	0.0	98.5
Sigambra tentaculata	P	0	4	0	0	0	14	0	8	6	4	0.0	98.6
Lepton sp.	M	0	0	0	0	0	31	0	0	0	3	0.0	98.6
Diastoma varium	M	0	0	0	0	0	0	0	0	30	3	0.0	98.6
Sigambra bassi	P	2	4	0	0	0	8	0	16	0	3	0.0	98.7
Megalomma bioculatum	P	0	12	0	16	0	1	0	0	0	3	0.0	98.7
Listriella clymenellae	C	0	28	0	0	0	1	0	0	0	3	0.0	98.7
Neanthes succinea	P	21	0	8	0	0	0	0	0	0	3	0.0	98.8
Cyclopoida (commensal)	C	2	0	0	24	0	0	0	0	0	3	0.0	98.8
Ancistrosyllis jonesi	P	0	24	0	0	0	1	0	0	0	3	0.0	98.8
Nuculana concentrica	M	0	20	0	0	0	5	0	0	0	3	0.0	98.8

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Callianassa sp.	C	11	0	4	0	2	1	2	4	0	3	0.0	98.9
Lucina pectinata	M	0	0	0	0	0	0	0	0	24	3	0.0	98.9
Elasmopus sp.	C	0	0	0	0	0	0	0	0	24	3	0.0	98.9
Terebellidae (unidentified)	P	0	12	0	0	0	0	0	0	12	3	0.0	98.9
Ostracoda (unidentified)	C	2	0	8	0	2	0	11	0	0	3	0.0	99.0
Armandia maculata	P	0	0	0	0	0	5	0	0	18	3	0.0	99.0
Axiothella mucosa	P	0	8	0	0	0	2	0	0	12	3	0.0	99.0
Paranaitis speciosa	P	0	12	0	8	0	1	0	0	0	2	0.0	99.0
Ilyocryptus spinifer	C	0	0	0	0	0	0	20	0	0	2	0.0	99.0
Pilargis berkelyae	P	0	12	0	8	0	0	0	0	0	2	0.0	99.1
Vitrinellidae (unidentified)	M	0	12	0	8	0	0	0	0	0	2	0.0	99.1
Hauchiella sp.	P	0	20	0	0	0	0	0	0	0	2	0.0	99.1
Nassarius acutus	M	0	0	0	16	0	4	0	0	0	2	0.0	99.1
Pandora trilineata	M	0	8	0	8	0	4	0	0	0	2	0.0	99.1
Polydora sp.	P	0	0	0	0	0	0	19	0	0	2	0.0	99.2
Hemicyclops sp.	C	0	0	0	16	0	2	0	0	0	2	0.0	99.2
Ogyrides limicola	C	0	0	0	0	2	12	0	4	0	2	0.0	99.2
Anaitides mucosa	P	0	0	0	0	0	0	0	0	18	2	0.0	99.2
Apoprionospio pygmaea	P	0	0	0	0	0	0	0	0	18	2	0.0	99.2
Capitellides jonesi	P	0	0	0	0	0	0	0	0	18	2	0.0	99.3
Crepidula fornicata	M	0	0	0	0	0	0	0	0	18	2	0.0	99.3
Spiorbis sp.	P	0	0	0	0	0	0	0	0	18	2	0.0	99.3
Sarsiella texana	C	0	8	0	0	0	4	0	0	6	2	0.0	99.3
Monoculodes sp.	C	0	16	0	0	0	1	0	0	0	2	0.0	99.3
Cerebratulus lacteus	N	0	16	0	0	0	0	0	0	0	2	0.0	99.3
Spiophanes bombyx	P	0	4	0	0	0	0	0	0	12	2	0.0	99.4
Ancistrosyllis sp.	P	0	0	0	16	0	0	0	0	0	2	0.0	99.4
Megalops	C	5	4	0	0	0	1	0	0	6	2	0.0	99.4
Diopatra cuprea	P	0	4	0	0	5	7	0	0	0	2	0.0	99.4

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Sipuncula (unidentified)	S	10	0	0	0	0	0	0	0	6	2	0.0	99.4
Texidina sphinctostoma	M	0	0	0	0	0	0	7	8	0	2	0.0	99.4
Phascolion strombi	S	0	0	0	0	0	14	0	0	0	2	0.0	99.4
Pista palmata	P	0	8	0	0	0	0	0	0	6	2	0.0	99.5
Echiuridae (unidentified)	O	0	12	0	0	0	1	0	0	0	1	0.0	99.5
Nudibranchia (unidentified)	M	0	0	4	0	0	0	3	0	6	1	0.0	99.5
Rictaxis punctostriatus	M	0	8	0	0	5	0	0	0	0	1	0.0	99.5
Litocorsa stremma	P	0	0	0	0	0	0	0	0	12	1	0.0	99.5
Parvilucina multilineata	M	0	0	0	0	0	0	0	0	12	1	0.0	99.5
Laevicardium mortoni	M	0	0	0	0	0	0	0	0	12	1	0.0	99.5
Hesionidae (unidentified)	P	0	0	0	0	0	0	0	0	12	1	0.0	99.5
Pycnogonida (unidentified)	O	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Amphipoda (unidentified)	C	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Chione cancellata	M	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Fabriciola trilobata	P	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Brachyuran zoea	C	0	12	0	0	0	0	0	0	0	1	0.0	99.6
Sarsiella spinosa	C	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Terebellides stroemi	P	0	0	0	0	0	0	0	0	12	1	0.0	99.6
Pholadidae (unidentified)	M	0	0	0	0	0	0	0	12	0	1	0.0	99.6
Nassarius vibex	M	0	0	0	0	2	10	0	0	0	1	0.0	99.7
Corophium sp.	C	0	0	0	8	0	4	0	0	0	1	0.0	99.7
Eulimostoma sp.	M	0	4	0	0	7	0	0	0	0	1	0.0	99.7
Eteone heteropoda	P	2	0	0	0	0	2	0	0	6	1	0.0	99.7
Malacoceros indicus	P	0	0	4	0	0	0	0	0	6	1	0.0	99.7
Scolelepis texana	P	0	0	4	0	0	0	0	0	6	1	0.0	99.7
Gastropoda	M	0	0	0	0	0	10	0	0	0	1	0.0	99.7

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
(unidentified)													
Callinectes sapidus	C	2	4	4	0	0	0	0	0	0	1	0.0	99.7
Ampelisca verrilli	C	0	8	0	0	0	1	0	0	0	1	0.0	99.7
Sarsiella disparalis	C	0	8	0	0	0	1	0	0	0	1	0.0	99.7
Asychis elongata	P	0	0	0	0	0	8	0	0	0	1	0.0	99.8
Macoma tenta	M	0	0	0	0	0	1	1	0	6	1	0.0	99.8
Cyclaspis varians	C	0	8	0	0	0	0	0	0	0	1	0.0	99.8
Tellina sp.	M	0	4	4	0	0	0	0	0	0	1	0.0	99.8
Mysidopsis almyra	C	0	0	0	0	5	0	3	0	0	1	0.0	99.8
Magelona rosea	P	0	0	0	0	0	7	0	0	0	1	0.0	99.8
Sarsiella zostericola	C	0	0	0	0	0	1	0	0	6	1	0.0	99.8
Gammarus mucronatus	C	0	0	4	0	0	0	3	0	0	1	0.0	99.8
Schistomeringos rudolphi	P	0	4	0	0	0	2	0	0	0	1	0.0	99.8
Mysidopsis sp.	C	0	4	0	0	2	0	0	0	0	1	0.0	99.8
Amaenana trilobata	P	0	4	0	0	0	2	0	0	0	1	0.0	99.8
Asychis sp.	P	0	0	0	0	0	0	0	0	6	1	0.0	99.8
Bowmaniella brasiliensis	C	0	0	0	0	0	0	0	0	6	1	0.0	99.8
Leptochela serratorbita	C	0	0	0	0	0	0	0	0	6	1	0.0	99.8
Pagurus annulipes	C	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Erichthonias brasiliensis	C	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Callinectes similis	C	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Mysidopsis bahia	C	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Cerithium lutosum	M	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Micropanope scultites	C	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Platynereis dumerilii	P	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Melanella jamaicensis	M	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Odostomia canaliculata	M	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Malmgreniella sp.	P	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Pista cristata	P	0	0	0	0	0	0	0	0	6	1	0.0	99.9

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Chione grus	M	0	0	0	0	0	0	0	0	6	1	0.0	99.9
Polydora websteri	P	0	0	0	0	0	0	6	0	0	1	0.0	99.9
Rangia flexuosa	M	0	0	4	0	0	0	1	0	0	1	0.0	99.9
Hydrozoa (unidentified)	C	5	0	0	0	0	0	0	0	0	1	0.0	99.9
Eupolymnia sp.	P	0	0	0	0	0	5	0	0	0	1	0.0	99.9
Eumida sanguinea	P	0	4	0	0	0	0	0	0	0	0	0.0	99.9
Magelona phyllisae	P	0	4	0	0	0	0	0	0	0	0	0.0	99.9
Ensis minor	M	0	4	0	0	0	0	0	0	0	0	0.0	100.0
Mercenaria campechiensis	M	0	4	0	0	0	0	0	0	0	0	0.0	100.0
Diplodonta punctata	M	0	4	0	0	0	0	0	0	0	0	0.0	100.0
Parahesione luteola	P	0	0	0	0	0	0	0	4	0	0	0.0	100.0
Hirudinea (unidentified)	O	0	0	4	0	0	0	0	0	0	0	0.0	100.0
Spionidae (unidentified)	P	0	0	0	0	0	0	0	4	0	0	0.0	100.0
Amphinomidae (unidentified)	P	0	0	0	0	0	4	0	0	0	0	0.0	100.0
Haploscoloplos sp.	P	0	0	0	0	2	1	0	0	0	0	0.0	100.0
Sabellidae (unidentified)	P	0	0	0	0	0	1	2	0	0	0	0.0	100.0
Damselfly numphs	C	2	0	0	0	0	0	1	0	0	0	0.0	100.0
Polinices duplicatus	M	0	0	0	0	0	2	0	0	0	0	0.0	100.0
Phyllodocidae (unidentified)	P	2	0	0	0	0	0	0	0	0	0	0.0	100.0
Samythella eliasoni	P	0	0	0	0	0	0	2	0	0	0	0.0	100.0
Tagelus plebeius	M	0	0	0	0	0	0	2	0	0	0	0.0	100.0
Ancistrosyllis papillosa	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Podarke obscura	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Nephtys picta	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Aricidea fragilis	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Aricidea taylori	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Trachypenaeus constrictus	C	0	0	0	0	0	1	0	0	0	0	0.0	100.0

Species Name	Taxa Group	BR	CB	CL	EM	LB	MB	RG	SB	SO	Mean abund.	Mean as %	Cum. %
Cabira incerta	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Goniadidae (unidentified)	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Ampharetidae (unidentified)	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Ninoe nigripes	P	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Agriopoma texasianum	M	0	0	0	0	0	1	0	0	0	0	0.0	100.0
Pseudodiaptomus pelagicus	C	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Acetes americanus	C	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Tellidora cristata	M	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Penaeus setiferus	C	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Munnidae sp.	C	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Diptera (unidentified)	C	0	0	0	0	0	0	1	0	0	0	0.0	100.0
Total		5176	17913	7654	14678	3801	8672	10272	4089	26189	10938	100.0	

Table 5. Pearson correlation coefficients between principal component scores and biological metrics for all estuaries and all hypotheses. Number in parenthesis represents the p value. A relationship with a p value less than 0.05 is considered significant and is shown in bold.

Hypotheses	Principal Component (PC) Number	Biomass (g m^{-2})	Abundance (n m^{-2})	N1 Diversity	N
Coastwide / Ho2	Water Quality PC1	-0.5266	**-0.7490**	**-0.7685**	9
		(0.1452)	**(0.0202)**	**(0.0156)**	9
	Water Quality PC2	-0.2551	0.1768	-0.2227	9
		(0.5077)	(0.6492)	(0.5647)	9
	Sediment PC1	-0.2831	-0.5446	-0.2886	9
		(0.4604)	(0.1295)	(0.4514)	9
	Sediment PC2	0.5336	0.0418	0.2112	9
		(0.139)	(0.9149)	(0.5854)	9
Ho1	Water Quality PC1	0.2192	**0.3773**	0.0143	28
		(0.2625)	**(0.0478)**	(0.9426)	28
	Water Quality PC2	-0.2386	-0.0493	-0.1301	28
		(0.2215)	(0.8034)	(0.5094)	28
	Sediment PC1	**0.7794**	0.6368	0.5671	7
		(0.0388)	(0.1241)	(0.1843)	7
	Sediment PC2	0.0848	0.2555	0.4772	7
		(0.8565)	(0.5802)	(0.2789)	7
Ho2	Water Quality PC1	**-0.2838**	**-0.4020**	**-0.4689**	154
		(0.0004)	**(<.0001)**	**(<.0001)**	154
	Water Quality PC2	0.0811	**0.1855**	-0.0989	154
		(0.3176)	**(0.0213)**	(0.2224)	154
	Sediment PC1	**-0.3458**	**-0.3687**	**-0.3773**	41
		(0.0268)	**(0.0177)**	**(0.015)**	41
	Sediment PC2	**0.3743**	**0.5098**	**0.3513**	41
		(0.0159)	**(0.0007)**	**(0.0243)**	41
Ho3	Water Quality PC1	-0.2563	-0.2268	**-0.6820**	37
		(0.1258)	(0.1771)	**(<.0001)**	37
	Water Quality PC2	-0.0335	0.1133	0.0813	37
		(0.8442)	(0.5043)	(0.6325)	37
	Sediment PC1	-0.1979	-0.3353	-0.0250	10
		(0.5836)	(0.3435)	(0.9454)	10
	Sediment PC2	0.0404	0.3256	0.4386	10
		(0.9118)	(0.3586)	(0.2048)	10
Ho4	Water Quality PC1	**-0.4637**	**-0.4611**	**-0.6018**	56
		(0.0003)	**(0.0003)**	**(<.0001)**	56
	Water Quality PC2	-0.1961	-0.2393	**-0.3650**	56

Hypotheses	Principal Component (PC) Number	Biomass (g m^{-2})	Abundance (n m^{-2})	N1 Diversity	N
		(0.1476)	(0.0757)	**(0.0057)**	56
	Sediment PC1	**(-0.72757)**	**(-0.68509)**	**(-0.77584)**	14
		0.0032	**0.0069**	**0.0011**	14
	Sediment PC2	(0.16076)	(0.1715)	(0.14625)	14
		(0.583)	(0.5577)	(0.6179)	14
Ho5	Water Quality PC1	**-0.45798**	**-0.44537**	**-0.32353**	122
		(<.0001)	**(<.0001)**	**(0.0003)**	122
	Water Quality PC2	-0.07747	**-0.21835**	-0.11034	122
		(0.3964)	**(0.0157)**	(0.2263)	122
	Sediment PC1	**-0.54187**	**-0.35814**	**-0.36706**	36
		(0.0006)	**(0.032)**	**(0.0277)**	36
	Sediment PC2	0.1442	0.19459	0.06664	36
		(0.4014)	(0.2554)	(0.6994)	36
Ho6	Water Quality PC1	**-0.2675**	-0.1399	**-0.4486**	134
		(0.0018)	(0.1069)	**(<.0001)**	134
	Water Quality PC2	0.0077	0.0075	0.0065	134
		(0.9298)	(0.9315)	(0.941)	134
	Sediment PC1	-0.1921	**-0.3495**	-0.0388	35
		(0.2689)	**(0.0396)**	(0.8248)	35
	Sediment PC2	0.1997	0.1020	0.1251	35
		(0.2501)	(0.5599)	(0.4739)	35
Ho7	Water Quality PC1	**-0.4129**	**-0.4834**	**-0.3265**	101
		(<.0001)	**(<.0001)**	**(0.0009)**	101
	Water Quality PC2	0.1406	0.0345	0.0768	101
		(0.1608)	(0.7322)	(0.4456)	101
	Sediment PC1	**-0.6303**	**-0.4639**	-0.3052	30
		(0.0002)	**(0.0098)**	(0.101)	30
	Sediment PC2	0.1002	0.1542	-0.0689	30
		(0.5984)	(0.4159)	(0.7175)	30
Ho8	Water Quality PC1	**-0.4712**	-0.0249	**-0.7346**	41
		(0.0019)	(0.877)	**(<.0001)**	41
	Water Quality PC2	-0.1654	**-0.4499**	-0.0834	41
		(0.3015)	**(0.0032)**	(0.6041)	41
	Sediment PC1	-0.5882	**-0.8871**	-0.3441	11
		(0.057)	**(0.0003)**	(0.3001)	11
	Sediment PC2	-0.2454	0.1350	-0.3413	11
		(0.467)	(0.6922)	(0.3043)	11

Table 6. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing East Matagorda and the Lavaca-Colorado estuary (Ho_1). Underlined station means are not significantly different at 0.05 level. Month = sampling month-year combination.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Bay	2	19.7709	9.8855	31.94	**<.0001**
	Month	3	12.3717	4.1239	13.32	**<.0001**
	Bay*Month	6	3.8881	0.6480	2.09	0.0644
	Error	72	22.2851	0.3095		
Biomass (g m^{-2})						
	Bay	2	42.2127	21.1064	38.89	**<.0001**
	Month	3	6.0010	2.0003	3.69	**0.0158**
	Bay*Month	6	4.7424	0.7904	1.46	0.2055
	Error	72	39.0760	0.5427		
N1 Diversity (N1 35 cm^{-2})						
	Bay	2	156.7866	78.3933	18.58	**<.0001**
	Month	3	17.2156	5.7385	1.36	0.2618
	Bay*Month	6	30.4985	5.0831	1.2	0.3138
	Error	72	303.7609	4.2189		

Bay	Matagorda	E. Matagorda	Lavaca
n	24	36	24
Abundance			
Mean (n m^{-2})	25,941	14,678	5,838
Tukey Grouping	————	————	
Biomass			
Mean (g m^{-2})	12.84	10.90	0.98
Tukey Grouping	————	————	
Diversity			
Mean (N1 35-cm^{-2})	6.72	5.12	3.11
Tukey Grouping			

Table 7. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing East Matagorda, Matagorda Christmas, South and Lavaca Bays, and Cedar Lakes over various years (Ho_2). Underlined station means are not significantly different at 0.05 level. Year = fiscal year, Season = sampling month (not month-year combination). NB. N1 diversity of Matagorda and East Matagorda Bays are not significantly different from each other but are significantly different from every other estuary.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Estuary	5	71.3483	14.2697	91.13	**<.0001**
	Year	4	19.4587	4.8647	31.07	**<.0001**
	Season	3	2.1922	0.7307	4.67	**0.0037**
	Estuary*Season	15	10.6480	0.7099	4.53	**<.0001**
	Year*Season	12	9.3201	0.7767	4.96	**<.0001**
	Error	176	27.5591	0.1566		
Biomass (g m^{-2})						
	Estuary	5	67.9663	13.5933	59.13	**<.0001**
	Year	4	8.1916	2.0479	8.91	**<.0001**
	Season	3	3.0670	1.0223	4.45	**0.0049**
	Estuary*Season	15	5.3238	0.3549	1.54	0.0943
	Year*Season	12	1.3435	0.1120	0.49	0.9205
	Error	176	181.9982	1.0341		
N1 Diversity (35 cm^{-2})						
	Estuary	5	651.1775	130.2355	125.94	**<.0001**
	Year	4	42.1560	10.5390	10.19	**<.0001**
	Season	3	20.9474	6.9825	6.75	**0.0002**
	Estuary*Season	15	140.0794	9.3386	9.03	**<.0001**
	Year*Season	12	37.5896	3.1325	3.03	**0.0007**
	Error	176	181.9982	1.0341		

	Estuary	East Matagorda Bay	Christmas Bay	South Bay	Matagorda Bay	Cedar Lakes	Lavaca Bay
	n	12	24	24	60	36	36
Abundance							
	Mean (n m^{-2})	14,678	17,924	26,189	11,497	7,654	3,801
	Tukey Grouping	———	———		———	———	———
			———	———			
Biomass							
	Mean (g m^{-2})	10.90	8.75	6.90	5.69	2.28	0.71
	Tukey Grouping	———	———	———	———		
			———	———			
N1 Diversity							
	Mean (35 cm^{-2})	5.12	8.19	6.77	5.58	2.63	2.44
	Tukey Grouping					———	———
		———	······	······	———		

Table 8. Analysis of Variance on log transformed abundance and biomass, and untransformed N1 diversity comparing the Rio Grande and South Bay and eight sampling months in the 2001 and 2002 fiscal years (Ho_3). Month = sampling month-year combination.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Estuary	1	11.5061	11.5061	26.83	**<.0001**
	Month	7	13.3484	1.9069	4.45	**0.0002**
	Estuary*Month	7	18.2499	2.6071	6.08	**<.0001**
	Error	104	44.6014	0.4289		
Biomass (g m^{-2})						
	Estuary	1	6.1100	6.1100	8.92	**0.0035**
	Month	7	2.9716	0.4245	0.62	0.7387
	Estuary*Month	7	6.4216	0.9174	1.34	0.2395
	Error	104	71.2563	0.6852		
N1 Diversity (N1 35 cm^{-2})						
	Estuary	1	488.5633	488.5633	216.47	**<.0001**
	Month	7	196.6869	28.0981	12.45	**<.0001**
	Estuary*Month	7	222.2308	31.7473	14.07	**<.0001**
	Error	104	234.7219	2.2569		

Estuary	South Bay	Rio Grande
n	48	72
Abundance		
Mean (n m^{-2})	26,189	17,633
Tukey Grouping		
Biomass		
Mean (g m^{-2})	6.90	3.93
Tukey Grouping		
Diversity		
Mean (N1 35-cm^{-2})	6.77	2.65
Tukey Grouping		

Table 9. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing Matagorda, Lavaca and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes and four sampling months in the 2003 fiscal year (Ho_4). Underlined station means are not significantly different at 0.05 level. Month = sampling month-year combination.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Estuary	5	52.5293	10.5059	33.75	**<.0001**
	Month	3	5.6208	1.8736	6.02	**0.0007**
	Estuary*Month	15	26.5571	1.7705	5.69	**<.0001**
	Error	144	44.8305	0.3113		
Biomass (g m^{-2})						
	Estuary	5	55.0089	11.0018	38.98	**<.0001**
	Month	3	3.3587	1.1196	3.97	**0.0094**
	Estuary*Month	15	8.9486	0.5966	2.11	**0.0122**
	Error	144	40.6395	0.2822		
N1 Diversity (35 cm^{-2})						
	Estuary	5	1100.9070	220.1813	130.75	**<.0001**
	Month	3	6.3633	2.1211	1.26	0.2906
	Estuary*Month	15	37.6111	2.5074	1.49	0.1165
	Error	144	242.4908	1.6840		

	Estuary	Christmas Bay	Matagorda Bay	Cedar Lakes	Lavaca Bay	San Bernard River	Brazos River
	n	36	24	24	24	24	36
Abundance							
	Mean (n m^{-2})	19571	8592	5283	4810	5921	5113
	Tukey Grouping			―	―	―	―
Biomass							
	Mean (g m^{-2})	8.69	4.62	1.20	0.98	0.79	0.74
	Tukey Grouping			―	―	―	―
N1 Diversity							
	Mean (35-cm^{-2})	8.44	5.91	2.66	2.45	2.13	2.14
	Tukey Grouping			―	―	―	―

Table 10. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing the Rio Grande and Brazos River and twenty sampling months in the 2001 - 2005 fiscal years (Ho_5). Month = sampling month-year combination.

	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	River	1	9.1689	9.1689	99.62	**<.0001**
	Month	19	38.8459	2.0445	22.21	**<.0001**
	River*Month	19	25.4422	1.3391	14.55	**<.0001**
	Error	80	7.3629	0.0920		
Biomass (g m^{-2})						
	River	1	9.5431	9.5431	62.7	**<.0001**
	Month	19	10.0050	0.5266	3.46	**<.0001**
	River*Month	19	7.0650	0.3718	2.44	**0.003**
	Error	80	12.1757	0.1522		
N1 Diversity						
	River	1	1.2537	1.2537	8.08	**0.0057**
	Month	19	16.0451	0.8445	5.45	**<.0001**
	River*Month	19	13.5273	0.7120	4.59	**<.0001**
	Error	80	12.4048	0.1551		

River	Rio Grande	Brazos River
n	60	60
Abundance		
Mean (n m^{-2})	11,764	5,176
Tukey Grouping		
Biomass		
Mean (g m^{-2})	2.79	0.81
Tukey Grouping		
Diversity		
Mean (N1 35-cm^{-2})	2.49	2.29
Tukey Grouping		

Table 11. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing Matagorda and Lavaca Bays, Brazos and San Bernard Rivers and Cedar Lakes and twelve sampling months from the 2003-2005 fiscal years (Ho_6). Underlined station means are not significantly different at 0.05 level. Month = sampling month-year combination.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Estuary	4	21.4315	5.3579	59.12	**<.0001**
	Month	11	8.1760	0.7433	8.2	**<.0001**
	Estuary*Month	44	41.7586	0.9491	10.47	**<.0001**
	Error	120	10.8748	0.0906		
Biomass (g m^{-2})						
	Estuary	4	25.2005	6.3001	62.31	**<.0001**
	Month	11	4.0621	0.3693	3.65	**0.0002**
	Estuary*Month	44	13.1993	0.3000	2.97	**<.0001**
	Error	120	12.1328	0.1011		
N1 Diversity (35 cm^{-2})						
	Estuary	4	200.0044	50.0011	159.35	**<.0001**
	Month	11	15.9826	1.4530	4.63	**<.0001**
	Estuary*Month	44	45.3806	1.0314	3.29	**<.0001**
	Error	120	37.6538	0.3138		

	Estuary	Matagorda Bay	Cedar Lakes	San Bernard River	Brazos River	Lavaca Bay
	n	36	36	36	36	36
Abundance						
	Mean (n m^{-2})	6693	7654	4089	4914	3179
	Tukey Grouping	———	———			
Biomass						
	Mean (g m^{-2})	3.58	2.28	0.52	0.74	0.62
	Tukey Grouping			———	———	———
N1 Diversity						
	Mean (35 cm^{-2})	4.99	2.63	2.46	2.31	2.15
	Tukey Grouping			———	———	———
			———	———	———	

Table 12. Analysis of Variance on log transformed abundance and biomass, and untransformed N1 diversity comparing the Rio Grande, San Bernard and Brazos Rivers and twelve sampling months in the 2001 - 2005 fiscal years (Ho_7). Month = sampling month-year combination.

	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	River	2	4.3481	2.1741	23.12	**<.0001**
	Month	11	29.9002	2.7182	28.9	**<.0001**
	River*Month	22	21.5808	0.9809	10.43	**<.0001**
	Error	72	6.7710	0.0940		
Biomass (g m^{-2})						
	River	2	4.9495	2.4748	22.97	**<.0001**
	Month	11	5.2053	0.4732	4.39	**<.0001**
	River*Month	22	4.6015	0.2092	1.94	**0.0188**
	Error	72	7.7585	0.1078		
N1 Diversity						
	River	2	0.4052	0.2026	0.96	0.3869
	Month	11	12.6253	1.1478	5.45	**<.0001**
	River*Month	22	16.6858	0.7584	3.6	**<.0001**
	Error	72	15.1598	0.2106		

River	Rio Grande	Brazos River	San Bernard
n	36	36	36
Abundance			
Mean (n m^{-2})	7,852	4,914	4,089
Tukey Grouping			
Biomass			
Mean (g m^{-2})	2.04	0.74	0.52
Tukey Grouping		—	—
Diversity			
Mean (N1 35-cm^{-2})	2.38	2.31	2.46
Tukey Grouping	—	—	—

Table 13. Analysis of Variance and Tukey multiple comparison tests on log transformed abundance and biomass, and untransformed N1 diversity comparing Christmas and South Bays, Rio Grande and Brazos River and four sampling months from the 2002 fiscal year (Ho_8). Underlined station means are not significantly different at 0.05 level. Month = sampling month-year combination.

Variable	Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Abundance (n m^{-2})						
	Estuary	3	13.2015	4.4005	45.90	**<.0001**
	Month	3	2.0596	0.6865	7.16	**0.0008**
	Estuary*Month	9	5.1209	0.5690	5.93	**<.0001**
	Error	32	3.0682	0.0959		
Biomass (g m^{-2})						
	Estuary	3	18.5438	6.1813	46.51	**<.0001**
	Month	3	2.5292	0.8431	6.34	**0.0017**
	Estuary*Month	9	2.8245	0.3138	2.36	**0.0357**
	Error	32	4.2529	0.1329		
N1 Diversity (35 cm^{-2})						
	Estuary	3	310.9385	103.6462	145.88	**<.0001**
	Month	3	7.6116	2.5372	3.57	**0.0246**
	Estuary*Month	9	45.5730	5.0637	7.13	**<.0001**
	Error	32	22.7349	0.7105		

<table>
<tr><th></th><th>Estuary
n</th><th>Christmas Bay
12</th><th>South Bay
12</th><th>Rio Grande
12</th><th>Brazos River
12</th></tr>
<tr><td>Abundance</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Mean (n m^{-2})</td><td>16278</td><td>20493</td><td>22542</td><td>6177</td></tr>
<tr><td></td><td>Tukey Grouping</td><td colspan="3">————————————</td><td></td></tr>
<tr><td>Biomass</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Mean (g m^{-2})</td><td>8.80</td><td>8.10</td><td>3.36</td><td>0.94</td></tr>
<tr><td></td><td>Tukey Grouping</td><td colspan="2">————————</td><td></td><td></td></tr>
<tr><td>N1 Diversity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Mean (35-cm^{-2})</td><td>7.93</td><td>7.06</td><td>2.47</td><td>2.42</td></tr>
<tr><td></td><td>Tukey Grouping</td><td colspan="2">————————</td><td colspan="2">————————</td></tr>
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Figure 1: Sampling locations within South Bay Coastal Preserve and Rio Grande.

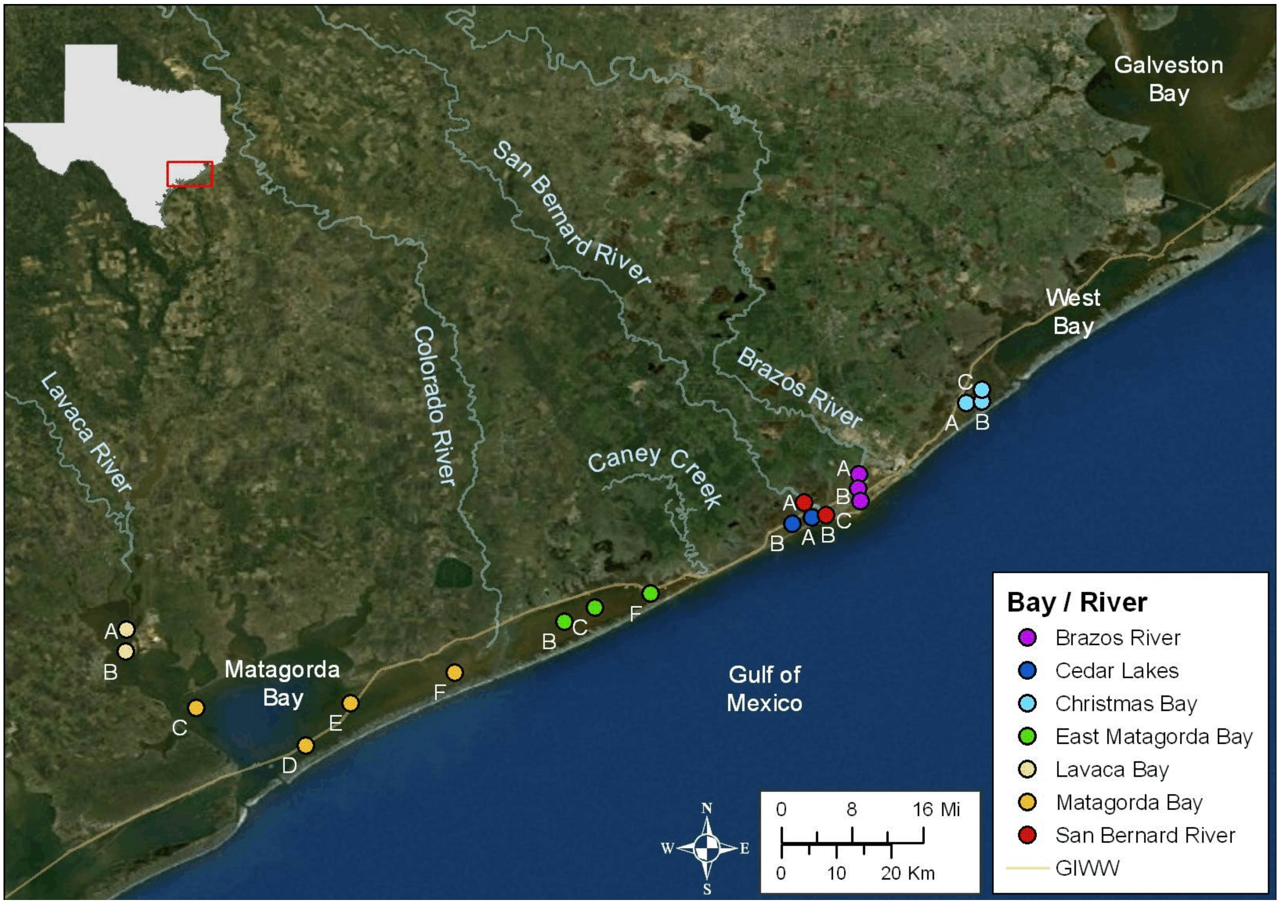

Figure 2: Sampling locations within Brazos River, Cedar Lakes, Christmas Bay, East Matagorda Bay, Lavaca Bay, Matagorda Bay and San Bernard River. GIWW = Gulf Intra-coastal Water Way.

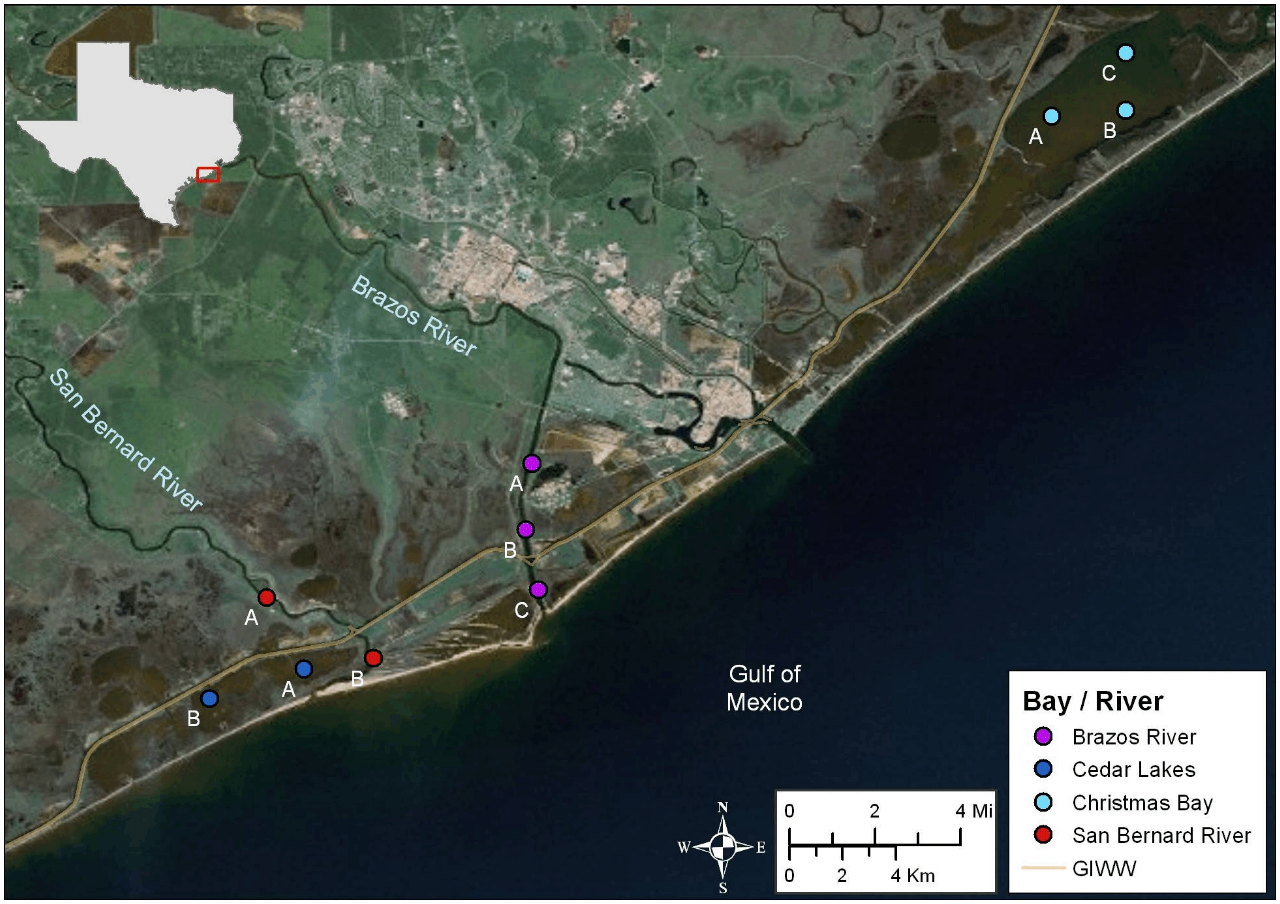

Figure 3. Sampling locations within Brazos River, Cedar Lakes, Christmas Bay, and San Bernard River. GIWW = Gulf Intra-coastal Water Way.

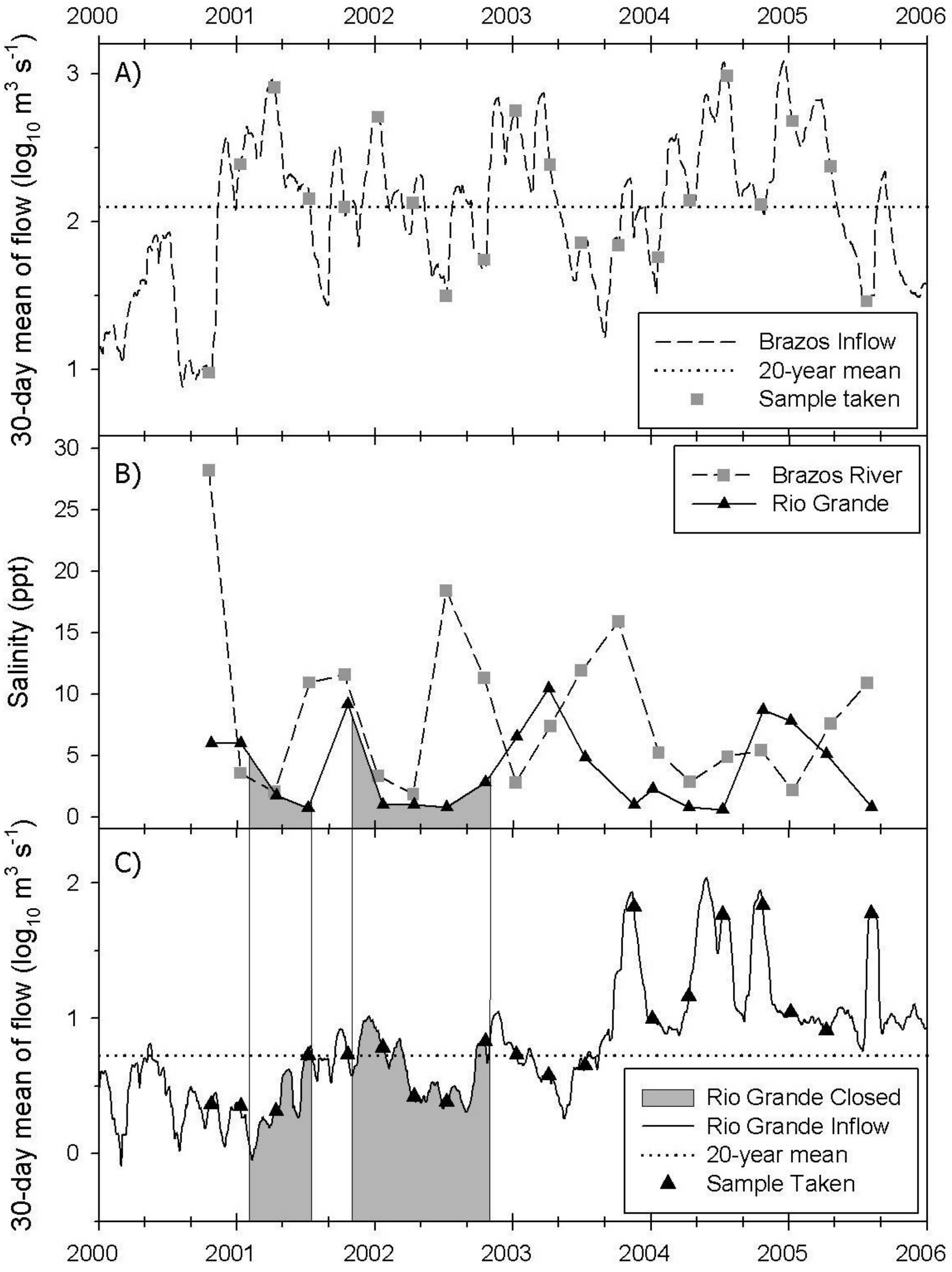

Figure 4. Mean daily flow at the Brazos River (A) and the Rio Grande (C) and quarterly salinity measurements at the same river-estuaries (B).

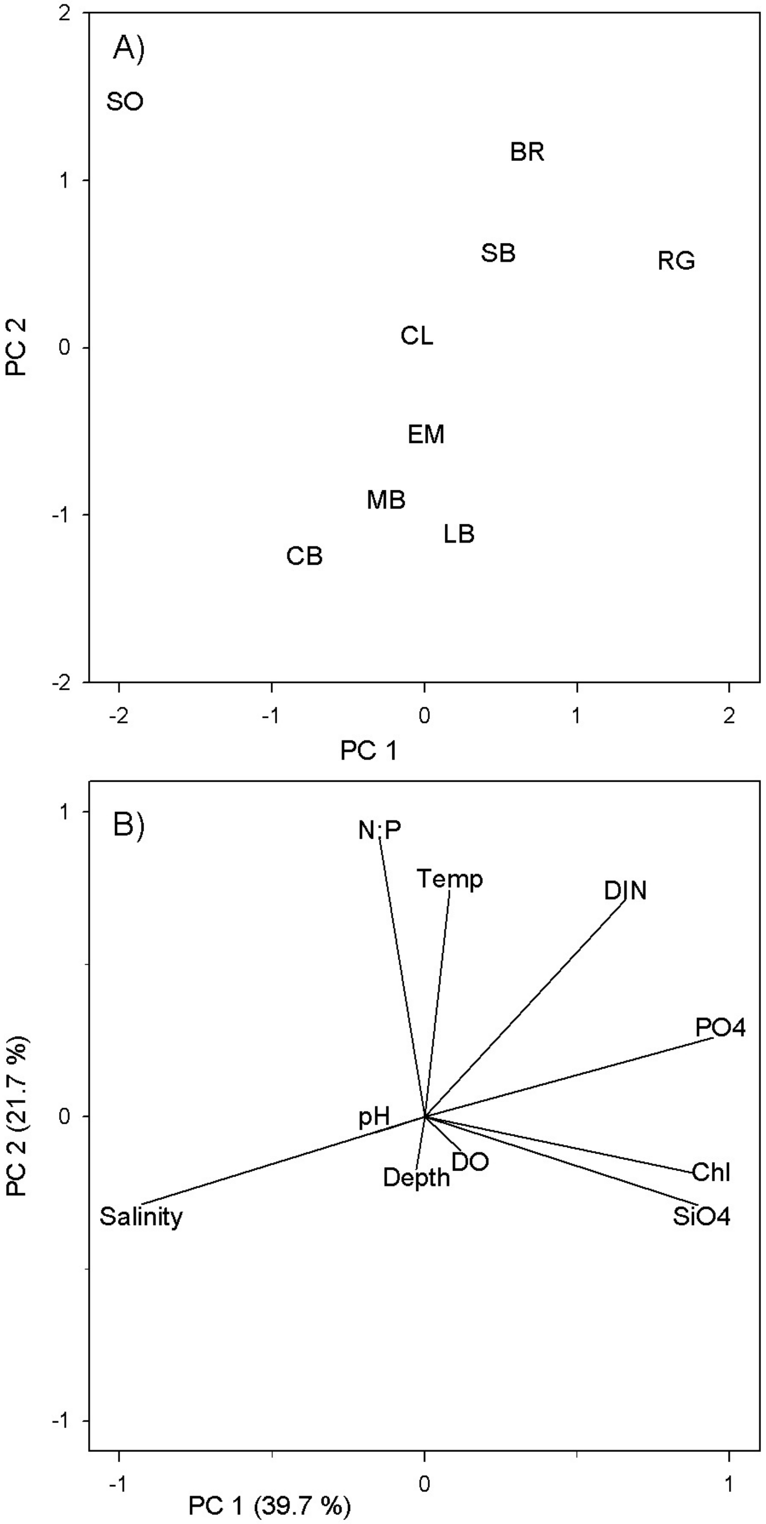

Figure 5: Plots of the first two principal components (PC) resulting from analysis of water quality data for all estuaries sampled. A) PC station scores labeled by station and B) PC loadings. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

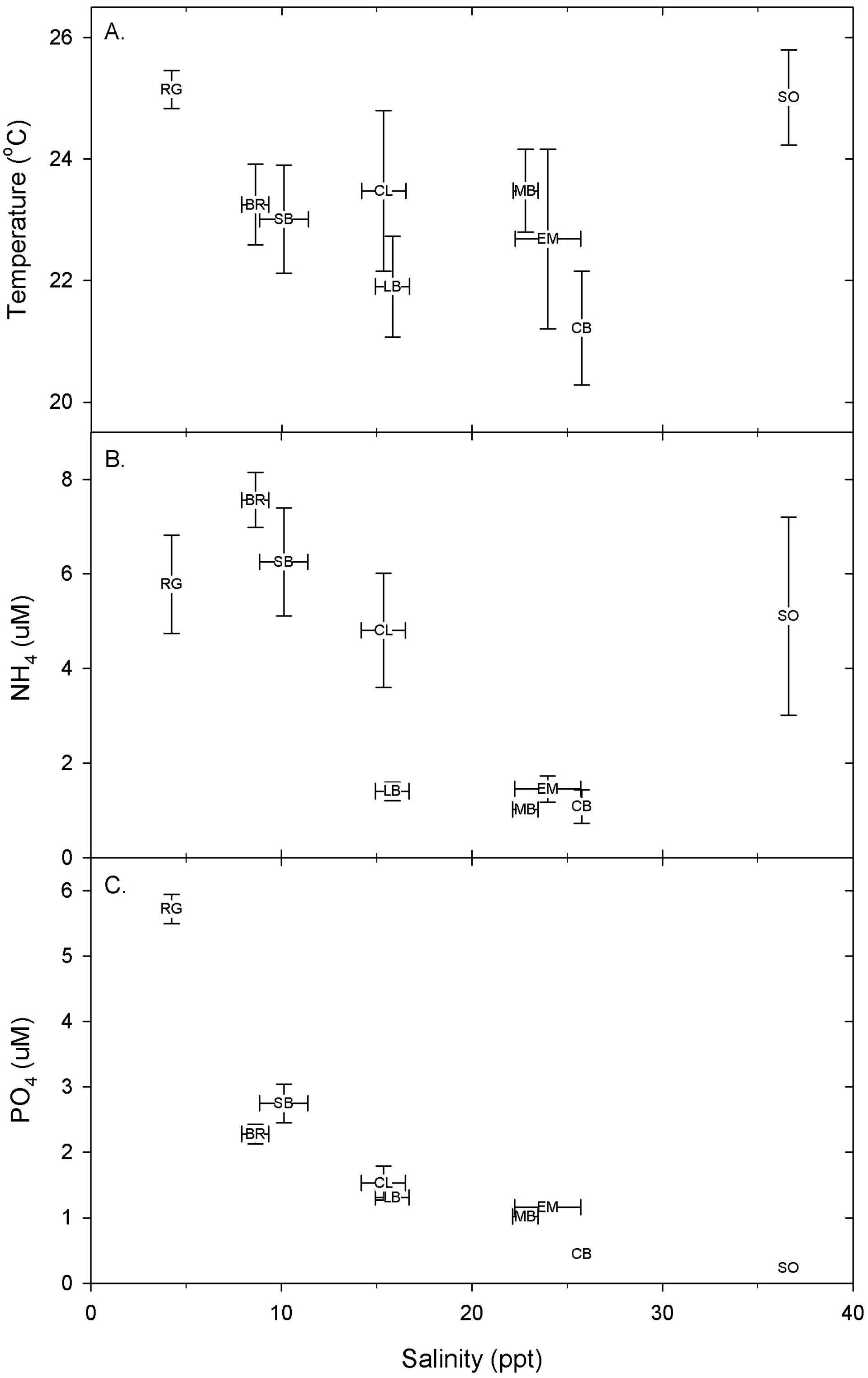

Figure 6: Mean (± standard error) salinity versus mean (± standard error) A) temperature, B) ammonium, and C) phosphate for minor bays, river-dominated estuaries, and major estuaries along the Texas coastline from 2001-2005. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

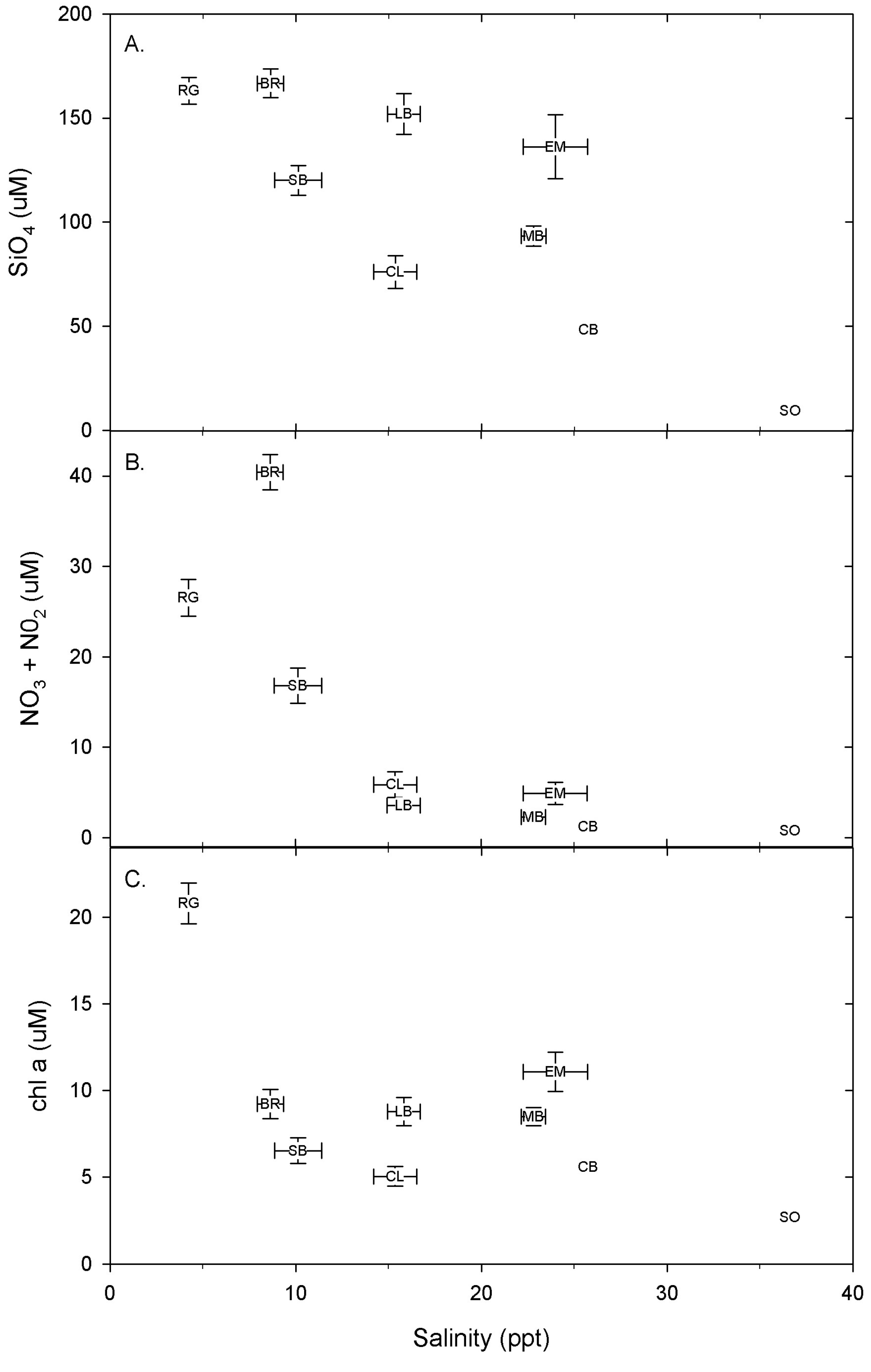

Figure 7: Mean (± standard error) salinity versus mean (± standard error) A) silicate, B) nitrate plus nitrite and C) chlorophyll-*a* for minor bays, river-dominated estuaries, and major estuaries along the Texas coastline from 2001-2005. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

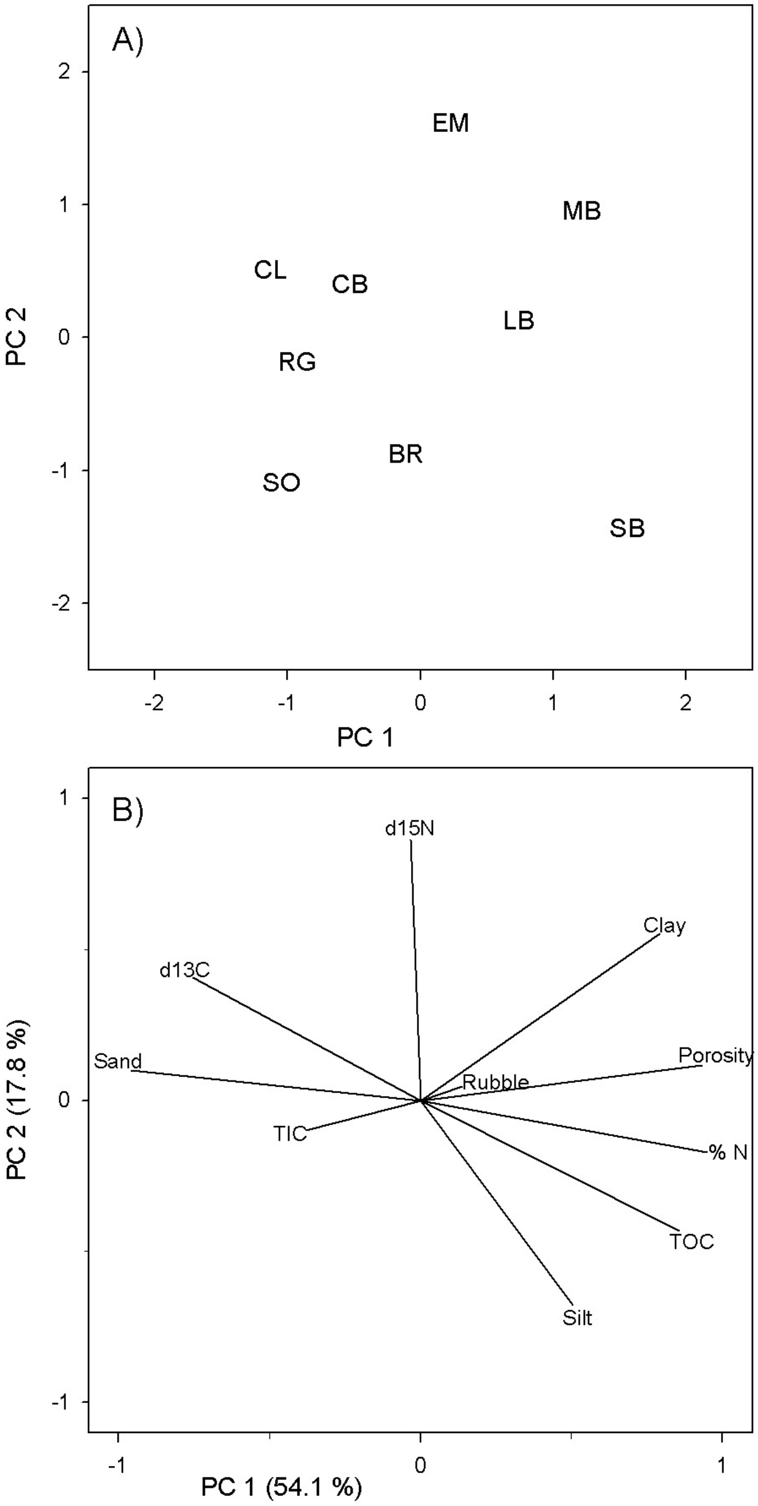

Figure 8: Plots of the first two principal components (PC) resulting from analysis of sediment data for all estuaries sampled. A) PC station scores labeled by station and B) PC loadings. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

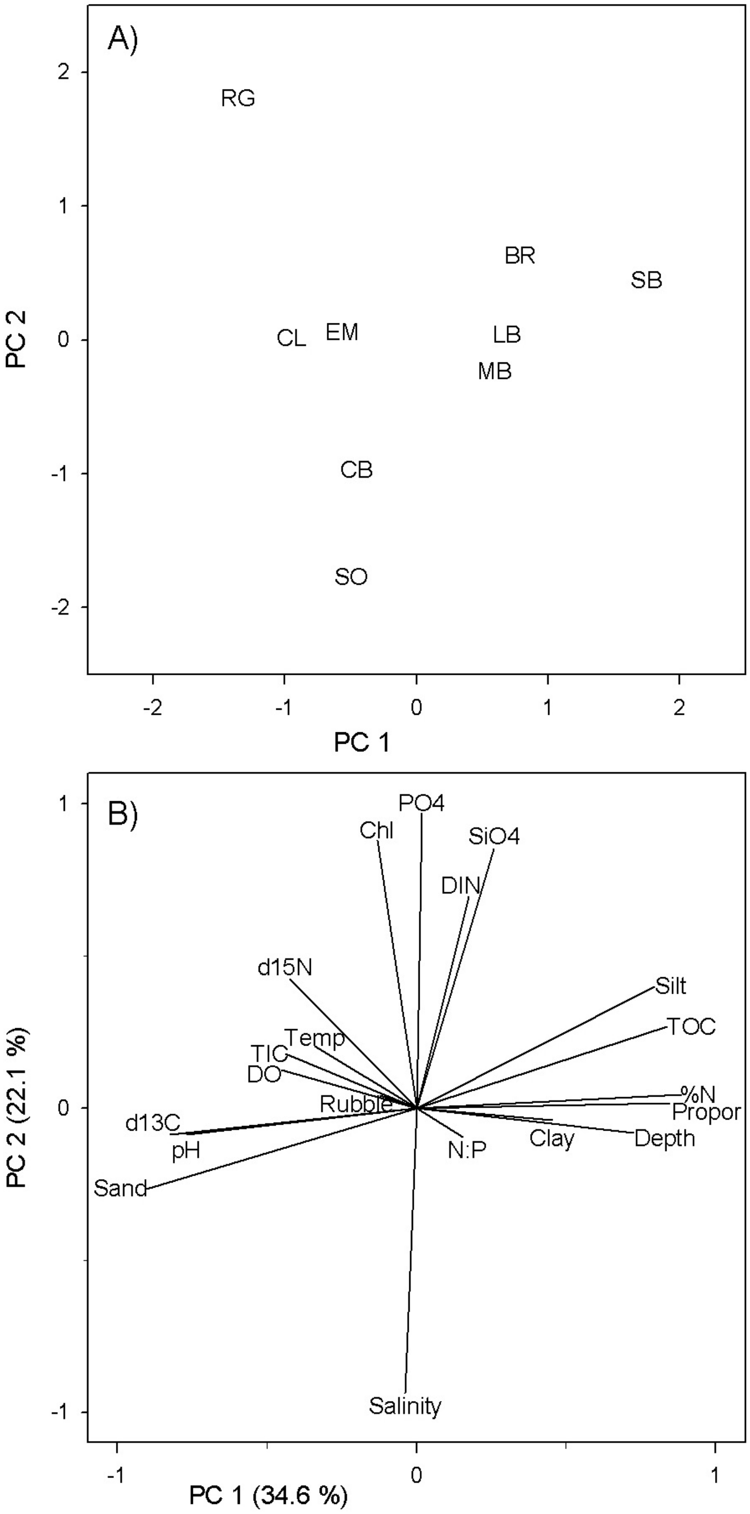

Figure 9: Plots of the first two principal components (PC) resulting from analysis of sediment and water quality data for all estuaries sampled. A) PC station scores labeled by station and B) PC loadings. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

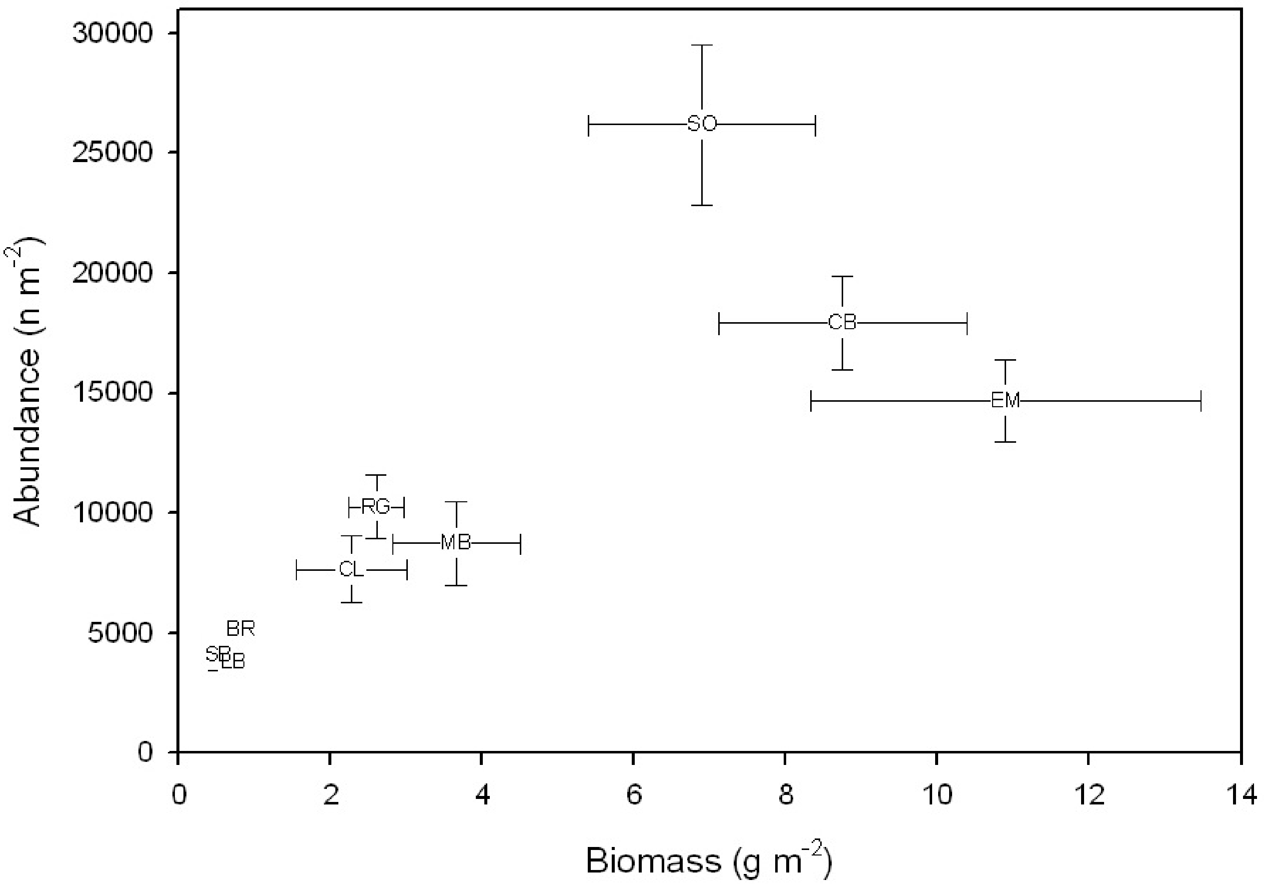

Figure 10: Mean (± standard error) biomass versus mean (± standard error) macrofaunal abundance for minor bays, river-dominated estuaries, and major estuaries along the Texas coastline from 2001-2005. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

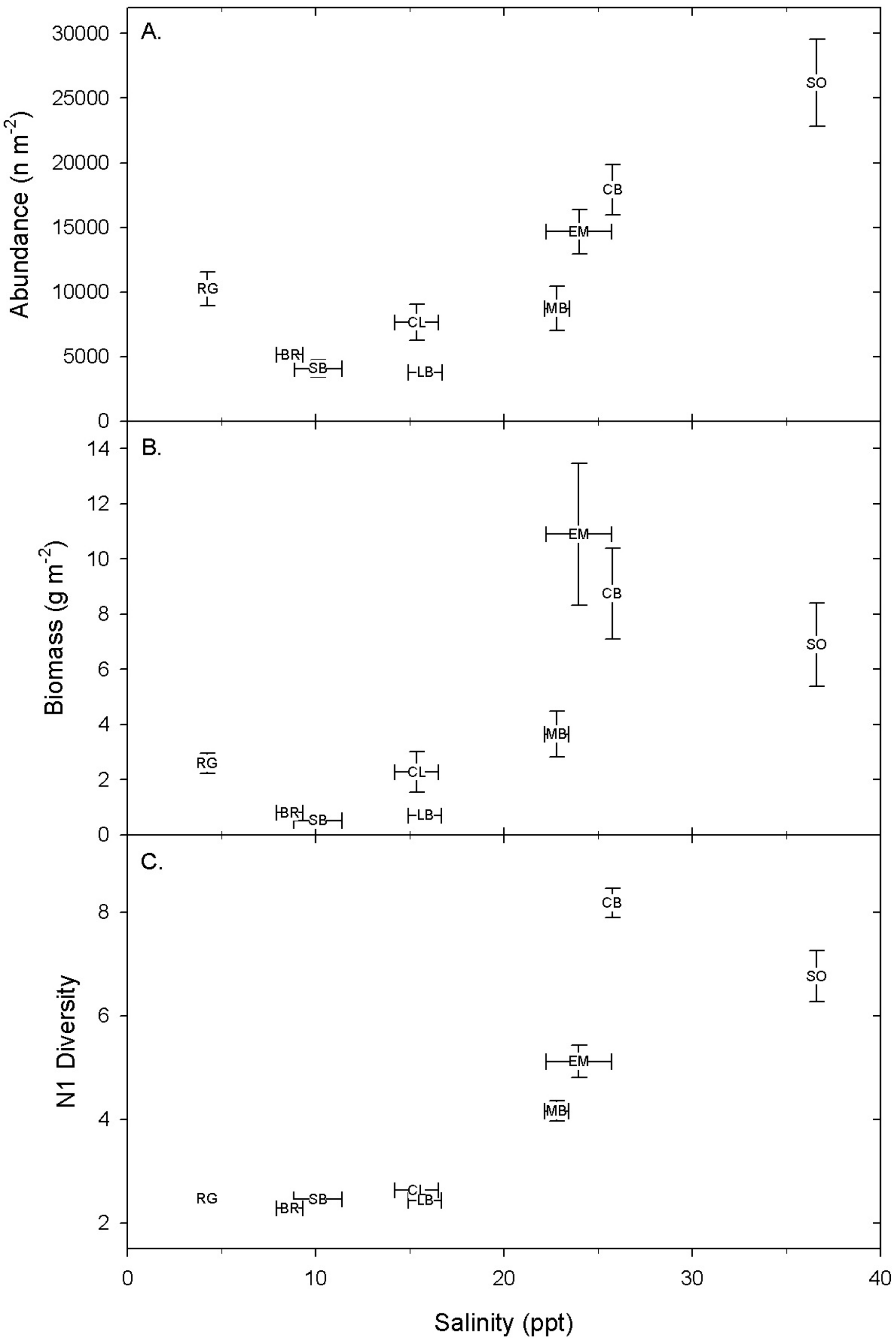

Figure 11: Mean (± standard error) salinity versus mean (± standard error) macrofaunal A) abundance, B) biomass and C) N1 diversity for minor bays, river-dominated estuaries, and major estuaries along the Texas coastline from 2001-2005. Diversity is reported in 35 cm^2. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay.

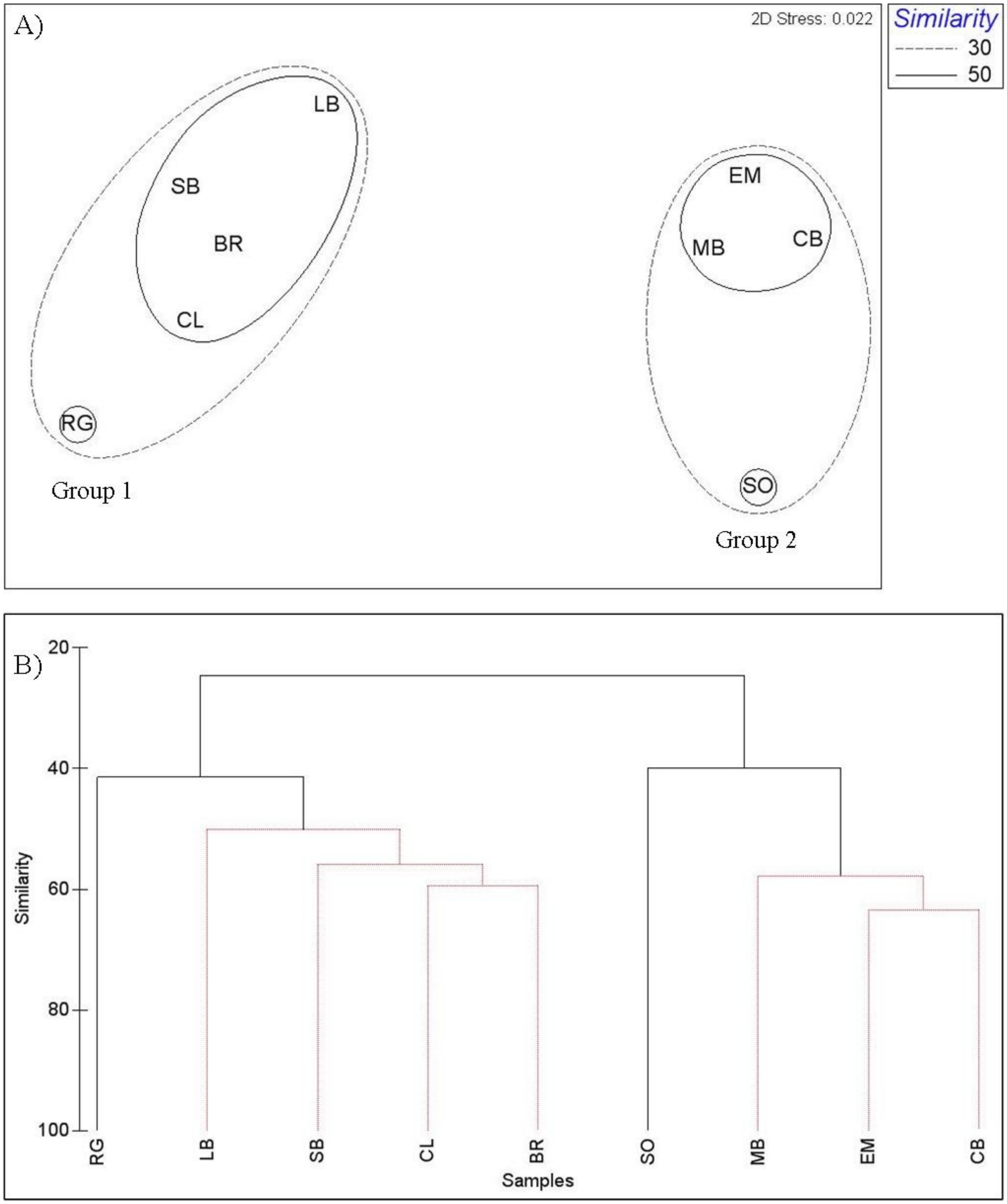

Figure 12: Multidimensional scaling plot and cluster analysis of macrofauna communities for each estuary. BR=Brazos River, CB=Christmas Bay, CL=Cedar Lakes, EM=East Matagorda Bay, LB = Lavaca Bay, MB=Matagorda Bay, RG=Rio Grande, SB=San Bernard River, SO=South Bay. Clusters of macrofauna assemblages are significantly different to each other if they are separated by solid lines in the cluster analysis.

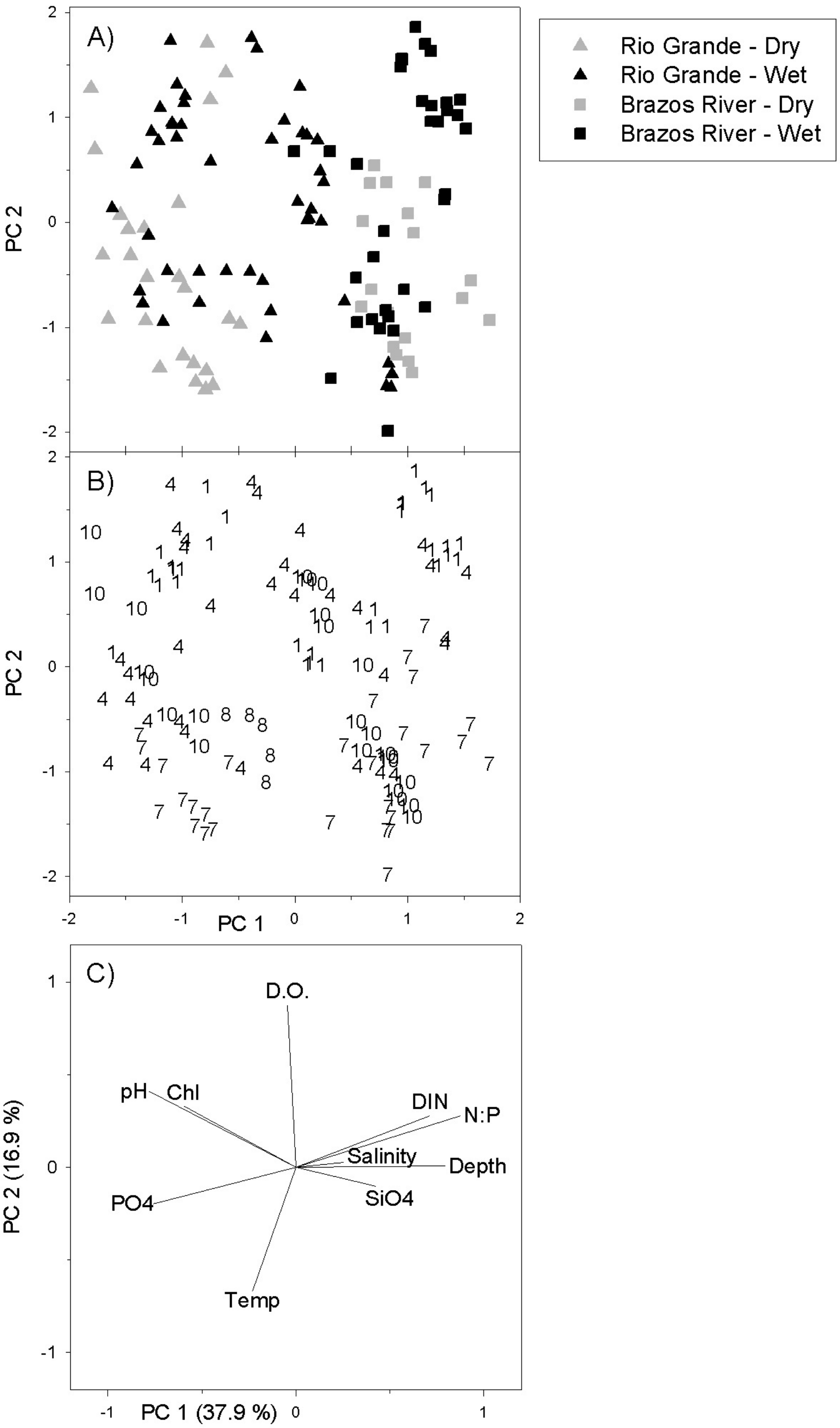

Figure 13: Plots of the first two principal components (PC) resulting from analysis of water quality data for the Rio Grande and Brazos Rivers (Ho_5) showing samples taken in wet and dry periods. A) PC station scores labeled by river, B) PC station scores labeled by month number and C) PC loadings.

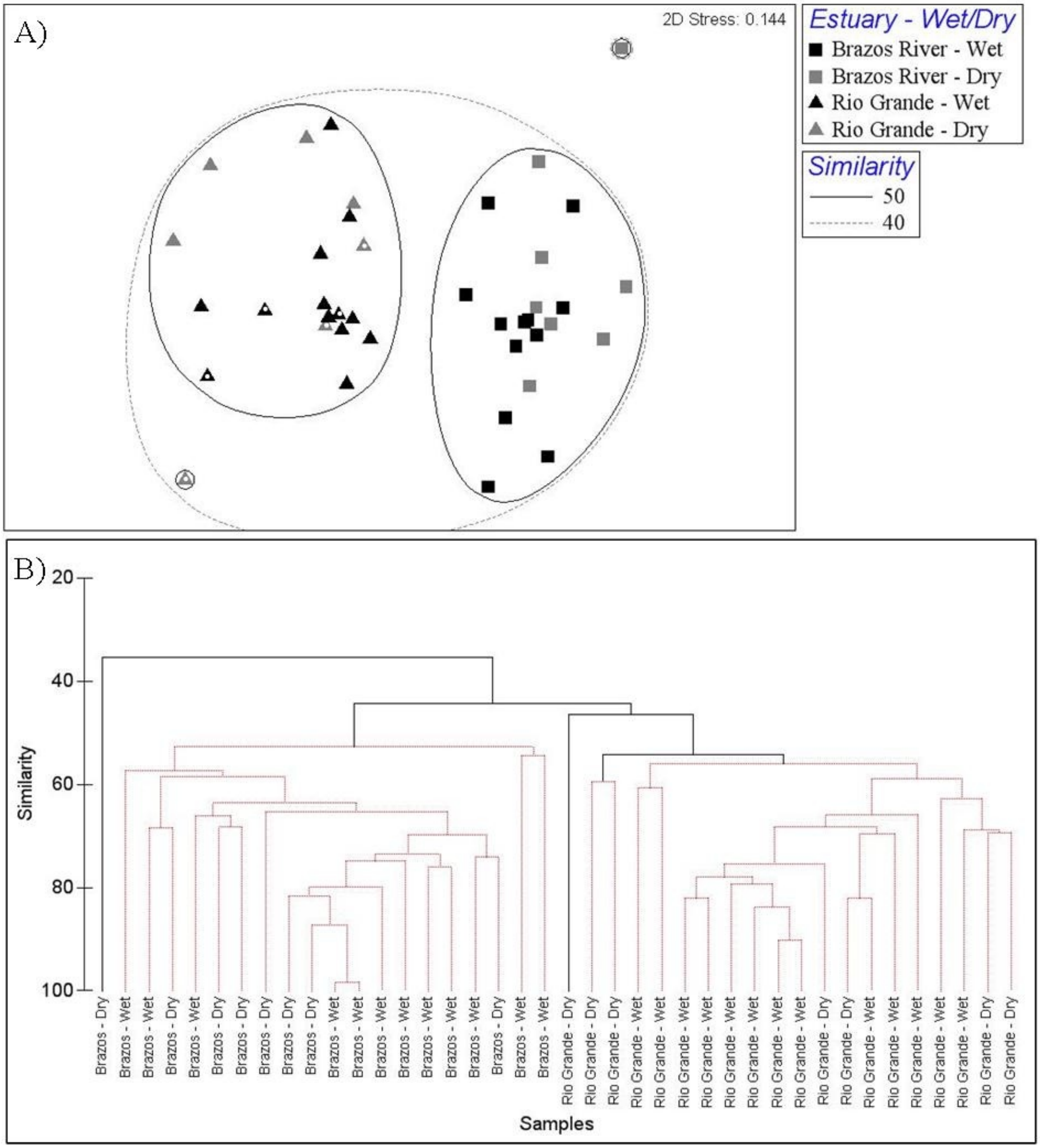

Figure 14: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in wet and dry years in the Rio Grande and Brazos River (Ho_5) overlaid with similarity contours from cluster analysis (B). Triangles with white dots indicate that the Rio Grande mouth was blocked on that sampling date. Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

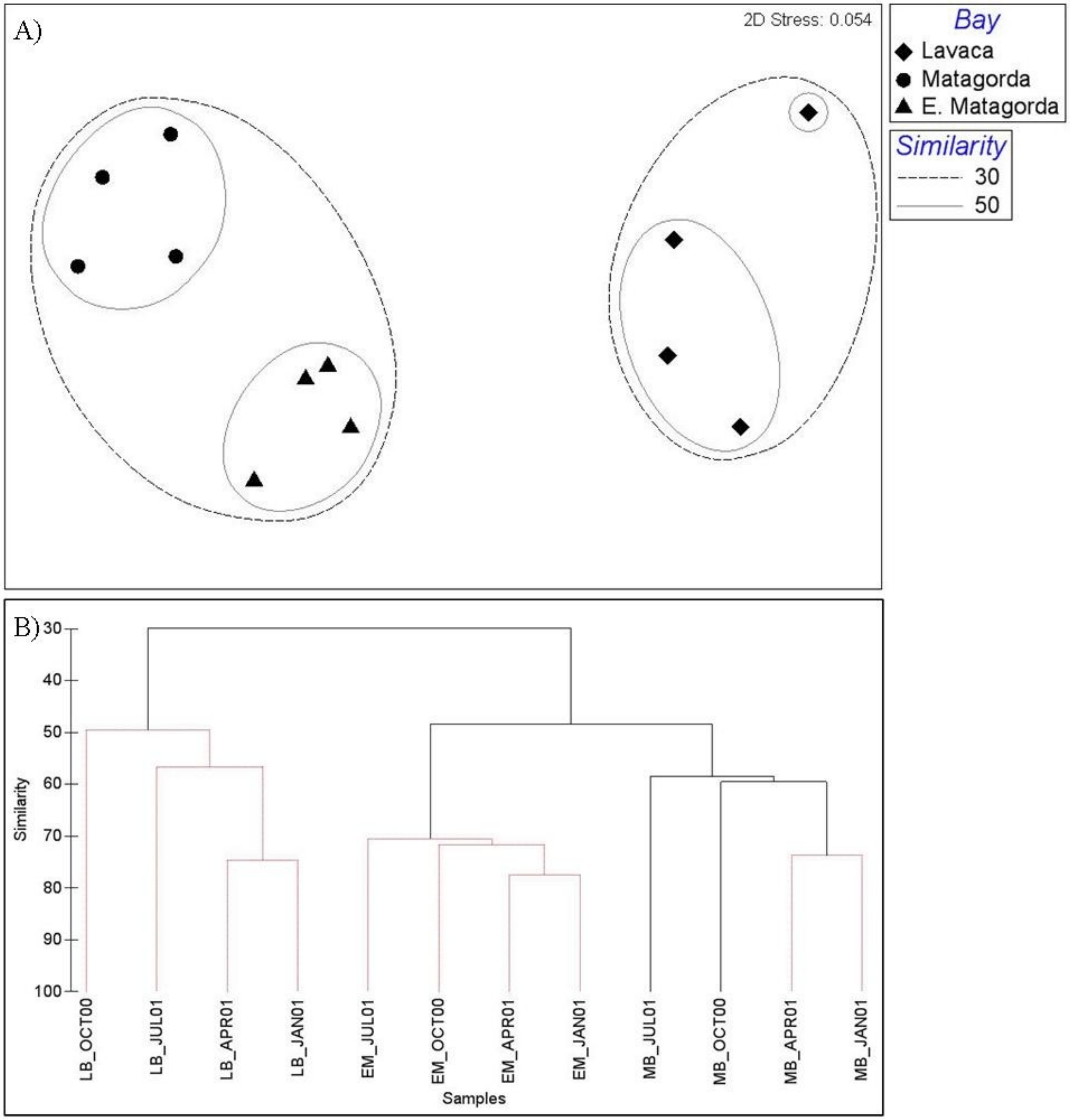

Figure 15: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in East Matagorda (EM), Matagorda (MB) and Lavaca (LB) Bays (Ho_1) averaged by date, overlaid with similarity contours from cluster analysis (B). Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

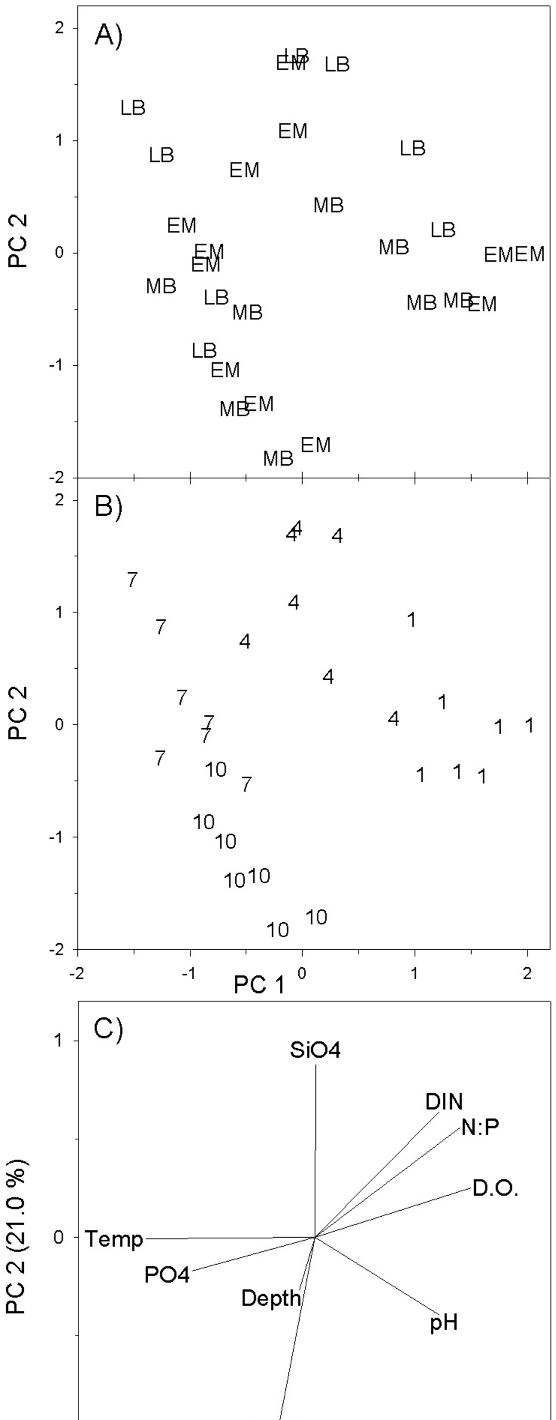

Figure 16: Plots of the first two principal components (PC) resulting from analysis of water quality data for East Matagorda, Matagorda, and Lavaca Bays (Ho_1). A) PC station scores labeled by bay-station, B) PC station scores labeled by month number and C) PC loadings. MB=Matagorda Bay, EM=East Matagorda Bay, LB=Lavaca Bay, 10=Oct 2000, 1=Jan 2001, 4=April 2001, 7=July 2001.

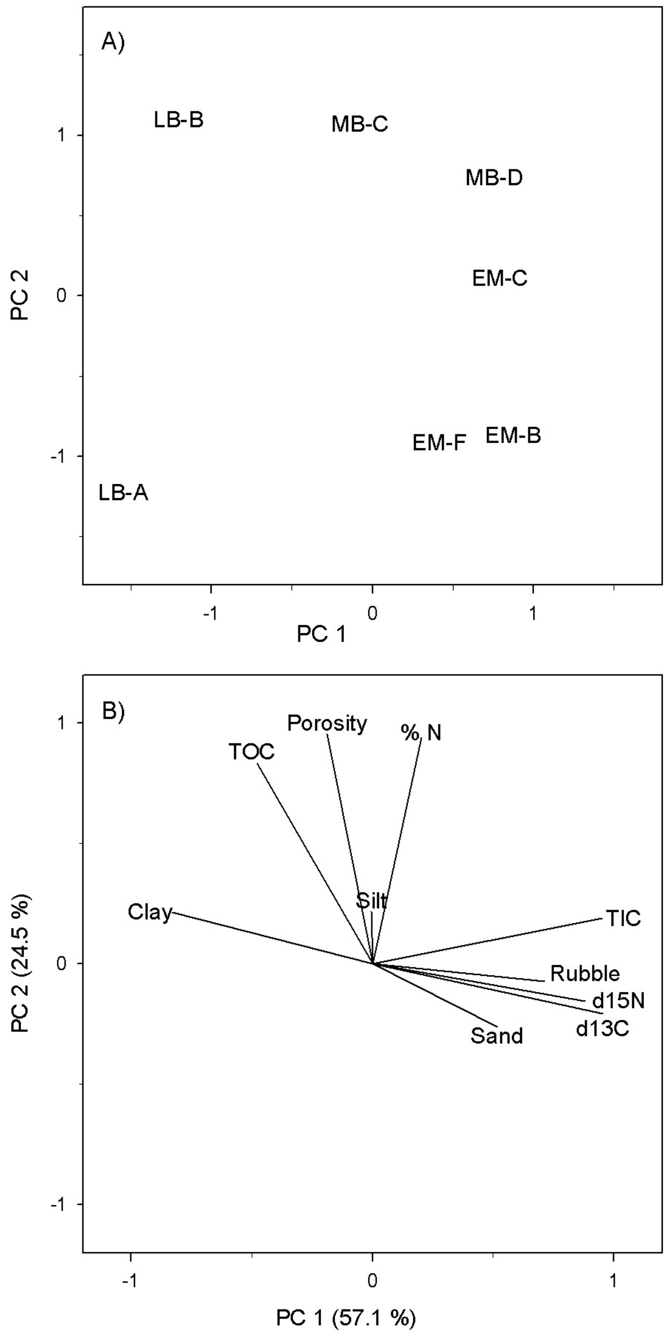

Figure 17: Plots of the first two principal components (PC) resulting from analysis of sediment data for East Matagorda, Matagorda, and Lavaca Bays (Ho_1). A) PC station scores labeled by bay-station and B) PC loadings. MB=Matagorda Bay, EM=East Matagorda Bay, LB=Lavaca Bay.

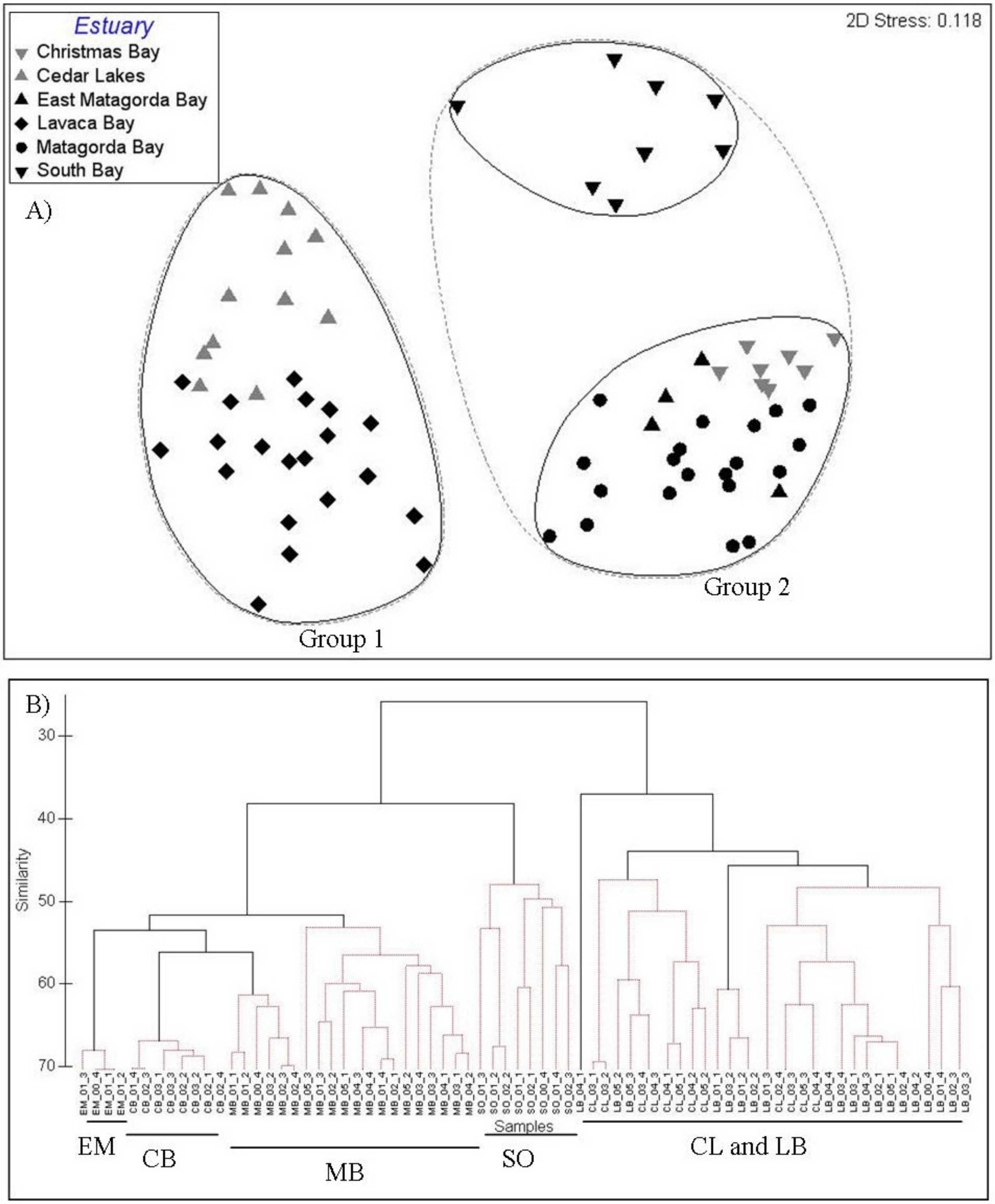

Figure 18: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in the minor and major bays (Ho_2) averaged by date and overlaid with similarity contours from cluster analysis (B). Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

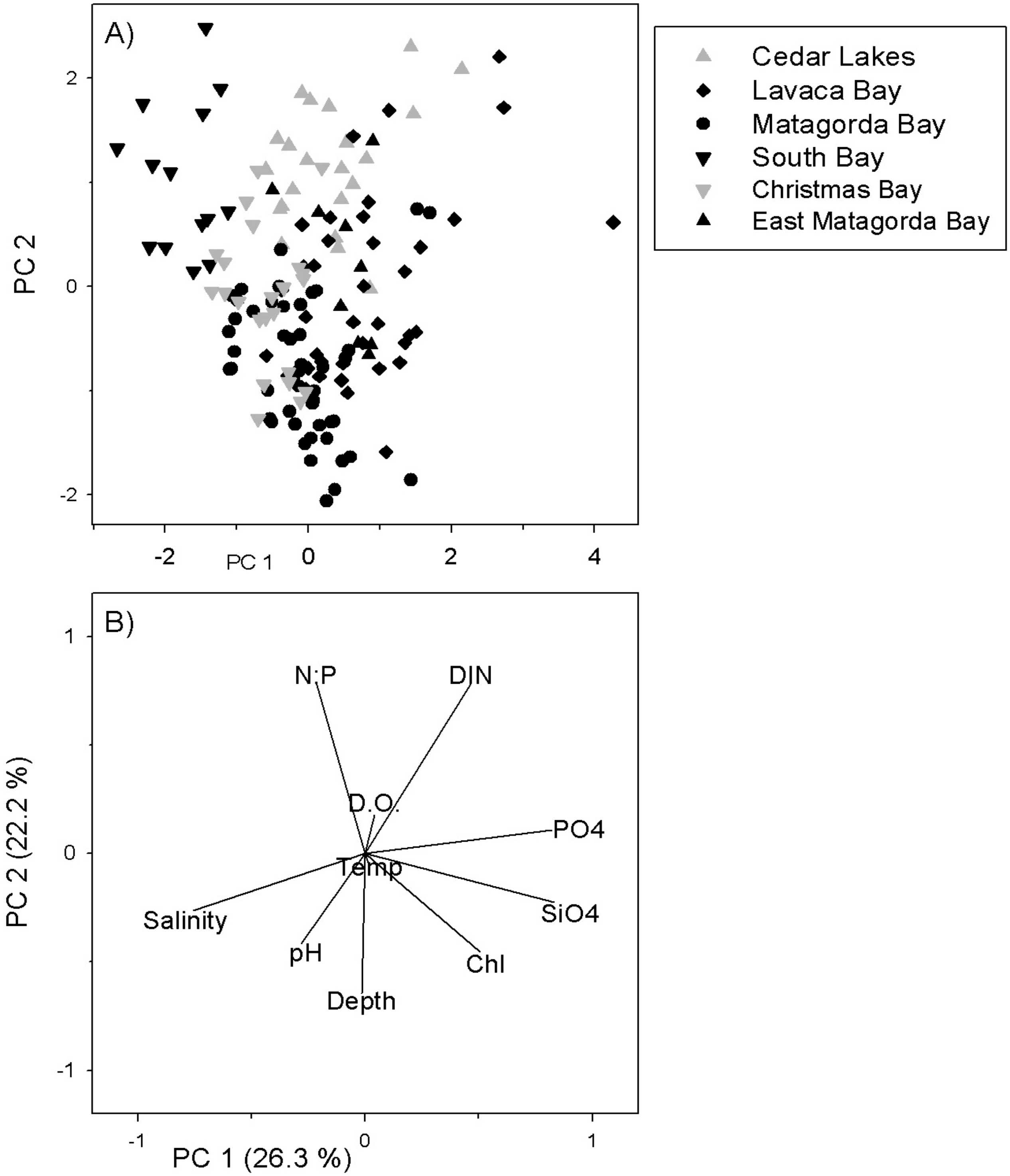

Figure 19: Plots of the first two principal components (PC) resulting from analysis of water quality data in minor and major bays (Ho_2). A) PC station scores labeled by estuary, B) PC loadings.

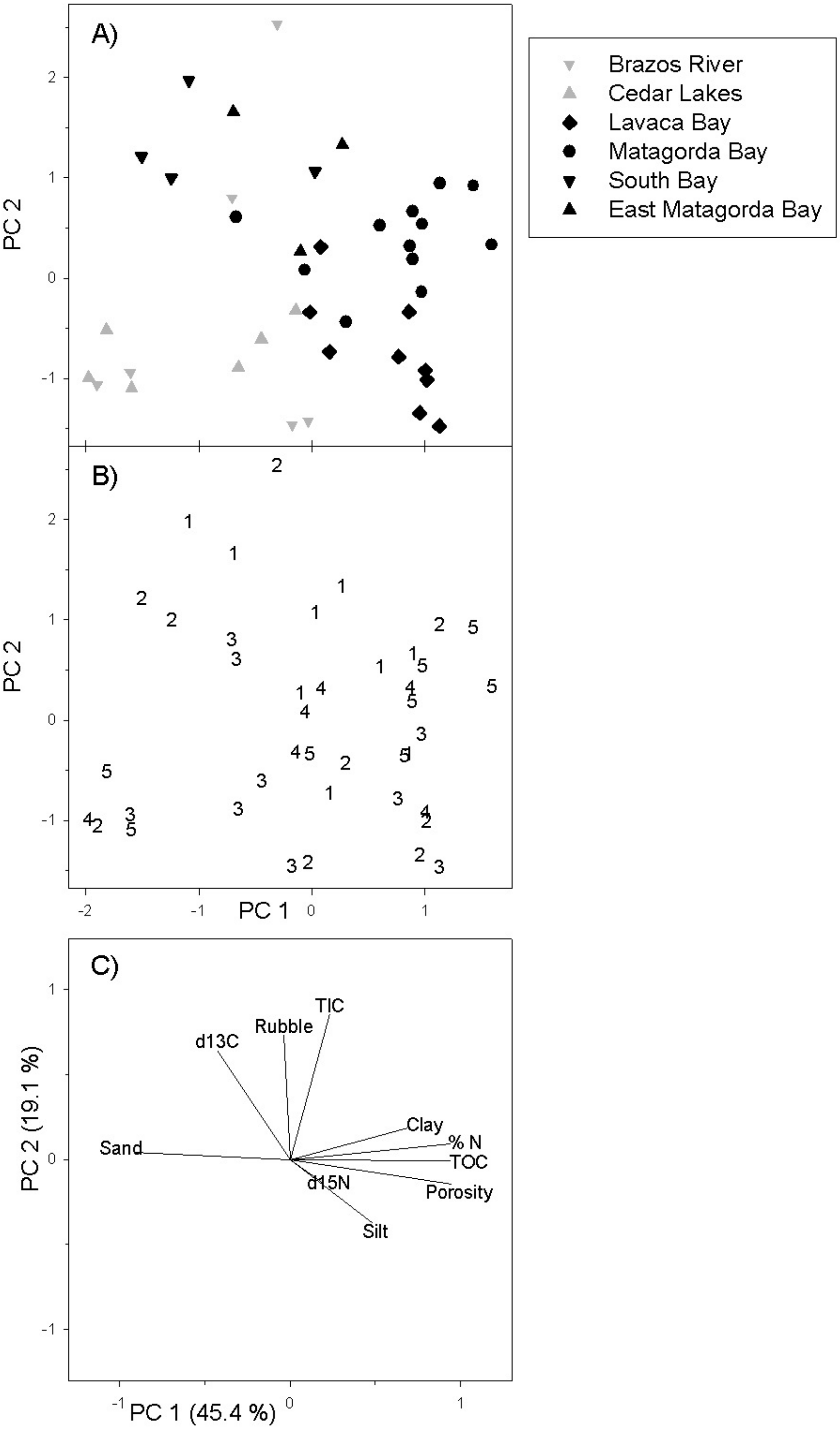

Figure 20: Plots of the first two principal components (PC) resulting from analysis of sediment quality data in minor and major bays (Ho_2). A) PC station-date scores labeled by estuary, B) PC station-date scores labeled by fiscal year, and C) PC loadings.

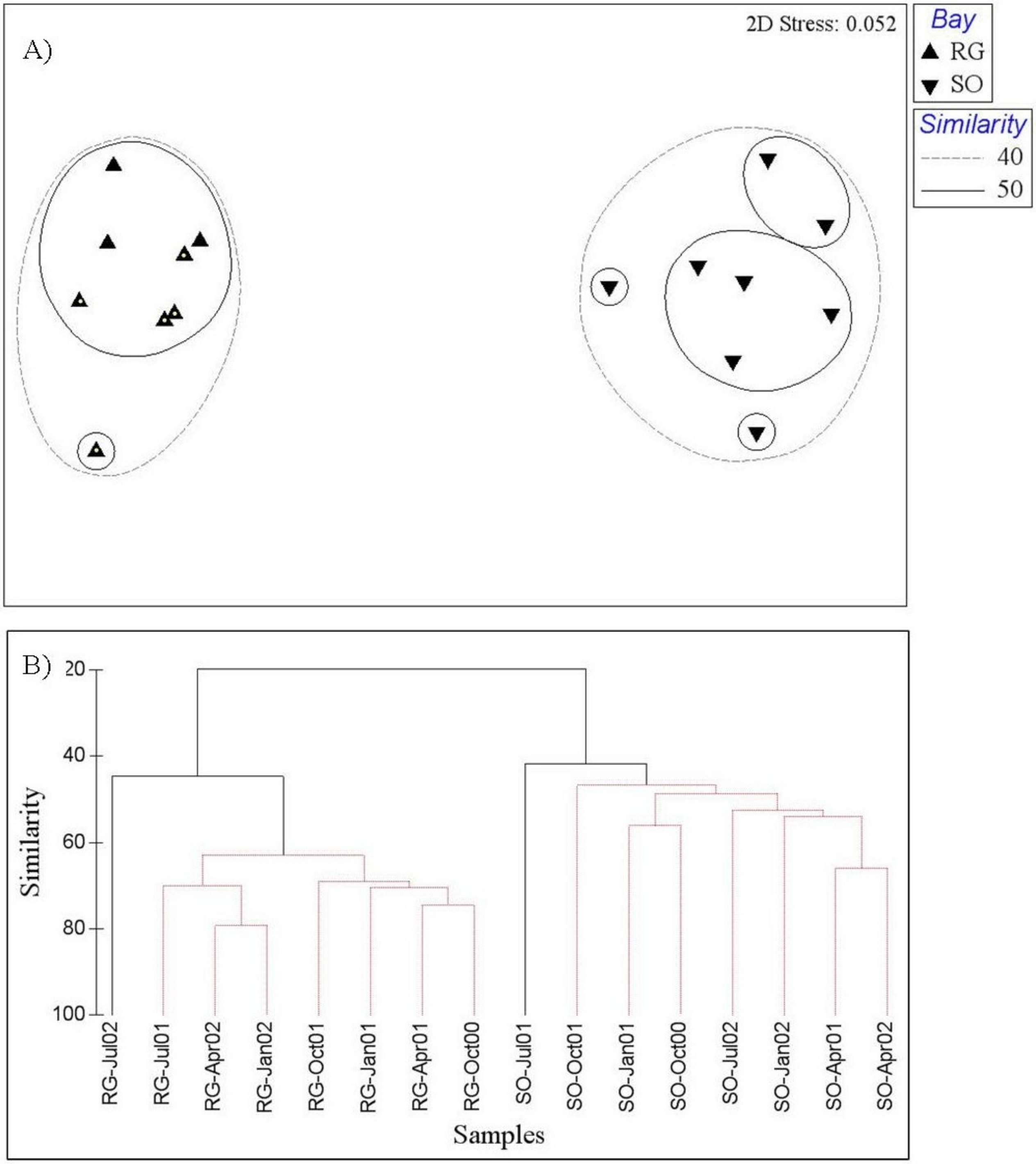

Figure 21: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in the Rio Grande (RG) and South Bay (SO; Ho$_3$) averaged by date, overlaid with similarity contours from cluster analysis (B). Triangles with white dots indicate that the Rio Grande mouth was blocked on that sampling date. Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

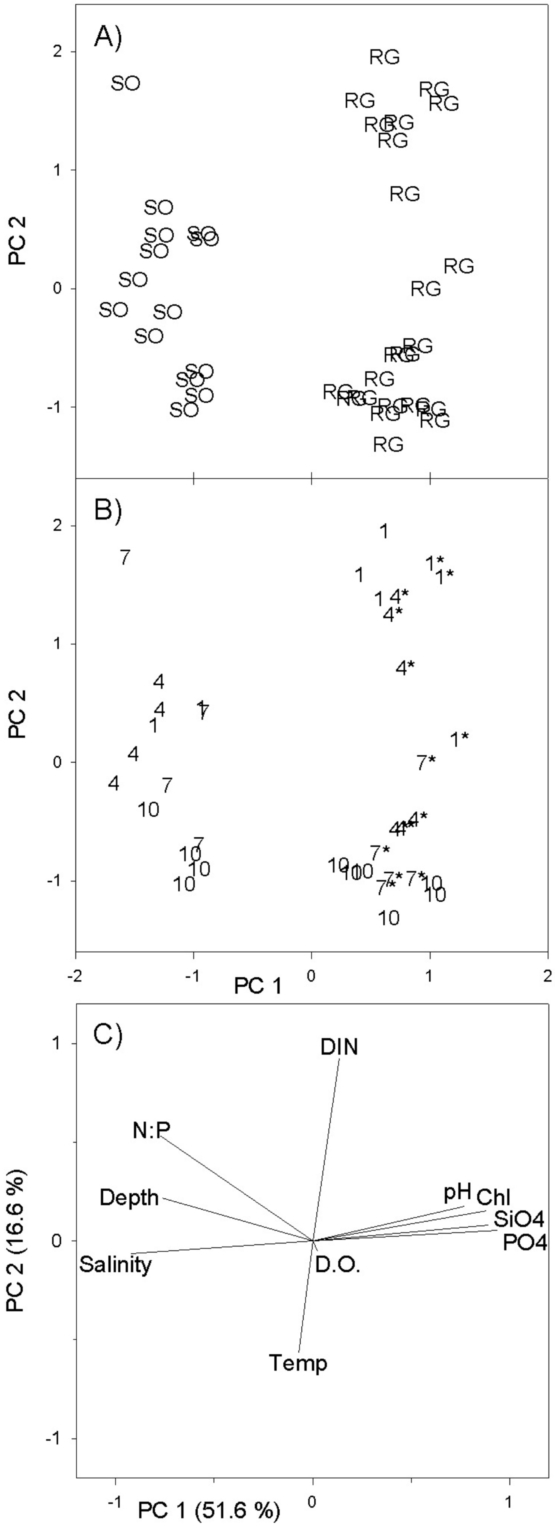

Figure 22: Plots of the first two principal components (PC) resulting from analysis of water quality data for South Bay and Rio Grande (Ho$_3$). A) PC station scores labeled by estuary, B) PC station scores labeled by month number and C) PC loadings. SO=South Bay, RG=Rio Grande, 10=Oct 2000, 1=Jan 2001, 4=April 2001, 7=July 2001. Month numbers with asterisks beside them represent months when the Rio Grande was closed to the Gulf of Mexico.

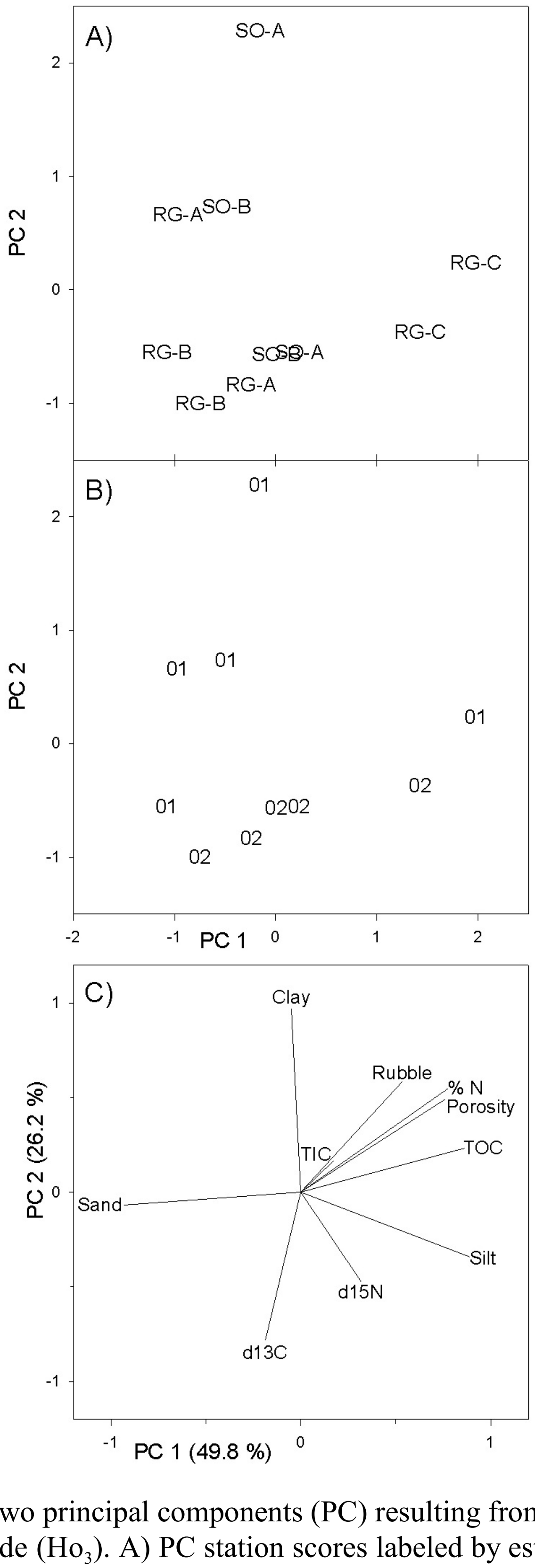

Figure 23: Plots of the first two principal components (PC) resulting from analysis of sediment data for South Bay and Rio Grande (Ho_3). A) PC station scores labeled by estuary, B) PC station scores labeled by sampling month and C) PC loadings. SO=South Bay, RG=Rio Grande.

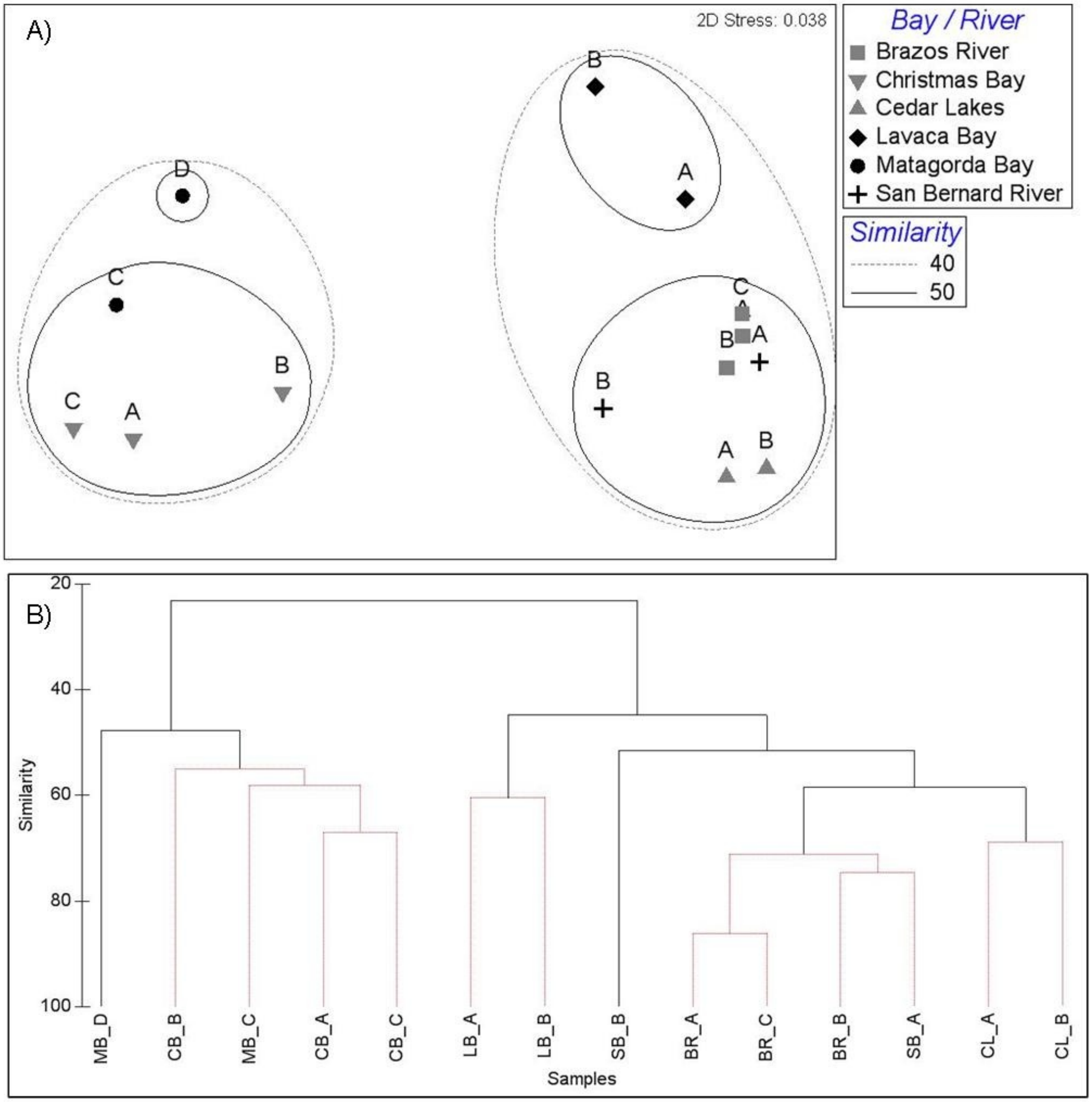

Figure 24: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in Matagorda, Lavaca and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_4), averaged by station for each sampling quarter in the 2003 fiscal year, overlaid with similarity contours from cluster analysis (B). Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

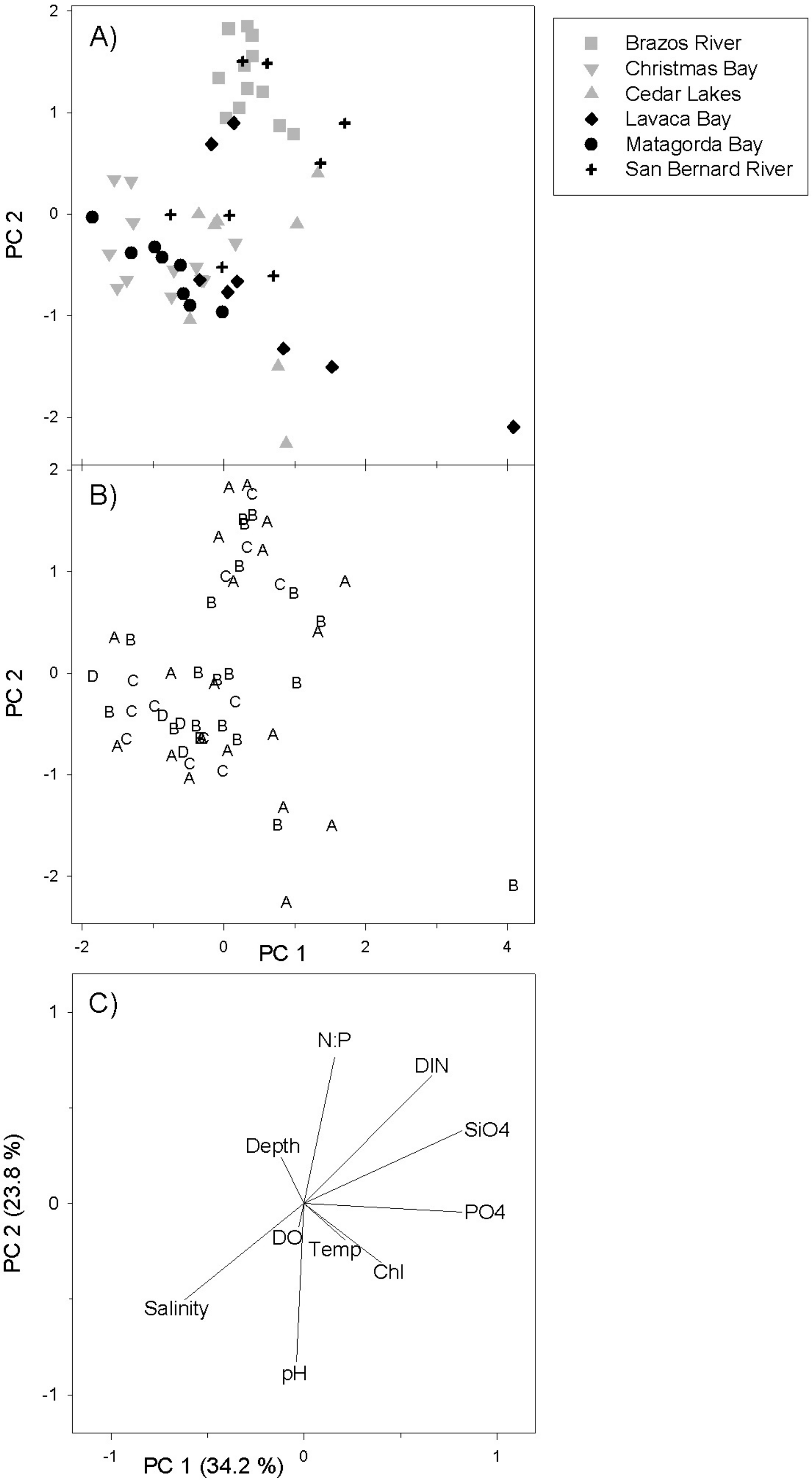

Figure 25: Plots of the first two principal components (PC) resulting from analysis of water quality data for Matagorda, Lavaca, and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_4). A) PC station scores labeled by estuary and station and B) PC loadings.

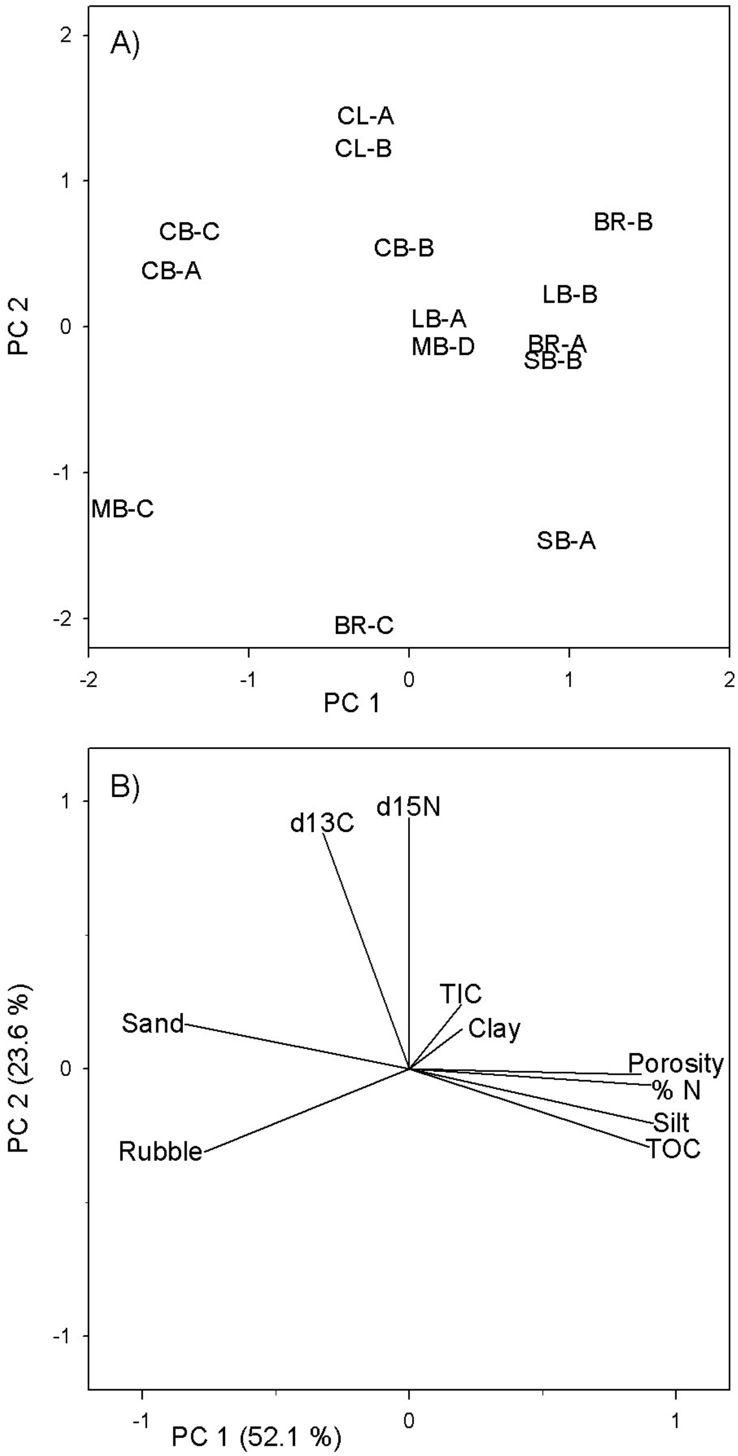

Figure 26: Plots of the first two principal components (PC) resulting from analysis of sediment data for Matagorda, Lavaca, and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_4). A) PC station scores labeled by estuary-station and B) PC loadings. CL=Cedar Lakes, CB=Christmas Bay, SB=San Bernard River, BR=Brazos River, MB=Matagorda Bay, LB=Lavaca Bay.

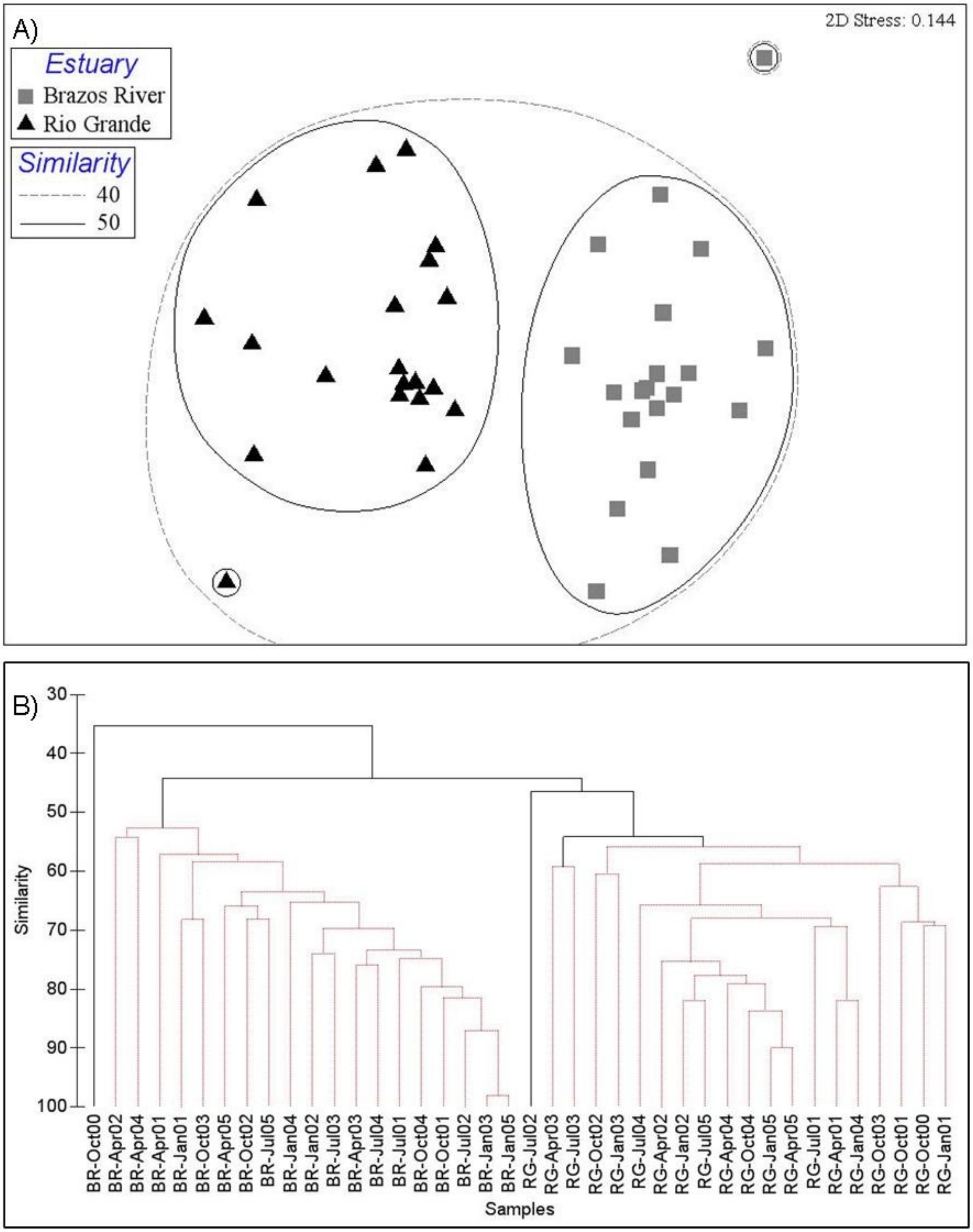

Figure 27: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in the Rio Grande and Brazos Rivers (Ho_5) averaged by sampling month from fiscal years 2001 to 2005, overlaid with similarity contours from cluster analysis (B).

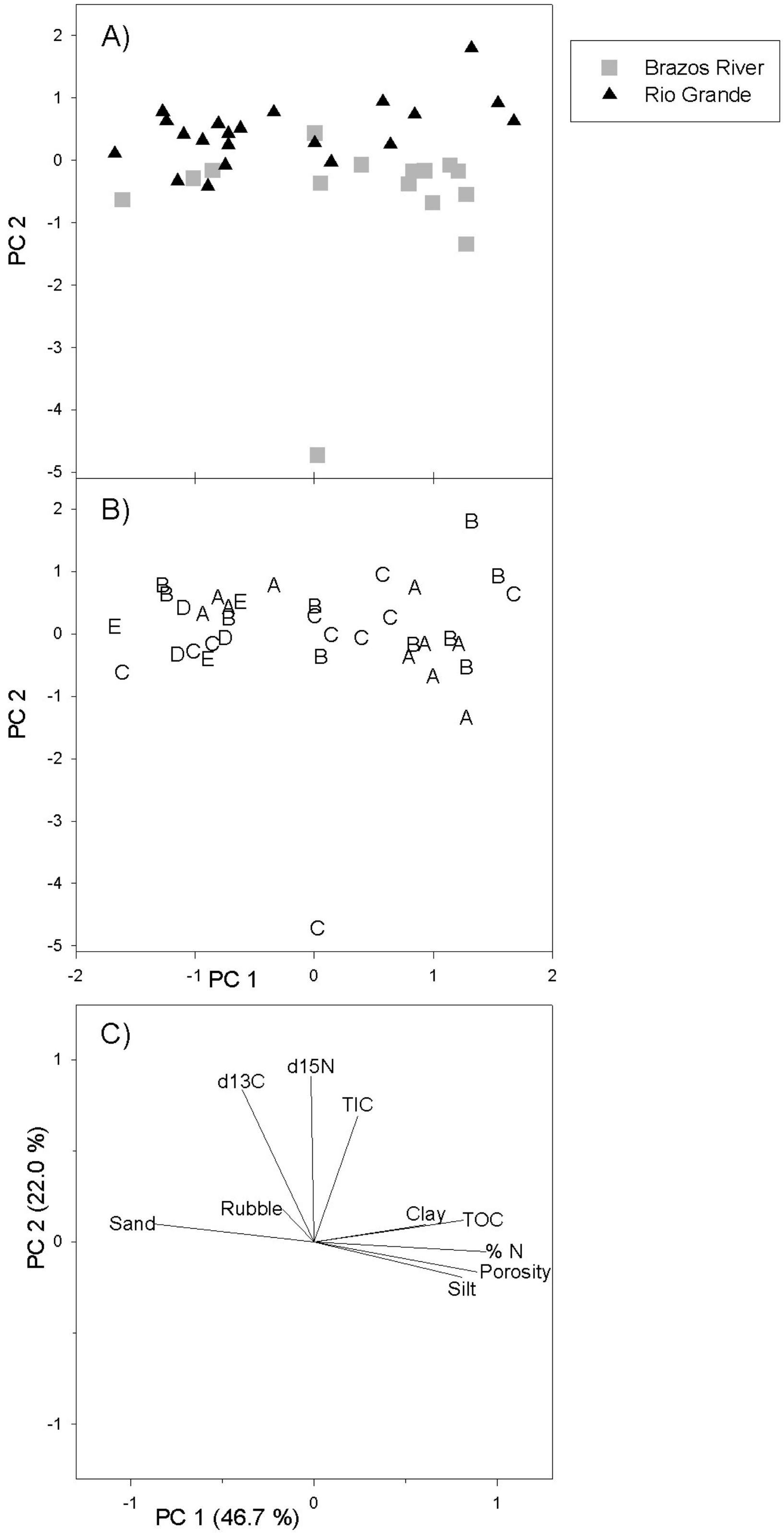

Figure 28: Plots of the first two principal components (PC) resulting from analysis of sediment data for the Rio Grande and Brazos Rivers (Ho_5). A) PC station scores labeled by river, B) PC station scores labeled by station and C) PC loadings.

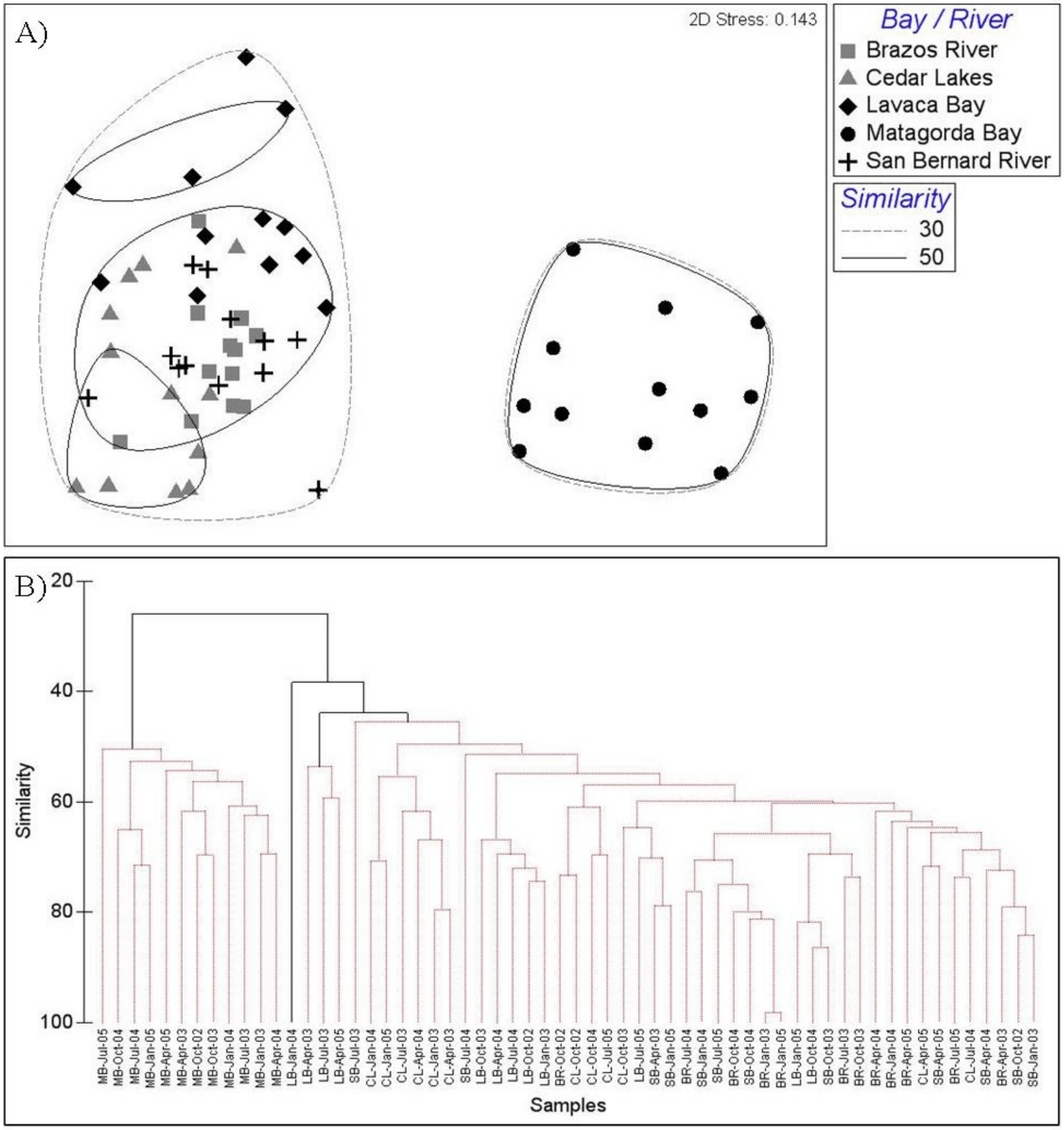

Figure 29: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in Matagorda and Lavaca Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_6), averaged by station for each sampling quarter in the 2003 - 2005 fiscal years, overlaid with similarity contours from cluster analysis (B). Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

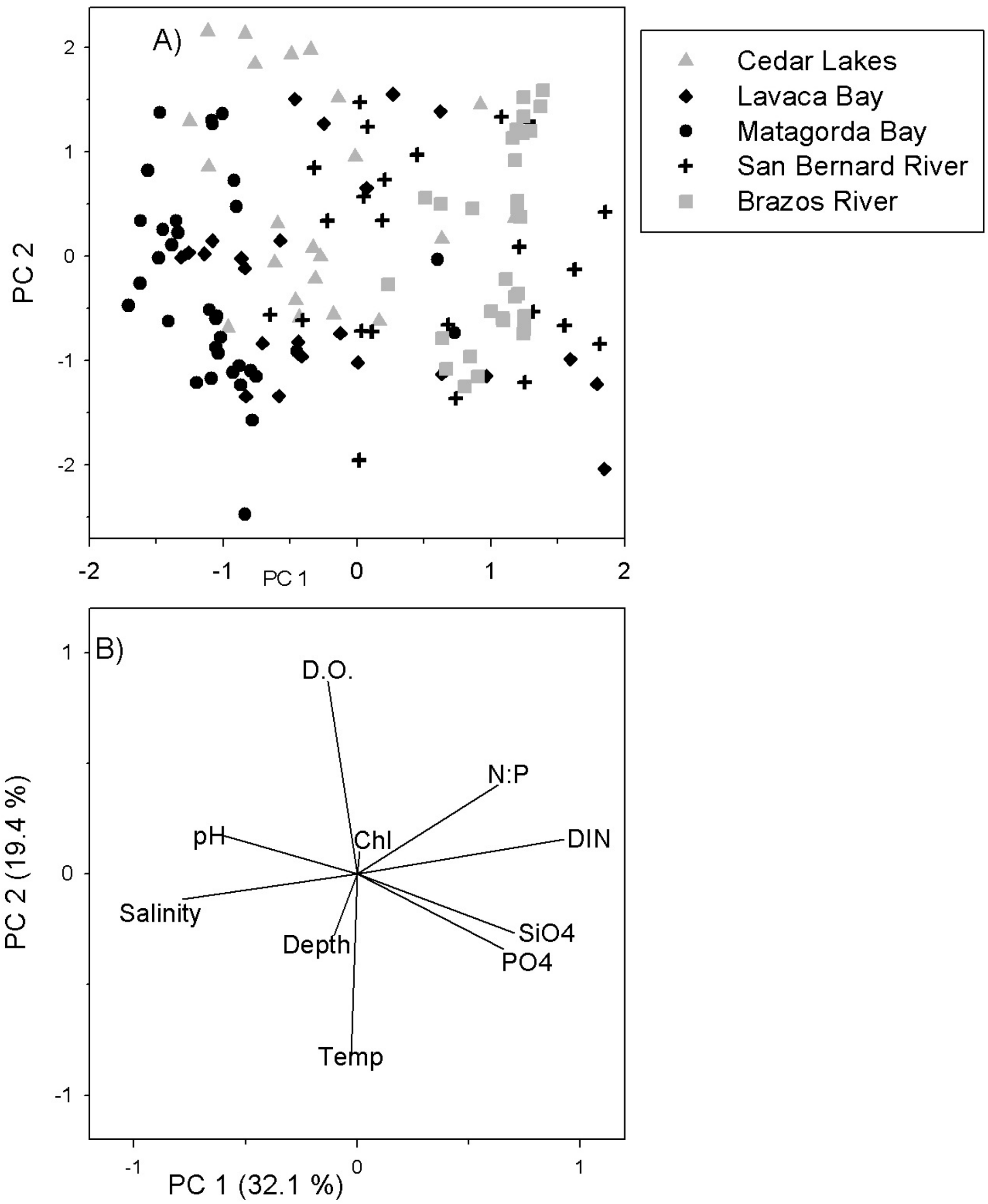

Figure 30: Plots of the first two principal components (PC) resulting from analysis of water quality data for Matagorda, Lavaca, and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_6).

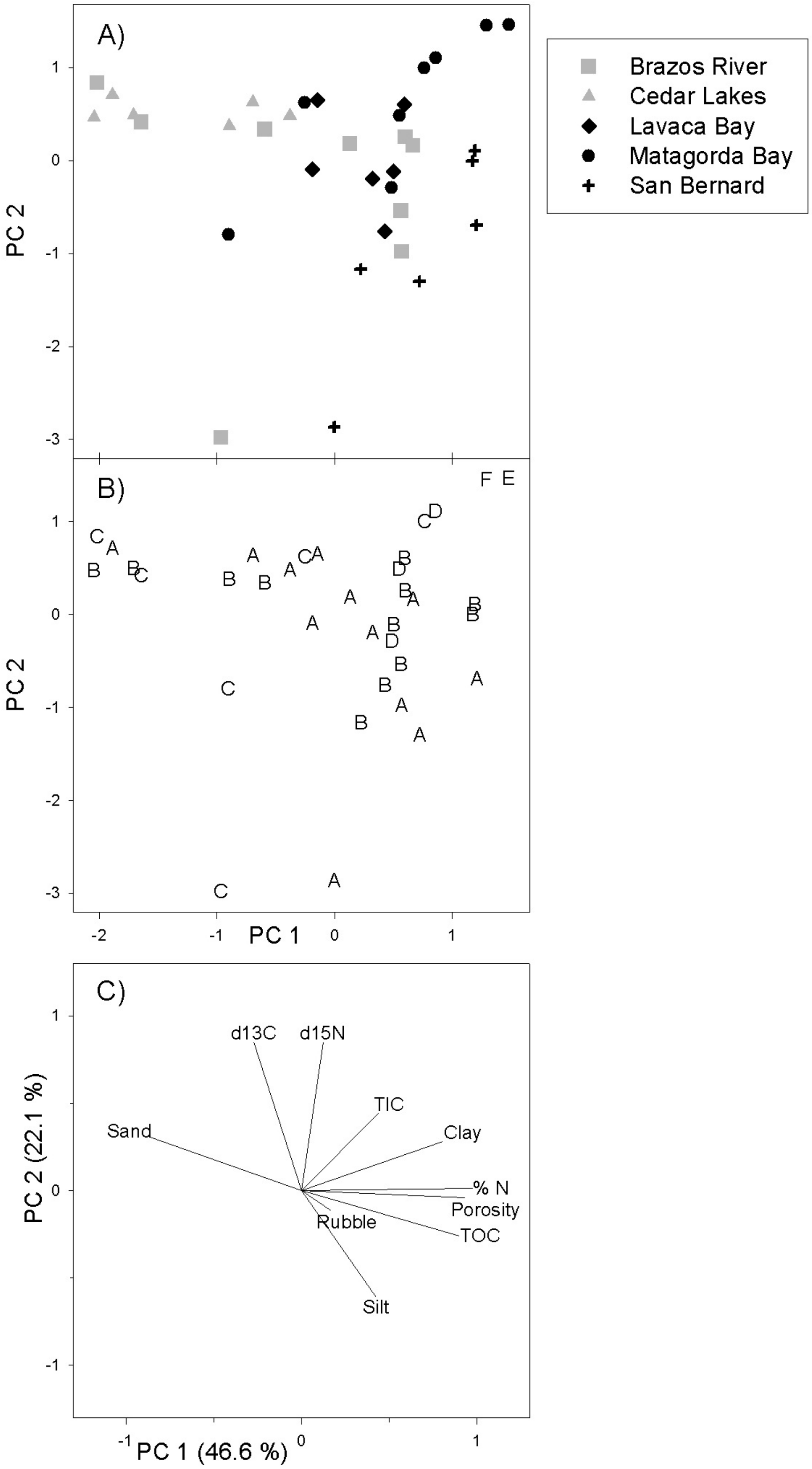

Figure 31: Plots of the first two principal components (PC) resulting from analysis of sediment data for Matagorda, Lavaca, and Christmas Bays, Brazos and San Bernard Rivers and Cedar Lakes (Ho_6). A) PC station scores labeled by estuary, B) PC station scores labeled by station and C) PC loadings.

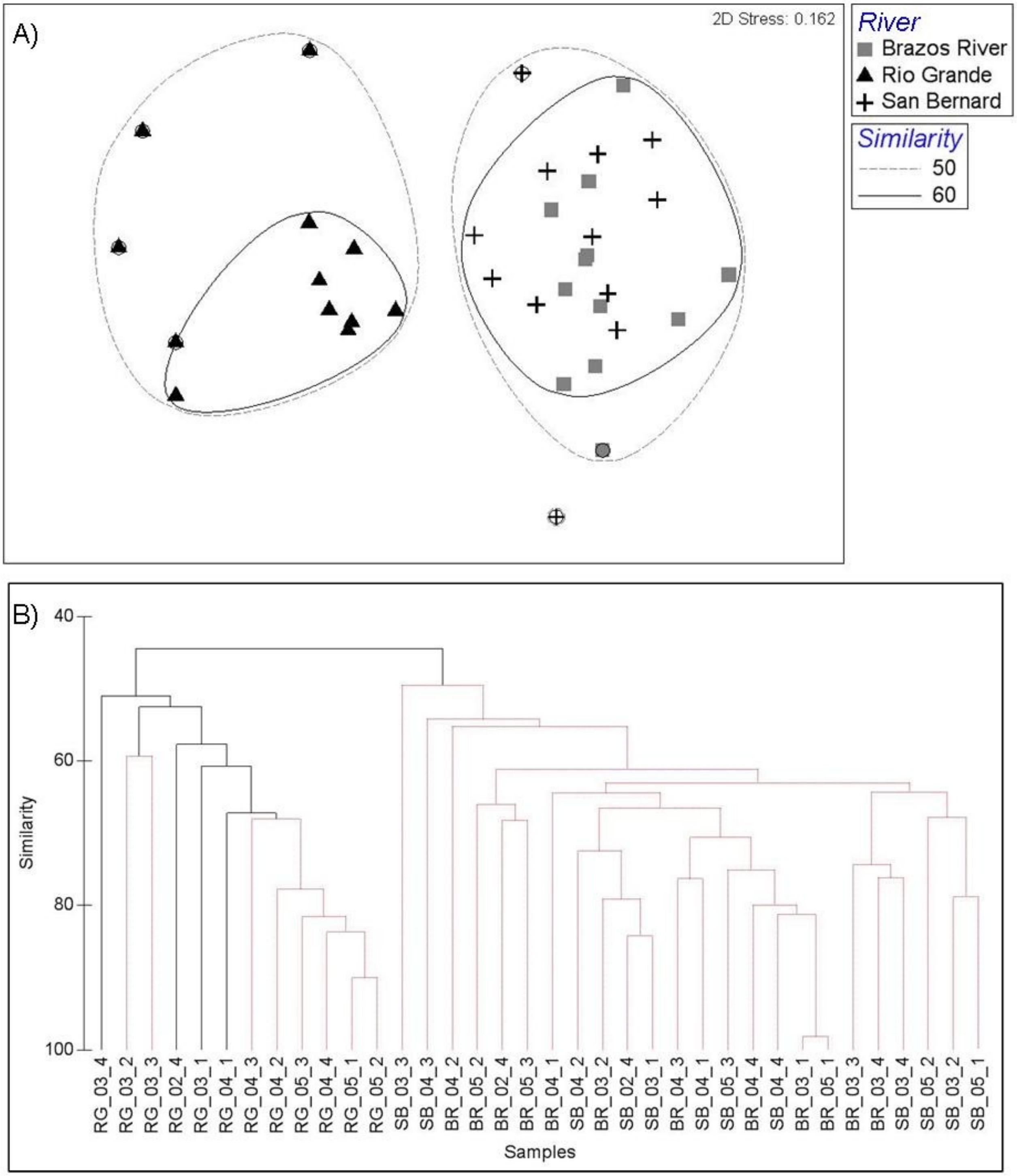

Figure 32: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in the Rio Grande, San Bernard and Brazos Rivers (Ho_7) averaged by sampling month from fiscal years 2002 to 2005, overlaid with similarity contours from cluster analysis. (A) Multi-Dimensional Scaling plot. (B) Clusters of macrofauna assemblages are significantly different to each other if they are separated by solid lines in the cluster analysis.

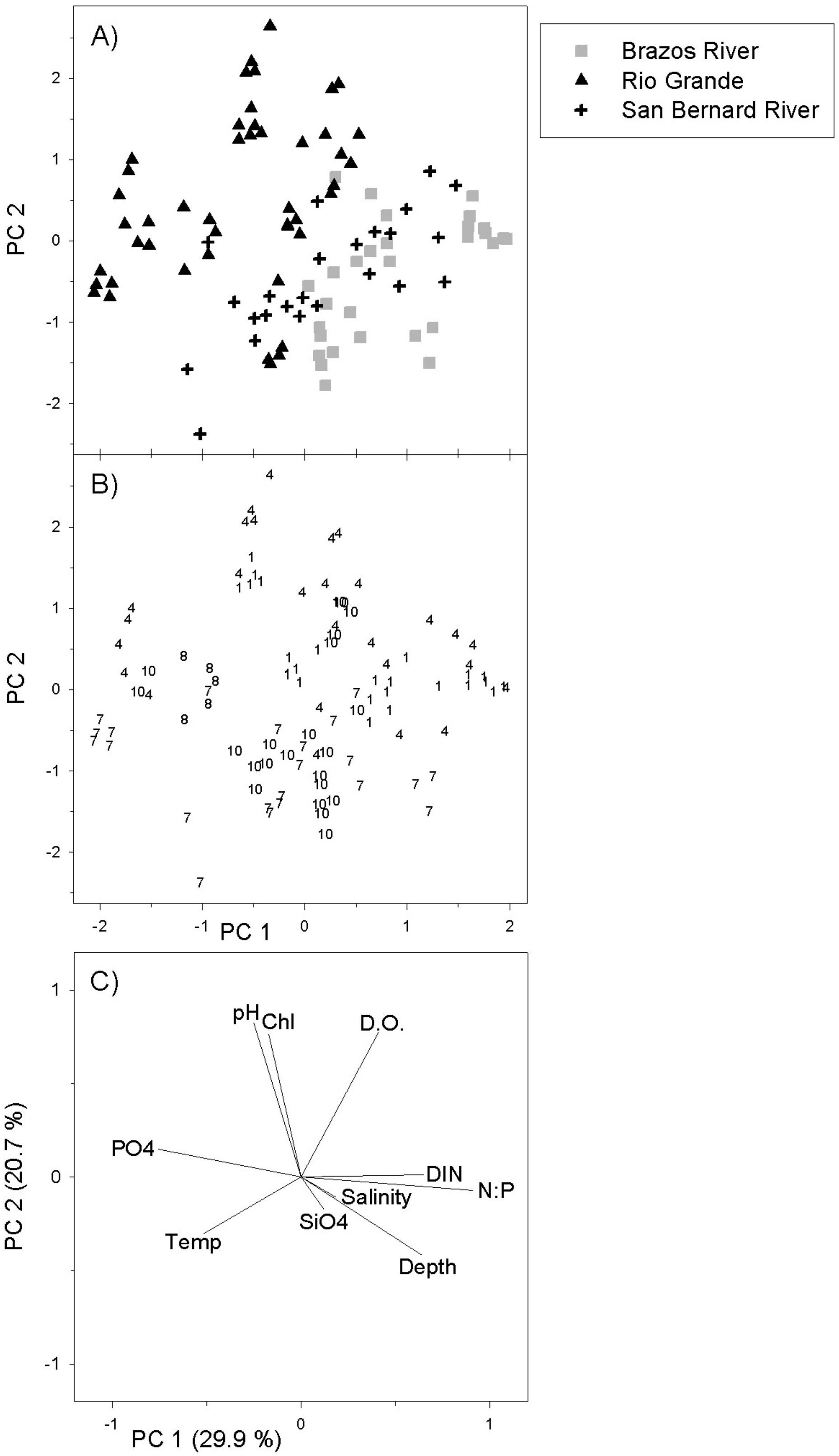

Figure 33: Plots of the first two principal components (PC) resulting from analysis of water quality for the Rio Grande , San Bernard and Brazos Rivers (Ho_7). A) PC station scores labeled by river, B) PC station scores labeled by month number and C) PC loadings.

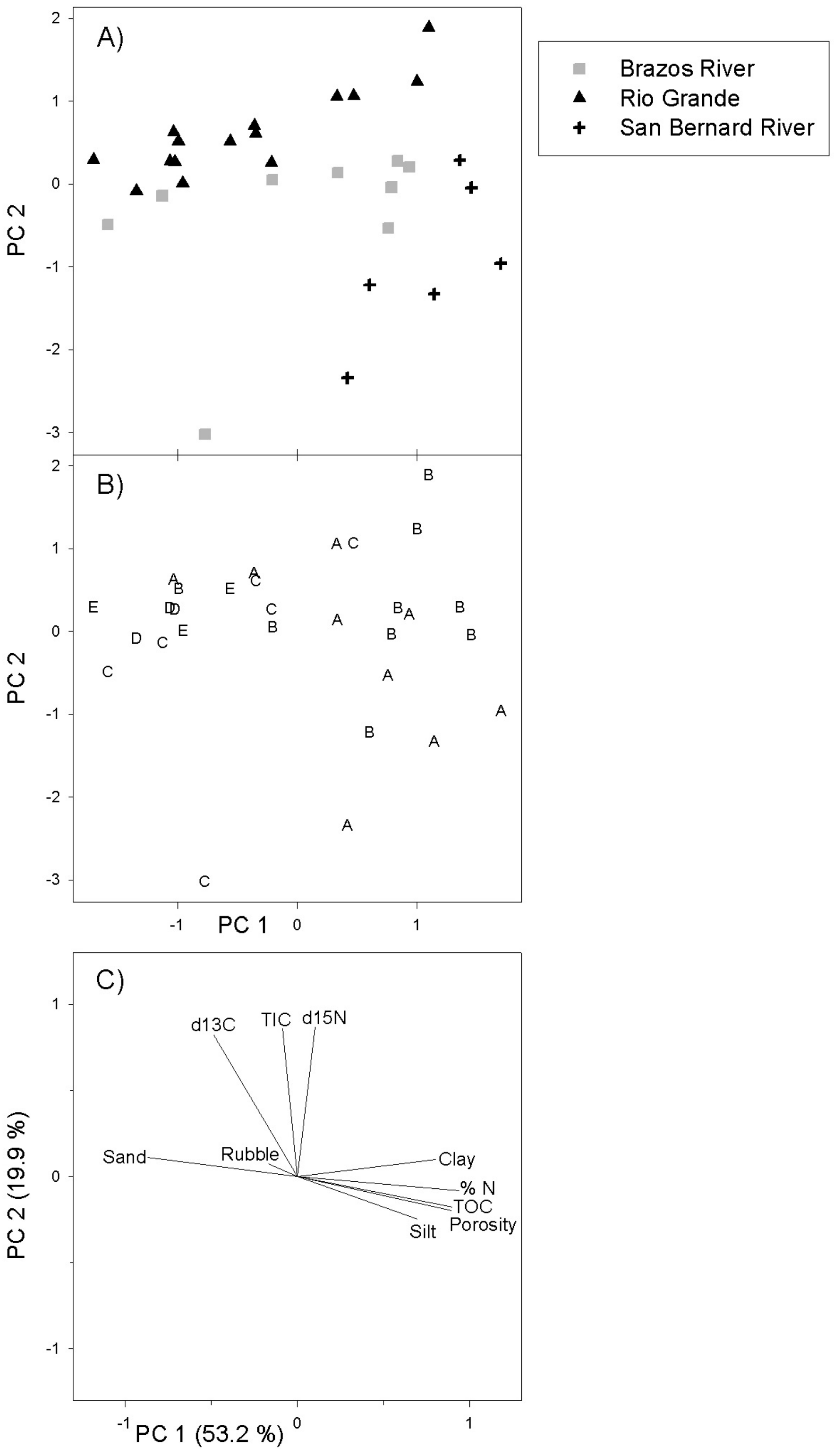

Figure 34: Plots of the first two principal components (PC) resulting from analysis of sediment data for the Rio Grande , San Bernard and Brazos Rivers (Ho_7). A) PC station scores labeled by river, B) PC station scores labeled by station and C) PC loadings.

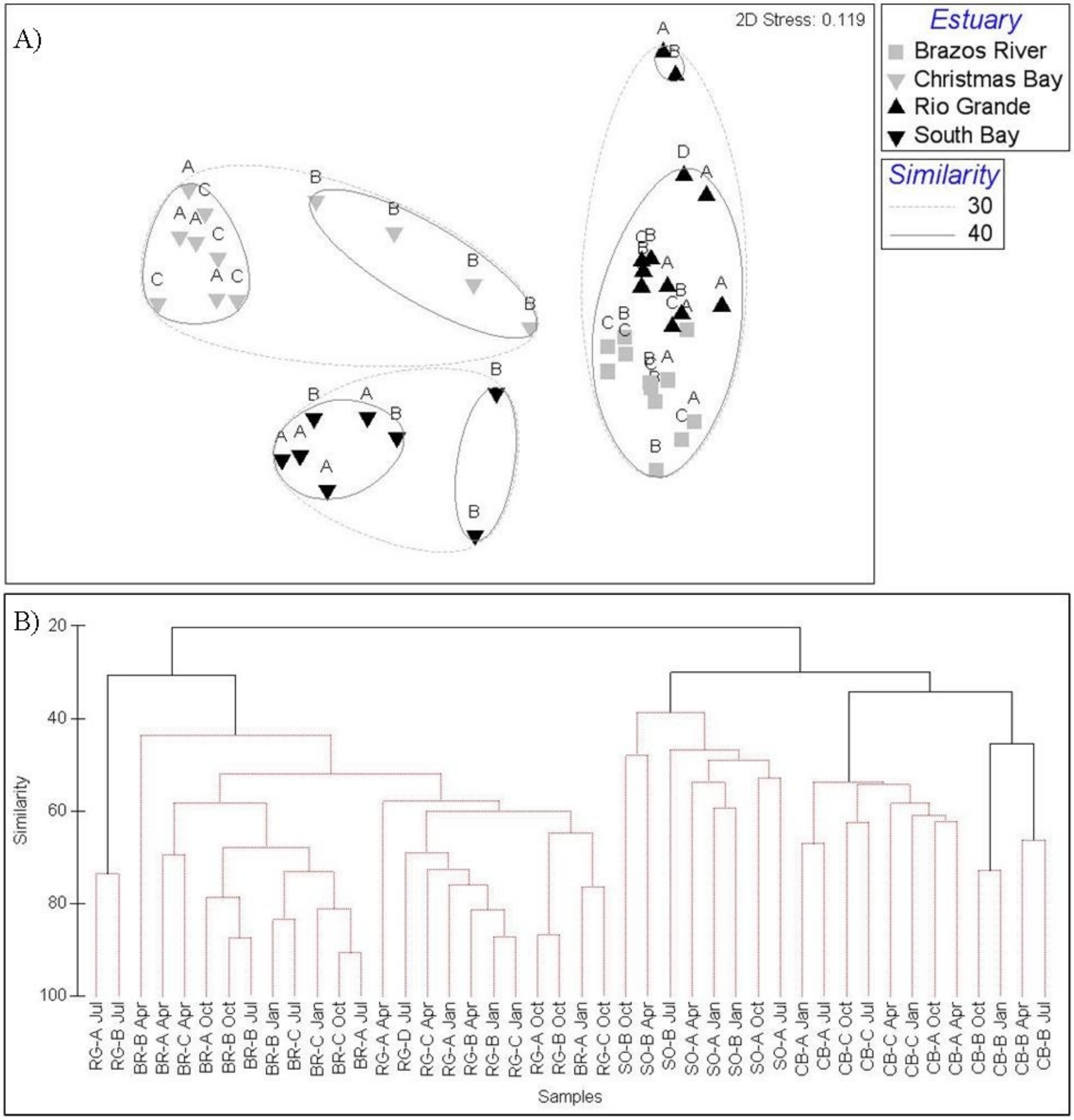

Figure 35: Multi-Dimensional Scaling plot (A) of macrofauna species abundances in Christmas and South Bays, Brazos River and Rio Grande (Ho_8), averaged by station for each sampling quarter in the 2002 fiscal year, overlaid with similarity contours from cluster analysis (B). MDS points are labeled by station letter. Clusters of macrofauna assemblages are significantly different to each other if they are separated by black lines in the cluster analysis.

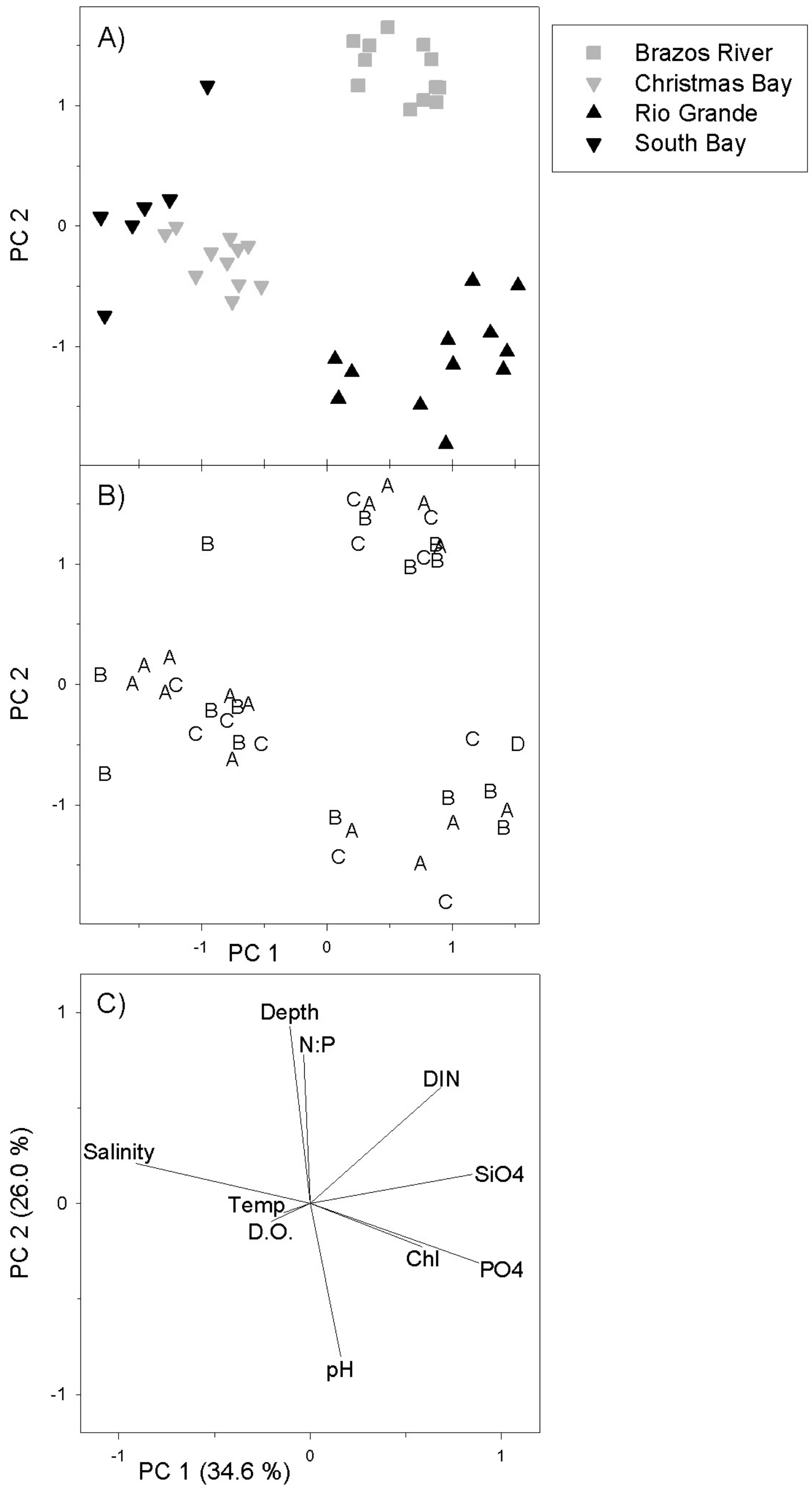

Figure 36: Plots of the first two principal components (PC) resulting from analysis of water quality for the Brazos River, Rio Grande, Christmas Bay, and South Bay (Ho_8). A) PC station scores labeled by estuary, B) PC station scores labeled by station and C) PC loadings.

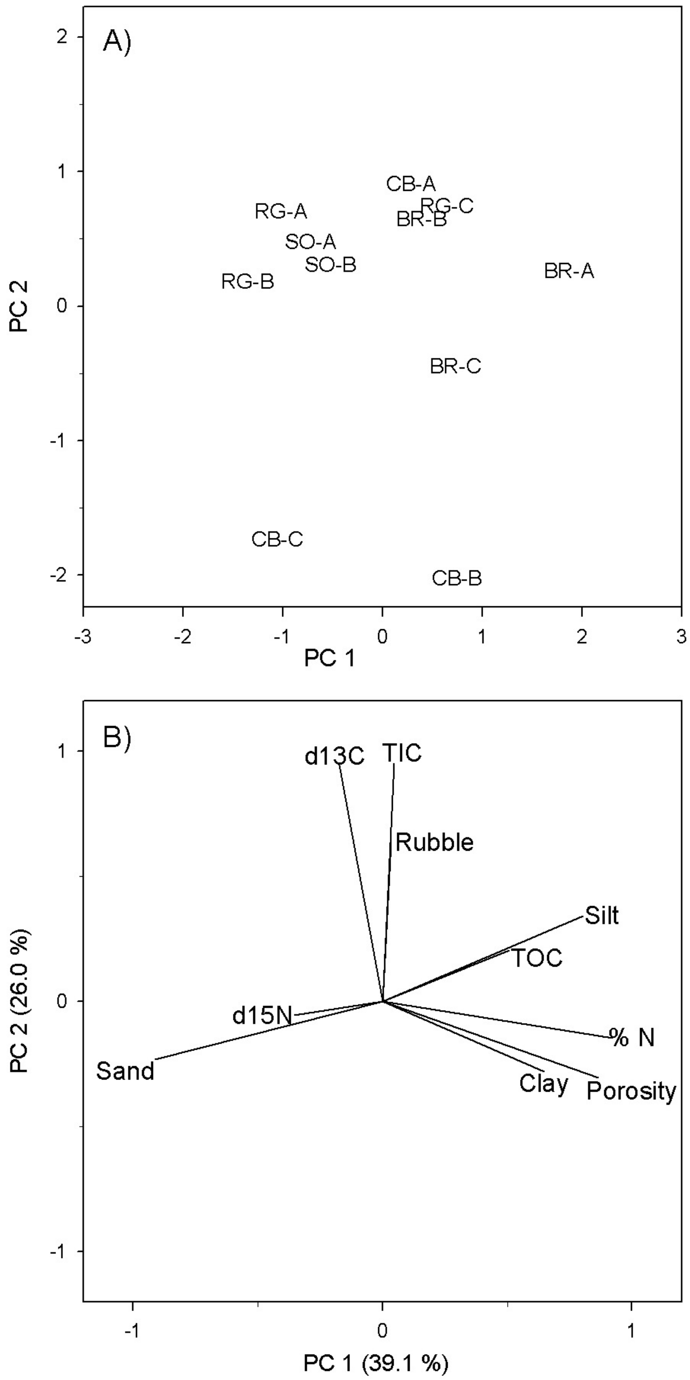

Figure 37: Plots of the first two principal components (PC) resulting from analysis of sediment for the Brazos River, Rio Grande, Christmas Bay, and South Bay (Ho$_8$). A) PC station scores labeled by estuary-station and B) PC loadings.

TWDB REVIEW AND RESPONSE

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January 28, 2008

Paul A. Montagna, Ph.D.
Principal Investigator
Harte Research Institute
Texas A&M University–Corpus Christi
6300 Ocean Drive, Unit 5869
Corpus Christi, Texas 78412-5869

Re: Research and Planning Fund Contract between the Texas Water Development Board (TWDB) and the University of Texas at Austin, Marine Science Institute (UTMSI), TWDB Contract No. 2006483026, Draft Final Report Comments

Dear Dr. Montagna:

Staff of the TWDB have completed a review of the draft report prepared under the above-referenced contract. ATTACHMENT I provides the comments resulting from this review. As stated in the TWDB contract, UTMSI will consider incorporating draft report comments from the EXECUTIVE ADMINISTRATOR as well as other reviewers into the final report. In addition, UTMSI will include a copy of the EXECUTIVE ADMINISTRATOR's draft report comments in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and nine (9) bound double-sided copies. UTMSI shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

If you have any questions concerning the contract, please contact Dr. Carla Guthrie, the TWDB's designated Contract Manager for this planning project at (512) 463-4179.

Sincerely,

William F. Mullican, III
Deputy Executive Administrator
Water Science and Conservation

Enclosures
c: Carla Guthrie, Ph.D., TWDB

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To provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas.
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Attachment I
Draft Final Report Review

Effect of Freshwater Inflow on Macrobenthos Productivity in Minor Bay and River-Dominated Estuaries - A Synthesis

Paul A. Montagna, Ph.D.

#2006-483-026

TWDB comments to final draft

<u>General Comments:</u>

This report is the conclusion and synthesis of results from a five year study designed to determine benthic invertebrate responses to freshwater inflows in various minor bay and river-dominated estuaries along the coast of Texas. The goal of the study is to demonstrate that estuarine benthic communities need established minimum inflow requirements to maintain community structure and productivity. The project collected much needed benthic community data along with measures of water quality and sediment characteristics, and the project provides useful descriptive information about the similarities and differences of benthics among different estuarine ecosystems. Specifically, the *Scope of Work* states that the report will:

> 1) Synthesize existing benthic data *to determine temporal and spatial variability* of *benthic characteristics related to freshwater inflow.*
>
> 2) Provide a literature review to *frame the context of benthic invertebrate response to inflow and salinity and to provide* a *context for interpreting the results.*

While the report succeeds in synthesizing previously collected benthic community data over spatial scales (or more aptly among different geographic locations), the report does not adequately address temporal changes in the communities and most importantly, the report does not directly relate benthic community responses to measures of freshwater inflow (such as, mean annual inflow; inflow in the period prior to sampling, etc.). The report instead relies on proxies of inflow, including geographic location, salinity, and sediment characteristics. It is suspected that the previous five annual reports contain more information about spatial and temporal responses of these benthic communities. As such, this point only needs to be referenced in the current report. However, this report should more strongly address the relationship of benthic response to freshwater inflow. If direct measures of inflow cannot be included in the analyses, then it will be helpful to list site-specific characteristics of hydrology and meteorology for the existing period of record and for the study period. The report should then include a discussion of the observed results in relation to long-term and short-term patterns of hydrology. In the current form, the report does not highlight the conclusion that minimum inflow requirements are needed and related to the defined tipping point of 17-21 ppt. Please expand the discussion of this point, and put this in a separate *Conclusions* section.

Finally, the report does not include much of a literature review, and it is recommended that the first introductory paragraph be expanded to provide more information to help frame the results of the study. The *Discussion* section in general is poorly written and not consistent with earlier parts of the report. Throughout the report, but particularly in the *Discussion,* many places in the report have extra spacing, missing commas, inconsistent notation, verb tense changes, etc. Several times San B~rnard is used. The correct spelling is San B~rnard. Also, Rio Grande River is incorrect. Prefer usage of *river estuary* rather than *rivers;* likewise, prefer use of *estuaries* rather than *bays,* since the study includes rivers and bays. Please thoroughly review the report to correct these issues.

<u>Additional Comments:</u>

The report fails to relate benthic community variability to freshwater inflows into minor bays and estuaries of Texas. No direct measures of the components of freshwater inflows (such as discharge, nutrients, and TSS) were made or otherwise used in the study. Contrary to what the report states, four times per year and 2-4 per bay point measurements of the in-bay salinity, nutrients, chlorophyll-a, etc. are inadequate measures of the freshwater inflow characteristics for those bays. Furthermore, four times per year and 2-4 per bay point measurements are inappropriate measures to use when trying to relate to benthic abundance, biomass and diversity since benthic organisms "integrate changes in temporal dynamics of ecosystem factors over long time scales and large spatial scales" (p. 1-2 of the draft report). Appropriate measures to use would be of some factors somehow aggregated over large spatial and temporal scales. Differences between bays and across time detected with ANOVA, non-metric MDS, and cluster analysis are incidental and can be attributed to any measured or unmeasured property or properties of those bays and not just to the unknown freshwater inflows. The report fails to answer the question implied in the scope of work: if a freshwater inflow (discharge, nutrients, TSS, etc) into a specific bay changes by some amount, what changes (i.e. "effect") do we expect in the bay's benthic biomass, abundance and diversity?

Specific Comments:

Section - Page	**Comment**	**UT-MSI Response**
Abstract - pg. v	3rd ¶; Check spelling of "San Bernard" throughout document	Done
	" ... 2) determine how climate affected the individual systems". Change climate to hydrology or inflows.	Climate is correct because there is a natural climatic gradient along the Texas coast
	3rd ;¶ According to abundance and biomass the x-number of samples sites can be divided into 3 groups, but the "coast" itself is not so easily divided, since RG and CL characterize mid-range sites .. but are widely separated geographically.	Done
	4rd ¶; State in the first sentence the two macrofaunal groupings (brackish and oligohaline), waiting until the last sentence leaves the reader to wonder and then retrace the words to figure out which group is brackish and which is oligohaline. Moreover, why was this designation assigned to each group?	Done
	What are the characteristic species of brackish v oligohaline? Why aren't these designations mentioned in the Results and Discussion?	Done
Acknowledgments - pg. vi	Last sentence; "benefitted" should be "benefited"	Done
Introduction – pg. 1	1st ¶, last sentence; Should "result of these studies is to ..." be "result of these studies has been to ... "	Amended
Methods, Study Area and Sampling Design - pg. 3	Last ¶ of section beginning with, "During each sampling period ... ": Provide the relationship (and reference) that allows one to "determine" inflow characteristics from measuring salinity, nutrients and chlorophyll in a bav	Word ‘inflow’ deleted. The relationship between flow and water column responses is described in ‘statistical methods’ section.

Methods, *Hydrographic Measurements* - pg. 3	Use consistent form of: mg/l or mg l^{-1}. Also, the term Hydrographic Measures is uncommon, would *Water Quality* be OK?	Done Done
	5th sentence; change "Salinities" to "Salinity"	Done
	spell pH correctly, clarify what "depths" are discussed	Done
Methods, *Hydrographic Measurements* - pg. 4	Top paragraph; Provide accuracy for salinity and depth.	Provided accuracy for salinity. Accuracy for depth is based on human error, so difficult to determine
Methods, *Chlorophyll...* - pg.4	Specify the type of glass fiber filter used.	Done
Methods, *Analytical Approach* - pg. 5	The 2nd approach, "within-system approach" is not included in the results. Please add.	Added
Methods, *Analytical Approach* - pg. 6	Top paragraph, 1st sentence; poor wording and improper punctuation	Done
	H_{04} hypothesis: run-on sentence	Done
	Last ¶ on page; The hypothesis (as well as all others) does not test for the climatic zone effect (or any other effect) because there was no random assignment of identical bays to different climatic zones. While the claimed effect may exist, the apparent effect (if present) can also be due to nutrient, temperature, tidal or infinite number of other known and unknown differences between the systems. So, there is no way of knowing if any difference is due to the difference in climatic zones (or any other specifically stated difference).	This statement is incorrect. There is no requirement for a “random assignment,” because this is a fixed effects design. The fixed effects are the bays sampled, and they are explicitly located in different climate zones of the State. We recognize that factors other than climate effect the bay, and this is why all the ancillary measurements of water and sediment quality are made and related to benthic response. No changes made.
Methods, *Statistical Methods* - pg. 7	No justification was given as to why the data were log-transformed. Did they need to be transformed to meet assumptions of analyses?	While there are no normality assumptions for non-parametric tests, transformation is a standard statistical procedure to improve test performance as cited in the reference.
Methods, *Statistical Methods* - pg. 9	When Primer is first mentioned, reference the version and Clarke and Gorely at that time.	Done
Results, *Within-System Approach -* pg. 9	This section is missing from the report. If this information is contained in the individual reports and therefore does not need to be repeated here, please reference those reports.	Added
Results, *Hypothesis-driven Approach -* pg. 9	Under H_{01}; Please define the use of "N1" as "untransformed data" -- this wasn't immediately clear.	It means the data was not log transformed

	Under H_{o1}: When referring to grouping of data points on a graph (here and elsewhere), use a numeric measure (such as similarity within and between groups) rather than visual appeal.	The results section is replete with specific numeric values.
	Under H_{o2}; Change subheading to read "Comparison of All Minor Bay and River-dominated Estuaries"	Done
Results, H_{o3}- pg. 11	How did the Rio Grande closure affect long-term patterns?	Done
Results, H_{o3}- pg. 12	Re: Figure 16 and text; The Brazos outlier data point is mentioned, but not the Rio Grande outlier. Please add comment about this point.	Done
	1st ¶, 3rd sentence; these are rivers not bays, so change "in each bay" to "in each estuary".	Done
	1st ¶, 41h sentence; Table 6 should be Table 7	Done
	3rd ¶; Which are wet/dry years in this discussion?	Done
Results, H_{o6}- pg. 13	1st ¶; 2nd sentence; change "constituted" to "consisted"	Done
	1st ¶, 6th sentence; Should the reference to Rio Grande macrofaunal community be Matagorda Bay instead?	Yes, changed
	2nd ¶, last two sentences; Did reference to PC1 and PC2 get switched?	Yes, changed
Results, H_{o7}- pg. 13	1st ¶; Should Table 7 be Table 9?	Done
Results, H_{o7}- pg. 14	2nd ¶, last sentence, instead of "physical differences within Bays ... " Use "estuaries",	Done
Results, H_{o8}- pg. 14	2nd ¶; 2nd to last sentence; " .. stations along PC?, while stations .. ," I think should read PC1?	Done
Discussion – Coast-wide approach - pg. 14	2nd ¶This paragraph says differences in hydrography were not observed. But, isn't this the main point of the study? What does this statement mean and how does Figure 10 show this?	Done
p. 14, last paragraph and other places in the report	"Differences in hydrography ... ". Change hydrography to water quality. Include reference to Figures 4 and 5 after this sentence.	Done
Discussion - Coast-wide approach - pg. 15	1st ¶; The phrase "This is likely due to nutrient loading from freshwater inflow" ... seems out of place given the prior sentence.	Done
	1st ¶; "The reference sites, Lavaca Bay and .... ". Include reference to relevant Figures.	Done
	2nd ¶; Change *"Macrofauna"* to *"Macrofaunal'*. Is the font size smaller for this paragraph?	Amended
	2nd ¶, 4th-sentence; *low biomass and*	Amended

	abundance are affected by flow velocities, but does high or low velocity cause low biom/abund?	
	2nd ¶, "Biomass and abundance ... (Figure 7)." It would be much easier to see the abundance-salinity relation if a separate plot of abundance vs. salinity were Provided.	Done
	3rd ¶; This paragraph talks about minor bays having higher diversity than river estuaries, but the last sentence talks about low diversity of minor estuaries, which is in contrast to earlier sentences. This paragraph needs more explanation. Also, is it "fluctuating water levels" or "fluctuating freshwater inflows"?	Fluctuating water levels. Paragraph improved but there is no inconsistency, because diversity increases with salinity, therefore, diversity is low at low salinities.
Discussion - System Approach - PQ. 15	Where is this section???	Inserted
Discussion - Hypothesis-Driven Approach - pg. 15	1st ¶, 1st sentence; remove the verb "have" and add *" .. .inflow from the Colorado River diversion; whereas, East Matagorda has .... "* This sentence needs to set up the contrast of inflow regimes for the two bays.	Done
	1st ¶, 3rd sentence; *"Matagorda and East Matagroda* ... ". Change Matagroda to Matagorda	Done
	2nd ¶, last sentence; This doesn't make sense; reword or remove.	Done
	3rd ¶, 1st sentence; change last word "location" to "reqion".	Done
Discussion - Hypothesis-Driven Approach - pg. 16	3rd ¶, 3rd sentence; Remove *"It does have direct communion,* ... " Replace with *"Although Christmas Bay* has *direct exchange with ...... with the GIWVV, previous studies have ... "*	Done
	3rd ¶, Item 3); Is spelling correct or is it *Streblosoio benedicti* ??	Spelling changed
	3rd ¶, Item 4); "community structure *represents* a climax community"	Done
	3rd ¶ last sentence; Cedar Lakes is hydrologically connected to the San Bernard and Brazos Rivers via inflow patterns. This *may* be part of the reason the communities are more similar than not.	Done
	4th¶, 1st sentence; Rio Grande and Brazos ARE larqe rivers.	Done
	4th ¶, 2nd sentence; *"Rio Grande Rivers"* is redundant (see also other sentences in paragraph).	Done
	4th ¶, 3rd sentence; Change to read *"The Rio Grand River has undergone ... "*	Done

	4th ¶, 4th sentence; Change to *"<u>In 2000,</u>* a *sand bar* ... "	Done
	4th ¶;*"The lake-like effect was evidenced by the decreasing salinities* ... " Is there a figure Showing this?	Done
	4th ¶, Figure 17; These PC graphics are not easy to read for the untrained eye, and it will be helpful if the text explains in more detail how it is that the figure demonstrates differences in hydrography. What constitutes measures of hydrography in this analysis? Additionally, I suggest using " .. and macrofaunal communities ...	Done
	4th ¶; Rio Grande closure and openings: are these dates correct? Mouth closed in Feb 2001 and was opened in July 2001; Mouth closed again in Nov. 2001, remained closed for a year, until natural breach occurred in Nov. 2002 from local heavy rains. Since 2002 the channel has remained opened. This entire section needs to be corrected.	Done
	4th ¶; Sentence beginning *"It is ironic ... "* is unclear, moreover, the Brazos has a connection not multiple connections with the GOM	Amended
	4th¶; Re-write the last sentence.	Done
	5th ¶; Change Figure 21 to Figures 4 and 5.	Done
Discussion - Hypothesis-Driven Approach - pg. 17	6th,·¶;As written the conclusion leads the reader to believe the Rio Grande is more fresh (on average) than the other upper coast rivers. If this is true, OK - but I suspect this is the case only for this study period, due to the closure of the mouth. If so, then rephrase the text to say, *"During this study period ..... "* Also, use wording other than "a *good deal more"*	Amended
	6th ¶, 3rd sentence; *"the Rio Grande had twice the abundance* ... ". Change "twice" to *"nearly twice".*	Done
	7th ¶, 2nd sentence; pairing sites *"along the* south Texas coast .... Christmas Bay *of the* central ... "	Done
	8th,¶;, Why are Lavaca and Cedar Lakes similar hydrologically? Lavaca Bay has the river's input, but Cedar Lakes is hydrologically more complex.	Done
	8th ¶; Mid-way into the ,·¶ discussion changes to *the other minor bays* stating these are more saline ... wording is unclear since Cedar Lakes is a minor bay too.	Done

Table 4.	Need to indicate which hypothesis is being addressed.	Done
	If N = sample size, please use lowercase *n* =	‘n’ is already used for no. of individuals
Figure 4 and others	Legend is missing LB = Lavaca Bay.	Inserted
Figure 8.	Were there any species-area effects affecting diversity measures between smaller and larger areas?	Difficult to determine in this study but probably not
All PCA and MDS figures	Please include some text describing what graphics are showing.	Explained in text
Figure 20.	Legend says 2003 - 2005 fiscal years. Were fiscal years used rather than calendar years?	Yes
Figure 19.	Please make symbols for wet years grey and dry years black for both systems. Currently, the symbol colors are reversed for each system - makes reading the chart confusing.	Done