Impacts of Droughts and Low Flows on Estuarine Health and Productivity

TEXAS A&M UNIVERSITY CORPUS CHRISTI | HARTE RESEARCH INSTITUTE FOR GULF OF MEXICO STUDIES

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Final Report

Texas A&M University – Corpus Christi

Harte Research Institute for Gulf of Mexico Studies

6300 Ocean Drive, Unit 5869

Corpus Christi, Texas 78412

Interagency Contract 1100011150

Report Submitted to the Texas Water Development Board

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ABSTRACT

Water planning in Texas is based in large part on evaluating water resource availability during periods when climatic conditions induce either low-flow or drought-of-record periods. During such periods, river flows are reduced, and consequently freshwater inflow to estuaries is also reduced, which leads to elevated salinities and reductions in sediment and nutrient loading. Most Texas estuaries are vulnerable to changes in freshwater inflow during droughts because of growing human populations, climate change, and an already parched climate. Therefore, there is a need to identify the response of natural estuarine resources in Texas bays to drought periods. The goal of the present study is to identify effects of droughts on benthic infauna and epifauna communities in central Texas estuaries.

The study was limited to three central estuaries of Texas ranging geographically from northeast to southwest: the Lavaca-Colorado, Guadalupe, and Nueces Estuaries. The Nueces Estuary is hydrologically balanced with a long-term salinity averaging 29, in contrast the two northern systems are positive and the average salinity is 20 in the Lavaca-Colorado estuary and 17 in the Guadalupe estuary.

Droughts were defined in two ways: using a hydrological approach and a salinity approach. The hydrological approach uses periods at least one year long where the mean inflow to the estuaries is less than 60 % of the long-term mean inflow. Droughts were classified using mass residual curves of inflow to estuaries along the central Texas coast, which is essentially the cumulative water deficit. The salinity approach uses mean monthly salinities that were in the upper quartile of historic salinities.

The infauna data stems from sample collections performed by Dr. Paul Montagna beginning in 1987, and the epifauna data stems from the Texas Parks and Wildlife Department, Coastal Fisheries Monitoring Program beginning in 1977. Hydrological, macrofaunal, and epifaunal characteristics were compared among drought and non-drought periods as indicators of the impacts of droughts and low flows on estuarine health and productivity.

Using the hydrological approach, it appears that the Nueces estuary is in drought conditions 75% of the time. The effects are clear. Drought conditions (low inflows) in the Nueces Estuary caused a loss in ecological integrity in Rincon Bayou by decreasing the number of dominant macrofauna species (N1 diversity) and the increasing the dominance by the disturbance-indicating polychaete *Streblospio benedicti*. The Guadalupe estuary is in drought 58% of the time. The Lavaca-Colorado estuary is in drought 62% of the time.

Overall, salinity decreases during wet periods. Turbidity increases during wet periods only in the wetter estuaries (Guadalupe and Lavaca-Colorado). Nutrients and Chlorophyll increase during wet periods. Nitrate plus nitrite, and silicate concentrations were lower in drought conditions in

Lavaca-Colorado Estuary, but not in the higher saline Nueces Bay. Relative concentrations of phosphate were inconsistent among different climatic conditions. Typically, macroinfauna community measures decrease during wet periods. Macrofauna diversity increased in drought conditions relative to other conditions in Lavaca-Colorado and Guadalupe Estuaries. There were no consistent trends in abundance, diversity or community composition among climate conditions; however indicator species for each estuary were identified. White shrimp and blue crabs decreased in mean abundance during drought periods and also changed their spatial distribution.

In summary, droughts dominate the region and have demonstrable effects on estuary water column condition. Droughts do not appear to important drivers of infauna, but there are long-term declines in the two wetter estuaries. However, there are drought effects on epifauna. Thus, data indicates that droughts negatively affect primary and secondary production in Texas estuaries that have brackish conditions.

INTRODUCTION

Water planning in Texas is based in large part on evaluating water resource availability during periods when climatic conditions induce either low-flow or drought-of-record situations. During such periods, river flows are reduced, and therefore freshwater inflow to the estuaries also is reduced leading to elevated salinities and to reductions in sediment and nutrient loads. Several published studies covering the response of Texas bays to drought during the 1950's record the impacts to the estuarine animal communities. However, aside from these isolated studies, the effects of low-flow and drought conditions on the productivity and health of Texas estuaries is poorly understood. In fact, the effect of drought on estuarine ecosystems is relatively poorly understood in other parts of the world, as well.

In Texas, a lack of guiding information on low-flow conditions has no doubt resulted in limited consideration of the specific impacts of low-inflow regimes on estuaries. Early legislation directing the freshwater inflow needs studies of major bays instead required state agencies to focus on beneficial inflows (Texas Water Code §11.147). Therefore, most efforts to determine freshwater inflow recommendations for the major bays have focused on assessing ecological needs under near-normal (or average) inflow conditions, leading to a lack of information and specific consideration of low inflows. However, more recent efforts to address freshwater inflow needs of estuaries recognize the importance of determining an appropriate inflow regime which is consistent with the natural variability (both intra- and interannual) in freshwater inflows. To do this, it is necessary to understand the role of low inflows in estuarine ecosystems.

This study provides an analysis of observed impacts of drought and low inflow conditions on in three Texas estuaries. The effects of drought and low-inflow conditions on the ecological characteristics of three estuaries in Texas: the Lavaca-Colorado, Guadalupe, and Nueces estuaries were identified. Analyses focus on the response of benthic organisms that are exposed to low-inflow and drought periods, by comparison to communities during non-drought periods. Emphasis is placed on changes in the bays of these estuaries by examining the benthic invertebrate community, also called macroinfauna or macrofauna, that were collected by Montagna using sediment cores; and the epifauna, also called the epibenthic, community collected by Texas Parks and Wildlife Department using epibenthic trawls.

In the past, most studies simply related flow rates and/or salinity as independent variables to biological responses as dependent variables. In contrast, the goal here is to identify specific drought periods and compare biological response in drought versus non-drought periods. The first problem to solve is how to identify drought. As in the past, drought could be defined either hydrologically or by salinity. The hydrological approach is based on direct inflows and this has the benefit of integrating watershed precipitation and runoff and only counting flow that flows directly into the estuary. However, it has the disadvantages of requiring specialized data and analyses, and the effect on salinity is a function of antecedent salinity conditions. The salinity approach has the advantage of using empirical in situ data, but the disadvantage of being data dependent. The Palmer Drought Severity Index (PDSI) is well-known and universally available, which is an advantage, however, it is based on conditions in the watershed, and may not reflect what is flowing into an estuary or estuary conditions. The PDSI can be combined with empirical data to fill data gaps in the salinity approach. Because both approaches have advantages and disadvantages, it was determined to use both approaches here. In the first approach, a hydrological analysis was used. The hydrological analysis was conducted by the Texas Water Development Board and used a method by Ward (2010) to identify drought periods. In the second approach, a combination of in situ salinity data and the PDSI was used to define drought. Both the hydrology and salinity approach are presented here.

The goal of this present study is to provide a better understanding of the effects of low flows on Texas estuaries. Ultimately, this study will guide further analyses of low-inflow effects and the development of inflow recommendations or constraints in the low-inflow regime. This is especially important as the state of Texas faces increasing demands for freshwater resources which has the potential to induce drought-like inflows at intervals more frequent than experienced by natural droughts.

STUDY AREA

This study addresses the effects of drought and low-inflow conditions on the ecological characteristics of three of the seven major estuaries in Texas: the Lavaca-Colorado, Guadalupe, and Nueces Estuaries (Figure 1). The estuary names are based on the name of the river (or rivers) that source freshwater inflow. However, these estuaries are often referred to as bay systems based on the name of the primary bay, so this is the Matagorda Bay system, San Antonio Bay system, and Corpus Christi Bay system respectively. The three estuaries lie in a climatic gradient with decreasing rainfall and inflow from northeast to southwest. Consequently, the long term (1976-2007) average salinity is 20 in the Lavaca-Colorado estuary, 17 in the Guadalupe estuary, and 29 in the Nueces estuary (Montagna et al. 2011). Although they receive similar inflow values, the bay volume of the Lavaca-Colorado Estuary is much larger than the Guadalupe Estuary, and this is why long-term salinity is lower in the Guadalupe.

ESTUARINE DATA ACQUISITION

Four or more stations within each estuary have been sampled quarterly for macrofauna and water quality for at least 15 years (Table 1, Figure 1). In addition, macrofauna and water quality samples were taken in Rincon Bayou on a mostly monthly frequency since 1994. Water quality measurements including salinity, temperature, dissolved oxygen and pH were taken simultaneously with macrofauna samples using YSI and Hydrolab datasondes.

Benthic macrofauna were sampled using a 6.7-cm diameter core tube (35.4 cm^2 area) to a depth of 10 cm. Three replicate cores were collected from each station on each sampling date and were preserved with 5 % buffered formalin. In the laboratory, organisms were extracted on a 0.5 mm sieve, sorted using a stereo microscope, identified to the lowest practical identifiable level (usually species), and enumerated. Biomass was determined after combining individual macrofauna into higher taxa levels (Crustacea, Mollusca, Polychaeta, and others) and drying at 50 °C for 24 h. Mollusc shells were removed with 1 N HCl prior to drying and weighing.

Texas Parks and Wildlife Department (TPWD) have used a standardized fishery-independent monitoring program, known as the Coastal Fisheries Monitoring Program (CFMP) to determine the relative abundance and size of fish and invertebrates in Texas coastal waters since the late 1970's (Martinez-Adrade et al. 2005). Trawl sampling of epifauna in each Texas estuary has been included in the sampling program since 1982. Trawls are 6.1 m wide at the mouth, with doors 1.2 m long by 0.5 m tall. Nets have a mesh of 3.8 cm. Epifauna was sampled bi-monthly using beam trawls in ten locations within each estuary using a stratified-random sampling design. Tows were taken in a circular pattern for 10 minutes. Samples are taken from two estuarine zones: 1) the upper bay near river, and 2) the lower bay farthest from river. Samples were collected during two periods of the month (days 1-15 and days 16-31) where half the samples are collected in each zone each period. Data used in this analysis was from the years 1982 to 2009.

Bi-monthly water quality data for each estuary were obtained from the TPWD to determine hydrological characteristics for drought and non-drought periods. TPWD have collected salinity, temperature, dissolved oxygen and turbidity data throughout each estuary simultaneously with the sampling of fish and invertebrates in the coastal fisheries monitoring program (Martinez-Andrade 2005). TPWD-derived data from the years 1982 to 2009 were used in the current analysis.

METHODS - ANALYSIS ONE - HYDROLOGY

Defining Droughts

Drought periods were calculated using monthly surface inflow data from the Texas Water Development Board (TWDB 2011). Surface inflow as calculated by TWDB consists of:

  Gaged flow in the estuary watershed (from USGS gages)
\+ Ungaged flow in estuary watershed (modeled flow)
\- Diverted flow
\+ Returned flow.

The methodology for calculating inflows in the Guadalupe Estuary (Guthrie 2010) is the same methodology used in the other two estuaries. The period of record for surface inflow data to each estuary is 1942 to 2009.

In this study, drought periods were determined using a modified method to that of Ward (2011). Droughts were defined as periods that met the following three criteria:

1. The first month of the period must have inflow less than 60 % of mean monthly flow ($\bar{Q}$).
2. The first year (12 months) of flow must have on average 60 % of mean monthly flow ($\bar{Q}$).
3. All monthly flows after the first year plus the twelve months of the first year must have on average 60 % of the mean monthly flow ($\bar{Q}$).

The 60 % of average flow' criterion was selected because it 'successfully identifies the historical droughts that have impacted the San Antonio Bay (Guadalupe Estuary) watershed' (Ward 2010).

If periods of below average flow met the first two criteria, they were displayed using plots of cumulative-residual-flow. Using the cumulative sum:

$$\sum(Q - \bar{Q})$$

Droughts in the plots were defined as periods of time where the downward segment of a curve is steeper than the straight line

$$y(t) = \sum(Q_0 - \bar{Q})(1 - f)\bar{Q}(t - t_0)$$

where (t_0, $\sum(Q_0 - \bar{Q})$) is the first point of the declining segment and f = 0.6 (Ward 2010).

Changes in Estuarine Water Quality

Mean salinity, temperature, dissolved oxygen and turbidity were determined for combined drought and non-drought periods for each estuary using the estuary-wide TPWD data. Summaries of water quality data (salinity, temperature and dissolved oxygen) for Rincon Bayou were determined using the data collected simultaneously with the macrofauna samples by the authors. Differences in water quality between drought and wet (non-drought) months were determined using one-way ANOVAs for each estuary. Data was $\log_e(x+1)$ transformed to improve the normality of the data.

Changes in Macrofauna Communities

Mean macrofaunal abundance, biomass and diversity were calculated for the primary and secondary bays within each estuary. Macrofaunal diversity was calculated using Hill's N1 diversity index (Hill, 1973). Hill's N1 was used because it has units of number of dominant species, and is more interpretable than most other diversity indices (Ludwig and Reynolds, 1988). Differences in macrofauna characteristics between the primary and secondary bays within each estuary and between drought and non-drought months were determined using one-way ANOVAs. Macrofaunal community structure was analyzed using non-metric multi-dimensional scaling (MDS) using a Bray-Curtis similarity matrix among stations to create a MDS plot (Clarke, 1993; Clarke & Warwick, 2001). Relationships within each MDS were highlighted using a Cluster Analysis using the group average method. Significant differences between each cluster were tested using the SIMPROF permutation procedure using a significance level of 5 % (0.05). Data were $\log_e(x + 1)$ transformed prior to MDS and Cluster analysis in Primer to decrease the effect of numerically dominant species on the interpretation of the community composition (Clarke & Gorley, 2006). Significant differences between bays and drought months were determined using a two-way PERMANOVA, a permutational multivariate analysis of variance (Anderson 2001, McArdle and Anderson 2001).

Identification of Vulnerable Species

Macrofauna species were deemed vulnerable to drought if they decreased in abundance in drought periods relative to wet periods. These drought-vulnerable species were identified using the similarity percentages (SIMPER) procedure (Clarke 1993) using PRIMER software (Clarke and Gorley 2006).

Presence / Absence of Marine Species

Macrofauna species were considered to be marine species if they increased in abundance in drought periods relative to wet periods. These drought-vulnerable species were identified using the similarity percentages (SIMPER) procedure (Clarke 1993) using PRIMER software (Clarke and Gorley 2006).

Changes in Epifaunal (Trawl-Collected) Communities

Epifaunal abundance, N1 diversity and species richness (number of species) were calculated for each sampling event and averaged by month within each estuary. MDS and cluster analysis were used to determine changes in community composition in drought periods relative to wet periods. Data was square-root transformed prior to MDS and cluster analysis. Differences in abundance, diversity and species richness between drought and wet periods and between months of the year were determined using a two-way ANOVA. Months were included in the ANOVA because of the strong seasonality of the epifauna. Epifauna abundance and N1 diversity were $\log_e(x+1)$ transformed prior to ANOVA to meet normality assumptions. Species richness resembled a normal distribution less after log transformation so was analyzed in the ANOVA without transformation.

METHODS - ANALYSIS TWO - SALINITY

Defining Droughts

The salinity of an estuary is by definition proportional to the volume of freshwater inflow that it receives. In times of drought, a reduction in precipitation, and therefore freshwater inflows, should theoretically increase the mean salinity of an estuary. The salinity of the upper region or secondary bay of Texas estuaries are suggested to be more greatly affected by changes in freshwater inflows because of the semi-arid climate in which the three estuaries exist. In this analysis, we will temporally divide the estuaries into drought, normal and wet periods using mean salinities of the largest secondary bay in each estuary. Nueces Bay is the major secondary bay in the Nueces Estuary and Lavaca Bay is the major secondary bay in the Lavaca-Colorado Estuary. The Guadalupe Estuary has no secondary bay therefore the upper portion of the primary bay, San Antonio Bay will be used as a surrogate for a secondary bay. The upper San Antonio Bay in this analysis is defined by the portion of San Antonio Bay lying north of the Gulf Intracoastal Water Way (GIWW, Figure 29).

Historical conditions for each estuary are determined to be in drought if mean monthly salinities of the associated secondary bay are within the upper quartile of monthly salinities from 1986 to 2009. Conversely, conditions will be determined as being in wet conditions if the mean monthly salinities of the associated secondary bay are within the lower quartile of all salinities. Normal conditions will be determined if salinities are in the interquartile range of historical salinities for the associated secondary bay. TPWD data from 1982 to 1985 was omitted from this study because there were fewer samples taken per month during this period than in later years.

Changes in Estuarine Water Quality

Mean salinity, temperature, dissolved oxygen and turbidity were determined for combined drought and non-drought periods for each estuary using the estuary-wide TPWD data. Summaries of water quality data (salinity, temperature and dissolved oxygen) for Rincon Bayou were determined using the data collected simultaneously with the macrofauna samples by the authors. Differences in water quality between drought and wet (non-drought) months were determined using one-way ANOVAs for each estuary. Data was $\log_e(x+1)$ transformed to improve the normality of the data.

Changes in Macrofauna Communities

Mean macrofaunal abundance, biomass and diversity were calculated for the primary and secondary bays within each estuary. Macrofaunal diversity was calculated using Hill's N1 diversity index (Hill, 1973). Hill's N1 was used because it has units of number of dominant species, and is more interpretable than most other diversity indices (Ludwig and Reynolds, 1988). Differences in macrofauna characteristics between the primary and secondary bays within each estuary and between drought and non-drought months were determined using one-way ANOVAs.

Macrofaunal community structure was analyzed using non-metric multi-dimensional scaling (MDS) using a Bray-Curtis similarity matrix among stations to create a MDS plot (Clarke, 1993; Clarke & Warwick, 2001). Relationships within each MDS were highlighted using a Cluster Analysis using the group average method. Significant differences between each cluster were tested using the SIMPROF permutation procedure using a significance level of 5 % (0.05). Data were $\log_e(x + 1)$ transformed prior to MDS and Cluster analysis in Primer to decrease the effect of numerically dominant species on the interpretation of the community composition (Clarke & Gorley, 2006).

Macrofauna community structure was linked with environmental variables using the BIO-ENV procedure. The BIO-ENV procedure calculates weighted Spearman rank correlations (ρw) between sample ordinations from all of the environmental variables and an ordination of biotic variables (Clarke and Ainsworth 1993). Correlations are then compared to determine the best match. BIO-ENV was calculated with Primer software (Clarke and Warwick 2001; Clarke and Gorley 2006).

Identification of Vulnerable Species

Macrofauna species were deemed vulnerable to drought if they decreased in abundance in drought periods relative to normal and wet periods and at least one of these decreases was significant. These drought-vulnerable species were identified using an ANOVA on $\log(x+1)$ transformed abundance data.

Presence / Absence of Marine Species

Macrofauna species were considered to be marine species if they had significantly greater (log transformed) abundance in bottom salinities of at least 30 than below 30 among all three estuaries. HRI macrofauna species abundance data from all bays except Rincon Bayou) was compared with simultaneously collected HRI bottom salinity data to select marine species. Additionally, abundances of marine species had to be at least three times more abundant in marine salinities (≥ 30) than non-marine salinities. The total abundance of the marine species expressed as mean $\log(x+1)$ transformed abundance, and percentage of total abundance were tested for differences among drought, normal and wet periods within each major bay using one-way ANOVAs and Tukey tests.

Changes in Epifaunal (Trawl-Collected) Communities

The relative abundance and spatial extent of four common and commercially important epifaunal species in drought, normal and wet periods were determined for all three estuaries. These species are blue crab (*Callinectus sapidis*), brown shrimp (*Farfantepenaeus aztecus*), and white shrimp (*Litopenaeus setiferus*). Only months when peak abundance of each species occurred were used in analysis because these species all migrate offshore to spawn (TPWD 2002). Months of peak abundance were determined by using the TPWD CFMP data to create histograms of monthly abundances over all three estuaries. Once the sub-yearly time range of peak abundance was determined for each species, yearly averages of abundance for each species were determined for each estuary.

Drought, wet, and normal years for each species were classified by determining the years that had mean salinities in the upper quartile, lower quartile and inter-quartile range respectively. Only salinity from the months of the associated species peak abundance plus the month prior were used to determine yearly averages of salinity, rather than using an mean salinity using data from the entire year. TPWD CFMP salinity data was used to classify drought, wet and normal conditions related to epifauna abundances.

Once drought, wet and normal conditions were determined, mean yearly salinity was correlated with mean yearly relative abundance, organism length, and abundance of juvenile organisms. The CFMP trawl data contains lengths for some (generally < 20) of each of these species. For each species, the number of juvenile organisms was determined by calculating the ratio of measured juveniles: total number of measured individuals and multiplying that ratio by the total number of organisms caught in the trawl. Organisms were arbitrarily classified as juveniles if they were less than half the length of a mature adult. Mature adult lengths were obtained from TPWD (2002).

Spatial changes in species distributions were also determined by plotting averages of epifaunal species abundances, lengths and juvenile abundances for each sampling station under drought, wet and normal conditions on maps using a Geographic Information System (GIS, ArcGIS 9.3, ESRI). Each sampling station was sampled at slightly different locations for each sampling event. Therefore the latitude and longitude of each sampling station for each condition has to be averaged alongside the univariate descriptors before being plotted.

METHODS - VERIFICATION OF DROUGHT DEFINITIONS

The applicability of using each drought definition method to define droughts was verified by comparing the mean Palmer Drought Severity Index (PDSI) for each drought condition (drought, wet, normal) for each estuary. The PDSI uses meteorological (dominantly temperature and rainfall) information to determine moisture deficiencies and in turn, the duration and intensity of droughts (Palmer 1965). The PDSI is one of the most widely used regional indices of drought and is particularly useful in determining long-term (several months) drought and wet periods (Alley 1984, Heddinghaus and Sabol, 1991). The PDSI has a scale where negative values indicate dry periods and positive values indicate wet periods (Palmer 1965, Table 5). An extreme drought is classified by having an index score of equal to or below -4, whereas an extreme wet period is classified by having a PDSI value of at least +4.

The National Climatic Data Center (NCDC) within the National Oceanic and Atmospheric Administration (NOAA) divides Texas (and all other states within the U.S.A.) into ten climatological divisions, and has publicly available, monthly PDSI data for each of these divisions (Figure 30, NCDC-NOAA 2011). Monthly PDSI for four climatological divisions (6, 7, 8 and 9) and mean PDSI of different combinations of the divisions were correlated with mean monthly TPWD data for each bay to determine if salinity was an appropriate proxy for drought, and which areas were correlated the highest with salinity. The four climatological divisions were chosen because either the estuaries or a large part of the catchment were located in those divisions.

Monthly means of estuary-wide salinity were correlated with the monthly PDSI values for each of the four climatological divisions to determine the climatological divisions that most highly influence the estuary. The mean PDSI of multiple climatological divisions were also correlated with mean estuarine salinity because multiple climatological zones most likely affect each estuary.

RESULTS – ANALYSIS ONE - HYDROLOGY

Macroinfauna

Nueces Estuary

The Nueces Estuary experienced drought conditions 75 % of the time between 1942 and 2009 (Table 2, Figure 2). Eleven of the 16 droughts that have occurred since 1942 have been less than 3 years long, however a 10 year long drought occurred from 1992 to 2002.

Salinity in the combined Nueces and Corpus Christi Bays (TPWD data: 1982 to 2009) is significantly higher in drought periods relative to wet periods ($p < 0.0001$; Figure 5). The mean salinity in drought periods is 31 and the mean salinity in wet periods is 23. Drought does not cause any significant change to water temperature, dissolved oxygen or turbidity in the combined Nueces and Corpus Christi Bays. Mean turbidity is lower in wet periods than drought periods in the Nueces Estuary. This is opposite to what occurs in the Guadalupe and Lavaca-Colorado Estuaries.

Rincon Bayou experiences significantly higher salinity in drought periods (mean = 30) relative to wet periods (mean = 8; $p < 0.001$; HRI data: 1994 to 2009). There were no significant differences in temperature, dissolved oxygen and pH in Rincon Bayou between drought and wet periods.

Nueces Bay and Corpus Christi Bay macrofauna stations were sampled on 46 to 56 different dates between 1987 and 2002 (Table 1). However, only one of these dates was during a wet period. Further analysis of macrofauna communities in Nueces and Corpus Christi Bays are severely restricted because of this massive imbalance in samples from drought and wet periods. Rincon Bayou was sampled on 110 different dates, of which 29 were during a wet period. Therefore the focus of the Nueces Estuary macrofauna community analysis is located in Rincon Bayou.

Macrofaunal abundance and biomass are significantly lower in wet periods relative to drought periods ($p < 0.0001$; Figure 7, Figure 8 and Figure 9). N1 Diversity, or the number of dominant species, is significantly higher in wet periods than drought periods in Rincon Bayou ($p < 0.0001$). In drought periods, the opportunistic polychaete *Streblospio benedicti*, is on average ten times more abundant than during wet periods (Table 3). *S. benedicti* is an indicator of disturbed environments (Levin 1984, Palmer *et al.* 2002), such as the high salinities of Rincon Bayou during drought conditions. The decrease in number of dominant species (N1 diversity) in wet periods can be partially attributed to the decreased numerical dominance of *S. benedicti*.

The largest change in abundance of individual species between drought and wet periods occurs with four of the five numerically dominant species (Table 10 and Table 14). In wet periods, Chironomid larvae increase in abundance, while Nemerteans and polychaetes *Laeonereis culveri*, *Mediomastus ambiseta,* and *S. benedicti* all decrease in abundance. Overall, these individual species changes alter the community composition of Rincon Bayou (Table 14). The macrofaunal community composition in drought conditions is significantly different to the community composition in wet conditions ($p < 0.001$).

Species that are considered vulnerable to drought in Rincon Bayou are those that decrease in abundance in drought relative to wet conditions. The most common vulnerable group of species in Rincon Bayou is the Insecta phyla. Chironomid and Ceratopogonidae larvae (both midges) commonly occur in wet periods but are rarer during droughts (Table 10). Ostracods (seed shrimp) and Nemerteans (proboscis worms) are also taxa groups that are vulnerable to droughts. The polychaete *Hobsonia florida* is also vulnerable to droughts but occurs in low abundances even in wet periods.

It must be noted the macrofauna communities are different in each of the three bays (Nueces, Corpus Christi and Rincon Bayou) regardless of whether they are in drought or wet conditions. Macrofauna communities in Rincon Bayou are significantly different to those occurring in Corpus Christi Bay ($p \leq 0.037$) but not significantly different to those occurring in Nueces Bay ($p \leq 0.098$). The communities in Corpus Christi and Nueces Bays are similar to each other ($p \leq 0.214$). The effect of droughts on macrofauna communities in Nueces and Corpus Christi Bays are speculative using this existing macrofauna data because only one date was sampled during a wet period and the community composition in Nueces and Corpus Christi Bays is dissimilar to that of Rincon Bayou. Diversity, biomass and abundance all increase in the 1 wet date relative to

53 drought dates sampled in Nueces Bay (Figure 7). In Corpus Christi Bay, macrofauna abundance and biomass decrease but diversity increases in the one wet date relative to 54 drought dates sampled.

Guadalupe Estuary

The Guadalupe Estuary experienced drought conditions 58 % of the time between 1942 and 2009 (Table 3 and Figure 3). Eight of the twelve droughts that have occurred since 1942 have been less than 2.5 years long. The longest drought was from 1947 to 1959, a drought almost 12 years long.

Salinity was significantly higher in drought periods relative to wet periods ($p < 0.0001$). The mean salinity was 21 in drought periods and 12 in wet periods. There were no significant differences in water temperature or dissolved oxygen between drought and wet periods but turbidity was significantly higher in wet periods relative to drought periods ($p \leq 0.002$). The mean turbidity was 25 NTU in dry periods and 29 NTU in wet periods.

Macrofauna abundance, biomass and N1 diversity were all higher in drought than wet years in both the upper and lower bay (Figure 7, Figure 12, Figure 13), however not all differences were significant (Table 9). Biomass was significantly higher in drought conditions than wet in both the upper and lower parts of the bay. Abundance was only significantly different between conditions in the upper part of the bay, and N1 diversity was only significantly different between conditions in the lower part of the bay. Aside from comparing droughts and wet periods, abundance and N1 diversity appear to be decreasing over the study period (1987 to 2009).

Macrofauna communities in all four combinations of estuary location (upper and lower bay) and drought condition (wet and dry) were significantly different to each other ($p < 0.001$). There was a gradation in community structure in the Guadalupe Estuary (Figure 18). The gradation of communities started at the left of the MDS plot, where salinities would be expected to be lowest (upper estuary in a wet period) and eventually ended at the right of the MDS plot, where salinities would be expected to be the highest (lower estuary in drought conditions). The left to right trend can be partially explained by the presence of the bivalve *Rangia cuneata*, gastropod *Texadina sphinctostoma* and Chironomid larvae being more abundant in wet-upper estuary conditions, and the polychaetes *Glycinde solitaria*, *Paraprionospio pinnata* and *Spiochaetopterus costarum* being more abundant in drought-lower estuary conditions (Table 12).

Vulnerable species to drought in the upper Guadalupe Estuary include the bivalve *R. cuneata*, gastropod *T. sphinctostoma*, polychaete *Hobsonia florida* and Chiromonid larvae (Table 15). All of these species are within the top twelve most abundant species in the upper estuary and decreased in abundance in drought conditions relative to wet. Several other abundant species were more prevalent in drought conditions than wet ones, notably *Mulinia lateralis* (bivalve), unidentified nemerteans, *Streblospio benedicti* (polychaete) and *Mediomastus ambiseta* (polychaete).

Vulnerable species in the lower Guadalupe Estuary include the bivale *Macoma mitchelli*, the gastropod *T. sphinctostoma* and the polychaete *Parandalia ocularis* (Table 16). All of these species are among the ten most abundant species in the lower estuary and are more abundant in wet then drought conditions. The polychaetes *Glycinde solitaria*, *Paraprionospio pinnata* and *Spiochaetopterus costarum*, unidentified nemerteans and cumacean *Cyclaspis varians* are all more abundant in drought than wet conditions.

Lavaca-Colorado Estuary

The Lavaca-Colorado Estuary experienced drought conditions for 62 percent of the time from 1942 to 2009. Thirteen out of the sixteen droughts that were experienced since 1942 were less than three years in length. The longest consecutive drought was almost ten years and occurred predominantly in the 1950's.

Salinity was significantly higher in drought conditions than wet conditions ($p < 0.0001$; Figure 5). The mean salinity for the Lavaca-Colorado Estuary in drought conditions was 24 whereas in wet conditions the mean salinity was 16. Both dissolved oxygen ($p \leq 0.0045$) and turbidity ($p < 0.0001$) were significantly higher in wet than drought conditions although there was no significant difference in temperature. Mean dissolved oxygen was 7.4 mg l^{-1} in drought conditions and 7.8 mg l^{-1} in wet conditions. Mean turbidity was 26 NTU in drought conditions and 37 NTU in wet conditions.

For both Lavaca and Matagorda Bays, abundance (Lavaca: $p \leq 0.0078$, Matagorda $p \leq 0.0004$), biomass ($p \leq 0.0007$, $p < 0.0001$) and N1 diversity ($p < 0.0001$, $p < 0.0001$) were significantly higher in drought than wet conditions (Figure 7, Figure 14,Figure 15). Macrofaunal abundance, biomass and N1 diversity appear to be decreasing over the study period (1988 to 2009)

Macrofauna community composition in Matagorda Bay was significantly different to that of Lavaca Bay ($p < 0.001$; Figure 19, Figure 14, Figure 15). Community composition was also significantly different between drought and wet conditions within each bay (both $p < 0.001$). There was a gradation in community composition starting on the left side of the MDS plot with Lavaca Bay in wet conditions, transitioning into Lavaca Bay in drought conditions, transitioning again into Matagorda Bay in wet conditions and ultimately transitioning into Matagorda Bay with drought conditions on the right of the plot. As the overall community composition transitions toward that occurring in Matagorda Bay in drought conditions, the polychates *Minuspio cirrifera* and *Gyptis vittata*, and the ophiuroid *Amphiodia atra* all increase in abundance.

In Lavaca Bay, organisms vulnerable to drought include nemerteans, chironomid larvae, the bivalve mollusk *Macoma mitchelli*, and the polychaetes *Capitella capitata* and *Mediomastus ambiseta*. However the low (< 1) dissimilarity:standard deviation ratio in the SIMPER analysis means that there was a lot of variability in species abundances among samples. All of these taxa were less abundant in drought periods relative to wet conditions and all but chironomid larvae were among the top ten most abundant species in Lavaca Bay. Several species also increased in abundance in drought conditions relative to wet conditions including the bivalve *Mulinia lateralis*, polychaetes *Cossura delta* and *Glycinde solitaria*, and the amphipod *Ampelisca abdita*.

In Matagorda Bay, species vulnerable to drought were polychaetes *Streblospio benedicti*, *Sigambra tentaculata*, *Cirrophorus lyra* and *Aricidea bryani*. All of these species decreased in abundance in drought conditions relative to wet conditions; however *S. benedicti* was the only species in the top ten most abundant species. Species more abundant during drought conditions included polychaetes *Gyptis vittata*, *Minuspio cirrifera*, *Polydora caulleryi*, *Paraprionospio pinnata*, *Glycinde solitaria* and the ophiuroid *Amphiodia atra*.

Epifauna

Nueces Estuary

Epifauna abundance and species richness had a strong seasonal trend, having significantly lower abundance and number of species in the winter time than the rest of the year (Figure 20, Figure 23). There were no significant differences in species richness or epifauna abundance between drought and wet periods (Table 19, Table 20). N1 diversity of epifaunal species was significantly higher in drought than wet periods in Nueces Estuary.

There was no difference in overall community composition between wet and drought periods in the Nueces Estuary (Figure 26), however some differences in abundance of individual species occurred. Hydroids, pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), sea nettle (*Chrysaora quinquechirrha*) and Atlantic bumper (*Chloroscombrus chrysurus*) occurred in greater densities in wet periods relative to drought periods in the Nueces Estuary`(Table 21). In drought periods, phosphorus jelly (*Mnemiopsis mccradyi*), moon jelly (*Aurelia aurita*) and brown shrimp were more abundant.

Guadalupe Estuary

Epifauna abundance, N1 diversity and species richness had a strong seasonal trend in the Guadalupe Estuary, having significantly lower abundance, N1 diversity and number of species in the winter time (generally December to February) than the rest of the year (Figure 24, Figure 27). There were no significant differences in species richness, N1 diversity or epifauna abundance between drought and wet periods (Table 19, Table 20).

There was no difference in overall community composition between wet and drought periods in the Guadalupe Estuary (Figure 27), however some differences in abundance of individual species occurred. Phosphorus jelly (*Mnemiopsis mccradyi*), brown shrimp (*Farfantepenaeus aztecus*), sea walnut (*Beroe ovata*), blue catfish (*Ictalurus furcatus*), spot (*Leiostomus xanthurus*) and white shrimp (*Litopenaeus setiferus*) were more abundant in dry than wet periods in the Guadalupe Estuary (Table 22). Comb jellies (Phylum Ctenophora), eastern oyster (*Crassostrea virginica*) and sea nettle (*Chrysaora quinquechirrha*) were more abundant in wet periods relative to dry periods.

Lavaca-Colorado Estuary

Epifauna abundance, N1 diversity and species richness had a strong seasonal trend in the Lavaca-Colorado Estuary, having significantly lower abundance, N1 diversity and number of species in the winter time (generally December to February) than the rest of the year (Figure 25, Figure 28). There were no significant differences in species richness, N1 diversity or epifauna abundance between drought and wet periods (Table 19, Table 20).

Like the other two estuaries, there was no difference in overall community composition between wet and drought periods (Figure 28) but there were differences in individual abundances of species. Comb jellies (phylum Ctenophora), Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*) were more abundant in drought periods relative to wet periods in the Lavaca-Colorado Estuary (Table 23). In wet periods, sea walnut (*Beroe ovata*), hydroids (order Hydroidea), sea nettle (*Chrysaora quinquechirrha*), cannonball jelly (*Stomolophus meleagris*) and Atlantic bumper (*Chloroscombrus chrysurus*) were more abundant.

RESULTS – ANALYSIS TWO - SALINITY

Drought Definition

The upper and lower quartiles of salinity in the secondary bay of each estuary defines the lower limit of drought and upper limit of wet conditions respectively for each estuary (Figure 31, Figure 32, Figure 33). Therefore, using the second drought methodology, droughts occur when mean monthly salinities are above 32.4, 19.5 and 24.4 in Nueces Bay, upper San Antonio Bay, and Lavaca Bay respectively (Figure 34). Similarly, wet conditions occur when mean monthly salinities are below 21.3, 5.2 and 12.1 in Nueces Bay, upper San Antonio Bay and Lavaca Bay respectively.

Although salinity minima and maxima within each primary bay did not always co-occur with the salinity-based wet and drought conditions of the associated secondary bays, salinity was still significantly different among drought, normal and wet conditions in each primary bay (Figure 41). This means that changes in salinity in the secondary bays are usually consistent with changes in the primary bays of each estuary.

Changes in Estuarine Water Quality

Water quality varied both by location (bay) and by conditions (drought, normal and wet conditions). Salinity significantly increased from wet to normal and normal to drought conditions in all bays including Rincon Bayou (Table 26, Figure 41 and Figure 42). Among all bay-condition combinations, salinity was highest (> 35) during the drought conditions of Corpus Christi Bay (35.1), Nueces Bay (36.4) and Rincon Bayou (52.3) and lowest (< 10) during the wet conditions of upper and lower San Antonio Bay (1.9 and 6.9), Lavaca Bay (6.6) and Rincon - Bayou (7.6). Mean salinity for each bay-climate condition was correlated with the associated mean salinity to allow for similarities among bays to be determined and overall trends to be determined. Rincon Bayou was excluded from correlations because of it is unique in that it is not a true bay as the others are. The water quality-related characteristics of Rincon Bayou are still described for completeness.

Temperature was significantly higher in wet conditions relative to normal but not drought conditions in upper and lower San Antonio Bay. No significant differences in temperature were detected using HRI-collected data. There were no significant linear regression or rank-based relationships between salinity and temperature when comparing the mean conditions in each bay (both $|r| < 0.1$, $p \leq 0.68$ to 0.90; Figure 44).

Dissolved oxygen (DO) concentrations were significantly lower in upper and lower San Antonio Bay during drought conditions than normal and wet conditions when analysis used TPWD-collect data but not HRI-collected data. DO concentrations were also significantly lower in drought conditions than either normal or wet conditions in Rincon Bayou. DO concentrations in drought conditions were significantly lower than only wet conditions in Nueces Bay, regardless of the data used in the analysis. Using TPWD data, significantly higher DO concentrations were detected in wet conditions than normal conditions but no significant differences in DO were detected between drought conditions and either wet or normal conditions. DO was significantly and negatively correlated with salinity among bay-condition combinations ($r_{pearson}$ = -0.79, $r_{spearman}$ = -0.81, both $p < 0.0001$; Figure 44B). The relationship between salinity and DO was strongly linear although DO concentrations in upper and lower San Antonio Bay were higher than other bay-condition combinations with similar salinities.

Turbidity was significantly lower during drought and normal conditions than during wet conditions in upper and lower San Antonio, Lavaca and Matagorda Bays, but not in Nueces or Corpus Christi Bays (Figure 41). Turbidity significantly decreased with salinity among bay-condition combinations ($r_{pearson}$ = -0.71, $r_{spearman}$ = -0.62, $p_{pearson} \leq 0.001$, $p_{spearman} \leq 0.006$; Figure 44C). Nueces Bay in drought conditions had a mean turbidity that was higher than all other bays in drought and normal conditions. Corpus Christi Bay has the lowest turbidity regardless of the condition.

pH was significantly higher in Nueces Bay during wet conditions than normal conditions but pH in drought conditions was not significantly different than either of these other conditions (Table 27). pH was significantly, negatively correlated with salinity among bay-condition combinations although the relationship was week ($r_{pearson}$ = -0.51, $r_{spearman}$ = -0.59, $p_{pearson} \leq 0.03$, $p_{spearman} \leq 0.01$; Figure 45C). Lavaca Bay during wet conditions had the lowest mean pH`(8.0), despite the concurrent low mean salinity. The range of mean pH values was small among all means (8.0 to 8.4).

Chlorophyll concentrations were significantly lower in normal and drought conditions than in wet conditions in Matagorda Bay (Table 27, Figure 43). There was a significant difference in chlorophyll concentrations between conditions in Nueces Bay (as detected in ANOVA), however Tukey-Kramer tests did not specify what the difference was. Chlorophyll concentrations in Nueces Bay appear to be lower in drought and normal conditions than those in wet conditions. There is a significant negative relationship among bay-condition combinations between salinity and chlorophyll concentrations ($r_{pearson}$ = -0.73, $r_{spearman}$ = -0.82, $p_{pearson} \leq 0.0005$, $p_{spearman} < 0.0001$; Figure 45B). Rincon Bayou had high mean chlorophyll concentrations regardless of the climate condition ($\geq 31\ \mu g\ l^{-1}$) relative to concentrations in the major bays ($\leq 14\ \mu g\ l^{-1}$). Upper San Antonio Bay over all climate conditions, lower San Antonio Bay in wet and normal conditions, and Lavaca Bay in wet conditions all have highly variable chlorophyll concentrations (standard error 2.0 to 5.4 $\mu g\ l^{-1}$) relative to the other bay-condition combinations (standard error 0.5 to 1.4 $\mu g\ l^{-1}$).

Nitrate plus nitrite (NO_x) concentrations were significantly higher in wet conditions than drought and normal conditions in Lavaca and Matagorda Bays but only significantly higher than drought conditions in lower San Antonio Bay. There is a significant negative relationship among bay-condition combinations between salinity and NO_x ($r_{pearson}$ = -0.74, $r_{spearman}$ = -0.74, $p_{pearson} \leq$

0.0004, $p_{spearman} < 0.0001$; Figure 45A). Nueces and Corpus Christi Bays increase in NO_x concentrations during drought conditions, whereas all other bays progressively decrease in NO_x concentrations from wet to normal to drought conditions. Upper San Antonio Bay has higher NO_x concentrations (13 to 38 μmol l^{-1}) than all other bays (0.4 to 11 μmol l^{-1}), although concentrations within this bay still decrease from drought to normal to wet conditions. Rincon Bayou has consistently low NO_x concentrations among climate conditions (0.4 to 0.9 μmol l^{-1}, drought to wet).

Phosphate concentrations were significantly higher during wet conditions than during drought and normal conditions in Rincon Bayou. Significant differences in phosphate were detected by ANOVA among conditions in Lavaca Bay, however Tukey-Kramer tests did not find differences among the condition means. Phosphate concentrations decreased from wet to normal to drought conditions. Phosphate was significantly, negatively correlated with salinity among bay–condition combinations ($r_{pearson} = -0.70$, $r_{spearman} = -0.74$, $p_{pearson} \leq 0.001$, $p_{spearman} \leq 0.002$; Figure 46B). Phosphate concentrations in Lavaca Bay during normal conditions were highly variable (standard error 1.3 μmol l^{-1}) relative to the other major bays (standard error 0.1 to 0.8 μmol l^{-1}). Upper San Antonio Bay had the highest concentrations of phosphate (3.3 to 3.9 μmol l^{-1}) and increased in concentration with salinity, contrary to the overall trend among mean salinities among other bay-condition combinations.

Silicate concentrations were significantly lower in drought conditions than normal and wet conditions in upper San Antonio Bay, lower San Antonio Bay and Matagorda Bay, but only significantly lower than wet conditions in Lavaca Bay. Silicate had the highest correlation with salinity among bay–condition combinations ($r_{pearson} = -0.86$, $r_{spearman} = -0.85$, $p_{pearson} < 0.0001$, $p_{spearman} < 0.0001$; Figure 46C). Upper San Antonio Bay during wet conditions had the highest mean silicate concentration (227 μmol l^{-1}) relative to the other major bays (32 – 163 μmol l^{-1}). Rincon Bayou had the highest mean salinities of all bays (216 to 359 μmol l^{-1}) and the largest mean salinity occurred during drought conditions.

Multivariate water quality was analyzed using Principal Components Analysis (PCA). Principal Component One and Two (PC 1 and 2) accounted for 43 and 27 % of the total variation when using all HRI-collected data to enable the inclusion of Rincon Bayou water quality (Figure 47). Rincon Bayou has high mean ammonium, silicate and chlorophyll concentrations relative to other bays and in normal and drought conditions, higher mean salinity and temperature.

PC 1 and 2 accounted for 56 and 15 % of total variation when using a combination of higher resolution TPWD-collected data (salinity, temperature, dissolved oxygen, turbidity) and lower resolution HRI-collected data (nutrients, chlorophyll, pH) and no Rincon Bayou water quality (Figure 48). Water quality during drought and normal conditions in Rincon Bayou were very different than all other bays in any of the conditions (Figure 47). There was a continuum in water quality from high salinities and low nutrients during drought and normal conditions in Corpus Christi Bay through to low salinities and higher nutrients in wet and normal conditions in upper San Antonio Bay and lower San Antonio Bay during wet conditions (Figure 47 and Figure 48).

Changes in Macrofauna Communities

Macrofauna abundance was significantly higher in drought conditions than in normal conditions in Lavaca Bay and higher than in wet conditions in Matagorda Bay (Table 28, Figure 49). In lower San Antonio Bay and Rincon Bayou, abundance was significantly higher in normal than wet conditions but not significantly different from drought conditions. There was no significant linear correlation between macrofauna abundance and salinity among major bays (Figure 50). Abundance was consistently high in upper San Antonio Bay (15000 to 23000 n m^{-2}) relative to the other major bays (5600 to 21000 n m^{-2}) regardless of the climate condition. The highest abundance of all bays occurred during drought conditions in Rincon Bayou (26000 n m^{-2}).

In upper San Antonio Bay and Matagorda Bay, macrofauna biomass in wet conditions was significantly lower than in drought conditions (Figure 49). In upper San Antonio Bay, macrofauna biomass in normal conditions was not significantly higher than in wet conditions but not significantly different to conditions in drought conditions. Macrofauna biomass during normal conditions in Matagorda Bay was not significantly different to that in drought or wet conditions. Macrofauna biomass was significantly higher in normal than wet conditions but not significantly different to biomass in drought conditions. Biomass in Corpus Christi Bay was significantly lower in drought than normal conditions but not significantly different to biomass in wet conditions. There was no significant linear correlation between macrofauna biomass and salinity among major bays (Figure 50). Macrofauna biomass was highest in upper San Antonio Bay during normal and drought conditions (14 and 22 g m^{-2}). Biomass was low in Rincon Bayou (0.6 to 1.9 g m^{-2}). Biomass in other bays ranges from 0.9 g m^{-2} in Lavaca Bay during wet conditions to 10.5 g m^{-2} in Corpus Christi Bay, also during wet conditions.

Macrofauna N1 diversity was significantly lower in drought conditions than normal and wet conditions in Rincon Bayou (Figure 49). N1 diversity was significantly higher in drought condition than both other conditions in Lavaca, Matagorda and lower San Antonio Bays. In lower San Antonio Bay, diversity was also significantly higher in normal than wet conditions. In upper San Antonio Bay, diversity was significantly higher in normal than wet conditions; however diversity in drought conditions was not significantly different to in either of these conditions. Diversity among major bay-condition combinations was positively, significantly correlated with salinity (($r_{pearson} = 0.80$, $r_{spearman} = 0.83$, $p_{pearson} < 0.0001$, $p_{spearman} < 0.0001$; Figure 50). N1 diversity in Rincon Bayou (N1 < 2.0 sp 35-cm^{-2}) was the lowest of all bay—condition combinations (N1: 2.4 to 8.3 sp 35-cm^{-2}).

Macrofauna communities in Rincon Bayou were in a significantly different group than communities in the major bays regardless of the climate condition (Figure 51). This difference is predominantly attributed to the lower diversity that occurs in Rincon Bayou (Figure 52) and the higher abundance of chironomid larvae rather than the occurrence of species unique to Rincon Bayou. The communities of major bays with lower mean salinities (Lavaca Bay, upper and lower San Antonio Bays) were in a significantly different group than communities in major bays with higher mean salinities (Nueces Bay, Corpus Christi Bay, Matagorda Bay). The bays with higher mean salinities have higher N1 diversity (Figure 50), which in part explains the difference in macrofauna communities between low salinity and high salinity bays. As conditions progress from wet to drought conditions in Lavaca Bay and San Antonio Bay, the macrofauna communities within them more closely resemble the macrofauna communities of Matagorda, Corpus Christi and Nueces Bays, which are more stable among conditions. As conditions in Lavaca and San Antonio Bays tended from wet toward drought conditions, the abundance of chiromomid larvae (Insecta) decreases and the abundance of several species increases; including polychaete species, *Gyptis vittata*, *Branchioasychis americana*, *Polydora caulleryi*, *Tharyx setigera*, *Schistomeringos rudolphi*, amphipod *Listriella barnardi*, and gastropod *Turbonilla* sp.

Of all water quality variables measured, the macrofaunal communities of major bays (not Rincon Bayou) are most highly correlated with concurrently measured nitrate + nitrite (BIO-ENV procedure; ρ_w 0.665), salinity (ρ_w 0.543),and phosphate (ρ_w 0.519). These three variables combined with temperature provide the highest correlations with macrofauna communities among major bays (ρ_w 0.692) and without temperature provide the second highest correlation (ρ_w 0.690).

Identification of Vulnerable Species

Taxa were considered vulnerable within a bay if they had significantly lower abundances during drought conditions than normal and/or wet conditions (Table 29). Ten taxa were considered vulnerable; however, only two of these taxa were considered to be vulnerable in more than one bay. Chironomid larvae (Insecta) had significantly higher abundances in wet than other periods in Rincon Bayou, Upper San Antonio Bay and Lavaca Bay. *Capitella capitata* (Polychaeta) was significantly more abundant in wet than other periods in Matagorda Bay, and significantly more in normal conditions than drought conditions in Rincon Bayou.

Presence / Absence of Marine Species

Eighty-four species were identified as being much more prevalent in salinities above 30 and were labeled ‘marine species’ (Table 30). The total abundance of these marine species in drought conditions was significantly higher than during wet conditions in upper San Antonio Bay and Matagorda Bay and significantly higher than in both normal and wet conditions in lower San Antonio and Lavaca Bays (Table 31). The change in the number of marine species among conditions was also analyzed as a percentage of the total abundance. Marine abundance as a percentage of total abundance in drought conditions were significantly higher than in wet conditions in lower San Antonio Bay and Matagorda Bay and significantly higher than both normal and drought conditions in Lavaca Bay. There were no significant changes among the three conditions in Rincon Bayou, Nueces Bay or Corpus Christi Bay.

Changes in Epifaunal (Trawl-Collected) Communities

White Shrimp

White shrimp (*Litopenaeus setiferus*) characteristics were correlated with salinity using yearly averages of each estuary as individual data points. White shrimp were most abundant in Texas estuaries from July to December, so shrimp data was only used from these seven months (Figure 54). (In comparison, the peak monthly occurrence for the Nueces Estuary was determined by Pulich et al. (2002) to be July to November). Salinity data was used from June to December because preceding salinity in the estuaries is thought to affect the timing of inshore immigration to the estuaries. The yearly means of these seven-month (for white shrimp) and eight-month periods (for salinity) are hereinafter termed 'yearly means'. Shrimp characteristics measured include mean yearly white shrimp abundance (all lengths), mean yearly white shrimp length, and juvenile white shrimp (< 76 mm, 3") abundance, both per unit area and as a percentage of total white shrimp abundance.

Yearly salinity among the three estuaries was significantly, negatively correlated with white shrimp abundance and significantly, positively correlated with mean white shrimp length, juvenile white shrimp abundance and the proportion of juvenile white shrimp (Figure 55). Juvenile and overall white shrimp abundance was highest, and consequently mean length was lowest, in the Guadalupe Estuary during wet conditions (Figure 56). The lowest mean overall and juvenile abundance occurred in the Nueces Estuary during drought conditions.

White shrimp were more widely distributed spatially in wet conditions in Guadalupe and Lavaca-Colorado Estuaries than during normal and drought conditions (Figure 57Figure 58). White shrimp were most concentrated on the eastern arm of Matagorda Bay, Lavaca Bay and the western side of San Antonio Bay during normal and drought conditions. Shrimp lengths increased from the major tributaries within each estuary toward the Gulf of Mexico in all estuaries (Figure 58). Mean shrimp length increased in upper San Antonio Bay as conditions progressed from wet to normal to drought. Shrimp length did not change as much in Lavaca Colorado and Nueces Estuaries as in Guadalupe Estuary.

Juvenile white shrimp were abundant throughout the Guadalupe Estuary during wet conditions and decreased in spatial distribution as conditions got drier (Figure 59). Juvenile white shrimp abundance did not change much in Nueces or Lavaca-Colorado Estuaries. The percentage of juvenile white shrimp decreased its spatial distribution from wet through to drought conditions, especially in the Guadalupe Estuary (Figure 59). The percentage of juveniles was more prevalent in upper Corpus Christi Bay during wet conditions.

Blue Crab

Blue crabs (*Callinectes sapidis*) were most abundant in Texas estuaries from March through to July (Figure 61), which is the same period of maximum abundance in the Nueces Estuary as identified by Pulich et al. (2002). Only data from March to July for blue crabs, and February to July for salinity were used when comparing yearly averages of blue crab characteristics and salinity.

Yearly salinity was significantly and negatively correlated with blue crab abundance and juvenile (< 51 mm, 2”) abundance (Figure 62). Salinity was significantly and positively correlated with carapace width. Overall and juvenile abundance was higher in the Guadalupe Estuary than any other estuary regardless of the condition (Figure 63). Abundance decreased in all estuaries when moving from wet to drought conditions but the spatial distribution changed most obviously in the Guadalupe Estuary (**Error! Reference source not found.**). Blue crab were abundant throughout the Guadalupe Estuary in wet conditions but decreased in spatial extent toward the middle of the bay in the progression to normal and then drought conditions.

The spatial extent of juvenile blue crabs was similar between wet and normal conditions in the Nueces and Guadalupe Estuaries, but decreased during drought conditions (Figure 66). The spatial extent of juvenile blue crabs appear to increase from wet to normal conditions, but is lower in drought conditions than both other conditions. High proportions (>20 %) of juvenile crabs decreased in spatial extent in drought relative to normal conditions in Guadalupe and Lavaca-Matagorda Estuaries (Figure 67). However, high proportions of juvenile crabs decreased in spatial extent from normal to wet conditions in Lavaca-Colorado Estuary. The spatial extent of high proportions of juvenile blue crabs was similar among all three conditions in the Nueces Estuary and between wet and normal conditions in the Guadalupe Estuary.

It was difficult to determine any spatial differences in blue crab carapace width among the three climate conditions in any of the estuaries (Figure 65).

Brown Shrimp

Brown shrimp (*Farfantepenaeus aztecus*) was overwhelmingly more abundant in the months from April to July than any other month (Figure 68), which is the same period of maximum abundance in the Nueces Estuary as identified by Pulich et al. (2002). Brown shrimp abundance was positively correlated with salinity but this relationship is only significant when correlating using a Spearman-rank correlation coefficient and not when using a Pearson correlation coefficient (Figure 69). Mean brown shrimp abundance was highest during normal than wet and dry conditions in each estuary; however mean abundance in drought and normal conditions in the Nueces Estuary were similar (Figure 70).

In the Guadalupe estuary, Lavaca-Colorado Estuary, and Nueces Bay, brown shrimp occurred over the greatest area in normal conditions, and the smallest area in wet conditions (Figure 71). Brown shrimp are much more abundant toward Lavaca Bay in the Lavaca-Colorado Estuary in normal conditions relative to drought and wet conditions. In normal and drought conditions, brown shrimp occurred over a greater proportion of the entire estuary in Nueces Bay than the other two estuaries.

Brown shrimp length was significantly and positively correlated with salinity, although the correlation is weak ($r = 0.35$, $r_s = 0.27$). The largest shrimp occurred in the Lavaca-Colorado Estuary during drought conditions (Figure 70). Spatial distributions of different brown shrimp lengths appeared consistent among conditions in the Nueces and Guadalupe Estuary (Figure 72). Mean shrimp length increased when moving from wet to drought conditions in the Guadalupe and Lavaca-Colorado Estuaries but the opposite occurred in the Nueces Estuary.

The percentage of juvenile shrimp (< 75 mm, 3") decreased with increasing salinity; however this relationship is only significant with Pearson, and not Spearman-rank, correlations (Figure 69). The abundance of juvenile shrimp was not significantly correlated with salinity. Juvenile brown shrimp were most abundant and covered a large spatial extent in the Guadalupe Estuary during normal conditions (Figure 73, Figure 74). Juvenile brown shrimp were largely absent in the Lavaca-Matagorda Estuary in drought and wet conditions. The spatial extent of juvenile brown shrimp is consistent among conditions in the Nueces estuary apart from in Nueces Bay. There were an estimated 48 juvenile brown shrimp in one of the nine sampling events that occurred at the sampling station (31). No other juvenile brown shrimp were recorded in Nueces Bay.

RESULTS - VERIFICATION OF DROUGHT DEFINITIONS

Mean monthly salinity of each estuary was correlated with monthly PDSI values of climate divisions that spatially overlapped the estuary's drainage basins using Pearson correlation coefficient (Figure 30, Table 24). The means of multiple climate divisions that overlapped drainage basins were also correlated with mean monthly salinity. Salinity in each estuary was significantly and negatively correlated ($p < 0.0001$) with the PDSI of each climate division and combination of climate divisions. Although specific results are not reported here, Spearman rank correlation coefficients were also used to correlate salinity and PDSI and each correlation was also significant ($p < 0.0001$). Within each estuary, the PDSI values of the climate regimes (drought, normal and wet) were all deemed significantly different to each other regardless of what climate division was compared (all $p < 0.0001$, Table 25).

The salinity of Nueces Bay had the highest correlations ($r < -0.73$) with climate division nine, which covered the majority of the Nueces River Basin, and the combination of climate divisions seven and nine, which also included more of the Nueces River Basin and the area immediately surrounding the Nueces Estuary. When comparing the mean PDSI value of the salinity-based drought classifications most highly correlated with salinity (Divisions 7&9, Division 9, Table 25) with the associated PDSI drought classifications (Table 5), drought, normal and wet conditions are classified as moderate drought, near normal and moderately wet to very wet respectively.

Salinity in upper San Antonio Bay had the highest correlation (r = -0.67) with the combination of climate divisions seven and nine, which covered the majority of the San Antonio and Guadalupe River Basins, the immediate catchment of the estuary's southwestern shoreline and much of the catchment of the Nueces River. When comparing the mean PDSI value of the salinity-based drought classifications most highly correlated with salinity (Divisions 7&9, Division 6, 7 & 9, Table 25) with the associated PDSI drought classifications (Table 5), drought, normal and wet conditions are classified as mild to moderate drought, near normal and moderately wet respectively.

The salinity of Lavaca Bay had the highest correlation (r = -0.80) with the combination of climate divisions seven and eight, which covered the entire Lavaca River Basin, the catchment immediately surrounding the Lavaca-Colorado Estuary, and the lower Colorado River Basin. When comparing the mean PDSI value of the salinity-based drought classifications most highly correlated with salinity (Divisions 7 & 8, Division 6, 7 & 8, Table 25) with the associated PDSI drought classifications (Table 5), drought, normal and wet conditions are classified as moderate drought, near normal and moderately wet respectively.

Method One

The mean PDSI of Nueces Bay during drought conditions (PDSI = -0.43; Table 6) was similar to the "near normal" conditions category ($-0.5 < PDSI < 0.5$; Table 5). Wet conditions varied a lot depending on which climatological division(s) was used. The climatological divisions that were most highly correlated with estuarine salinity (Division 9, Divisions 7 & 9) determined that wet conditions as defined in method one, equated to from very wet to extremely wet conditions according to the PDSI classification.

Drought conditions as determined by method one in the Guadalupe and Lavaca-Colorado Estuaries equated to a PDSI classification of mild drought ($-2 < PDSI \leq -1$). Wet conditions as determined by method one in the Guadalupe and Lavaca-Colorado Estuaries equated to the PDSI classifications of slightly to moderately wet ($1 \leq PDSI < 3$).

Method Two

Using method two to classify droughts, drought and normal conditions equated to the PDSI classifications of moderate drought ($2 \leq PDSI < 3$) and near normal conditions ($0.5 < PDSI < 0.5$) respectively in all estuaries. Wet conditions equated to a PDSI classification of moderately wet conditions in Guadalupe and Lavaca-Colorado Estuaries but moderately wet to very wet conditions ($2 \leq PDSI < 4$) in the Nueces Estuary.

DISCUSSION

Comparison of the Two Drought Definitions

Two different methods were used to define drought in the context of three Texas estuaries. The first method classified droughts using mass residual curves of inflow to estuaries (essentially a cumulative water deficit) to determine periods of at least a year that had less than 60 % of the long-term mean inflow. In this first method, time was split into drought and wet periods for each estuary.

The second method classified droughts as times when the salinity of the primary bay of the estuary was in the upper quartile of the long-term range for each primary bay. Wet periods for each estuary were considered to be times when primary bay salinities were within the lower quartile of the long-term range. The remainder of the time (salinities within interquartile range), were defined as 'normal'.

Using the first classification method, all three estuaries studied are dominated by drought, with the Nueces, Guadalupe and Lavaca-Colorado estuary experiencing drought 75, 58 and 62 percent of the time. Using the second classification method, each estuary experienced drought conditions approximately 25 percent of the time. Method two selects droughts of greater severity than method one. Evidence of this selectivity is apparent when comparing drought and wet periods with a widely used drought index, the Palmer Drought Severity Index (PDSI). PDSI values from the most appropriate climatological divisions, which were those most highly correlated with salinity in each estuary, were compared in drought conditions as defined by each method. Mean PDSI values in the estuary's basins (Figure 30) were classified as being 'near normal' to 'mild drought' (Mean PDSI: -1.3 to -0.4) during droughts as defined by drought method one, and 'mild drought' to 'moderate drought' during droughts as defined by method two (Mean PDSI: -2.3 to -1.9; Table 5, Table 6 and Table 25). The method of drought definition differs most in the Nueces Estuary (method one: -0.4, method two: -2.2 to -2.1), partly because the sporadic nature of rainfall, and therefore inflow, in the Nueces Estuary basin.

The emphasis of the discussion will be on the effects of droughts as defined by method two. This is because method two more accurately describes droughts than method one.

Changes in Estuarine Water Quality

As expected, droughts caused significant estuary-wide increases in salinity relative to wet and normal conditions. The rise in estuary-wide salinities associated with droughts also corresponded with low phosphate, silicate, and nitrate plus nitrite concentrations when comparing the three conditions among bays (Figure 45 and Figure 46). Consequently, decreased nutrient concentrations coincided with decreased primary production (chlorophyll-a concentrations) in the water column. The inverse relationship that droughts (low inflow/high salinity periods) have with water nutrients and water column primary production is expected (e.g. Caffrey et al. 2007, Pollack et al. 2009, Palmer et al. 2011). In the Patos Lagoon, Brazil, drought periods led to low phytoplankton biomass due to lower nutrients (mainly silicate; Abreu et al. 2010). However in high inflow periods, phytoplankton also decreased. The decrease in phytoplankton biomass at high inflows was attributed to the phytoplankton being flushed out of the lagoon. A similar effect may occur in upper San Antonio Bay during wet periods, when mean silicate, and nitrate plus nitrite values are the highest among the three conditions, yet chlorophyll-a concentrations are the lowest. The highest chlorophyll-*a* concentrations in the downstream lower San Antonio Bay occur during wet periods, which supports the hypothesis that phytoplankton is getting flushed downstream in times of high inflow.

There are significantly lower concentrations of silicate, and nitrate plus nitrite concentrations in drought conditions relative to wet and/or normal conditions within bays of the Guadalupe and Lavaca-Colorado Estuaries (except for nitrate plus nitrite concentrations in upper San Antonio Bay; Figure 43). However, there is not the same significant decrease in phosphate concentrations in the same two estuaries except for in Lavaca Bay. Paerl et al. (2006) noted surprisingly high annual phosphorus concentrations during drought periods in the Nuese River Estuary, North Carolina. This increase during drought times was attributed to the relative change from the normally dominant non-point source (agriculture and urban runoff) to phosphorus-enriched point sources (wastewater effluent). These types of complications could contribute to relationship of salinity with phosphate among bays being weaker than of salinity with silicate, and nitrate plus nitrite.

The Nueces Estuary is profoundly different to the other two estuaries in terms of nutrient concentrations. Silicate is non-significantly lower in drought conditions than the other conditions in the Nueces Estuary. Phosphate is lower during normal conditions and mean nitrate plus nitrite concentrations are small regardless of the condition (Nueces Bay ~1 μmol l^{-1}, Corpus Christi Bay ~0.5 μmol l^{-1}). The Nueces Estuary is unique among the three estuaries studies because it receives an approximate order of magnitude lower volume of inflow (Montagna et al. 2010) and has consistently higher salinities. The impact of the lower inflow volume could be exacerbated by large volumes of submarine groundwater discharge that enter the bay (Breier and Edmonds 2007).

Dissolved oxygen concentrations and turbidity were also lower in drought conditions in most bays (Figure 41) and had statistically significant inverse relationships with salinity (Figure 44**Error! Reference source not found.**). Lower turbidity during drought conditions could be a direct result of less high-turbidity freshwater mixing with low-turbidity estuary water. The positive relationship between turbidity and inflow (negative relationship with salinity) is common (e.g. Alden 1997, Atrill and Power 2000) and is often attributed to the higher amounts of watershed erosion and suspended sediment load that occurs as flows increase. Lower primary productivity during drought conditions could also cause lower turbidity because of less living organic matter that is suspended in the water column.

The lower dissolved oxygen concentrations that occur at higher salinities could be a result of the simultaneous lower primary production (lower chlorophyll-*a* concentrations), or differences in weather phenomena (wind speed and direction, etc.) during drought conditions. Seasonal low dissolved oxygen concentrations that occur during the drier and warmer summers in the Thames Estuary, England were attributed the higher residence time and break down of organic matter rates in the estuary (Attrill and Power 2000 and references therein). However when comparing drought versus non-drought periods, the same authors actually observed higher dissolved oxygen concentrations during drought summers and no difference between drought and non-drought winter periods. Dissolved oxygen concentrations were positively correlated with flow in Chesapeake Bay (Alden 1997).

Changes in Macrofauna Communities

Macrofauna diversity increased during drought conditions in the two high-flow estuaries (Guadalupe and Lavaca-Matagorda) however not in the low flow Nueces Estuary, where salinities are already high. There is a significant positive relationship between salinity and macrofauna diversity (Figure 50), which is well documented in other studies (e.g. Remane and Schlieper 1971). High macrofaunal diversity in high salinity water is often attributed to the increasing number of marine species present (Montagna and Kalke 1992). The positive relationship between salinity and macrofauna diversity reverses in hypersaline salinities, as observed in Rincon Bayou and other locations in Texas (Palmer et al. 2011). Rincon Bayou experiences extreme hypersaline salinities (> 50 in drought conditions) and partially because of this, had the lowest macrofauna diversity. The observation of low diversity in the often hypersaline Rincon Bayou is not new (e.g. Montagna et al. 2002, Palmer et al. 2002), however, the fact that the positive relationship between macrofauna diversity and salinity reverses at high salinities (low inflows) is important.

Macrofaunal abundance is highest during drought conditions in both major bays of the Lavaca-Colorado Estuary (Figure 49). Macrofauna biomass is highest during drought conditions in Matagorda Bay and upper San Antonio Bay but lowest during drought conditions in Corpus Christi Bay. However, there are no significant relationships between salinity and either abundance or biomass among bays and drought conditions (Figure 50). Salinity in the Lavaca-Colorado Estuary has been reported to have estuary-wide positive relationships with abundance and biomass using yearly averages over a long time period (Pollack et al. 2011). Decreases in freshwater inflow (increases in salinity) are thought change the dominant trophic guild from filter feeder to deposit feeder in the Lavaca-Colorado and other Texas estuaries (Kim and Montagna 2009, 2012). This change of dominant trophic guild as inflow decreases is in fact a decrease in functional diversity because a trophic guild is lost.

Macrofaunal communities in the bays with the highest salinities (Matagorda, Corpus Christi and Nueces Bays) had similar macrobenthic communities and did not vary much among drought, normal and wet conditions (Figure 51). There was a consistent directional change in marine communities among Lavaca, upper San Antonio and lower San Antonio Bays. Communities in bays experiencing drought conditions had higher diversity than those same bays experiencing normal and wet conditions (Figure 52). The communities of Lower San Antonio Bay during drought and normal conditions were similar to those of Lavaca Bay experiencing drought conditions. The communities in Lower San Antonio Bay during wet conditions were similar to those in upper San Antonio Bay during drought conditions, which indicates that the spatial location of specific community types changes in an upstream or downstream direction depending on salinity.

Rincon Bayou had a totally different macrofauna community than any other bay. Rincon Bayou is much shallower, more isolated and experiences more extreme environmental conditions than the other bays so the differences in macrofaunal communities are understandable.

Identification of Vulnerable Species

Chironomid larvae (Insecta) was the only taxa considered vulnerable in all three estuaries, however it only was considered vulnerable in the secondary bay of each estuary, except for the Nueces Estuary where it is considered vulnerable in Rincon Bayou (Table 29). Chironomid larve are most common in oligohaline (low salinity) conditions around the world (e.g. Grenon 1982, Schlacher and Wooldridge 1996) including Texas (e.g. Pollack et al. 2009, Palmer et al. 2011) and is a good indicator of wet conditions. Chironomid larvae were rarely found in the three primary bays or Nueces Bay in this current study.

Rincon Bayou lost the most species during drought conditions (five taxa). The loss in Rincon Bayou is probably due to the extreme changes in inflow and therefore salinity that occurs there.

Presence / Absence of Marine Species

The total abundance of the eighty-four marine species (Table 30) was significantly higher during drought than wet (and sometimes normal) conditions in the Lavaca-Colorado and Guadalupe Estuaries (Table 31). However, there were no differences among total abundance of marine species in either Nueces or Corpus Christi Bays. The consistent presence of marine species over time in Corpus Christi Bay is somewhat expected because it has consistently the highest salinities of all bays in this study, regardless of the climatic condition. Nueces Bay has similar salinity ranges to Matagorda Bay for each climatic condition, yet Matagorda Bay has significantly more marine species during drought and normal conditions than wet conditions. Matagorda Bay is directly connected to the Gulf of Mexico and this could aid in the recruitment of marine species from the Gulf in times of drought. Self-recruitment of marine species within Matagorda Bay could also be quicker and because Matagorda Bay is also a lot larger than Nueces Bay.

Changes in Epifauna Communities

Despite all that is known about brown and white shrimp in the northern Gulf of Mexico, the direct influence of inflow and salinity on adult and juvenile penaeid shrimp populations is not conclusive (Rozas et al. 2005, de Mutsert and Cowan 2012). There were more school prawn (Metapenaeus macleayi) during flood conditions relative to drought conditions in New South Wales, Australia estuaries (Gillson et al. 2012). Nearby at the mouth of the Logan River, in Queensland, Australia, king prawns (Penaeus plebejus) and the total abundance of prawns (penaeid shrimp) increased with summer inflow (Loneragan and Bunn 1999). In the Bohai Sea, China, indices of recruitment of Penaeid shrimp decreased over time because of key nutrient limitation (particularly phosphorus) induced by a freshwater deficit (Ning et al. 2010).

Brown shrimp (*Farfantepenaeus aztecus*) have commonly been reported as being most abundant at higher salinities (10-20, Pulich et al. 1998; > 15, e.g. Barrett and Gillespie 1973, Longley 1994, Minello 1999) although some studies report the opposite, where brown shrimp were more abundant at lower salinities (< 10, Parker 1970, Thomas 1999). In this study, the response of brown shrimp to inflows (and therefore salinity) is also inconsistent. There is no significant relationship between salinity and brown shrimp abundance (all ages), juvenile abundance or shrimp length among all bays and climatic conditions (Figure 70). Within estuaries, brown shrimp has markedly higher abundance during normal than drought or wet climatic conditions in the Guadalupe and Lavaca-Colorado Estuaries. However, in the Nueces Estuary, where both the highest salinities, and mean densities of brown shrimp occur, brown shrimp are more abundant in normal and drought conditions. Brown shrimp are largest during drought years in the Guadalupe and Lavaca-Colorado Estuaries and wet years in the Nueces Estuary. The mean salinities when these bay-specific maxima occur are from 24 to 29. This non-linear relationship between salinity and brown shrimp characteristics is consistent with other studies that claim that too much freshwater can negatively impact brown shrimp production (e.g. Adamack 2010, Rozas and Minello 2011). However this current study suggests that droughts decrease the abundance of brown shrimp relative to normal conditions within the Guadalupe and Lavaca-Colorado Estuary.

Salinity has a much higher correlation with white shrimp (*Litopenaeus setiferus*) abundance and length than brown shrimp abundance and length, especially within Guadalupe Estuary (Figure 56). White shrimp abundance and juvenile white shrimp abundance are both negatively correlated with salinity (positively correlated with inflow) but white shrimp length is positively correlated with salinity. The maxima of white shrimp abundance among estuaries occurred during wet conditions in the Guadalupe Estuary (mean salinity = 7) and is consistent with the preference of white shrimp in the Guadalupe Estuary as determined by Texas Parks and Wildlife Department (5-10, Pulich et al. 1998). White shrimp are found in higher abundances over a greater spatial range during wet conditions in all three estuaries (Figure 57). White shrimp tend to decrease their spatial extent as conditions get drier and are found where salinities are generally lower in places such as close to the mouths of tributaries and the west side of the Guadalupe Estuary. As with brown shrimp, the largest mean white shrimp occur in drought conditions in the Guadalupe and Lavaca-Colorado Estuaries. The mean length of white shrimp in the Nueces Estuary is similar among all three climatic conditions.

Rozas and Minello (2011) suggest that white shrimp and brown shrimp productivity are lower in lower salinities because of less food available (infauna) and the higher metabolic costs of living in lower salinity waters. The suggestion of lower productivity in low salinities probably does not apply to this current study because white shrimp, of which there are 10 times more than brown shrimp, are more abundant in wet conditions (the lowest salinities) than any other condition. However the link between macrofauna as available food and shrimp productivity is relevant to this study. Macrofauna biomass is lowest during wet conditions the Guadalupe and Lavaca-Colorado estuary (Figure 49, Figure 50), suggesting that penaeid shrimp, especially white shrimp, may play a role in regulating macrofauna standing stocks. Blue crabs (*Callinectes sapidus*), also much more abundant in wet conditions than other conditions (Figure 63), may also play a role regulating macrofauna standing stocks, but probably mostly in the Guadalupe Estuary, where densities are much higher than any other estuary.

The salinity preference for blue crab in the Guadalupe Estuary as reported by Pulich et al. (1998) is 5-15. In the current study, peak blue crab abundance occurs in wet conditions in the Guadalupe Estuary (mean salinity = 7, Figure 63). However, variability in abundance is high among all climatic conditions in the Guadalupe Estuary. Blue crab abundances are consistently higher in the Guadalupe Estuary than the other estuaries regardless of the climatic condition. Blue crab abundance is lowest during drought conditions within each estuary. The spatial extent of abundant blue crab (>7 crabs tow^{-1}) is smaller in drought conditions than wet and normal conditions.

CONCLUSION

Droughts cause a decrease in nutrient loading to estuaries and therefore also negatively affect primary production (chlorophyll-a concentrations). Decreased inflow and droughts cause an increase in the total abundance and biomass of macrofauna in the Guadalupe and Lavaca-Colorado Estuary, however, this is attributed to the increase in marine species that proliferate during drought conditions. Drought conditions negatively affect important spifauna species such as white shrimp, blue crab and to a lesser extent, brown shrimp. The Nueces Estuary does not react the same way to decreased inflows and droughts as the Guadalupe or Lavaca-Colorado Estuaries. The greater variability and low overall volume of inflow to Nueces Estuary causes greater fluctuations in Nueces Bay salinity and a smaller influence on the estuary's primary bay (Corpus Christi Bay) than the other two estuaries. This difference in hydrology causes less variability in water quality, macrofauna communities, and selected epifauna (penaeid shrimp and blue crab) abundance among climatic conditions (drought, normal, wet) than the Guadalupe and Lavaca-Colorado Estuaries.

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TABLES

Table 1. Water and macrofauna samples taken by HRI (before 2010).

		Water			Macrofauna		
Estuary	Station	First Date	Last Date	Number of Dates	First	Last	Number of Dates
Guadalupe	A	Jan 1987	Oct 2009	80	Jan 1987	Oct 2009	77
Guadalupe	B	Jan 1987	Oct 2009	81	Jan 1987	Oct 2009	77
Guadalupe	C	Jan 1987	Oct 2009	79	Jan 1987	Oct 2009	77
Guadalupe	D	Jan 1987	Oct 2009	78	Jan 1987	Oct 2009	77
Lavaca-Colorado	A	Apr 1988	Oct 2009	93	Apr 1988	Jan 2009	82
Lavaca-Colorado	B	Apr 1988	Oct 2009	89	Apr 1988	Jan 2009	82
Lavaca-Colorado	C	Apr 1988	Oct 2009	85	Apr 1988	Jan 2009	82
Lavaca-Colorado	D	Apr 1988	Oct 2009	85	Apr 1988	Jan 2009	82
Lavaca-Colorado	E	Jan 1993	Oct 2009	56	Jan 1993	Jan 2009	50
Lavaca-Colorado	F	Jan 1993	Oct 2009	55	Jan 1993	Jan 2009	50
Nueces	A	Oct 1987	Oct 2009	86	Oct 1987	Jul 2002	54
Nueces	B	Oct 1987	Oct 2009	85	Oct 1987	Jul 2002	53
Nueces	C	Oct 1987	Oct 2009	86	Oct 1987	Jul 2002	56
Nueces	D	Oct 1987	Oct 2009	84	Oct 1987	Jul 2002	54
Nueces	E	Apr 1991	Oct 2009	76	Oct 1990	Jul 2002	46
Nueces	RBC	Oct 1994	Dec 2009	129	Oct 1994	Dec 2009	110
Nueces	RBF	Oct 1994	Dec 2009	129	Oct 1994	Dec 2009	109
Nueces	RBG	Apr 1996	Dec 2009	91	Oct 2002	Dec 2009	84

Table 2. Nueces Estuary droughts (Method One).

Drought #	Start		End		Duration (Years)
	Year	Month	Year	Month	
1	1942	11	1944	5	1.58
2	1947	8	1949	3	1.67
3	1949	9	1951	8	2.00
4	1951	10	1953	8	1.92
5	1953	12	1957	4	3.42
6	1961	3	1967	8	6.50
7	1968	8	1971	7	3.00
8	1971	12	1973	5	1.50
9	1973	12	1975	5	1.50
10	1977	7	1979	5	1.92
11	1979	7	1980	7	1.08
12	1981	12	1987	6	5.58
13	1987	8	1992	5	4.83
14	1992	7	2002	6	10.00
15	2005	1	2007	6	2.50
16	2007	10	2009	12	2.25
Total Drought					51.25
Total Non-Drought					16.75
Total Years					68.00

Table 3. Guadalupe Estuary droughts (Method One).

Drought #	Start		End		Duration (Years)
	Year	Month	Year	Month	
1	1943	2	1944	2	1.08
2	1947	6	1959	4	11.92
3	1961	8	1967	8	6.08
4	1970	8	1971	9	1.17
5	1979	10	1981	5	1.67
6	1982	6	1986	9	4.33
7	1987	12	1991	12	4.08
8	1993	8	1994	9	1.17
9	1995	2	1997	5	2.33
10	1999	4	2001	2	1.92
11	2005	7	2007	3	1.75
12	2007	12	2009	12	2.08
Total Drought					39.58
Total Non-Drought					28.42
Total Time					68.00

Table 4. Lavaca-Colorado Estuary droughts (Method One).

Drought #	Start		End		Duration (Years)
	Year	Month	Year	Month	
1	1942	8	1943	12	1.42
2	1947	2	1949	9	2.67
3	1949	11	1959	9	9.92
4	1961	10	1968	5	6.67
5	1970	8	1971	8	1.08
6	1975	8	1976	11	1.33
7	1977	7	1978	8	1.17
8	1979	10	1981	5	1.67
9	1983	8	1984	9	1.17
10	1985	5	1986	9	1.42
11	1987	8	1991	11	4.33
12	1993	7	1994	9	1.25
13	1995	7	1997	2	1.67
14	1999	2	2001	8	2.58
15	2005	6	2006	12	1.58
16	2007	10	2009	12	2.25
Total Drought					42.17
Total Non-Drought					25.83
Total Years					68.00

Table 5. Palmer Drought Severity Index Classes (from Palmer 1965).

PDSI Value	Class
≥ 4.00	Extremely wet.
3.00 to 3.99	Very wet.
2.00 to 2.99	Moderately wet.
1.00 to 1.99	Slightly wet.
0.50 to 0.99	Incipient wet spell.
0.49 to -0.49	Near normal.
-0.50 to -0.99	Incipient drought.
-1.00 to -1.99	Mild drought.
-2.00 to -2.99	Moderate drought.
-3.00 to -3.99	Severe drought.
≤ -4.00	Extreme drought.

Table 6. Mean Palmer Drought Severity Index value for drought and wet periods in each estuary (Method 1).

Bold text indicates where PDSI is most highly correlated with salinity (see Table 24). Drought and wet conditions within each estuary were significantly different than each other, as determined by one-way ANOVA ($p < 0.0001$).

Division	Nueces Estuary				Guadalupe Estuary				Lavaca-Colorado Estuary			
	Drought		Wet		Drought		Wet		Drought		Wet	
	Mean (s.d.)	n	Mean (s.d.)	n	Mean (s.d.)	n	Mean (s.d.)	n	Mean (s.d.)	n	Mean (s.d.)	n
6	-0.48 (2.25)	253	1.62 (2.27)	35	-1.15 (1.92)	170	1.11 (2.29)	118	-1.23 (1.86)	173	1.3 (2.2)	115
7	-0.28 (2.68)	253	1.79 (2.35)	35	-1.36 (2.16)	170	1.88 (2.28)	118	-1.48 (2.02)	173	2.15 (2.13)	115
8	0.19 (2.25)	253	1.78 (1.79)	35	-0.56 (2)	170	1.74 (1.9)	118	-0.73 (1.81)	173	2.05 (1.8)	115
9	**-0.43 (2.39)**	**253**	**5.47 (1.55)**	**35**	-1.3 (1.69)	170	2.57 (3.01)	118	-1.37 (1.66)	173	2.77 (2.86)	115
Mean (6,9)	-0.45 (2.14)	253	3.54 (1.76)	35	-1.22 (1.6)	170	1.84 (2.38)	118	-1.3 (1.56)	173	2.04 (2.22)	115
Mean(7, 8)	-0.05 (2.34)	253	1.79 (1.96)	35	-0.96 (1.89)	170	1.81 (2.01)	118	**-1.1 (1.7)**	**173**	**2.1 (1.88)**	**115**
Mean (7, 9)	**-0.36 (2.41)**	**253**	**3.63 (1.75)**	**35**	**-1.33 (1.76)**	**170**	**2.23 (2.36)**	**118**	-1.42 (1.68)	173	2.46 (2.16)	115
Mean (6, 7, 8)	-0.19 (2.16)	253	1.73 (1.97)	35	-1.02 (1.77)	170	1.58 (1.89)	118	**-1.15 (1.6)**	**173**	**1.83 (1.78)**	**115**
Mean (6, 7, 9)	-0.4 (2.23)	253	2.96 (1.84)	35	**-1.27 (1.69)**	**170**	**1.86 (2.16)**	**118**	-1.36 (1.61)	173	2.07 (1.98)	115

Table 7. Means and significance of differences for water quality between drought and wet periods in each estuary (Method One, data is from TPWD).

Water Quality		**Nueces**	**Guadalupe**	**Lavaca-Colorado**
Dissolved Oxygen (mg l^{-1})				
Drought	mean	7.35	7.94	7.41
Drought	s.d.	1.13	1.29	1.30
Wet	mean	7.32	8.08	7.80
Wet	s.d.	1.24	1.43	1.25
	Pr < F	0.8372	0.4785	**0.0045**
Salinity				
Drought	mean	30.68	21.28	23.93
Drought	s.d.	4.21	5.75	4.92
Wet	mean	22.81	11.65	16.20
Wet	s.d.	4.80	5.82	5.60
	Pr < F	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature (°C)				
Drought	mean	23.16	22.75	23.24
Drought	s.d.	5.82	6.15	6.30
Wet	mean	25.07	22.91	22.13
Wet	s.d.	5.65	5.80	5.96
	Pr < F	0.0800	0.6818	0.1742
Turbidity (NTU)				
Drought	mean	22.09	24.54	26.34
Drought	s.d.	17.11	16.08	11.20
Wet	mean	15.79	28.73	36.94
Wet	s.d.	4.90	16.02	18.02
	Pr < F	0.0937	**0.0022**	**< 0.0001**
Number of Months sampled				
Drought		301	213	195
Wet		35	123	141

Table 8. Means and significance of differences for nutrients between drought and wet periods in each bay (Method One).

Nutrient		**Rincon Bayou**	**Nueces**	**Corpus Christi**	**upper SA Bay**	**lower SA Bay**	**Lavaca**	**Matagorda**
Chlorophyll								
Drought	mean	33.72	5.49	4.23	12.77	7.34	6.80	6.45
Drought	s.d.	18.15	5.35	2.64	12.99	6.94	5.02	4.13
Wet	mean	31.01	10.28	6.36	10.44	13.51	8.94	9.13
Wet	s.d.	19.26	3.99	2.89	7.25	9.94	5.31	4.37
	Pr < F	0.4370	**0.0015**	**0.0220**	0.7233	**0.0202**	0.0843	**0.0203**
Ammonium								
Drought	mean	15.28	2.60	1.72	3.19	1.93	2.74	2.00
Drought	s.d.	82.39	3.13	2.55	3.73	2.62	2.91	1.95
Wet	mean	0.69	0.99	1.10	3.71	1.68	3.24	1.87
Wet	s.d.	0.34	1.26	1.37	4.81	1.60	7.73	2.02
	Pr < F	0.0921	0.0965	0.3695	0.3650	0.8744	0.6270	0.6406
Nitrate + Nitrite								
Drought	mean	0.61	2.64	0.94	15.21	2.49	5.08	1.98
Drought	s.d.	1.83	3.56	1.52	14.75	3.30	11.67	3.39
Wet	mean	0.89	1.21	1.02	38.23	9.69	5.94	3.38
Wet	s.d.	1.65	0.67	1.20	33.26	14.29	8.11	4.46
	Pr < F	0.0892	0.5090	0.5502	**0.0018**	**0.0128**	0.0977	0.0845
Phosphate								
Drought	mean	0.86	1.81	0.64	3.51	1.72	1.43	1.24
Drought	s.d.	1.06	1.11	0.49	3.04	1.46	1.37	0.80
Wet	mean	1.66	1.46	0.94	3.35	2.27	2.90	0.96
Wet	s.d.	1.30	0.97	1.05	2.36	2.01	8.68	0.81
	Pr < F	**0.0004**	0.2897	0.2072	0.9677	0.3088	0.3467	0.0729
Silicate								
Drought	mean	257.34	103.83	46.77	112.14	81.78	100.63	56.02
Drought	s.d.	180.41	68.83	39.21	63.63	48.94	73.79	40.39
Wet	mean	228.00	109.26	47.50	196.86	141.28	110.40	64.27
Wet	s.d.	78.59	98.23	45.55	180.22	76.57	60.50	38.92
	Pr < F	0.5744	**0.0242**	0.0661	**0.0005**	**0.0006**	0.3455	0.1643

Table 9. Mean abundance, biomass and N1 diversity for drought and wet periods (Method One). p = (Pr < F) in one-way ANOVA, SA = San Antonio.

Nutrient		**Rincon Bayou**	**Nueces**	**Corpus Christi**	**upper SA Bay**	**lower SA Bay**	**Lavaca**	**Matagorda**
Abundance (n m^{-2})								
Drought	mean	18601	12688	18145	23373	10222	6653	13556
Drought	s.d.	28520	12784	16920	25483	11722	5246	14571
Wet	mean	3040	19760	13079	17714	8919	5307	9432
Wet	s.d.	3527	15461	10285	16814	8485	4295	7740
	p	**< 0.0001**	0.1717	0.6978	**0.0324**	0.0751	**0.0078**	**0.0004**
Biomass (g m^{-2})								
Drought	mean	1.55	7.40	9.60	18.06	5.21	1.51	6.63
Drought	s.d.	4.32	11.89	11.99	42.15	38.21	2.47	11.73
Wet	mean	0.45	14.04	6.29	7.69	2.34	0.88	3.88
Wet	s.d.	0.76	21.31	6.78	16.76	6.62	1.12	5.61
	p	**< 0.0001**	0.4559	0.4744	**< 0.0001**	**0.0019**	**0.0007**	**< 0.0001**
N1 Diversity (35-cm^{-2})								
Drought	mean	1.58	5.61	7.98	3.09	3.83	3.23	5.88
Drought	s.d.	0.89	3.71	4.31	1.13	2.20	1.76	2.98
Wet	mean	1.96	10.20	10.08	2.91	2.77	2.38	4.95
Wet	s.d.	1.17	7.67	3.57	1.15	1.33	0.84	2.45
	p	**0.0001**	**0.0403**	0.1183	0.0874	**< 0.0001**	**< 0.0001**	**< 0.0001**
No. of dates								
Drought		81	53	54	47	47	47	48
Wet		29	1	1	30	30	35	35

Table 10. Thirty most abundant macrofauna species in Rincon Bayou during drought and wet periods (Method One).
Number in parentheses = number of dates sampled. Taxa codes: Bi = Bivalvia, Cr = Crustacea, Ec = Echinodermata, Ga = Gastropoda, He = Hemichordata, In = Insecta, Ne = Nemertea, Ol = Oligochaeta, Ph = Phoronida, Pl = Platyhelminthes, Po = Polychaeta, Si = Sipuncula.

Taxa	Species / LPIL	Abundance (n m^{-2})			% of Total	Cum %
		Drought (47)	Wet (30)	Mean		
Po	*Streblospio benedicti*	16221	1517	8869	82.1	82.1
In	Chironomidae (larvae)	352	637	494	4.6	86.7
Po	*Laeonereis culveri*	704	256	480	4.4	91.1
Po	*Mediomastus ambiseta*	511	216	364	3.4	94.5
Ol	Oligochaeta (unidentified)	391	29	210	1.9	96.5
Cr	Ostracoda (unidentified)	52	87	69	0.6	97.1
Cr	*Corophium louisianum*	79	35	57	0.5	97.6
Ne	Nemertea (unidentified)	32	79	56	0.5	98.1
Bi	*Mulinia lateralis*	42	45	43	0.4	98.5
Ol	*Paranais grandis*	76	0	38	0.4	98.9
In	Ceratopogonidae (larvae)	22	44	33	0.3	99.2
Po	*Polydora ligni*	10	21	16	0.1	99.3
Po	Nereididae (unidentified)	11	9	10	0.1	99.4
Po	*Hobsonia florida*	0	18	9	0.1	99.5
Po	*Capitella capitata*	12	3	8	0.1	99.6
Cr	*Hemicyclops* sp.	13	1	7	0.1	99.7
In	*Rhaphium campestre*	9	0	5	0.0	99.7
Cr	*Mysidopsis almyra*	5	3	4	0.0	99.7
Bi	*Macoma mitchelli*	8	0	4	0.0	99.8
Po	*Pseudeurythoe* sp. A	8	0	4	0.0	99.8
Cr	*Grandidierella bonnieroides*	4	0	2	0.0	99.8
Po	*Microphthalmus abberrans*	4	0	2	0.0	99.9
Ga	*Rictaxis punctostriatus*	4	0	2	0.0	99.9
In	Damselfly nymphs	0	3	2	0.0	99.9
Bi	*Rangia cuneata*	3	0	1	0.0	99.9
Po	*Eteone heteropoda*	2	0	1	0.0	99.9
Cr	*Pseudodiaptomus pelagicus*	2	0	1	0.0	99.9
Po	*Heteromastus filiformis*	0	1	1	0.0	99.9
In	*Berosus* sp.	0	1	1	0.0	99.9
Bi	*Nuculana acuta*	0	1	1	0.0	99.9
	Total (all species)	18585	3015	10800	100	

Table 11. Forty most abundant macrofauna species in Nueces and Corpus Christi Bays (n m^{-2}) during drought and wet periods (Method One).
Number in parentheses = number of dates sampled. Taxa codes as in Table 10.

Taxa	Species Name	Nueces		Corpus Christi		Estuary				
		Drought (54)	Wet (1)	Drought (53)	Wet (1)	Drought (54)	Wet (1)	Mean	% of Total	Cum %
Po	*Mediomastus ambiseta*	3948	4444	4244	1229	4096	2836	3466	21.7	21.7
Po	*Polydora caulleryi*	670	1418	3017	2364	1844	1891	1867	11.7	33.4
Po	*Tharyx setigera*	612	1891	2257	1387	1435	1639	1537	9.6	43.1
Po	*Streblospio benedicti*	2011	95	889	95	1450	95	772	4.8	47.9
Po	*Pomatoceros americanus*	13	2269	53	725	33	1497	765	4.8	52.7
Bi	*Mulinia lateralis*	1436	331	176	0	806	165	486	3.0	55.8
Po	*Paleanotus heteroseta*	23	47	704	945	364	496	430	2.7	58.5
Ol	Oligochaeta (unidentified)	16	0	653	788	335	394	364	2.3	60.7
Po	*Axiothella* sp. A	84	1182	18	158	51	670	360	2.3	63.0
Ne	Nemertea (unidentified)	115	189	371	347	243	268	255	1.6	64.6
Po	*Clymenella torquata*	334	95	272	284	303	189	246	1.5	66.2
Po	*Gyptis vittata*	245	47	323	347	284	197	241	1.5	67.7
Po	*Eupomatus protulicola*	10	804	25	0	17	402	210	1.3	69.0
Po	*Cossura delta*	156	0	288	347	222	173	198	1.2	70.2
Po	*Cirrophorus lyra*	0	0	370	378	185	189	187	1.2	71.4
Ga	*Crepidula plana*	14	662	7	0	10	331	171	1.1	72.5
Cr	Caprellidae (unidentified)	38	520	44	0	41	260	150	0.9	73.4
Po	*Paraprionospio pinnata*	25	0	194	347	109	173	141	0.9	74.3
Po	*Glycinde solitaria*	119	142	162	126	140	134	137	0.9	75.1
Bi	*Nuculana acuta*	126	95	157	158	142	126	134	0.8	76.0
Bi	*Mysella planulata*	450	47	31	0	240	24	132	0.8	76.8
Po	*Ceratonereis irritabilis*	27	331	69	32	48	181	115	0.7	77.5
Po	*Brania furcelligera*	15	425	4	0	9	213	111	0.7	78.2
Po	*Notomastus latericeus*	39	0	76	315	58	158	108	0.7	78.9
Po	*Sphaerosyllis* sp. A	132	142	147	0	139	71	105	0.7	79.6
Ga	*Turbonilla* sp.	10	47	45	315	27	181	104	0.7	80.2
Po	*Melinna maculata*	72	284	40	0	56	142	99	0.6	80.8
Po	*Lumbrineris parvapedata*	37	47	143	158	90	102	96	0.6	81.4
Ph	*Phoronis architecta*	67	236	68	0	67	118	93	0.6	82.0
Po	*Euclymene* sp. B	76	47	86	158	81	102	92	0.6	82.6
Cr	*Ampelisca abdita*	250	95	20	0	135	47	91	0.6	83.2
Po	*Schistomeringos* sp. A	22	95	216	0	119	47	83	0.5	83.7
Po	*Isolda pulchella*	13	142	4	158	8	150	79	0.5	84.2
Ec	*Amphiodia atra*	12	0	178	126	95	63	79	0.5	84.7
Po	*Spiochaetopterus costarum*	26	0	62	221	44	110	77	0.5	85.2
Bi	*Lyonsia hyalina floridana*	102	189	14	0	58	95	76	0.5	85.6
Bi	*Periploma* cf. *orbiculare*	7	0	105	189	56	95	75	0.5	86.1
Ch	*Schizocardium* sp.	0	0	201	95	101	47	74	0.5	86.6
Po	*Brada* cf. *villosa capensis*	1	189	3	95	2	142	72	0.5	87.0
Bi	*Ischadium recurvum*	0	284	2	0	1	142	72	0.4	87.5
	Total (all species)	12806	19760	18143	13079	15474	16420	15947	100.0	

Table 12. Forty most abundant macrofauna species in the Guadalupe Estuary (n m^{-2}) during drought and wet periods (Method One).
Number in parentheses = number of dates sampled. Taxa codes as in Table 10.

Taxa	Species Name	Upper		Lower		Estuary				
		Drought (47)	Wet (30)	Drought (47)	Wet (30)	Drought (47)	Wet (30)	Mean	% of Total	Cum %
Po	*Mediomastus ambiseta*	8090	5181	5230	5046	6660	5113	5887	39.1	39.1
Po	*Streblospio benedicti*	8129	2603	1240	838	4684	1721	3203	21.2	60.3
Ga	*Texidina sphinctostoma*	3015	5479	322	418	1669	2948	2308	15.3	75.6
Bi	*Mulinia lateralis*	1393	2658	558	933	976	1796	1386	9.2	84.8
Ne	Nemertea (unidentified)	263	112	224	131	243	121	182	1.2	86.0
Po	*Spiochaetopterus costarum*	1	0	537	124	269	62	166	1.1	87.1
Cr	*Ampelisca abdita*	606	0	27	5	316	2	159	1.1	88.2
Ol	Oligochaeta (unidentified)	353	188	26	0	190	94	142	0.9	89.1
Po	*Capitella capitata*	260	224	23	44	142	134	138	0.9	90.0
Po	*Hobsonia florida*	65	427	0	24	33	225	129	0.9	90.9
Bi	*Rangia cuneata*	133	340	0	9	66	175	121	0.8	91.7
Bi	*Macoma mitchelli*	47	176	40	165	44	171	107	0.7	92.4
Po	*Parandalia ocularis*	85	55	89	137	87	96	92	0.6	93.0
Po	*Polydora caulleryi*	0	0	282	6	141	3	72	0.5	93.5
Po	*Haploscoloplos foliosus*	110	9	68	98	89	54	71	0.5	93.9
Po	*Glycinde solitaria*	51	6	163	65	107	35	71	0.5	94.4
Cr	*Cyclaspis varians*	106	13	126	41	116	27	71	0.5	94.9
Cr	*Monoculodes sp.*	99	33	23	54	61	43	52	0.3	95.2
In	Chironomidae (larvae)	23	140	0	5	12	72	42	0.3	95.5
Po	*Lysidice ninetta*	0	0	0	147	0	73	37	0.2	95.8
Ga	Gastropoda (unidentified)	133	0	3	2	68	1	34	0.2	96.0
Ga	*Crepidula plana*	0	0	2	126	1	63	32	0.2	96.2
Po	*Paraprionospio pinnata*	12	0	70	35	41	17	29	0.2	96.4
Cr	*Hemicyclops* sp.	14	3	49	46	32	24	28	0.2	96.6
Po	*Cossura delta*	0	0	57	38	29	19	24	0.2	96.7
Ga	*Acteocina canaliculata*	16	2	62	9	39	6	22	0.1	96.9
Po	*Polydora ligni*	64	11	6	5	35	8	22	0.1	97.0
Cr	*Oxyurostylis* sp.	36	2	32	13	34	7	21	0.1	97.2
Cr	*Oxyurostylis smithi*	7	0	65	0	36	0	18	0.1	97.3
Ph	*Phoronis architecta*	0	0	61	11	31	6	18	0.1	97.4
Pl	Turbellaria (unidentified)	7	6	10	44	9	25	17	0.1	97.5
Po	*Gyptis vittata*	9	3	31	17	20	10	15	0.1	97.6
Po	Maldanidae (unidentified)	0	0	49	2	25	1	13	0.1	97.7
Po	*Scolelepis texana*	4	0	27	16	16	8	12	0.1	97.8
Po	*Eteone heteropoda*	16	9	4	17	10	13	12	0.1	97.9
Po	*Haploscoloplos fragilis*	11	0	29	6	20	3	12	0.1	97.9
Po	*Neanthes succinea*	7	6	18	14	13	10	11	0.1	98.0
Po	*Clymenella torquata*	0	2	33	8	17	5	11	0.1	98.1
Po	*Diopatra cuprea*	3	2	31	5	17	3	10	0.1	98.2
Bi	*Mysella planulata*	1	0	34	5	18	2	10	0.1	98.2
	Total (all species)	23386	17772	10217	8920	16801	13346	15074	100	

Table 13. Forty most abundant macrofauna species in the Lavaca-Colorado Estuary (n m^{-2}) during drought and wet periods (Method One).
Number in parentheses = number of dates sampled. Taxa codes as in Table 10.

Taxa	Species Name	Lavaca		Matagorda		Estuary				
		Drought (47)	Wet (35)	Drought (47)	Wet (35)	Drought (47)	Wet (35)	Mean	% of Total	Cum %
Po	*Mediomastus ambiseta*	3535	3651	4958	3739	4246	3695	3971	43.0	43.0
Cr	*Apseudes* sp. A	0	0	2343	423	1171	212	692	7.5	50.5
Po	*Streblospio benedicti*	1041	783	256	582	648	683	666	7.2	57.7
Po	*Polydora caulleryi*	0	0	1174	721	587	360	474	5.1	62.9
Po	*Cossura delta*	210	116	455	558	332	337	335	3.6	66.5
Bi	*Mulinia lateralis*	425	217	443	213	434	215	325	3.5	70.0
Ol	Oligochaeta (unidentified)	23	5	542	464	282	235	259	2.8	72.8
Ne	Nemertea (unidentified)	89	95	380	267	234	181	208	2.2	75.1
Po	*Minuspio cirrifera*	0	0	426	229	213	114	164	1.8	76.8
Cr	*Ampelisca abdita*	337	16	93	7	215	11	113	1.2	78.1
Po	*Paraprionospio pinnata*	60	8	199	153	130	81	105	1.1	79.2
Po	*Gyptis vittata*	18	3	245	131	132	67	99	1.1	80.3
Bi	*Corbula contracta*	0	0	331	30	165	15	90	1.0	81.2
Ec	*Amphiodia atra*	0	0	201	155	100	77	89	1.0	82.2
Po	*Glycinde solitaria*	97	23	107	97	102	60	81	0.9	83.1
Bi	*Periploma cf. orbiculare*	0	0	259	61	130	30	80	0.9	84.0
Bi	*Lepton* sp.	3	0	180	133	91	67	79	0.9	84.8
Bi	*Macoma mitchelli*	92	142	34	20	63	81	72	0.8	85.6
Po	*Paraonidae* Grp. B	0	0	247	36	123	18	71	0.8	86.4
Po	*Tharyx setigera*	0	3	233	44	116	23	70	0.8	87.1
He	*Schizocardium sp.*	1	0	191	70	96	35	65	0.7	87.8
Po	*Drilonereis magna*	1	0	177	7	89	4	46	0.5	88.3
Po	*Cirrophorus lyra*	0	0	31	123	15	61	38	0.4	88.7
Po	*Lumbrineris parvapedata*	0	0	74	70	37	35	36	0.4	89.1
Po	*Haploscoloplos foliosus*	45	27	44	18	45	23	34	0.4	89.5
Ga	*Acteocina canaliculata*	71	1	45	7	58	4	31	0.3	89.8
Po	*Naineris* sp. A	0	0	65	59	33	29	31	0.3	90.2
Po	*Aricidea bryani*	0	0	35	77	17	38	28	0.3	90.5
Bi	*Nuculana acuta*	2	0	75	26	39	13	26	0.3	90.7
Po	*Parandalia ocularis*	63	22	10	7	37	14	25	0.3	91.0
Po	*Capitella capitata*	37	53	2	10	19	31	25	0.3	91.3
Po	*Paleanotus heteroseta*	0	0	81	11	40	6	23	0.3	91.6
Po	*Sigambra tentaculata*	0	0	32	57	16	29	22	0.2	91.8
Po	*Aricidea catharinae*	0	0	46	42	23	21	22	0.2	92.0
Bi	*Periploma margaritaceum*	0	0	21	63	11	31	21	0.2	92.3
Cn	Anthozoa (unidentified)	5	4	40	33	23	19	21	0.2	92.5
Po	*Branchioasychis americana*	3	0	44	35	23	18	20	0.2	92.7
Cr	Ostracoda (unidentified)	13	16	26	26	20	21	20	0.2	92.9
Po	*Spiochaetopterus costarum*	9	0	54	11	32	6	19	0.2	93.1
Po	Maldanidae (unidentified)	9	0	44	18	27	9	18	0.2	93.3
	Total (all species)	**6652**	**5307**	**15536**	**9421**	**11094**	**7364**	**9229**	**100.0**	

Table 14. Similarity percentages - species (SIMPER) in Rincon Bayou in drought and wet periods (Method One).

Only top 90 % of species are included in list. Average dissimilarity between groups is 59 %. Diss = dissimilarity, SD = standard deviation, Contrib = contribution.

Species/LPIL Taxa	Mean log abundance		Mean Diss	Diss/ SD	Contrib (%)	Cumulative Contrib (%)
	Drought	Wet				
Streblospio benedicti	8.32	5.53	9.54	0.98	16.18	16.18
Chironomidae (larvae)	2.06	4.24	8.91	1.08	15.11	31.29
Laeonereis culveri	3.27	2.54	7.77	1.08	13.19	44.48
Mediomastus ambiseta	2.7	2.39	6.7	0.92	11.37	55.86
Nemertea (unidentified)	0.98	2.14	5.48	0.84	9.3	65.16
Ceratopogonidae (larvae)	0.39	1.12	2.91	0.57	4.94	70.09
Ostracoda (unidentified)	0.45	1.03	2.61	0.53	4.42	74.51
Mulinia lateralis	0.91	0.64	2.58	0.52	4.38	78.89
Oligochaeta (unidentified)	1.03	0.5	2.42	0.5	4.1	82.99
Hobsonia florida	0.02	0.54	1.18	0.32	1.99	84.99
Polydora ligni	0.28	0.33	0.96	0.3	1.62	86.61
Corophium louisianum	0.26	0.4	0.92	0.32	1.56	88.17
Nereididae (unidentified)	0.13	0.25	0.87	0.26	1.48	89.64
Capitella capitata	0.26	0.12	0.76	0.26	1.29	90.93

Table 15. Similarity percentages – macrofauna species (SIMPER) in the upper Guadalupe Estuary in drought and wet periods (Method One).

Only top 90 % of species are included in list. Average dissimilarity between groups is 53 %. Diss = dissimilarity, SD = standard deviation, Contrib= contribution.

Species/LPIL Taxa	Mean log abundance		Mean Diss	Diss/ SD	Contrib (%)	Cumulative Contrib (%)
	Drought	Wet				
Texadina sphinctostoma	5.82	5.09	4.31	1.11	8.06	8.06
Mulinia lateralis	3.71	4.26	4.01	1.21	7.5	15.56
Nemertea (unidentified)	2.54	3.7	3.14	1.05	5.88	21.45
Streblospio benedicti	5.97	7.69	3.08	0.92	5.76	27.21
Capitella capitata	2.51	2.83	3.03	1.06	5.66	32.87
Rangia cuneata	2.58	1.97	2.98	0.96	5.58	38.46
Oligochaeta (unidentified)	2.17	2.32	2.84	0.95	5.32	43.77
Chironomidae (larvae)	2.35	0.64	2.5	0.85	4.68	48.46
Hobsonia florida	2.16	1.01	2.49	0.8	4.65	53.11
Parandalia ocularis	1.58	1.71	2.23	0.86	4.18	57.29
Macoma mitchelli	1.79	1.12	2.1	0.78	3.93	61.22
Mediomastus ambiseta	7.46	8.68	1.96	0.81	3.67	64.89
Monoculodes sp.	0.9	1.57	1.78	0.75	3.32	68.21
Cyclaspis varians	0.27	1.76	1.69	0.7	3.16	71.38
Glycinde solitaria	0.3	1.36	1.42	0.62	2.66	74.03
Polydora ligni	0.47	0.73	0.98	0.5	1.83	75.86
Ampelisca abdita	0	0.79	0.7	0.36	1.32	77.18
Haploscoloplos foliosus	0.11	0.68	0.68	0.35	1.28	78.46
Callianassa sp.	0.26	0.49	0.67	0.4	1.25	79.71
Mysidopsis almyra	0.32	0.32	0.56	0.36	1.05	80.76
Acteocina canaliculata	0.08	0.52	0.49	0.36	0.92	81.69
Neanthes succinea	0.24	0.3	0.46	0.33	0.86	82.55
Paraprionospio pinnata	0	0.46	0.46	0.31	0.86	83.41
Edotea montosa	0.32	0.26	0.44	0.35	0.82	84.23
Gyptis vittata	0.09	0.4	0.44	0.32	0.82	85.05
Hemicyclops sp.	0.15	0.33	0.44	0.31	0.82	85.86
Eteone heteropoda	0.25	0.28	0.43	0.32	0.81	86.67
Oxyurostylis sp.	0.08	0.39	0.39	0.29	0.73	87.4
Pectinaria gouldii	0	0.41	0.36	0.29	0.67	88.07
Brachidontes exustus	0.28	0.07	0.3	0.24	0.57	88.64
Turbellaria (unidentified)	0.24	0.16	0.3	0.29	0.55	89.19
Microprotopus sp.	0	0.35	0.29	0.27	0.54	89.73
Haploscoloplos fragilis	0	0.28	0.29	0.23	0.54	90.27

Table 16. Similarity percentages – macrofauna species (SIMPER) in the lower Guadalupe Estuary in drought and wet periods (Method One).
Only top 75 % of species are included in list. Average dissimilarity between groups is 62 %. Diss = dissimilarity, SD = standard deviation, Contrib= contribution.

Species/LPIL Taxa	Mean log abundance		Mean Diss	Diss/ SD	Contrib (%)	Cumulative Contrib (%)
	Drought	Wet				
Mulinia lateralis	2.99	3.21	3.25	1.04	5.22	5.22
Glycinde solitaria	1.55	3.09	2.8	1.01	4.5	9.72
Nemertea (unidentified)	3.03	4.01	2.77	0.95	4.46	14.18
Parandalia ocularis	2.62	1.8	2.71	0.92	4.35	18.53
Macoma mitchelli	2.4	1.21	2.34	0.88	3.76	22.28
Spiochaetopterus costarum	0.73	2.45	2.33	0.8	3.75	26.04
Texadina sphinctostoma	2.04	1.01	2.24	0.75	3.59	29.63
Cyclaspis varians	0.88	2.16	2.18	0.81	3.5	33.13
Streblospio benedicti	6.16	5.48	2.12	0.79	3.41	36.54
Paraprionospio pinnata	1.13	1.94	2.06	0.81	3.31	39.85
Haploscoloplos foliosus	1.05	1.36	1.57	0.69	2.53	42.38
Cossura delta	0.88	1.17	1.4	0.64	2.25	44.63
Gyptis vittata	0.71	1.21	1.28	0.65	2.05	46.69
Hemicyclops sp.	0.8	0.78	1.28	0.53	2.05	48.74
Mediomastus ambiseta	8.08	8.11	1.25	0.69	2.01	50.75
Capitella capitata	0.94	0.6	1.2	0.55	1.93	52.68
Acteocina canaliculata	0.26	1.35	1.19	0.58	1.91	54.59
Monoculodes sp.	0.9	0.62	1.14	0.55	1.83	56.42
Polydora caulleryi	0.3	1.31	1.07	0.56	1.72	58.14
Scolelepis texana	0.55	0.84	1.01	0.54	1.63	59.77
Oxyurostylis sp.	0.27	0.94	0.93	0.5	1.49	61.26
Phoronis architecta	0.19	0.98	0.91	0.48	1.46	62.73
Diopatra cuprea	0.23	1.04	0.89	0.53	1.43	64.15
Haploscoloplos fragilis	0.3	0.71	0.78	0.45	1.26	65.41
Pectinaria gouldii	0.34	0.55	0.74	0.42	1.19	66.6
Neanthes succinea	0.42	0.53	0.69	0.43	1.11	67.71
Ampelisca abdita	0.23	0.65	0.62	0.42	0.99	68.7
Clymenella torquata	0.1	0.85	0.6	0.45	0.97	69.67
Turbellaria (unidentified)	0.33	0.4	0.58	0.36	0.93	70.6
Melinna maculata	0	0.71	0.48	0.38	0.78	71.38
Eteone heteropoda	0.49	0.19	0.48	0.37	0.77	72.15
Callianassa sp.	0.32	0.16	0.47	0.3	0.75	72.9
Maldanidae (unidentified)	0.08	0.54	0.44	0.33	0.71	73.61
Microprotopus sp.	0.08	0.46	0.44	0.33	0.7	74.31
Axiothella mucosa	0.16	0.44	0.4	0.34	0.64	74.96

Table 17. Similarity percentages – macrofauna species (SIMPER) in Lavaca Bay in drought and wet periods (Method One).
Only top 85 % of species are included in list. Average dissimilarity between groups is 54 %.
Diss = dissimilarity, SD = standard deviation, Contrib = contribution.

Species/LPIL Taxa	Mean log abundance		Mean Diss	Diss/ SD	Contrib (%)	Cumulative Contrib (%)
	Drought	Wet				
Mulinia lateralis	3.52	2.33	4.09	1.09	7.63	7.63
Cossura delta	2.95	1.64	3.71	0.99	6.92	14.55
Nemertea (unidentified)	2.69	2.94	3.5	0.96	6.52	21.08
Macoma mitchelli	2.06	2.12	3.32	0.93	6.18	27.26
Ampelisca abdita	2.38	0.73	2.82	0.85	5.26	32.51
Glycinde solitaria	1.82	1	2.57	0.79	4.79	37.3
Capitella capitata	0.95	1.23	2.22	0.67	4.13	41.43
Parandalia ocularis	1.23	0.93	2.13	0.67	3.97	45.4
Streblospio benedicti	6.2	6.13	2.11	0.73	3.94	49.34
Paraprionospio pinnata	1.66	0.39	1.98	0.7	3.7	53.04
Mediomastus ambiseta	7.76	7.91	1.52	0.6	2.83	55.87
Acteocina canaliculata	1.38	0.07	1.45	0.57	2.71	58.57
Haploscoloplos foliosus	0.92	0.48	1.32	0.51	2.47	61.04
Chironomidae (larvae)	0.15	0.66	1.02	0.42	1.9	62.94
Leucon sp.	0.93	0.07	1	0.44	1.86	64.8
Eulimastoma sp.	0.84	0.21	0.99	0.48	1.85	66.66
Gyptis vittata	0.79	0.13	0.96	0.45	1.79	68.44
Oligochaeta (unidentified)	0.59	0.26	0.94	0.41	1.75	70.2
Ostracoda (unidentified)	0.33	0.43	0.85	0.39	1.58	71.77
Texidina sphinctostoma	0.32	0.29	0.71	0.34	1.32	73.09
Haploscoloplos fragilis	0.47	0.15	0.7	0.36	1.3	74.39
Hobsonia florida	0	0.53	0.62	0.34	1.16	75.55
Cyclaspis varians	0.59	0.07	0.57	0.36	1.06	76.61
Laeonereis culveri	0.15	0.26	0.47	0.29	0.87	77.48
Diopatra cuprea	0.36	0.21	0.46	0.33	0.86	78.34
Edotea montosa	0.4	0.07	0.45	0.31	0.84	79.19
Polydora ligni	0.07	0.34	0.4	0.28	0.74	79.93
Anthozoa (unidentified)	0.2	0.2	0.39	0.29	0.73	80.66
Ogyrides limicola	0.24	0.07	0.34	0.25	0.64	81.3
Mysidopsis almyra	0.15	0.07	0.34	0.21	0.63	81.92
Nassarius acutus	0.36	0	0.33	0.27	0.62	82.55
Spiochaetopterus costarum	0.4	0	0.31	0.29	0.58	83.13
Corophium louisianum	0.1	0.14	0.31	0.21	0.57	83.7
Microprotopus sp.	0.28	0.07	0.29	0.26	0.55	84.25
Pseudodiaptomus pelagicus	0.21	0.07	0.28	0.23	0.52	84.77
Axiothella mucosa	0.38	0	0.28	0.28	0.51	85.28

Table 18. Similarity percentages - species in Matagorda Bay in drought and wet periods (Method One).
Only top 60 % of species are included in list. Average dissimilarity from SIMPER analyses between groups is 65 %. Diss = dissimilarity, SD = standard deviation, Contrib = contribution.

Species/LPIL Taxa	Mean log abundance		Mean Diss	Diss/ SD	Contrib (%)	Cumulative Contrib (%)
	Drought	Wet				
Streblospio benedicti	2.79	4.34	2.19	1.05	3.39	3.39
Oligochaeta (unidentified)	3.08	3.04	2.01	1.03	3.11	6.49
Gyptis vittata	3.86	3	1.78	1.01	2.75	9.25
Minuspio cirrifera	2.87	2.37	1.76	1.01	2.73	11.97
Polydora caulleryi	2.67	1.69	1.75	0.86	2.71	14.68
Amphiodia atra	3.02	2.73	1.7	1.04	2.63	17.31
Paraprionospio pinnata	4.02	3.31	1.68	0.94	2.6	19.91
Glycinde solitaria	2.38	2.12	1.6	0.93	2.48	22.39
Nemertea (unidentified)	4.76	4.59	1.41	0.82	2.18	24.57
Cossura delta	5.38	5.04	1.41	0.78	2.17	26.74
Mulinia lateralis	1.76	1.13	1.4	0.71	2.16	28.9
Apseudes sp. A	1.69	1.63	1.37	0.73	2.12	31.02
Lumbrineris parvapedata	1.63	1.59	1.29	0.84	1.99	33.01
Schizocardium sp.	1.84	1.26	1.28	0.8	1.97	34.98
Sigambra tentaculata	0.95	1.72	1.17	0.77	1.8	36.79
Cirrophorus lyra	0.99	1.37	1.09	0.69	1.69	38.47
Aricidea bryani	0.76	1.3	1.02	0.64	1.57	40.04
Lepton sp.	1.31	1.14	1	0.67	1.54	41.58
Periploma cf. *orbiculare*	1.44	0.93	0.95	0.69	1.46	43.04
Nuculana acuta	1.23	0.88	0.93	0.68	1.44	44.48
Corbula contracta	1.29	0.73	0.83	0.62	1.28	45.76
Anthozoa (unidentified)	1.12	0.85	0.83	0.66	1.28	47.04
Tharyx setigera	1.21	0.76	0.82	0.64	1.27	48.31
Turbellaria (unidentified)	1.06	0.69	0.79	0.61	1.23	49.53
Spiochaetopterus costarum	1.04	0.48	0.79	0.55	1.22	50.75
Mediomastus californiensis	8.02	7.81	0.77	0.58	1.19	51.94
Mysella planulata	0.73	0.81	0.73	0.55	1.13	53.07
Ampelisca abdita	1	0.26	0.73	0.47	1.12	54.19
Eudorella sp.	0.93	0.43	0.71	0.54	1.1	55.29
Aricidea catharinae	0.81	0.66	0.7	0.54	1.09	56.38
Branchioasychis americana	0.9	0.73	0.7	0.59	1.09	57.46
Naineris sp. A	0.92	0.79	0.7	0.59	1.08	58.55
Haploscoloplos foliosus	0.84	0.51	0.69	0.51	1.07	59.62
Sigambra bassi	0.59	0.7	0.67	0.51	1.03	60.65

Table 19. Two-way ANOVA of univariate trawl data (Method One).
No. of organisms and N1 diversity were log transformed prior to analysis. Bold typeface indicates a significant relationship. All units are per tow. DF = degrees of freedom, SS = sum of squares.

Estuary	Dependent	Source	DF	Type III SS	Mean Square	F Value	Prob < F
Nueces							
	No. of species	Drought	1	1.60	1.60	0.40	0.5264
		Month	11	253.29	23.03	5.80	**<0.0001**
		Drought*Month	11	40.85	3.71	0.93	0.5070
	Abundance	**Drought**	1	2.68	2.68	11.37	**0.0008**
		Month	11	4.71	0.43	1.81	0.0509
		Drought*Month	11	1.64	0.15	0.63	0.8016
	N1 diversity	**Drought**	1	0.46	0.46	17.29	**<0.0001**
		Month	11	1.75	0.16	6.04	**<0.0001**
		Drought*Month	11	0.26	0.02	0.91	0.5357
Guadalupe							
	No. of species	Drought	1	0.45	0.45	0.10	0.7523
		Month	11	718.67	65.33	14.63	**<0.0001**
		Drought*Month	11	37.80	3.44	0.77	0.6703
	Abundance	Drought	1	0.35	0.35	0.58	0.4466
		Month	11	100.02	9.09	15.05	**<0.0001**
		Drought*Month	11	2.68	0.24	0.40	0.9540
	N1 diversity	Drought	1	0.02	0.02	0.60	0.4379
		Month	11	1.76	0.16	4.81	**<0.0001**
		Drought*Month	11	0.36	0.03	0.99	0.4509
Lavaca-Colorado							
	No. of species	Drought	1	4.80	4.80	1.02	0.3136
		Month	11	1073.16	97.56	20.70	**<0.0001**
		Drought*Month	11	55.36	5.03	1.07	0.3870
	Abundance	Drought	1	0.33	0.33	1.06	0.3050
		Month	11	77.31	7.03	22.65	**<0.0001**
		Drought*Month	11	3.26	0.30	0.96	0.4867
	N1 diversity	Drought	1	0.13	0.13	3.69	0.0557
		Month	11	5.54	0.50	14.58	**<0.0001**
		Drought*Month	11	0.24	0.02	0.62	0.8117

Table 20. Summary statistics for epibenthic trawl data (Method One).
Means (standard deviations among dates).
Bold typeface indicates significant differences between drought and wet conditions (See Table 19). All units are per 10-minute tow.

	Estuary					
	Nueces		Guadalupe		Lavaca-Colorado	
Response	Drought	Wet	Drought	Wet	Drought	Wet
No. of Dates	297	35	212	124	195	137
Sp. Richness	12.0 (2.6)	11.9 (2.0)	8.1 (2.7)	8.2 (2.3)	9.4 (2.9)	8.9 (2.7)
N1 Diversity	**5.2 (1.2)**	**4.5 (0.9)**	3.7 (0.9)	3.7 (0.8)	4.6 (1.2)	4.3 (1.0)
Abundance	**166 (101)**	**194 (76)**	180 (166)	184 (155)	125 (115)	126 (110)

Table 21. Similarity percentages – epifauna species (SIMPER) in Nueces Estuary in drought and wet periods (Method One).
Only top 60 % of species are included in list.

Species	Common Name	Mean log abund		Mean Diss	Diss/ SD	Contrib (%)	Cum (%)
		Drought	Wet				
Order Hydroidea	Order hydroids	3.03	4.66	3.02	0.83	6.33	6.33
Phylum Bryozoa	Phylum moss animals	3.83	3.89	2.72	0.97	5.7	12.02
Lagodon rhomboides	Pinfish	6.19	8.49	1.84	1.32	3.85	15.88
Mnemiopsis mccradyi	Phosphorus jelly	3.49	3.32	1.77	0.98	3.71	19.58
Leiostomus xanthurus	Spot	4.67	6.41	1.56	1.26	3.27	22.86
Micropogonias undulatus	Atlantic croaker	3.03	3.11	0.98	1.21	2.06	24.92
Chrysaora quinquechirrha	Sea nettle	1.58	1.86	0.82	1.07	1.72	26.64
Aurelia aurita	Moon jelly	1.47	1.02	0.79	0.92	1.66	28.3
Chloroscombrus chrysurus	Atlantic bumper	0.97	1.69	0.79	0.99	1.65	29.95
Litopenaeus setiferus	White shrimp	2.08	1.95	0.76	0.89	1.6	31.55
Mugil cephalus	Striped mullet	0.98	1.33	0.74	1.06	1.56	33.11
Farfantepenaeus aztecus	Brown shrimp	2.19	1.76	0.72	0.95	1.51	34.61
Brevoortia patronus	Gulf menhaden	1.44	1.76	0.7	1.03	1.46	36.07
Crassostrea virginica	Eastern oyster	0.8	0.71	0.66	0.72	1.38	37.45
Ictalurus furcatus	Blue catfish	0.02	1.08	0.58	0.52	1.22	38.67
Class Ascidiacea	Class sessile tunicates	0.99	0.26	0.58	0.69	1.21	39.88
Anchoa mitchilli	Bay anchovy	2.1	2.2	0.57	0.77	1.2	41.08
Stomolophus meleagris	Cannonball jelly	0.95	0.85	0.57	1.15	1.19	42.27
Lolliguncula brevis	Atlantic brief squid	2.46	2.33	0.56	1.17	1.17	43.44
Farfantepenaeus duorarum	Pink shrimp	1.31	0.83	0.54	1.23	1.14	44.57
Bairdiella chrysoura	Silver perch	2.15	2.54	0.54	1.25	1.13	45.7
Mugil curema	White mullet	0.33	0.9	0.54	0.95	1.12	46.82
Dorosoma petenense	Threadfin shad	0.31	0.95	0.53	1.01	1.11	47.92
Ariopsis felis	Hardhead catfish	2.21	2.26	0.52	1.23	1.08	49.01
Selene setapinnis	Atlantic moonfish	0.81	1.46	0.51	1.15	1.07	50.07
Cantharus cancellarius	Cancellate cantharus	1.25	1.11	0.5	1.09	1.06	51.13
Dyspanopeus texanus	Gulf grassflat crab	0.84	0.49	0.49	0.95	1.03	52.16
Peprilus burti	Gulf butterfish	1.02	0.79	0.49	1.22	1.03	53.19
Callinectes similis	Lesser blue crab	1.72	1.05	0.49	0.83	1.02	54.21
Beroe ovata	(Sea walnut)	0.87	0	0.49	0.36	1.02	55.24
Clibanarius vittatus	Thinstripe hermit	0.73	0.87	0.46	0.97	0.97	56.21
Orthopristis chrysoptera	Pigfish	1.52	1.41	0.45	1.05	0.95	57.16
Polydactylus octonemus	Atlantic threadfin	0.71	0.43	0.45	0.92	0.94	58.1
Portunus gibbesii	Iridescent swimming crab	0.94	0.26	0.45	1.24	0.94	59.04
Order Alcyonacea	Order soft corals	0.71	0.26	0.45	0.64	0.94	59.97
Bagre marinus	Gafftopsail catfish	0.66	0.96	0.45	1.26	0.94	60.91

Table 22. Similarity percentages – epifauna species (SIMPER) in Guadalupe Estuary in drought and wet periods (Method One).
Only top 70 % of species are included in list.

Species	Common Name	Mean log abund		Mean Diss	Diss/ SD	Contrib (%)	Cum (%)
		Drought	Wet				
Mnemiopsis mccradyi	Phosphorus jelly	7.58	4.06	5.35	1.03	9.02	9.02
Phylum Ctenophora	Comb jellies	2.34	4.42	3.64	0.83	6.14	15.15
Farfantepenaeus aztecus	Brown shrimp	3.44	3.06	1.91	1	3.23	18.38
Micropogonias undulatus	Atlantic croaker	3.45	2.85	1.7	1.09	2.86	21.24
Crassostrea virginica	Eastern oyster	1.83	2.07	1.63	1.01	2.74	23.99
Chrysaora quinquechirrha	Sea nettle	1.28	2.26	1.6	0.78	2.7	26.69
Beroe ovata	Sea walnut	1.61	1.2	1.46	0.73	2.47	29.15
Ictalurus furcatus	Blue catfish	2.24	1.1	1.43	1.13	2.41	31.56
Leiostomus xanthurus	Spot	3.48	3.1	1.38	1.17	2.32	33.88
Litopenaeus setiferus	White shrimp	2.84	2.32	1.33	1.15	2.24	36.12
Lagodon rhomboides	Pinfish	3.03	3.03	1.28	1.19	2.16	38.29
Stomolophus meleagris	Cannonball jelly	0.5	1.77	1.17	0.71	1.98	40.27
Zoobotryon verticillatum	Sauerkraut bryozoan	0.53	1.89	1.15	0.28	1.94	42.21
Aurelia aurita	Moon jelly	0.75	1.38	1.04	0.64	1.76	43.97
Rangia cuneata	Atlantic rangia	0.79	1.29	1.03	0.68	1.74	45.71
Brevoortia patronus	Gulf menhaden	2.55	2.43	0.98	0.96	1.65	47.36
Lolliguncula brevis	Atlantic brief squid	1.54	1.97	0.9	1.2	1.52	48.88
Callinectes sapidus	Blue crab	2.34	2.3	0.88	0.89	1.48	50.36
Mugil cephalus	Striped mullet	1.14	0.81	0.84	0.83	1.41	51.78
Bagre marinus	Gafftopsail catfish	0.88	0.92	0.83	0.82	1.4	53.18
Bugula neritina	Common bugula	0.18	1.45	0.81	0.23	1.37	54.54
Bairdiella chrysoura	Silver perch	1.9	1.79	0.79	1.1	1.33	55.87
Anchoa mitchilli	Bay anchovy	2.32	2.27	0.73	1.02	1.24	57.11
Farfantepenaeus duorarum	Pink shrimp	0.61	0.87	0.71	0.91	1.2	58.31
Callinectes similis	Lesser blue crab	0.82	1.08	0.67	1	1.13	59.44
Chloroscombrus chrysurus	Atlantic bumper	0.48	0.79	0.66	0.6	1.12	60.56
Orthopristis chrysoptera	Pigfish	0.54	0.86	0.65	0.87	1.1	61.66
Order Hydroidea	Order hydroids	0.2	0.94	0.65	0.27	1.09	62.75
Rangia flexuosa	Brown rangia	0.67	0.52	0.64	0.62	1.08	63.83
Ariopsis felis	Hardhead catfish	1.44	1.53	0.62	1.02	1.05	64.88
Peprilus burti	Gulf butterfish	0.56	0.78	0.62	0.95	1.04	65.92
Sphoeroides parvus	Least puffer	0.56	0.85	0.54	1.06	0.92	66.84
Pogonias cromis	Black drum	0.66	0.51	0.54	0.95	0.91	67.74
Family Xanthidae	Rubble and pebble crabs	0.67	0.56	0.51	0.98	0.87	68.61
Citharichthys spilopterus	Bay whiff	0.73	0.67	0.51	1.12	0.87	69.47
Nemopsis bachei	Hydromedusa	0.39	0.43	0.49	0.25	0.83	70.3

Table 23. Similarity percentages – epifauna species (SIMPER) in Lavaca-Colorado Estuary in drought and wet periods (Method One).
Only top 60 % of species are included in list.

Species	Common Name	Mean log abund		Mean Diss	Diss/ SD	Contrib (%)	Cum (%)
		Drought	Wet				
Phylum Ctenophora	Phylum comb jellies	4.75	4.5	3.02	1.1	5.49	5.49
Beroe ovata	Sea walnut	2.48	2.85	2.18	0.79	3.97	9.46
Micropogonias undulatus	Atlantic croaker	4.07	3.17	1.69	1.13	3.08	12.54
Order Hydroidea	Order hydroids	0.72	2.72	1.67	0.44	3.04	15.58
Zoobotryon verticillatum	Sauerkraut bryozoan	1.56	1.67	1.46	0.38	2.66	18.24
Chrysaora quinquechirrha	Sea nettle	1.63	2.25	1.39	0.8	2.52	20.76
Leiostomus xanthurus	Spot	4.14	3.39	1.31	1.11	2.38	23.14
Stomolophus meleagris	Cannonball jelly	1.81	2.41	1.3	0.94	2.37	25.51
Chloroscombrus chrysurus	Atlantic bumper	1.3	1.85	1.21	0.84	2.2	27.71
Farfantepenaeus aztecus	Brown shrimp	2.23	2.02	1.16	1.06	2.11	29.82
Litopenaeus setiferus	White shrimp	2.69	2.4	1.06	1.02	1.92	31.74
Aurelia aurita	Moon jelly	0.67	1.8	1.03	0.81	1.88	33.63
Anchoa mitchilli	Bay anchovy	2.84	2.46	1	1.07	1.82	35.45
Mnemiopsis mccradyi	Phosphorus jelly	1.4	0.78	0.98	0.64	1.78	37.22
Crassostrea virginica	Eastern oyster	0.81	1.3	0.93	0.89	1.69	38.92
Lolliguncula brevis	Atlantic brief squid	2.9	2.94	0.84	1.1	1.52	40.44
Cynoscion nothus	Silver seatrout	1.36	1.08	0.83	1.08	1.5	41.94
Lagodon rhomboides	Pinfish	1.93	2.05	0.82	1.17	1.49	43.43
Brevoortia patronus	Gulf menhaden	2.29	1.81	0.77	0.86	1.41	44.84
Bagre marinus	Gafftopsail catfish	0.87	1	0.66	1.1	1.2	46.04
Peprilus burti	Gulf butterfish	1.32	1.33	0.65	1.14	1.18	47.22
Selene setapinnis	Atlantic moonfish	0.71	0.9	0.6	1.04	1.1	48.32
Callinectes similis	Lesser blue crab	1.28	1.3	0.59	1.04	1.08	49.4
Ariopsis felis	Hardhead catfish	1.67	1.68	0.59	0.85	1.08	50.48
Opisthonema oglinum	Atlantic thread herring	0.84	0.62	0.57	1.02	1.03	51.5
Neverita duplicata	Shark eye	0.72	0.79	0.56	0.82	1.02	52.53
Squilla empusa	Common mantis shrimp	0.81	1.01	0.55	1.11	1	53.52
Polydactylus octonemus	Atlantic threadfin	0.53	0.77	0.55	0.96	1	54.52
Trichiurus lepturus	Atlantic cutlassfish	1.18	0.82	0.54	1.16	0.99	55.5
Farfantepenaeus duorarum	Pink shrimp	0.72	0.61	0.54	0.96	0.98	56.48
Bairdiella chrysoura	Silver perch	1.46	1.51	0.52	0.85	0.94	57.42
Dorosoma petenense	Threadfin shad	0.76	0.67	0.52	1.06	0.94	58.36
Stellifer lanceolatus	Star drum	0.72	0.63	0.5	1.01	0.92	59.28
Cynoscion arenarius	Sand seatrout	1.44	1.44	0.5	1.07	0.91	60.19

Table 24. Pearson Correlations between mean monthly salinity and PDSI for different Texas climatic divisions in each bay.

N= 276 months (except Nueces Bay where N=275). All relationships had a significance of $p < 0.0001$.

Climate Division(s)	Nueces Estuary		Guadalupe Estuary		Lavaca-Colorado Estuary	
	Nueces Bay	Corpus Christi Bay	Upper SA Bay	Lower SA Bay	Lavaca Bay	Matagorda Bay
6	-0.52	-0.46	-0.55	-0.56	-0.59	-0.63
7	-0.60	-0.58	-0.65	-0.63	-0.76	-0.74
8	-0.50	-0.49	-0.55	-0.53	-0.76	-0.74
9	***-0.77***	-0.66	-0.62	-0.62	-0.62	-0.65
Mean (6, 9)	-0.71	-0.62	-0.64	-0.64	-0.66	-0.69
Mean(7, 8)	-0.58	-0.57	-0.64	-0.61	***-0.80***	-0.77
Mean (7, 9)	***-0.73***	-0.67	***-0.68***	-0.67	-0.73	-0.74
Mean (6, 7, 8)	-0.59	-0.56	-0.65	-0.63	***-0.77***	-0.77
Mean (6, 7, 9)	-0.70	-0.63	***-0.67***	-0.67	-0.72	-0.74

Table 25. Mean Palmer Drought Severity Index value for drought, normal and wet periods in each estuary.

Bold text indicates where PDSI is most highly correlated with salinity (see Table 24). All drought conditions within each estuary were significantly different than each other, as determined by one-way ANOVA ($p < 0.0001$) and Tukey tests.

Climate	**Nueces**			**Guadalupe**			**Lavaca-Colorado**		
Division	**Drought**	**Normal**	**Wet**	**Drought**	**Normal**	**Wet**	**Drought**	**Normal**	**Wet**
6	-1.30	-0.54	1.41	-1.65	-0.57	1.90	-1.91	-0.29	1.61
7	-2.01	-0.18	2.16	-2.37	0.00	2.25	-2.74	-0.10	2.82
8	-0.93	0.24	1.92	-1.25	0.46	1.85	-1.77	0.33	2.64
9	**-2.20**	**-0.18**	**3.61**	-1.78	-0.05	3.02	-2.04	0.14	2.91
Mean (6, 9)	-1.75	-0.36	2.51	-1.71	-0.31	2.46	-1.98	-0.08	2.26
Mean(7, 8)	-1.47	0.03	2.04	-1.81	0.23	2.05	**-2.26**	**0.12**	**2.73**
Mean (7, 9)	**-2.11**	**-0.18**	**2.88**	**-2.07**	**-0.03**	**2.64**	-2.39	0.02	2.87
Mean (6, 7, 8)	-1.41	-0.16	1.83	-1.75	-0.04	2.00	**-2.14**	**-0.02**	**2.36**
Mean (6, 7, 9)	-1.84	-0.30	2.39	**-1.93**	**-0.21**	**2.39**	-2.23	-0.09	2.45

Table 26. Mean salinity, temperature, dissolved oxygen and turbidity for each estuary-climate condition combination (Method Two, TPWD data).
N= 287 for Nueces and Corpus Christi Bays and 288 for all other bays.

Variable	**Condition**	**Parm.**	**Nueces**	**Corpus Christi**	**Upper SA**	**Lower SA**	**Lavaca**	**Matagorda**
Salinity								
	Drought	Mean	36.41	35.11	23.83	29.51	28.32	29.71
	Drought	s.d.	2.83	2.64	3.52	3.49	2.71	2.67
	Normal	Mean	27.78	31.09	12.26	20.80	18.77	24.25
	Normal	s.d.	3.05	2.75	4.40	4.86	3.48	3.39
	Wet	Mean	12.77	26.67	1.93	6.87	6.56	16.23
	Wet	s.d.	6.77	4.18	1.64	5.02	3.26	4.78
		Pr<F	**n/a**	**<0.0001**	**n/a**	**<0.0001**	**n/a**	**<0.0001**
Temperature (°C)								
	Drought	Mean	24.12	24.20	22.46	22.77	21.98	22.38
	Drought	s.d.	6.16	6.15	5.90	6.25	6.49	6.05
	Normal	Mean	23.27	22.93	21.95	22.29	22.64	22.88
	Normal	s.d.	5.80	5.67	6.29	6.24	6.73	6.34
	Wet	Mean	24.14	24.12	24.20	24.50	22.70	22.91
	Wet	s.d.	5.68	5.94	5.84	5.83	6.43	6.26
		Pr<F	0.5599	0.3141	**0.0389**	**0.0482**	0.7999	0.8877
Dissolved Oxygen (mg l^{-1})								
	Drought	Mean	6.98	7.19	7.64	7.65	7.40	7.51
	Drought	s.d.	1.45	1.31	1.44	1.54	1.50	1.13
	Normal	Mean	7.37	7.39	8.65	8.16	7.45	7.41
	Normal	s.d.	1.37	1.26	1.67	1.33	1.63	1.40
	Wet	Mean	7.89	7.53	8.14	8.15	7.83	7.87
	Wet	s.d.	1.59	1.39	1.29	1.35	1.51	1.34
		Pr<F	**0.0011**	0.2957	**<0.0001**	**0.0137**	0.1386	**0.0437**
Turbidity (NTU)								
	Drought	Mean	32.15	15.35	22.13	19.35	25.24	21.50
	Drought	s.d.	32.62	10.30	16.45	22.06	21.28	11.34
	Normal	Mean	26.63	13.38	24.53	19.53	22.35	21.44
	Normal	s.d.	23.87	9.09	19.42	16.40	12.95	13.20
	Wet	Mean	33.20	12.18	42.40	33.21	43.68	27.61
	Wet	s.d.	26.66	5.61	23.45	23.59	28.37	13.74
		Pr<F	0.0554	0.1057	**<0.0001**	**<0.0001**	**<0.0001**	**0.0009**

Table 27. Mean water quality for each bay-climate condition combination (Method Two, HRI data).

Variable	Condition	Parm.	Rincon Bayou	Nueces	Corpus Christi	Upper SA	Lower SA	Lavaca	Matagorda
Salinity									
	Drought	Mean	52.35	36.26	36.15	18.73	27.06	26.49	30.03
	Drought	s.d.	23.78	4.04	3.61	4.13	3.14	4.78	3.36
	Normal	Mean	25.96	27.90	31.91	9.80	18.76	16.74	25.40
	Normal	s.d.	11.81	4.53	3.59	5.46	5.97	6.08	3.71
	Wet	Mean	7.58	16.61	28.18	1.23	5.09	6.09	18.51
	Wet	s.d.	7.32	7.47	4.19	1.60	4.30	5.38	5.87
		Pr<F	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Temperature (°C)									
	Drought	Mean	25.29	23.19	23.47	21.73	21.36	21.75	22.04
	Drought	s.d.	5.97	6.65	6.28	6.71	6.83	6.66	6.39
	Normal	Mean	23.70	22.04	21.51	22.07	22.01	22.12	22.70
	Normal	s.d.	5.21	5.62	5.65	5.90	5.84	7.01	6.82
	Wet	Mean	22.72	23.21	23.17	24.52	24.30	20.94	21.49
	Wet	s.d.	6.08	7.05	6.78	6.74	6.85	6.75	6.50
		Pr<F	0.2275	0.8922	0.5725	0.4274	0.4176	0.9042	0.8791
Dissolved Oxygen (mg l^{-1})									
	Drought	Mean	6.92	6.85	6.37	8.65	8.27	7.85	7.54
	Drought	s.d.	1.84	1.62	1.55	2.39	2.14	1.52	1.35
	Normal	Mean	8.04	7.34	6.98	8.60	8.09	7.89	7.50
	Normal	s.d.	2.03	1.13	1.37	1.89	1.70	1.59	1.56
	Wet	Mean	7.97	8.07	6.92	8.01	8.20	8.05	7.51
	Wet	s.d.	1.82	1.58	1.59	1.19	1.32	1.56	1.39
		Pr<F	**0.0261**	**0.0096**	0.2631	0.6125	0.9255	0.8927	0.9790
pH									
	Drought	Mean	8.16	8.02	8.13	8.20	8.16	8.07	8.13
	Drought	s.d.	0.33	0.17	0.14	0.35	0.21	0.16	0.13
	Normal	Mean	8.30	8.07	8.07	8.37	8.19	8.19	8.10
	Normal	s.d.	0.42	0.27	0.24	0.46	0.25	0.70	0.30
	Wet	Mean	8.29	8.27	8.13	8.20	8.34	7.98	8.23
	Wet	s.d.	0.31	0.42	0.21	0.49	0.59	0.41	0.42
		Pr<F	0.2580	**0.0256**	0.4980	0.3124	0.2841	0.3697	0.3331
Chlorophyll (ug l^{-1})									
	Drought	Mean	31.43	4.42	5.17	13.76	5.88	5.27	6.02
	Drought	s.d.	14.19	3.03	2.95	16.95	3.18	3.74	2.93
	Normal	Mean	31.28	5.23	3.90	13.22	10.43	7.50	6.78
	Normal	s.d.	16.36	5.13	2.13	8.26	8.21	4.69	4.00
	Wet	Mean	35.60	8.90	5.33	7.54	12.72	10.69	11.53
	Wet	s.d.	22.19	5.88	3.26	5.91	12.16	6.54	4.54
		Pr<F	0.9311	**0.0304**	0.3266	0.1392	0.2788	0.0772	**0.0072**

(Table 27 continued)

Variable	Condition	Parm.	Rincon Bayou	Nueces	Corpus Christi	Upper SA	Lower SA	Lavaca	Matagorda
Ammonium (µmol l^{-1})									
	Drought	Mean	17.05	3.74	2.08	4.77	2.30	2.29	1.48
	Drought	s.d.	59.80	4.27	3.01	4.89	2.80	3.13	1.53
	Normal	Mean	17.34	2.31	1.49	3.18	1.30	3.43	1.78
	Normal	s.d.	96.93	2.77	2.61	4.76	1.04	7.28	1.97
	Wet	Mean	0.85	1.65	1.65	2.53	2.23	2.42	2.53
	Wet	s.d.	0.94	1.92	1.68	1.73	2.86	1.72	2.14
		Pr<F	0.1816	0.1911	0.6010	0.4238	0.4367	0.7680	0.1576
Nitrate + Nitrite (µmol l^{-1})									
	Drought	Mean	0.45	3.02	1.36	13.33	2.50	0.61	1.22
	Drought	s.d.	0.77	3.57	2.25	14.33	3.91	0.63	1.49
	Normal	Mean	0.63	2.46	0.83	25.09	4.00	5.05	2.00
	Normal	s.d.	2.18	2.91	1.34	20.10	6.30	11.14	3.37
	Wet	Mean	0.88	2.13	0.86	37.74	11.46	9.10	4.81
	Wet	s.d.	1.54	3.99	0.94	39.42	16.43	9.37	5.21
		Pr<F	0.1373	0.7288	0.5878	0.0525	**0.0429**	**0.0001**	**0.0071**
Phosphate (µmol l^{-1})									
	Drought	Mean	0.96	1.69	0.63	3.89	1.72	0.65	0.90
	Drought	s.d.	1.75	0.73	0.38	3.58	1.24	0.28	0.61
	Normal	Mean	0.68	1.65	0.54	3.28	1.69	2.71	1.13
	Normal	s.d.	0.52	1.17	0.44	2.30	1.62	8.06	0.77
	Wet	Mean	1.64	1.86	0.84	3.27	2.63	1.86	1.19
	Wet	s.d.	1.27	1.03	0.74	2.55	2.17	1.26	0.99
		Pr<F	**0.0001**	0.6071	0.0672	0.7254	0.1933	**0.0449**	0.7242
Silicate (µmol l^{-1})									
	Drought	Mean	358.55	84.98	39.37	94.93	66.84	60.74	32.05
	Drought	s.d.	287.04	67.96	47.17	57.55	47.59	37.84	26.94
	Normal	Mean	215.86	99.96	39.01	134.14	97.32	110.36	62.27
	Normal	s.d.	115.46	69.11	26.26	56.23	43.00	72.41	37.83
	Wet	Mean	239.28	120.60	60.39	227.48	163.05	121.70	71.71
	Wet	s.d.	95.07	79.40	46.13	221.40	83.78	61.53	43.37
		Pr<F	0.4519	0.5447	0.8815	**0.0016**	**0.0003**	**0.0286**	**0.0031**

Table 28. Mean macrofauna abundance, biomass and diversity in each bay in drought, normal and wet conditions (Method Two).

Variable	**Condition**	**Parm.**	**Rincon Bayou**	**Nueces**	**Corpus Christi**	**Upper SA**	**Lower SA**	**Lavaca**	**Matagorda**
Abundance (n m^{-2})									
	Drought	Mean	25858	9428	14353	22380	9367	7805	15817
	Drought	s.d.	24613	5250	3880	17659	9364	3791	6116
	Normal	Mean	18769	15049	21449	23479	11629	5576	13237
	Normal	s.d.	21079	11011	8950	23483	9864	4160	11726
	Wet	Mean	6230	11560	15362	15329	6367	5734	9715
	Wet	s.d.	8537	5096	3647	11594	4170	3875	5700
		Pr<F	**0.0028**	0.3449	0.3403	0.3611	**0.0268**	**0.0355**	**0.0452**
Biomass (g m^{-2})									
	Drought	Mean	1.4	6.5	6.7	21.8	3.6	1.8	9.9
	Drought	s.d.	1.6	2.9	2.6	20.7	3.6	1.8	8.4
	Normal	Mean	1.9	7.9	10.4	13.9	2.8	1.2	5.9
	Normal	s.d.	2.2	9.6	4.4	14.7	2.9	1.5	5.5
	Wet	Mean	0.6	8.4	10.5	5.6	1.7	0.9	4.1
	Wet	s.d.	0.6	4.3	5.0	4.1	1.8	0.8	2.7
		Pr<F	**0.0008**	0.5350	0.0359	**0.0204**	0.0539	0.0881	**0.0055**
N1 Diversity (35-cm^{-2})									
	Drought	Mean	1.1	6.0	7.8	2.9	4.5	3.9	7.0
	Drought	s.d.	0.5	2.3	2.1	0.5	1.7	1.5	2.2
	Normal	Mean	1.7	5.6	7.8	3.2	3.3	2.7	5.6
	Normal	s.d.	0.6	2.0	2.4	0.8	1.1	1.2	2.0
	Wet	Mean	1.9	5.8	8.3	2.7	2.6	2.4	5.2
	Wet	s.d.	0.7	2.1	1.5	0.6	1.0	0.5	1.4
		Pr<F	**< 0.0001**	0.6114	0.8279	**0.0158**	**0.0001**	**0.0002**	**0.0038**

Table 29. Taxa vulnerable to drought (bay specific, Method Two).
Taxa were considered vulnerable if their abundance was significantly lower in drought than normal and/or wet periods. Est = estuary, SA = San Antonio. Lines underneath abundance values denote Tukey groupings.

Species	Class	Est	Bay	Abundance ($n\ m^{-2}$) Drought	Normal	Wet	Prob < F
Nemertea (unidentified)	Nemertea	NC	Rincon Bayou	3	40	66	0.0008
Glycera americana	Polychaeta	NC	Corpus Christi	0	16	3	0.0258
Streblospio benedicti	Polychaeta	LC	Matagorda	216	322	685	0.0050
Capitella capitata	Polychaeta	LC	Matagorda	0	1	18	0.0061
Capitella capitata	Polychaeta	NC	Rincon Bayou	0	22	3	0.0296
Ampelisca abdita	Malacostraca	NC	Corpus Christi	4	30	9	0.0234
Listriella clymenellae	Malacostraca	NC	Corpus Christi	33	57	183	0.0454
Ceratopogonidae (larvae)	Insecta	NC	Rincon Bayou	2	10	58	0.0003
Chironomidae (larvae)	Insecta	GE	Upper SA	7	47	179	0.0002
Chironomidae (larvae)	Insecta	LC	Lavaca	0	3	27	0.0008
Chironomidae (larvae)	Insecta	NC	Rincon Bayou	75	312	716	< 0.0001
Texidina sphinctostoma	Gastropoda	GE	Lower SA	7	592	296	0.0449
Mediomastus ambiseta	Polychaeta	NC	Rincon Bayou	202	652	234	0.0010

Table 30. Mean abundance of individual marine species in the three estuaries.
Marine species are defined as being at least 3 times more abundant and having significantly greater abundance in salinities at least 30 than in salinities below 30.

Species	Class	Mean Abundance (n m^{-2}) Marine Sal ≥ 30	Other Sal < 30	Diff	Prob < F
Polydora caulleryi	Polychaeta	2139	455	1684	<0.0001
Tharyx setigera	Polychaeta	1131	238	893	<0.0001
Apseudes sp. A	Malacostraca	746	175	571	0.0001
Paleanotus heteroseta	Polychaeta	340	61	279	<0.0001
Cirrophorus lyra	Polychaeta	195	35	160	<0.0001
Nuculana acuta	Bivalvia	123	33	89	<0.0001
Periploma cf. *orbiculare*	Bivalvia	122	32	89	<0.0001
Corbula contracta	Bivalvia	111	26	85	0.0005
Schistomeringos sp. A	Polychaeta	83	23	60	<0.0001
Anthozoa (unidentified)	Anthozoa	76	22	54	<0.0001
Lepton sp.	Bivalvia	79	26	53	<0.0001
Euclymene sp. B	Polychaeta	59	12	47	<0.0001
Lyonsia hyalina floridana	Bivalvia	50	4	46	<0.0001
Aricidea bryani	Polychaeta	60	15	45	<0.0001
Pomatoceros americanus	Polychaeta	50	6	44	0.0017
Aligena texasiana	Bivalvia	55	17	38	0.0005
Notomastus latericeus	Polychaeta	47	11	37	<0.0001
Axiothella sp. A	Polychaeta	46	9	37	<0.0001
Listriella barnardi	Malacostraca	46	10	37	<0.0001
Listriella clymenellae	Malacostraca	48	12	36	<0.0001
Phascolion strombi	Sipuncula	51	15	35	<0.0001
Ceratonereis irritabilis	Polychaeta	41	8	33	<0.0001
Sabellidae (unidentified)	Polychaeta	32	2	29	0.0064
Branchioasychis americana	Polychaeta	38	13	26	<0.0001
Leucon sp.	Malacostraca	33	11	22	0.0007
Amaeana trilobata	Polychaeta	24	3	21	<0.0001
Polydora socialis	Polychaeta	25	6	19	0.0051
Microprotopus sp.	Malacostraca	28	9	19	0.0001
Spiophanes bombyx	Polychaeta	24	6	18	<0.0001
Malmgreniella taylori	Polychaeta	23	6	17	<0.0001
Armandia maculata	Polychaeta	20	4	16	<0.0001
Onuphis eremita	Polychaeta	18	4	14	<0.0001
Erichthonias brasiliensis	Malacostraca	20	6	14	<0.0001
Ancistrosyllis jonesi	Polychaeta	14	2	13	<0.0001
Pinnixa sp.	Malacostraca	18	6	12	<0.0001
Megalomma bioculatum	Polychaeta	14	4	10	<0.0001
Podarke obscura	Polychaeta	11	3	8	<0.0001

Species	Class	Mean Abundance (n m^{-2}) Marine Sal ≥ 30	Other Sal < 30	Diff	Prob < F
Tellina sp.	Bivalvia	12	4	8	0.0001
Syllidae (unidentified)	Polychaeta	8	0	8	0.0002
Isolda pulchella	Polychaeta	9	2	7	0.0001
Notomastus cf. latericeus	Polychaeta	7	1	5	0.0018
Lembos sp.	Malacostraca	6	0	5	<0.0001
Syllis cornuta	Polychaeta	8	2	5	0.0006
Brada cf. *villosa capensis*	Polychaeta	5	0	5	0.0001
Brania furcelligera	Polychaeta	7	2	5	0.0251
Terebellidae (unidentified)	Polychaeta	5	1	4	0.0004
Eudorella monodon	Malacostraca	5	0	4	0.0108
Megalops	Malacostraca	5	1	4	<0.0001
Corophium ascherusicum	Malacostraca	5	1	4	0.0151
Tagelus divisus	Bivalvia	4	0	4	0.0001
Caecum glabrum	Gastropoda	4	0	4	0.0076
Pagurus annulipes	Malacostraca	4	0	4	<0.0001
Magelona pettiboneae	Polychaeta	4	1	3	0.0002
Hauchiella sp.	Polychaeta	4	1	3	0.0010
Pinnixa chacei	Malacostraca	4	1	3	0.0473
Serpulidae (unidentified)	Polychaeta	3	0	3	0.0064
Haploscoloplos sp.	Polychaeta	4	1	3	0.0094
Eunoe cf. *nodulosa*	Polychaeta	4	1	3	0.0137
Paramya subovata	Bivalvia	3	1	3	0.0423
Ampelisca sp. B	Malacostraca	4	1	3	0.0079
Dentalium texasianum	Scaphopoda	3	0	2	0.0002
Chaetozone setosa	Polychaeta	3	1	2	0.0179
Anachis obesa	Gastropoda	2	0	2	0.0002
Holothuroidea (unidentified)	Holothuroidea	3	0	2	0.0002
Petricola pholadiformes	Bivalvia	2	0	2	0.0067
Parahesione luteola	Polychaeta	2	0	2	0.0072
Grandidierella bonnieroides	Malacostraca	3	0	2	0.0358
Macoma tenta	Bivalvia	3	1	2	0.0492
Eupomatus dianthus	Polychaeta	2	0	2	0.0173
Mitrella lunata	Gastropoda	2	0	2	0.0179
Pinnixa retinens	Malacostraca	2	0	2	0.0067
Pilargiidae (unidentified)	Polychaeta	2	0	2	0.0122
Bulla striata	Gastropoda	2	0	2	0.0449
Pista cristata	Polychaeta	2	0	2	0.0014
Sarsiella spinosa	Ostracoda	2	0	1	0.0067
Xanthidae (unidentified)	Malacostraca	1	0	1	0.0132
Allothyone mexicana	Holothuroidea	1	0	1	0.0099

Species	Class	Mean Abundance (n m^{-2}) Marine Sal ≥ 30	Other Sal < 30	Diff	Prob < F
Litocorsa stremma	Polychaeta	1	0	1	0.0067
Callinectes sapidus	Malacostraca	1	0	1	0.0067
Cantharus cancellarius	Gastropoda	1	0	1	0.0067
Sarsiella zostericola	Ostracoda	1	0	1	0.0067
Chione cancellata	Bivalvia	1	0	1	0.0067
Nematonereis hebes	Polychaeta	1	0	1	0.0067
Brada sp.	Polychaeta	1	0	1	0.0067

Table 31. Mean total abundance of marine species in drought, normal and wet conditions and one-way ANOVA among the three estuaries (Method Two).

Marine species are those listed in Table 24. Pearson Correlations between mean monthly salinity and PDSI for different Texas climatic divisions in each bay.

N= 276 months (except Nueces Bay where N=275). All relationships had a significance of $p < 0.0001$.

Climate Division(s)	Nueces Estuary		Guadalupe Estuary		Lavaca-Colorado Estuary	
	Nueces Bay	**Corpus Christi Bay**	**Upper SA Bay**	**Lower SA Bay**	**Lavaca Bay**	**Matagorda Bay**
6	-0.52	-0.46	-0.55	-0.56	-0.59	-0.63
7	-0.60	-0.58	-0.65	-0.63	-0.76	-0.74
8	-0.50	-0.49	-0.55	-0.53	-0.76	-0.74
9	***-0.77***	-0.66	-0.62	-0.62	-0.62	-0.65
Mean (6, 9)	-0.71	-0.62	-0.64	-0.64	-0.66	-0.69
Mean(7, 8)	-0.58	-0.57	-0.64	-0.61	***-0.80***	-0.77
Mean (7, 9)	***-0.73***	-0.67	***-0.68***	-0.67	-0.73	-0.74
Mean (6, 7, 8)	-0.59	-0.56	-0.65	-0.63	***-0.77***	-0.77
Mean (6, 7, 9)	-0.70	-0.63	***-0.67***	-0.67	-0.72	-0.74

Table 25. Mean Palmer Drought Severity Index value for drought, normal and wet periods in each estuary.

Bold text indicates where PDSI is most highly correlated with salinity (see Table 24). All drought conditions within each estuary were significantly different than each other, as determined by one-way ANOVA ($p < 0.0001$) and Tukey tests.

Climate	**Nueces**			**Guadalupe**			**Lavaca-Colorado**		
Division	**Drought**	**Normal**	**Wet**	**Drought**	**Normal**	**Wet**	**Drought**	**Normal**	**Wet**
6	-1.30	-0.54	1.41	-1.65	-0.57	1.90	-1.91	-0.29	1.61
7	-2.01	-0.18	2.16	-2.37	0.00	2.25	-2.74	-0.10	2.82
8	-0.93	0.24	1.92	-1.25	0.46	1.85	-1.77	0.33	2.64
9	**-2.20**	**-0.18**	**3.61**	-1.78	-0.05	3.02	-2.04	0.14	2.91
Mean (6, 9)	-1.75	-0.36	2.51	-1.71	-0.31	2.46	-1.98	-0.08	2.26
Mean(7, 8)	-1.47	0.03	2.04	-1.81	0.23	2.05	**-2.26**	**0.12**	**2.73**
Mean (7, 9)	**-2.11**	**-0.18**	**2.88**	**-2.07**	**-0.03**	**2.64**	-2.39	0.02	2.87
Mean (6, 7, 8)	-1.41	-0.16	1.83	-1.75	-0.04	2.00	**-2.14**	**-0.02**	**2.36**
Mean (6, 7, 9)	-1.84	-0.30	2.39	**-1.93**	**-0.21**	**2.39**	-2.23	-0.09	2.45

Table 26. Mean salinity, temperature, dissolved oxygen and turbidity for each estuary-climate condition combination (Method Two, TPWD data).
N= 287 for Nueces and Corpus Christi Bays and 288 for all other bays.

Variable	**Condition**	**Parm.**	**Nueces**	**Corpus Christi**	**Upper SA**	**Lower SA**	**Lavaca**	**Matagorda**
Salinity								
	Drought	Mean	36.41	35.11	23.83	29.51	28.32	29.71
	Drought	s.d.	2.83	2.64	3.52	3.49	2.71	2.67
	Normal	Mean	27.78	31.09	12.26	20.80	18.77	24.25
	Normal	s.d.	3.05	2.75	4.40	4.86	3.48	3.39
	Wet	Mean	12.77	26.67	1.93	6.87	6.56	16.23
	Wet	s.d.	6.77	4.18	1.64	5.02	3.26	4.78
		Pr<F	**n/a**	**<0.0001**	**n/a**	**<0.0001**	**n/a**	**<0.0001**
Temperature (°C)								
	Drought	Mean	24.12	24.20	22.46	22.77	21.98	22.38
	Drought	s.d.	6.16	6.15	5.90	6.25	6.49	6.05
	Normal	Mean	23.27	22.93	21.95	22.29	22.64	22.88
	Normal	s.d.	5.80	5.67	6.29	6.24	6.73	6.34
	Wet	Mean	24.14	24.12	24.20	24.50	22.70	22.91
	Wet	s.d.	5.68	5.94	5.84	5.83	6.43	6.26
		Pr<F	0.5599	0.3141	**0.0389**	**0.0482**	0.7999	0.8877
Dissolved Oxygen (mg l^{-1})								
	Drought	Mean	6.98	7.19	7.64	7.65	7.40	7.51
	Drought	s.d.	1.45	1.31	1.44	1.54	1.50	1.13
	Normal	Mean	7.37	7.39	8.65	8.16	7.45	7.41
	Normal	s.d.	1.37	1.26	1.67	1.33	1.63	1.40
	Wet	Mean	7.89	7.53	8.14	8.15	7.83	7.87
	Wet	s.d.	1.59	1.39	1.29	1.35	1.51	1.34
		Pr<F	**0.0011**	0.2957	**<0.0001**	**0.0137**	0.1386	**0.0437**
Turbidity (NTU)								
	Drought	Mean	32.15	15.35	22.13	19.35	25.24	21.50
	Drought	s.d.	32.62	10.30	16.45	22.06	21.28	11.34
	Normal	Mean	26.63	13.38	24.53	19.53	22.35	21.44
	Normal	s.d.	23.87	9.09	19.42	16.40	12.95	13.20
	Wet	Mean	33.20	12.18	42.40	33.21	43.68	27.61
	Wet	s.d.	26.66	5.61	23.45	23.59	28.37	13.74
		Pr<F	0.0554	0.1057	**<0.0001**	**<0.0001**	**<0.0001**	**0.0009**

Table 27. Mean water quality for each bay-climate condition combination (Method Two, HRI data).

Variable	Condition	Parm.	Rincon Bayou	Nueces	Corpus Christi	Upper SA	Lower SA	Lavaca	Matagorda
Salinity									
	Drought	Mean	52.35	36.26	36.15	18.73	27.06	26.49	30.03
	Drought	s.d.	23.78	4.04	3.61	4.13	3.14	4.78	3.36
	Normal	Mean	25.96	27.90	31.91	9.80	18.76	16.74	25.40
	Normal	s.d.	11.81	4.53	3.59	5.46	5.97	6.08	3.71
	Wet	Mean	7.58	16.61	28.18	1.23	5.09	6.09	18.51
	Wet	s.d.	7.32	7.47	4.19	1.60	4.30	5.38	5.87
		Pr<F	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Temperature (°C)									
	Drought	Mean	25.29	23.19	23.47	21.73	21.36	21.75	22.04
	Drought	s.d.	5.97	6.65	6.28	6.71	6.83	6.66	6.39
	Normal	Mean	23.70	22.04	21.51	22.07	22.01	22.12	22.70
	Normal	s.d.	5.21	5.62	5.65	5.90	5.84	7.01	6.82
	Wet	Mean	22.72	23.21	23.17	24.52	24.30	20.94	21.49
	Wet	s.d.	6.08	7.05	6.78	6.74	6.85	6.75	6.50
		Pr<F	0.2275	0.8922	0.5725	0.4274	0.4176	0.9042	0.8791
Dissolved Oxygen (mg l^{-1})									
	Drought	Mean	6.92	6.85	6.37	8.65	8.27	7.85	7.54
	Drought	s.d.	1.84	1.62	1.55	2.39	2.14	1.52	1.35
	Normal	Mean	8.04	7.34	6.98	8.60	8.09	7.89	7.50
	Normal	s.d.	2.03	1.13	1.37	1.89	1.70	1.59	1.56
	Wet	Mean	7.97	8.07	6.92	8.01	8.20	8.05	7.51
	Wet	s.d.	1.82	1.58	1.59	1.19	1.32	1.56	1.39
		Pr<F	**0.0261**	**0.0096**	0.2631	0.6125	0.9255	0.8927	0.9790
pH									
	Drought	Mean	8.16	8.02	8.13	8.20	8.16	8.07	8.13
	Drought	s.d.	0.33	0.17	0.14	0.35	0.21	0.16	0.13
	Normal	Mean	8.30	8.07	8.07	8.37	8.19	8.19	8.10
	Normal	s.d.	0.42	0.27	0.24	0.46	0.25	0.70	0.30
	Wet	Mean	8.29	8.27	8.13	8.20	8.34	7.98	8.23
	Wet	s.d.	0.31	0.42	0.21	0.49	0.59	0.41	0.42
		Pr<F	0.2580	**0.0256**	0.4980	0.3124	0.2841	0.3697	0.3331
Chlorophyll (ug l^{-1})									
	Drought	Mean	31.43	4.42	5.17	13.76	5.88	5.27	6.02
	Drought	s.d.	14.19	3.03	2.95	16.95	3.18	3.74	2.93
	Normal	Mean	31.28	5.23	3.90	13.22	10.43	7.50	6.78
	Normal	s.d.	16.36	5.13	2.13	8.26	8.21	4.69	4.00
	Wet	Mean	35.60	8.90	5.33	7.54	12.72	10.69	11.53
	Wet	s.d.	22.19	5.88	3.26	5.91	12.16	6.54	4.54
		Pr<F	0.9311	**0.0304**	0.3266	0.1392	0.2788	0.0772	**0.0072**

(Table 27 continued)

Variable	Condition	Parm.	Rincon Bayou	Nueces	Corpus Christi	Upper SA	Lower SA	Lavaca	Matagorda
Ammonium (µmol l^{-1})									
	Drought	Mean	17.05	3.74	2.08	4.77	2.30	2.29	1.48
	Drought	s.d.	59.80	4.27	3.01	4.89	2.80	3.13	1.53
	Normal	Mean	17.34	2.31	1.49	3.18	1.30	3.43	1.78
	Normal	s.d.	96.93	2.77	2.61	4.76	1.04	7.28	1.97
	Wet	Mean	0.85	1.65	1.65	2.53	2.23	2.42	2.53
	Wet	s.d.	0.94	1.92	1.68	1.73	2.86	1.72	2.14
		Pr<F	0.1816	0.1911	0.6010	0.4238	0.4367	0.7680	0.1576
Nitrate + Nitrite (µmol l^{-1})									
	Drought	Mean	0.45	3.02	1.36	13.33	2.50	0.61	1.22
	Drought	s.d.	0.77	3.57	2.25	14.33	3.91	0.63	1.49
	Normal	Mean	0.63	2.46	0.83	25.09	4.00	5.05	2.00
	Normal	s.d.	2.18	2.91	1.34	20.10	6.30	11.14	3.37
	Wet	Mean	0.88	2.13	0.86	37.74	11.46	9.10	4.81
	Wet	s.d.	1.54	3.99	0.94	39.42	16.43	9.37	5.21
		Pr<F	0.1373	0.7288	0.5878	0.0525	**0.0429**	**0.0001**	**0.0071**
Phosphate (µmol l^{-1})									
	Drought	Mean	0.96	1.69	0.63	3.89	1.72	0.65	0.90
	Drought	s.d.	1.75	0.73	0.38	3.58	1.24	0.28	0.61
	Normal	Mean	0.68	1.65	0.54	3.28	1.69	2.71	1.13
	Normal	s.d.	0.52	1.17	0.44	2.30	1.62	8.06	0.77
	Wet	Mean	1.64	1.86	0.84	3.27	2.63	1.86	1.19
	Wet	s.d.	1.27	1.03	0.74	2.55	2.17	1.26	0.99
		Pr<F	**0.0001**	0.6071	0.0672	0.7254	0.1933	**0.0449**	0.7242
Silicate (µmol l^{-1})									
	Drought	Mean	358.55	84.98	39.37	94.93	66.84	60.74	32.05
	Drought	s.d.	287.04	67.96	47.17	57.55	47.59	37.84	26.94
	Normal	Mean	215.86	99.96	39.01	134.14	97.32	110.36	62.27
	Normal	s.d.	115.46	69.11	26.26	56.23	43.00	72.41	37.83
	Wet	Mean	239.28	120.60	60.39	227.48	163.05	121.70	71.71
	Wet	s.d.	95.07	79.40	46.13	221.40	83.78	61.53	43.37
		Pr<F	0.4519	0.5447	0.8815	**0.0016**	**0.0003**	**0.0286**	**0.0031**

Table 28. Mean macrofauna abundance, biomass and diversity in each bay in drought, normal and wet conditions (Method Two).

Variable	**Condition**	**Parm.**	**Rincon Bayou**	**Nueces**	**Corpus Christi**	**Upper SA**	**Lower SA**	**Lavaca**	**Matagorda**
Abundance (n m^{-2})									
	Drought	Mean	25858	9428	14353	22380	9367	7805	15817
	Drought	s.d.	24613	5250	3880	17659	9364	3791	6116
	Normal	Mean	18769	15049	21449	23479	11629	5576	13237
	Normal	s.d.	21079	11011	8950	23483	9864	4160	11726
	Wet	Mean	6230	11560	15362	15329	6367	5734	9715
	Wet	s.d.	8537	5096	3647	11594	4170	3875	5700
		Pr<F	**0.0028**	0.3449	0.3403	0.3611	**0.0268**	**0.0355**	**0.0452**
Biomass (g m^{-2})									
	Drought	Mean	1.4	6.5	6.7	21.8	3.6	1.8	9.9
	Drought	s.d.	1.6	2.9	2.6	20.7	3.6	1.8	8.4
	Normal	Mean	1.9	7.9	10.4	13.9	2.8	1.2	5.9
	Normal	s.d.	2.2	9.6	4.4	14.7	2.9	1.5	5.5
	Wet	Mean	0.6	8.4	10.5	5.6	1.7	0.9	4.1
	Wet	s.d.	0.6	4.3	5.0	4.1	1.8	0.8	2.7
		Pr<F	**0.0008**	0.5350	0.0359	**0.0204**	0.0539	0.0881	**0.0055**
N1 Diversity (35-cm^{-2})									
	Drought	Mean	1.1	6.0	7.8	2.9	4.5	3.9	7.0
	Drought	s.d.	0.5	2.3	2.1	0.5	1.7	1.5	2.2
	Normal	Mean	1.7	5.6	7.8	3.2	3.3	2.7	5.6
	Normal	s.d.	0.6	2.0	2.4	0.8	1.1	1.2	2.0
	Wet	Mean	1.9	5.8	8.3	2.7	2.6	2.4	5.2
	Wet	s.d.	0.7	2.1	1.5	0.6	1.0	0.5	1.4
		Pr<F	**< 0.0001**	0.6114	0.8279	**0.0158**	**0.0001**	**0.0002**	**0.0038**

Table 29. Taxa vulnerable to drought (bay specific, Method Two).
Taxa were considered vulnerable if their abundance was significantly lower in drought than normal and/or wet periods. Est = estuary, SA = San Antonio. Lines underneath abundance values denote Tukey groupings.

Species	Class	Est	Bay	Abundance (n m^{-2}) Drought	Normal	Wet	Prob < F
Nemertea (unidentified)	Nemertea	NC	Rincon Bayou	3	40	66	0.0008
Glycera americana	Polychaeta	NC	Corpus Christi	0	16	3	0.0258
Streblospio benedicti	Polychaeta	LC	Matagorda	216	322	685	0.0050
Capitella capitata	Polychaeta	LC	Matagorda	0	1	18	0.0061
Capitella capitata	Polychaeta	NC	Rincon Bayou	0	22	3	0.0296
Ampelisca abdita	Malacostraca	NC	Corpus Christi	4	30	9	0.0234
Listriella clymenellae	Malacostraca	NC	Corpus Christi	33	57	183	0.0454
Ceratopogonidae (larvae)	Insecta	NC	Rincon Bayou	2	10	58	0.0003
Chironomidae (larvae)	Insecta	GE	Upper SA	7	47	179	0.0002
Chironomidae (larvae)	Insecta	LC	Lavaca	0	3	27	0.0008
Chironomidae (larvae)	Insecta	NC	Rincon Bayou	75	312	716	< 0.0001
Texidina sphinctostoma	Gastropoda	GE	Lower SA	7	592	296	0.0449
Mediomastus ambiseta	Polychaeta	NC	Rincon Bayou	202	652	234	0.0010

Table 30 Abundance per unit area was log transformed prior to ANOVA test. Bold p-value indicates abundance in drought periods is significantly different than wet periods. Italicized and bold p-value indicates abundance in drought periods is significantly different than both normal and wet periods.

Variable	Condition	Parm.	Rincon Bayou	Nueces	Corpus Christi	Upper SA	Lower SA	Lavaca	Matagorda
Abundance of Marine Species (n m^{-2})									
	Drought	Mean	0	2291	6652	68	831	266	5385
	Drought	s.d.	0	1893	3055	106	1376	236	3732
	Normal	Mean	16	2681	9254	40	403	62	4086
	Normal	s.d.	51	3907	7620	106	1150	112	7321
	Wet	Mean	0	2834	8293	0	60	36	2088
	Wet	s.d.	0	2877	3774	0	109	84	2943
		Pr<F	0.0383	0.5728	0.8214	**0.0473**	***<0.0001***	***<0.0001***	**0.0104**
Abundance of Marine Species (%)									
	Drought	Mean	0	20.7	39.9	0.4	7.0	3.8	25.6
	Drought	s.d.	0	17.7	15.9	0.7	5.4	3.5	11.1
	Normal	Mean	0.1	14.7	33.9	0.2	3.3	0.9	19.6
	Normal	s.d.	0.3	12.4	17.3	0.6	7.7	1.6	12.3
	Wet	Mean	0	16.2	43.3	0	0.7	0.7	15.7
	Wet	s.d.	0	13.7	17.6	0	1.7	2.2	9.5
		Pr<F	0.0660	0.4407	0.2477	0.0865	**0.0062**	***<0.0001***	**0.0319**

FIGURES

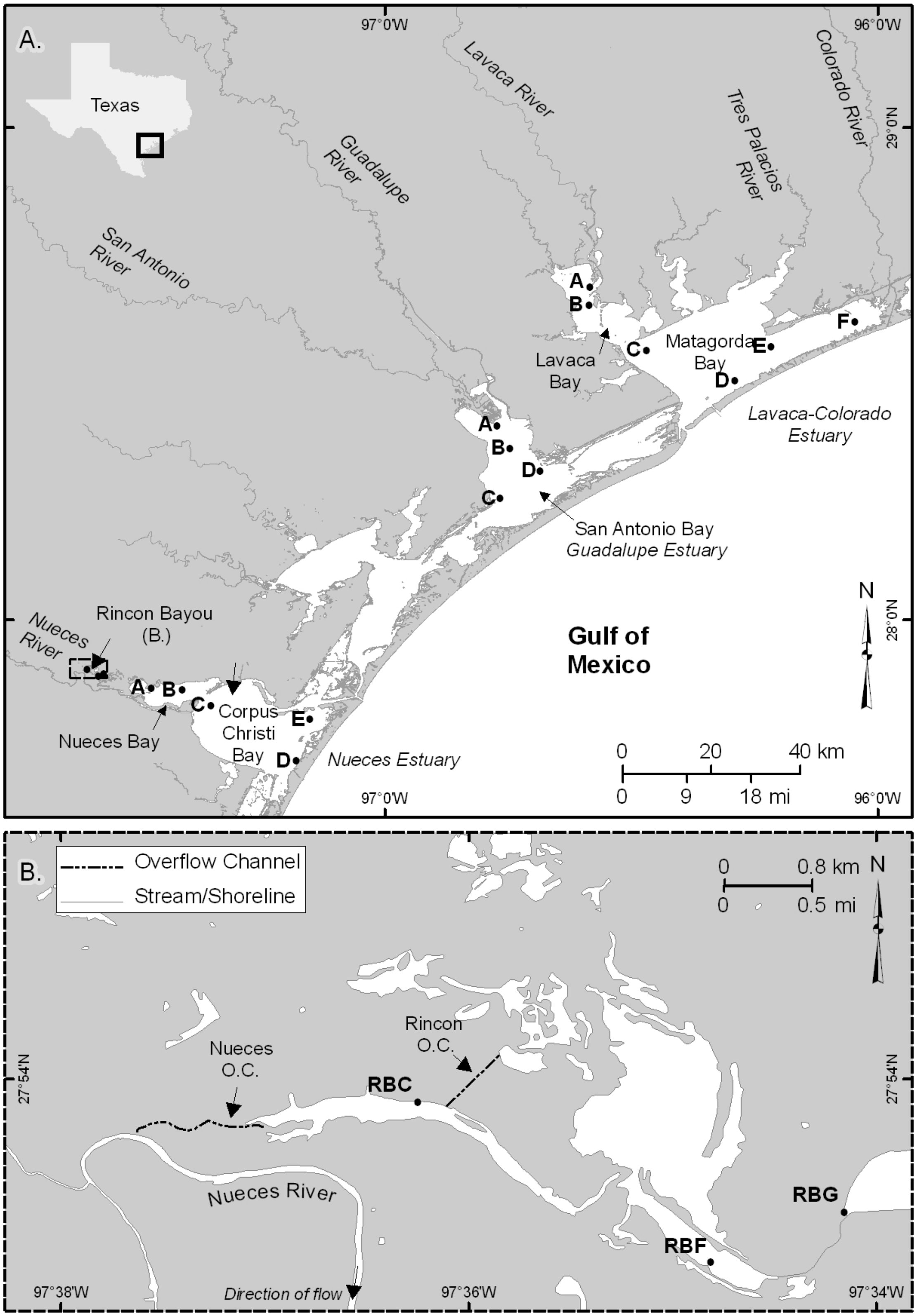

Figure 1. Station location map. A) Along the Texas coast and B) Rincon Bayou

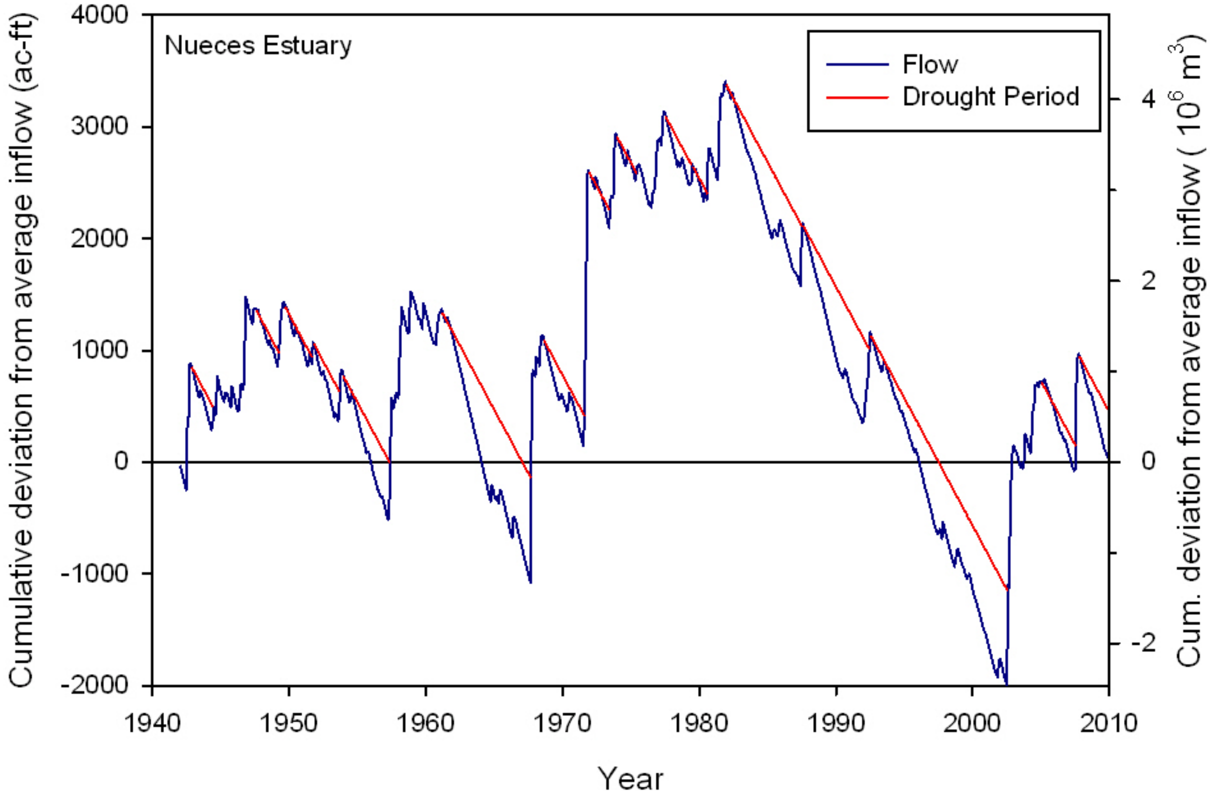

Figure 2. Cumulative deviation from average inflow to Nueces Estuary and definition of drought periods (Method One).

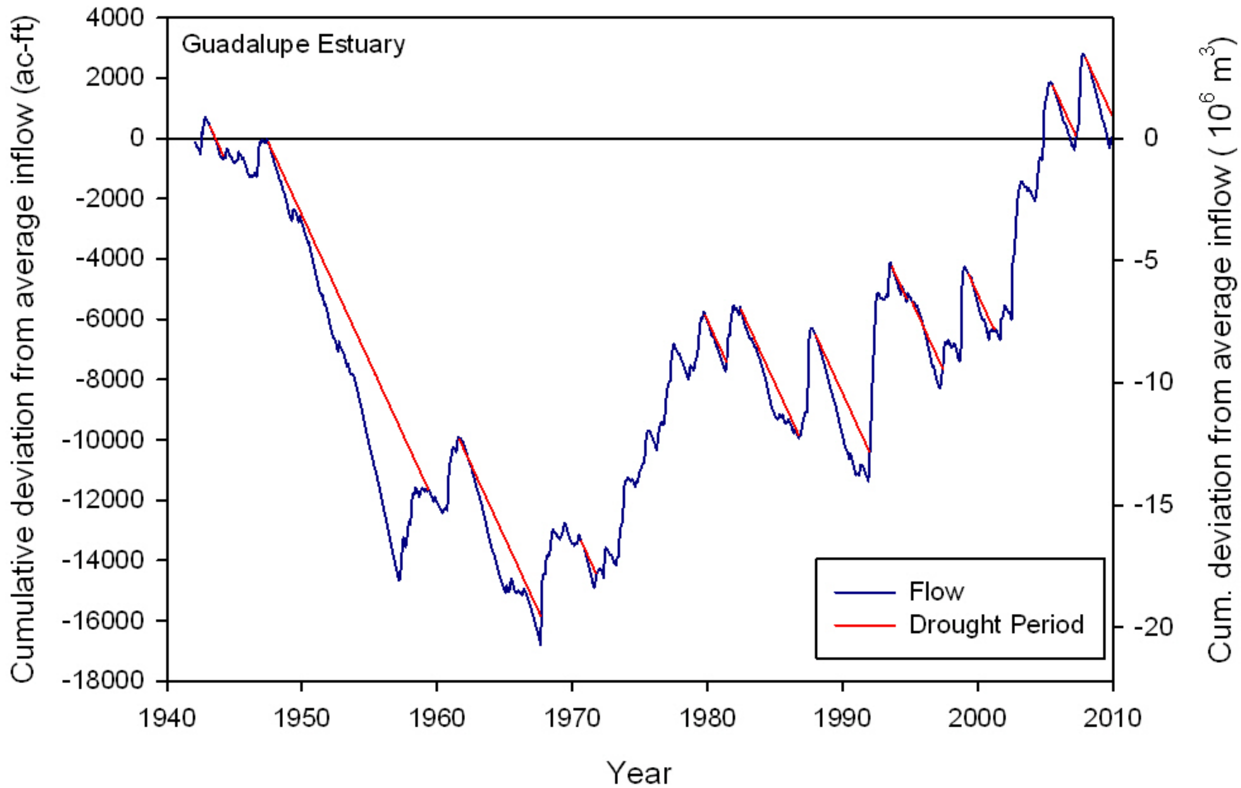

Figure 3. Cumulative deviation from average inflow to Guadalupe Estuary and definition of drought periods (Method One).

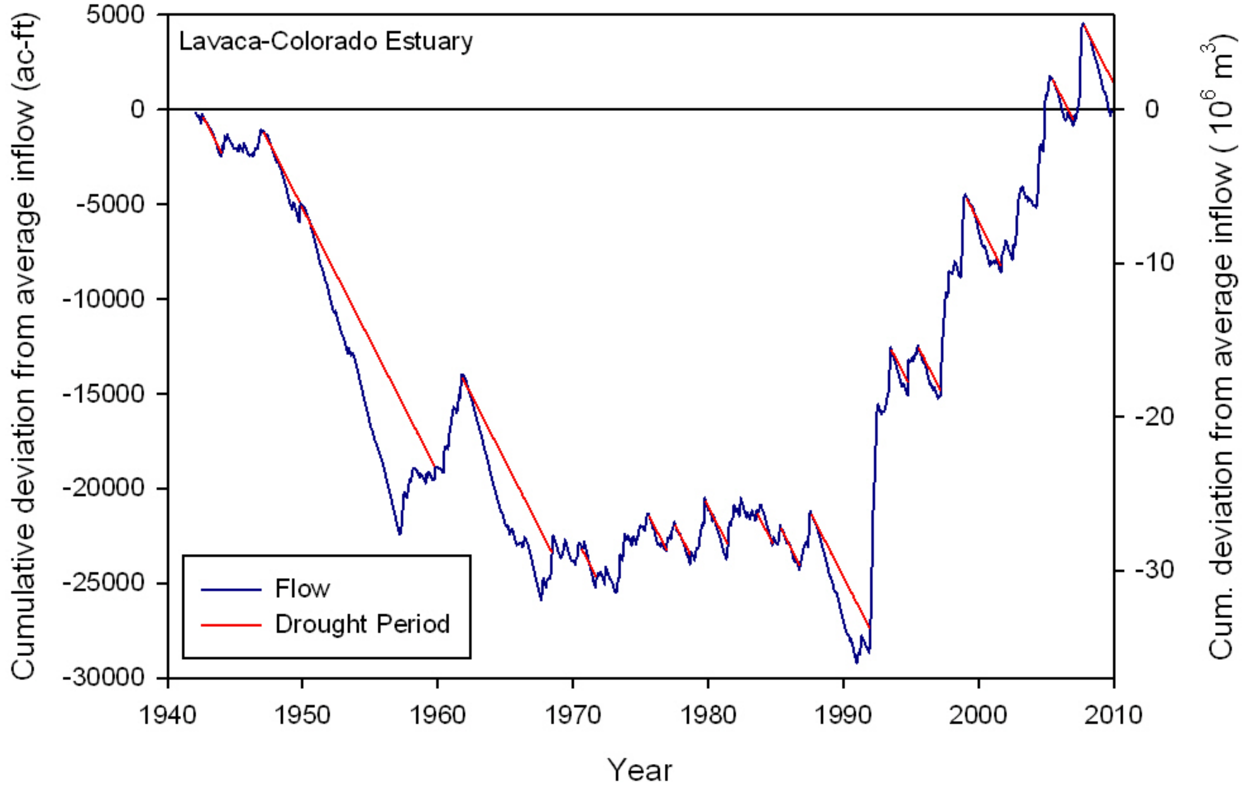

Figure 4. Cumulative deviation from average inflow to Lavaca-Colorado Estuary and definition of drought periods (Method One).

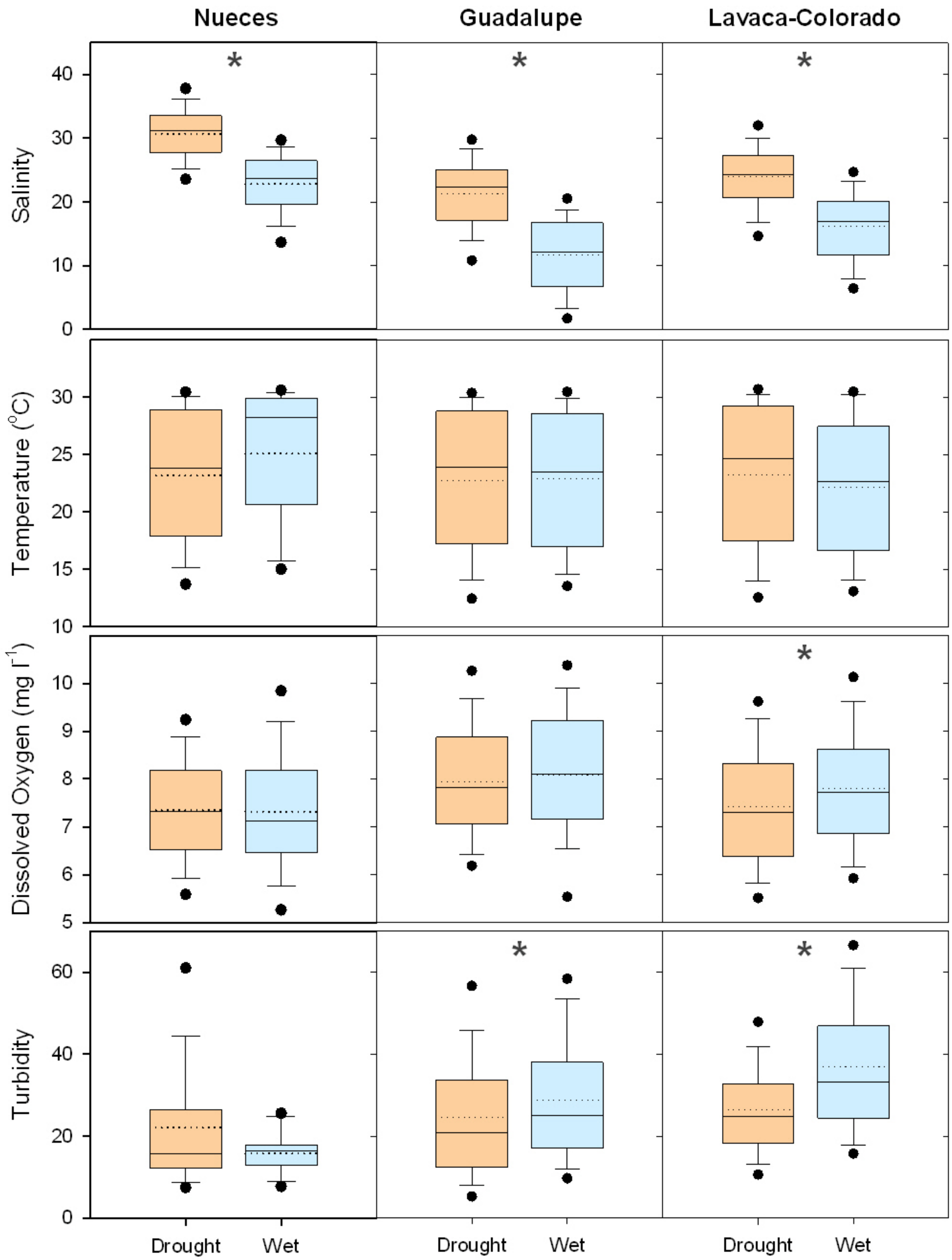

Figure 5. Box plots of drought and wet conditions for four water quality variables in each bay system (Method One).
* indicates significant differences between drought and wet months.

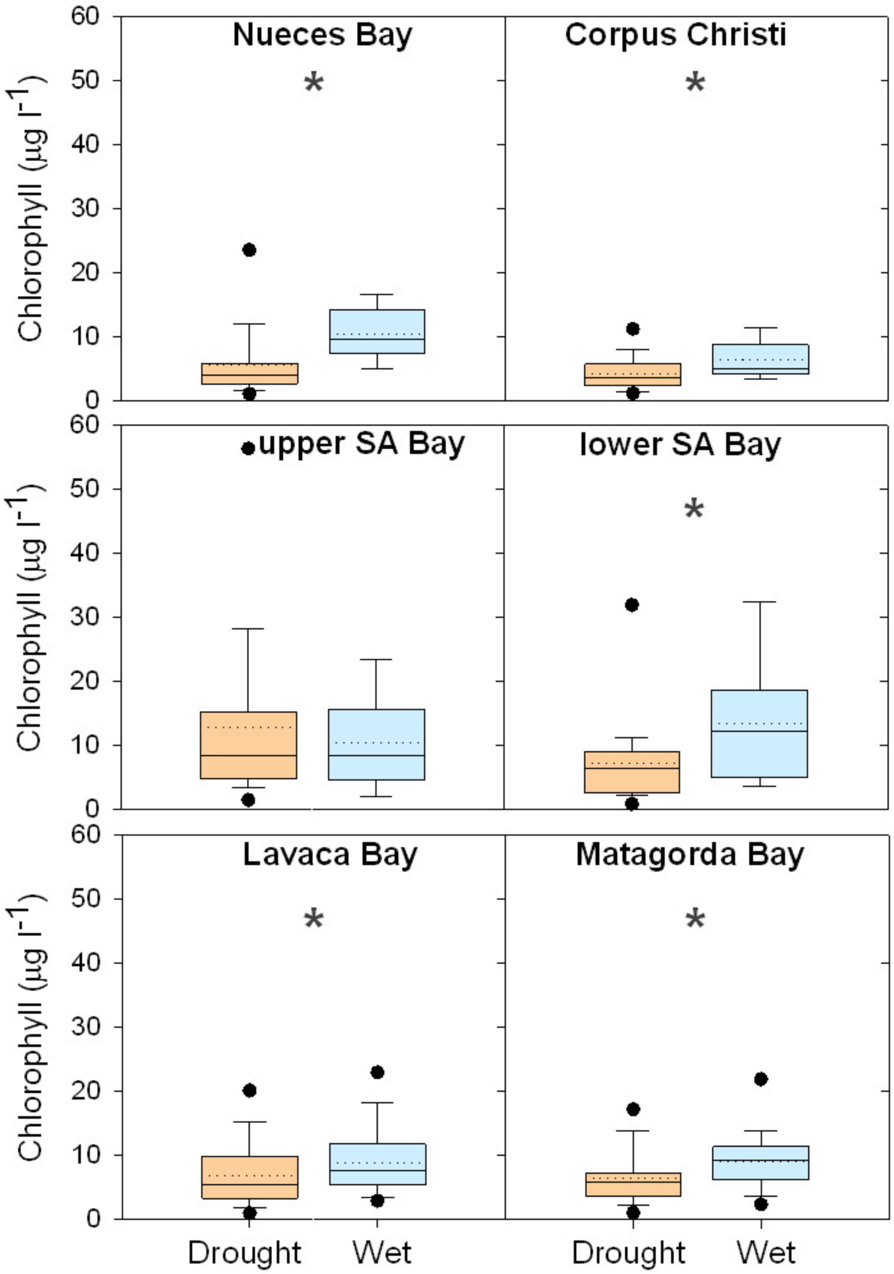

Figure 6. Box plots of chlorophyll conditions during drought and wet periods in primary and secondary bays (Method One).

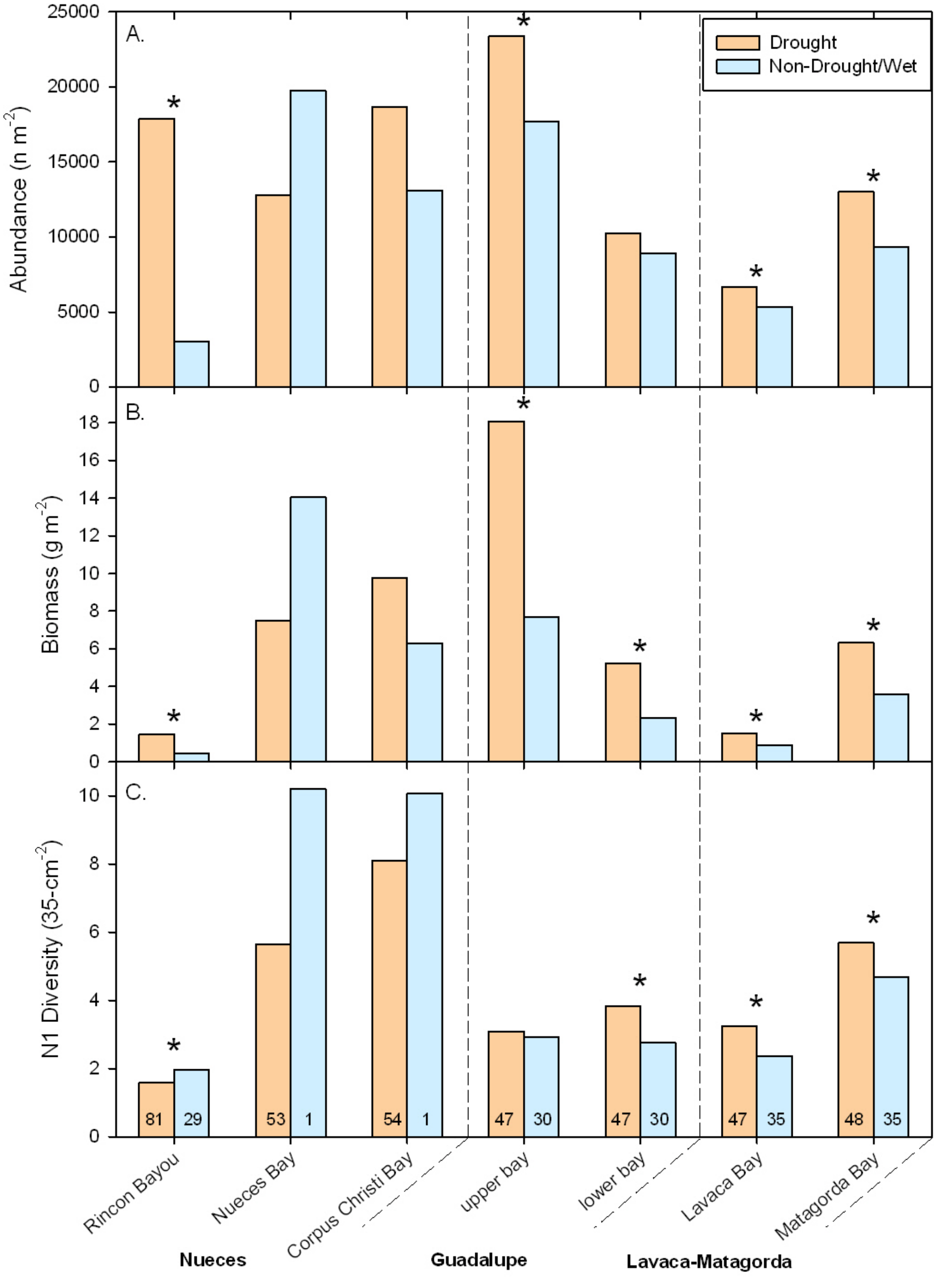

Figure 7. Mean macrofaunal abundance (A), biomass (B) and diversity (C) for the primary and secondary bays within each estuary (Method One).

* indicates significant differences between drought and wet months. Numbers in bars in (C) represents number of dates sampled.

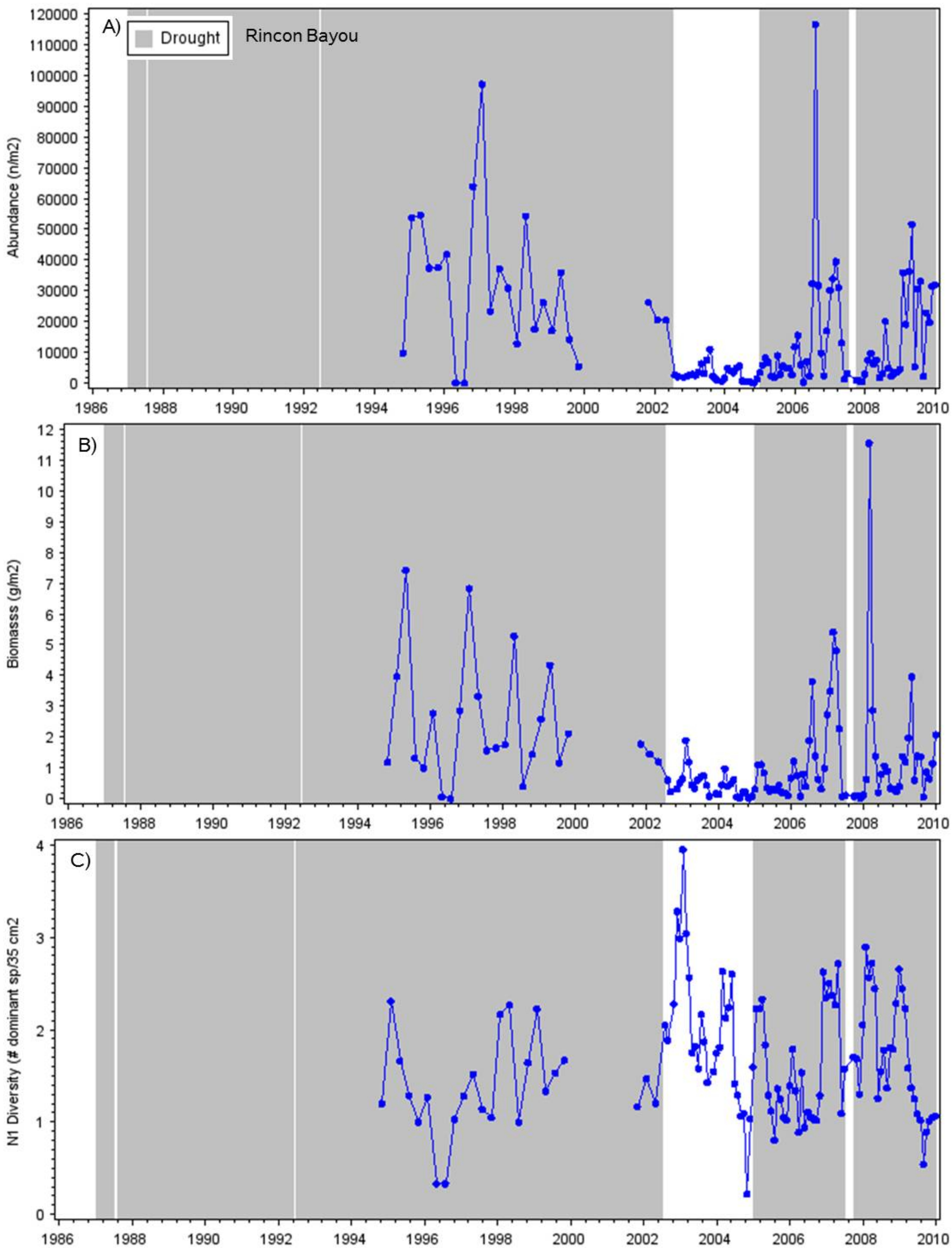

Figure 8. Monthly macrofaunal abundance (A), biomass (B), and diversity (C) in Rincon Bayou.

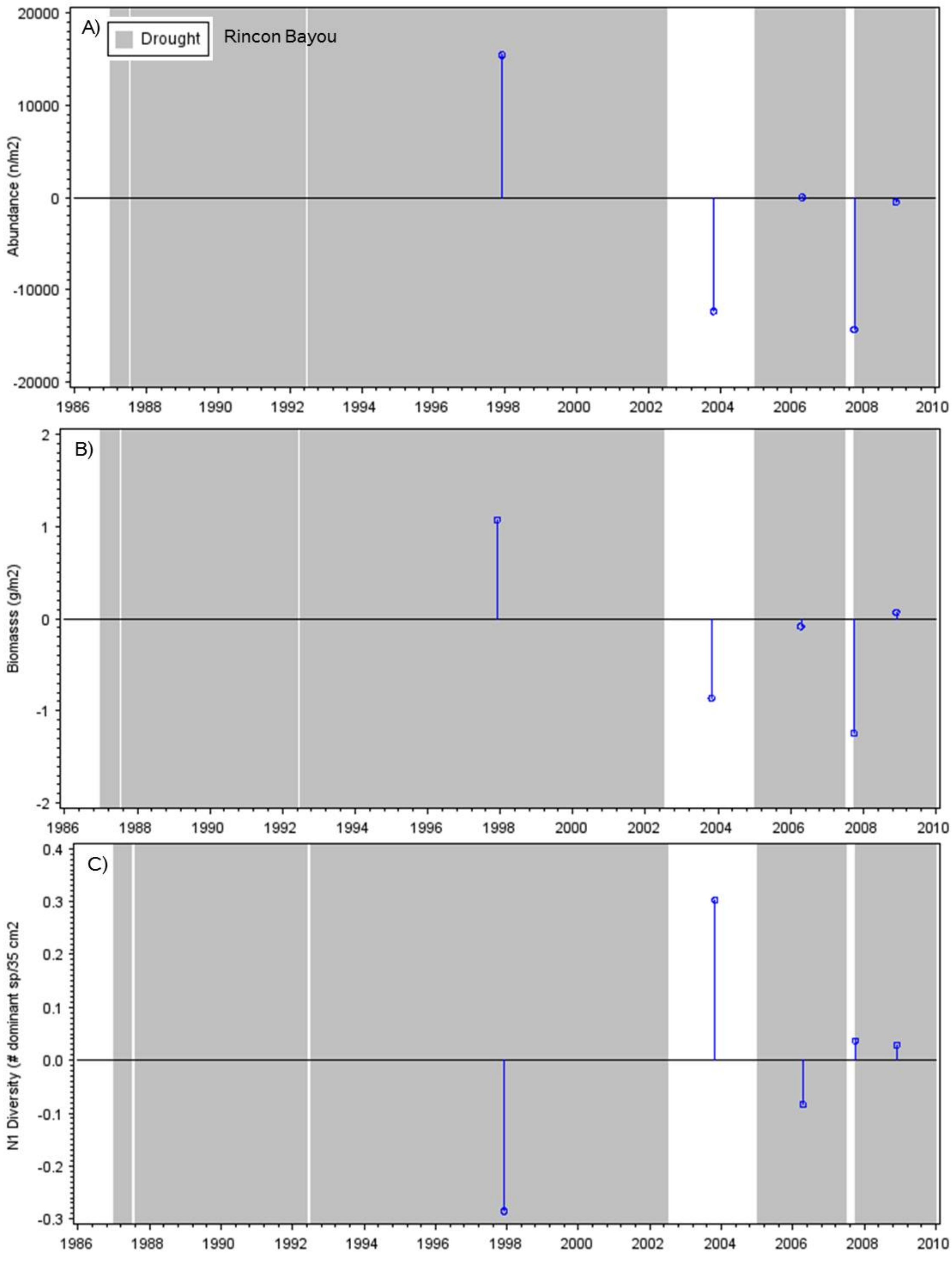

Figure 9. Mean difference from overall mean for macrofaunal abundance (A), biomass (B), and diversity (C) for each drought and wet periods in Rincon Bayou (Method One).

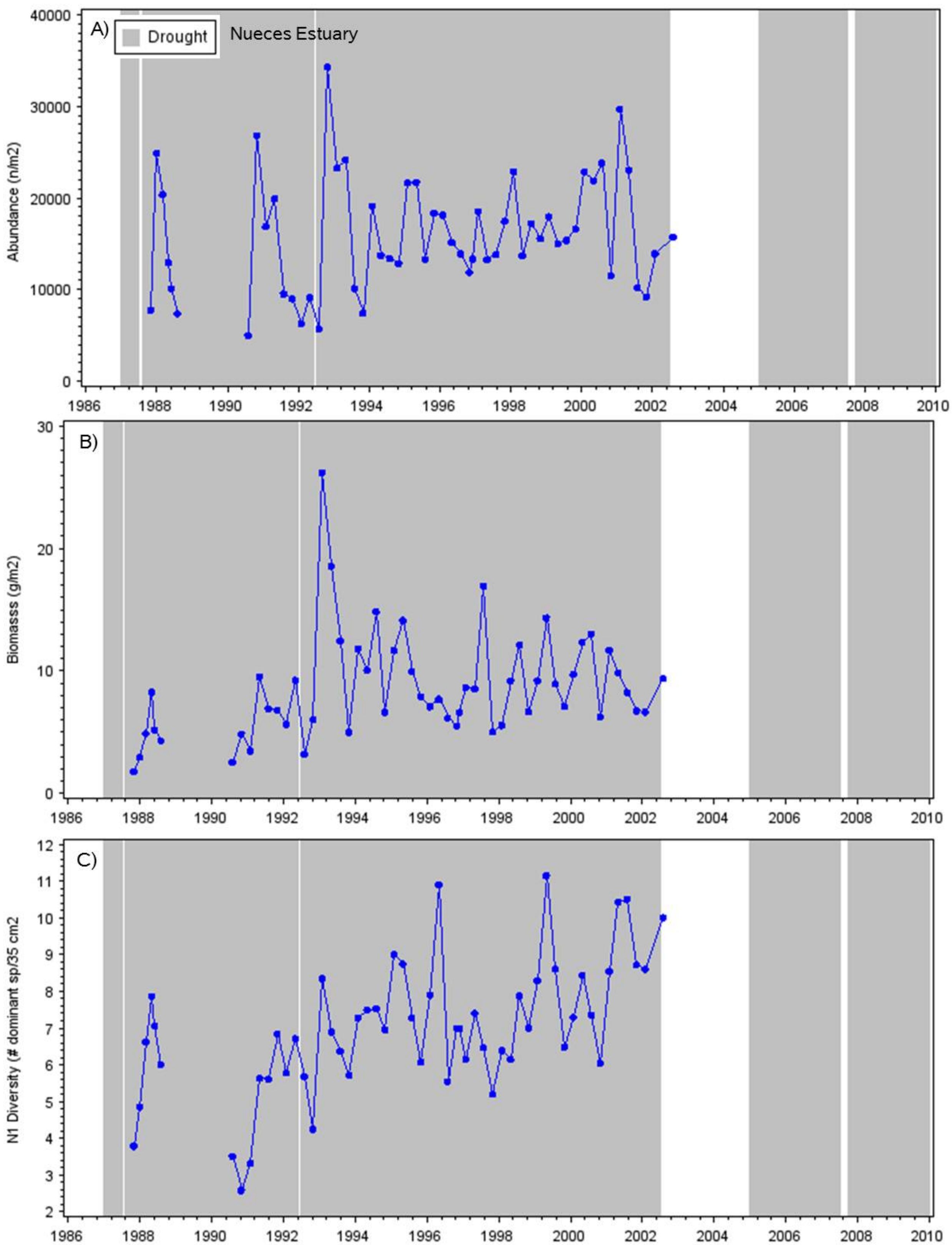

Figure 10. Monthly macrofaunal abundance (A), biomass (B), and diversity (C) in Nueces Estuary (Nueces and Corpus Christi Bays).

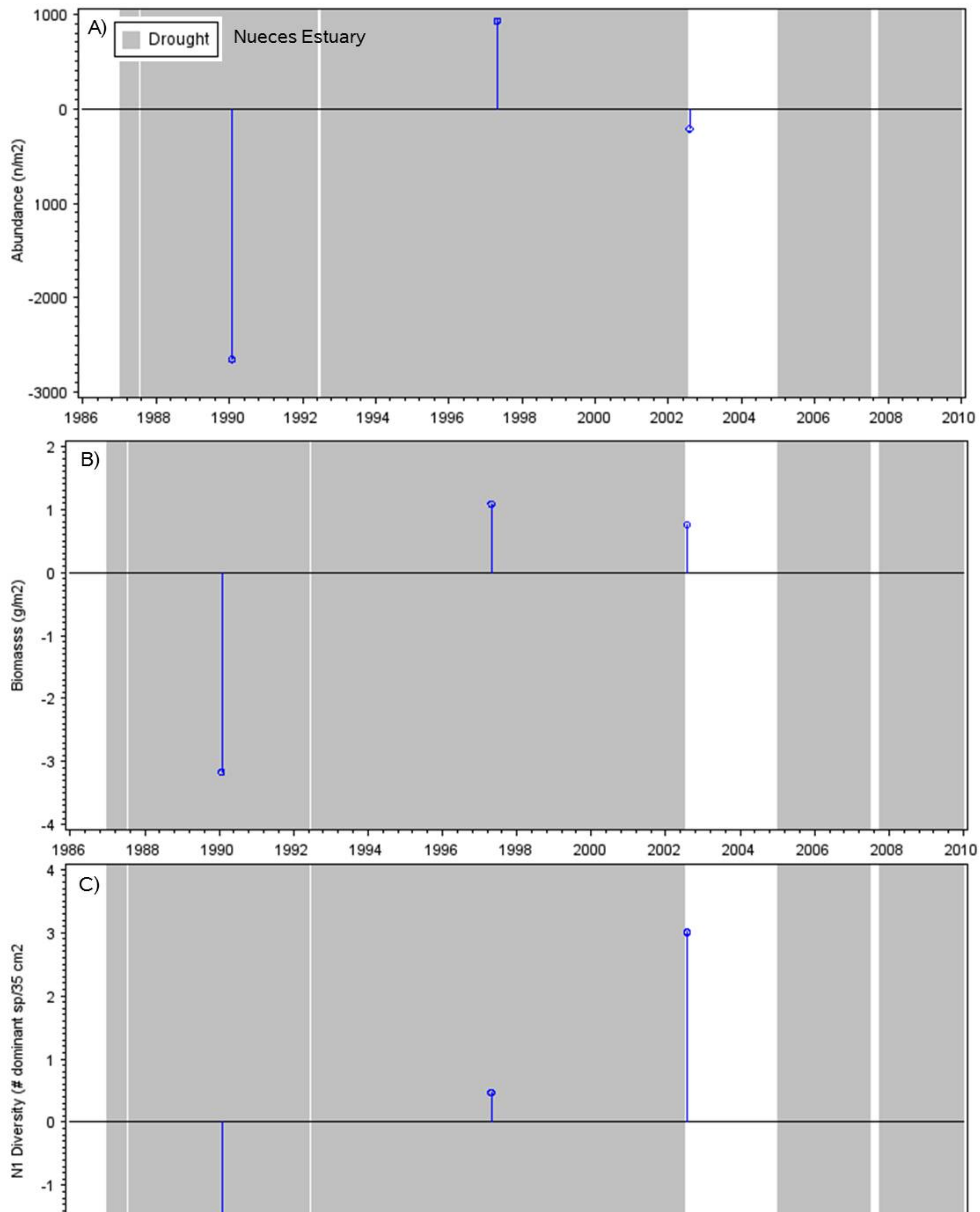

Figure 11. Mean difference from overall mean for macrofaunal abundance (A), biomass (B), and diversity (C) for each drought and wet period in Nueces Estuary (Nueces and Corpsu Christi Bays, Method One).

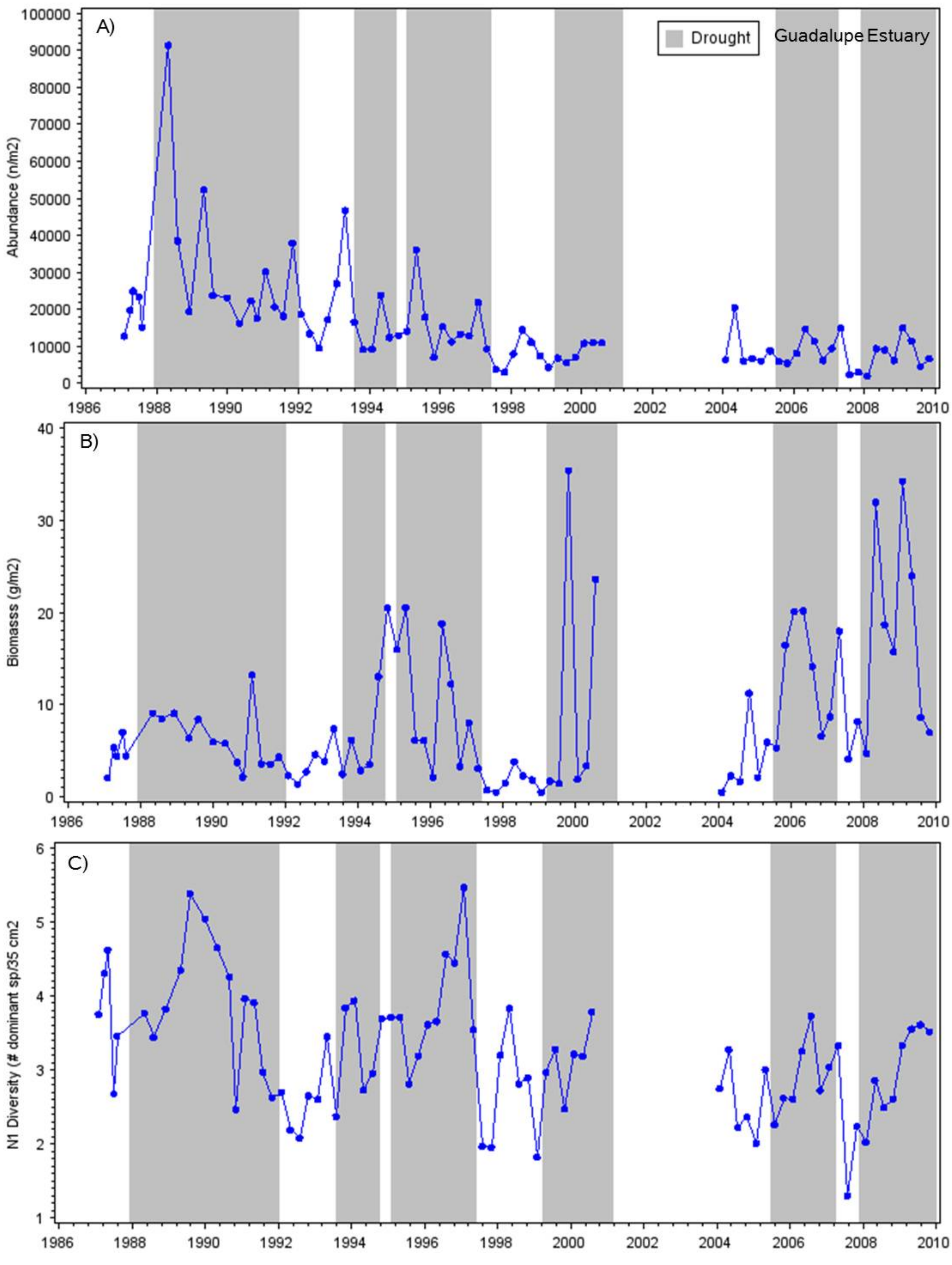

Figure 12. Monthly macrofaunal abundance (A), biomass (B), and diversity (C) in Guadalupe Estuary.

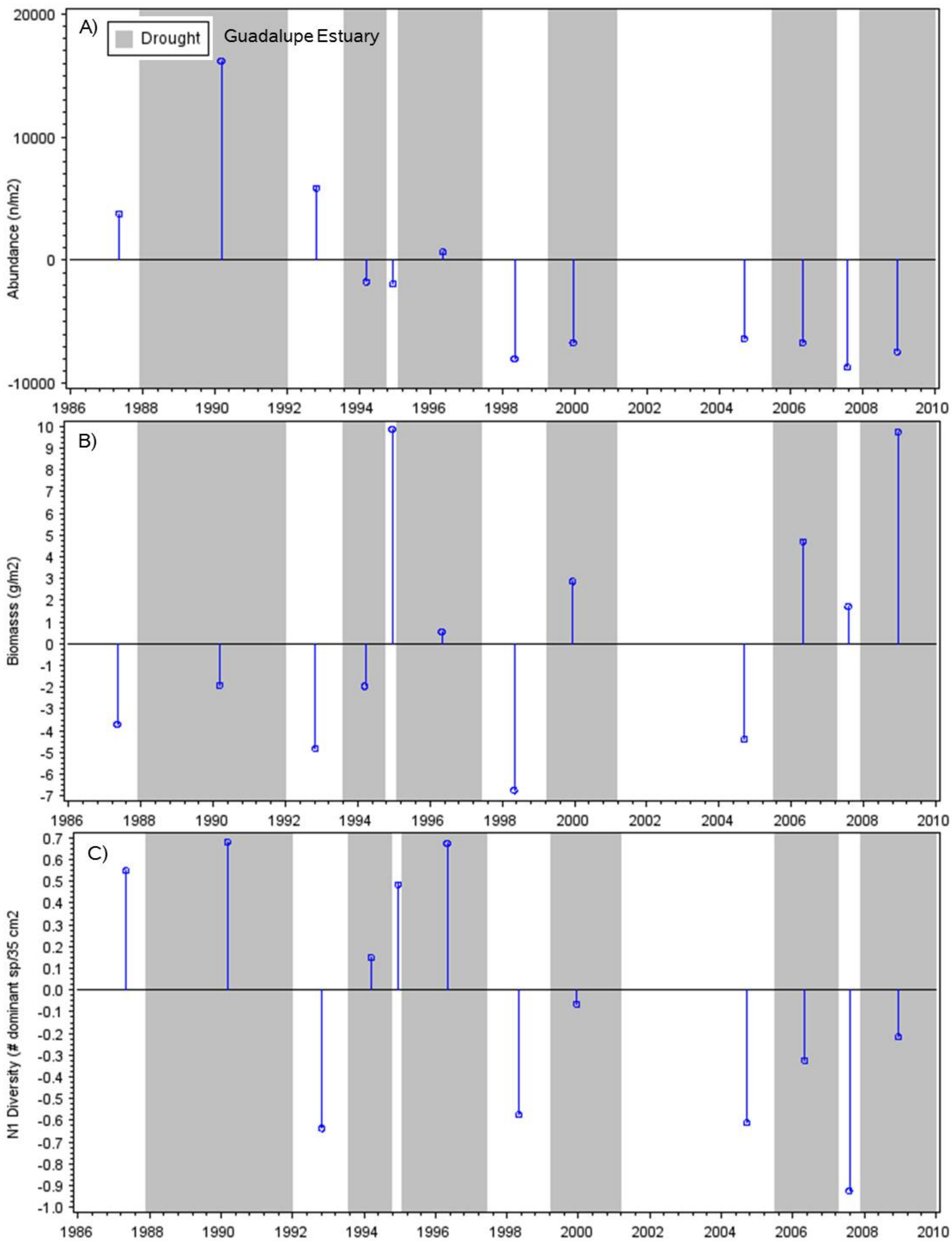

Figure 13. Mean difference from overall mean for macrofaunal abundance (A), biomass (B), and diversity (C) for each drought and wet period in Guadalupe Estuary (Method One).

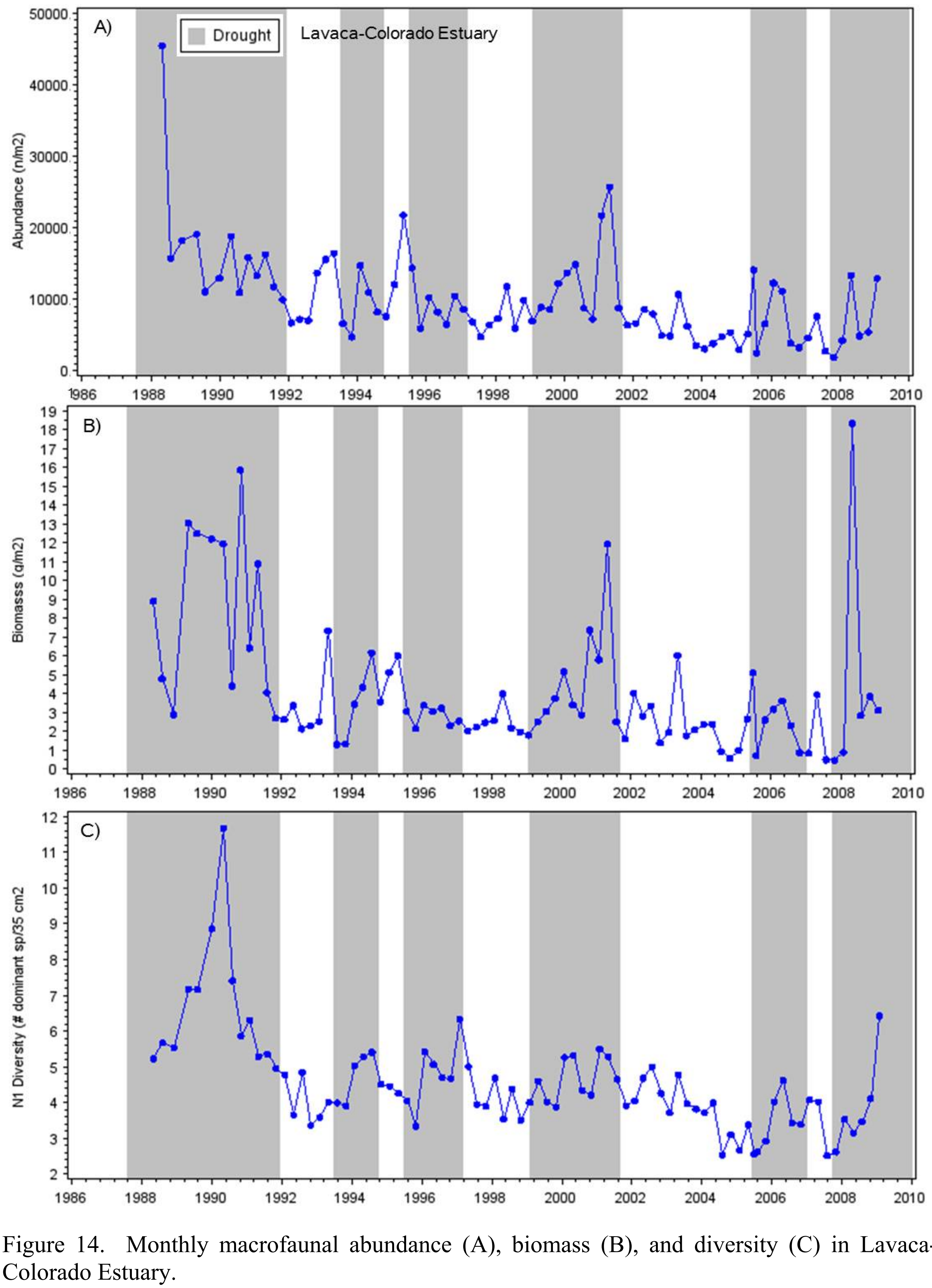

Figure 14. Monthly macrofaunal abundance (A), biomass (B), and diversity (C) in Lavaca-Colorado Estuary.

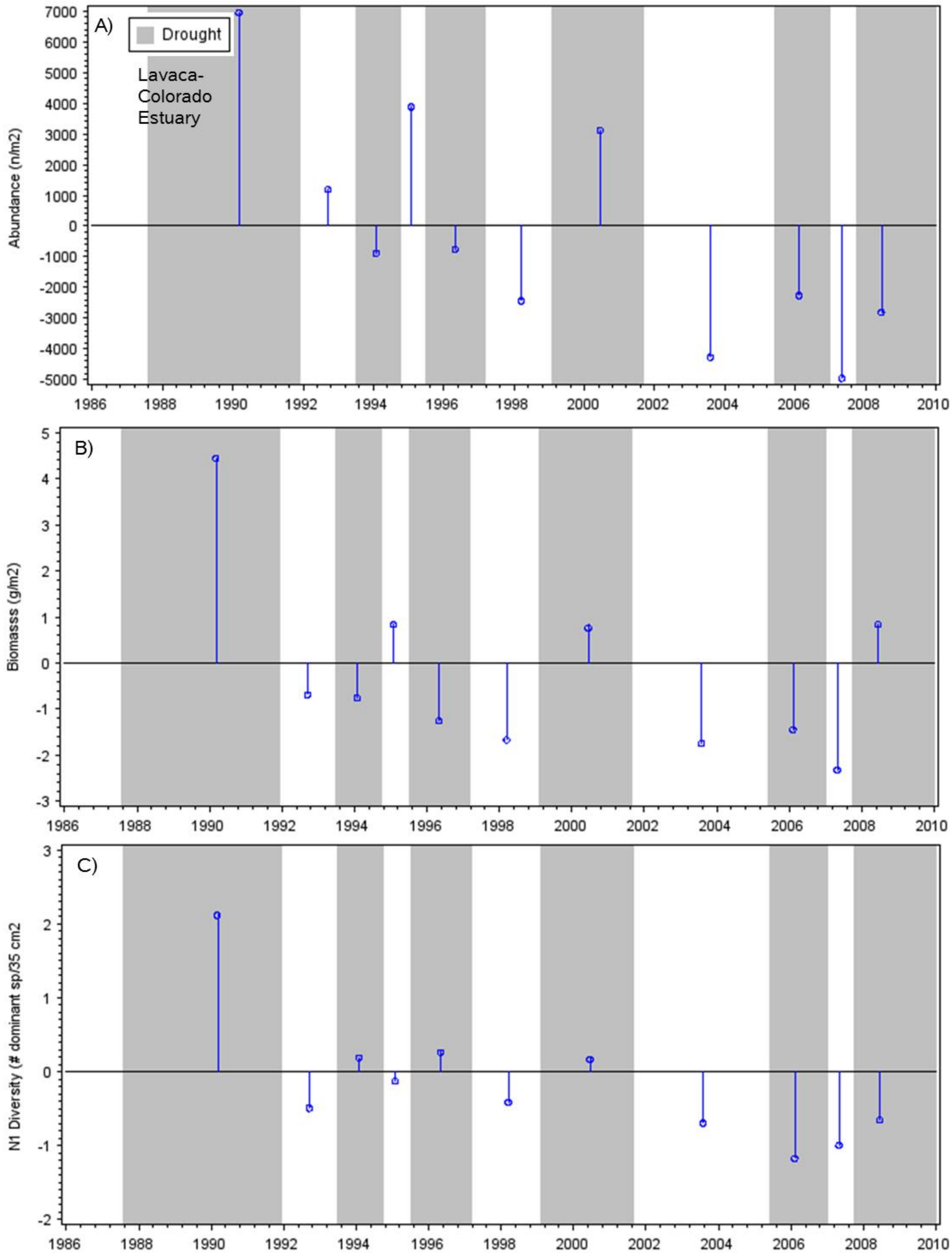

Figure 15. Mean difference from overall mean for macrofaunal abundance (A), biomass (B), and diversity (C) for each drought and wet period in Lavaca-Colorado Estuary (Method One).

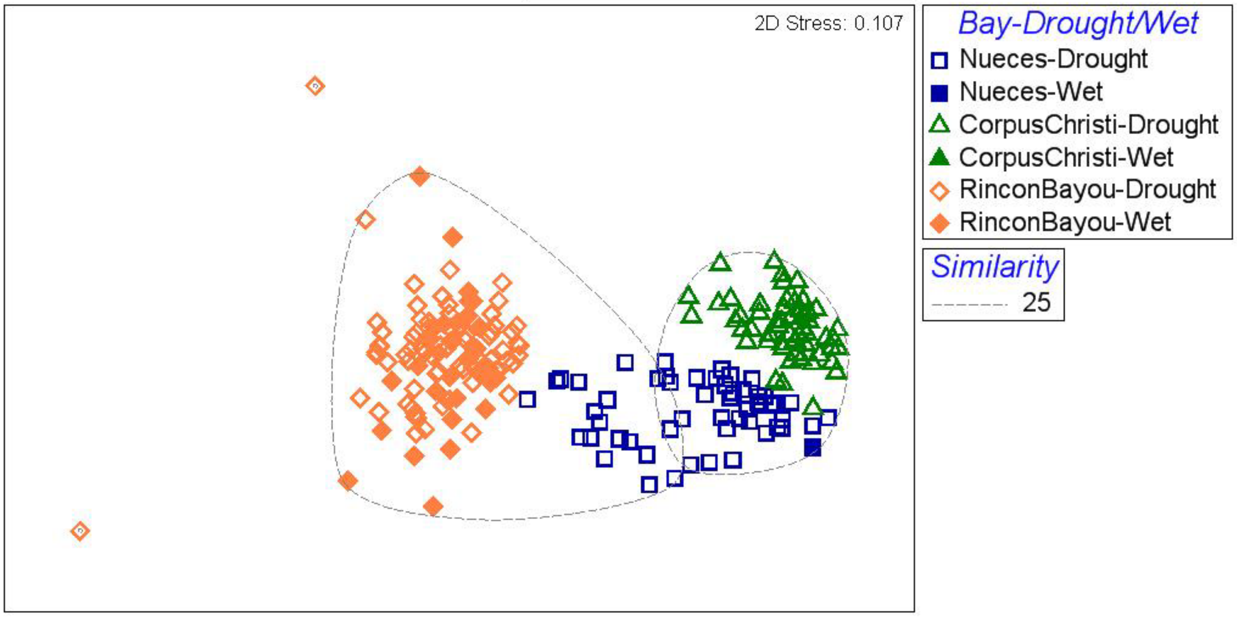

Figure 16. Wet and dry quarterly macrofauna community composition in Nueces Estuary (Method One).
Labeled by the bay/region of the estuary.

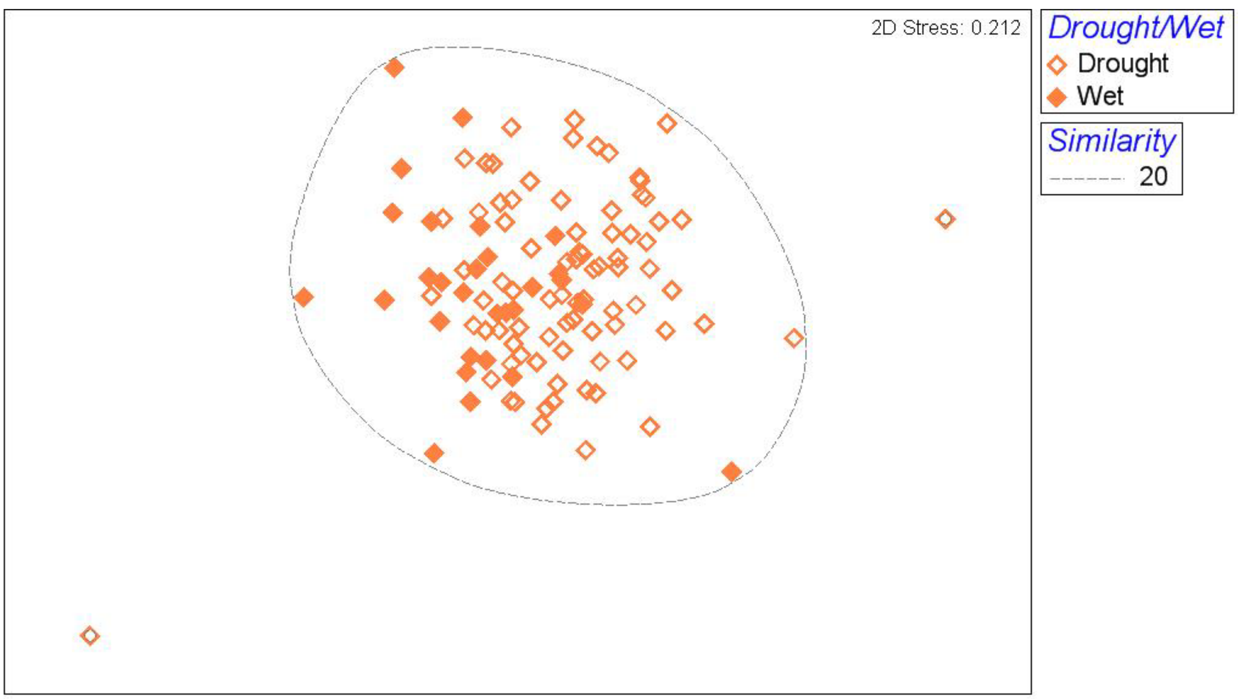

Figure 17. Wet and dry quarterly macrofauna community composition in Rincon Bayou (Method One).

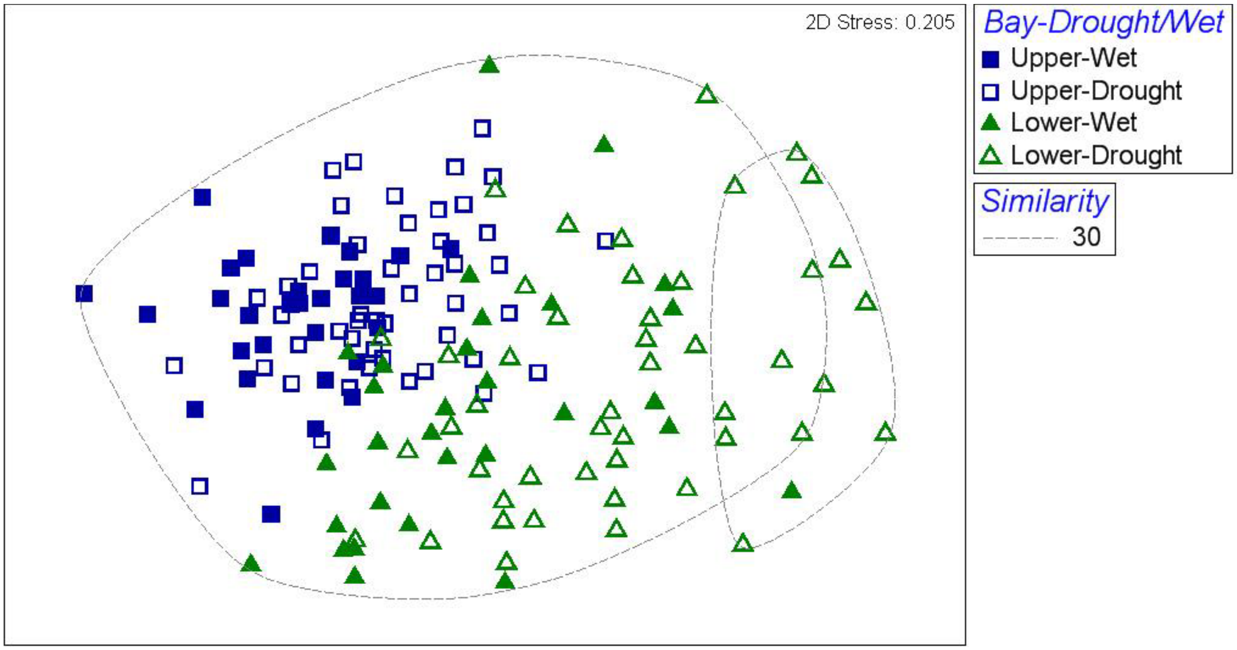

Figure 18. Wet and dry quarterly macrofauna community composition in Guadalupe Estuary (Method One).

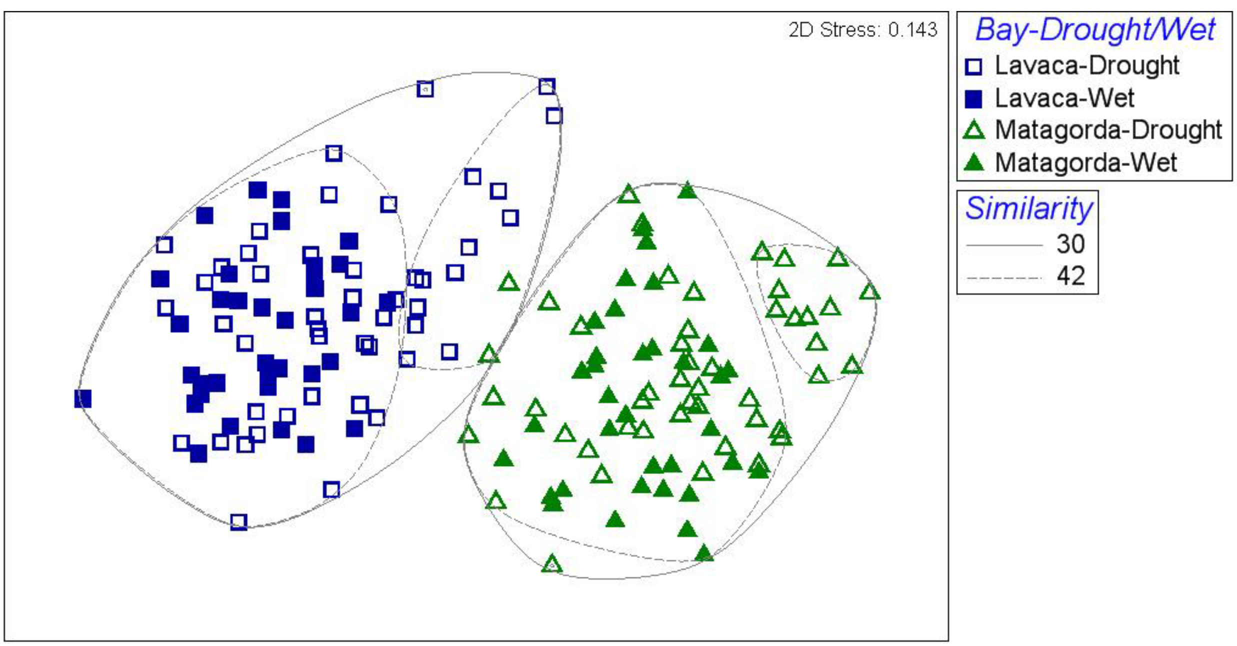

Figure 19. Wet and dry quarterly macrofauna community composition in Lavaca-Colorado Estuary (Method One).

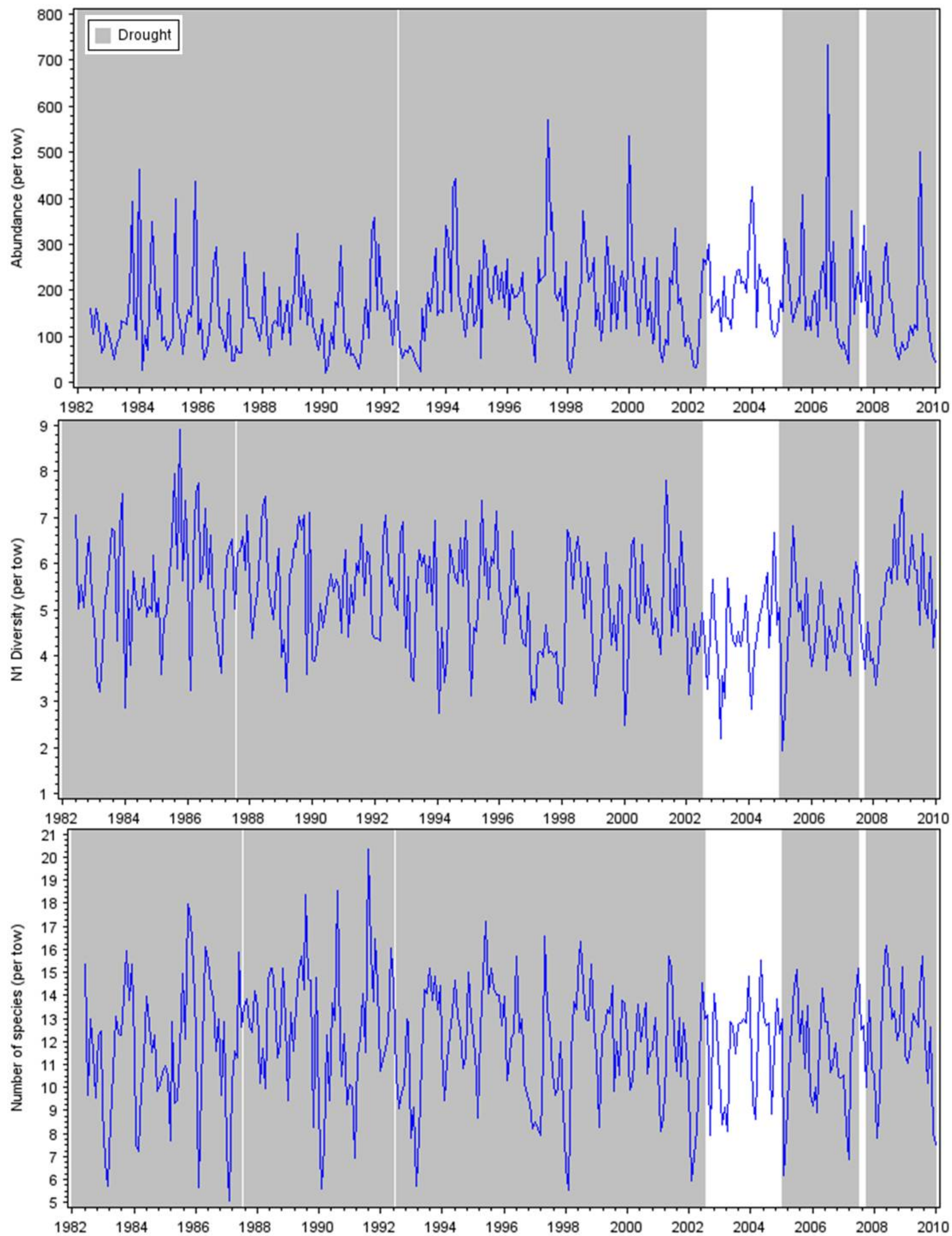

Figure 20. Mean monthly epifaunal abundance, N1 diversity, and species richness in Nueces Estuary

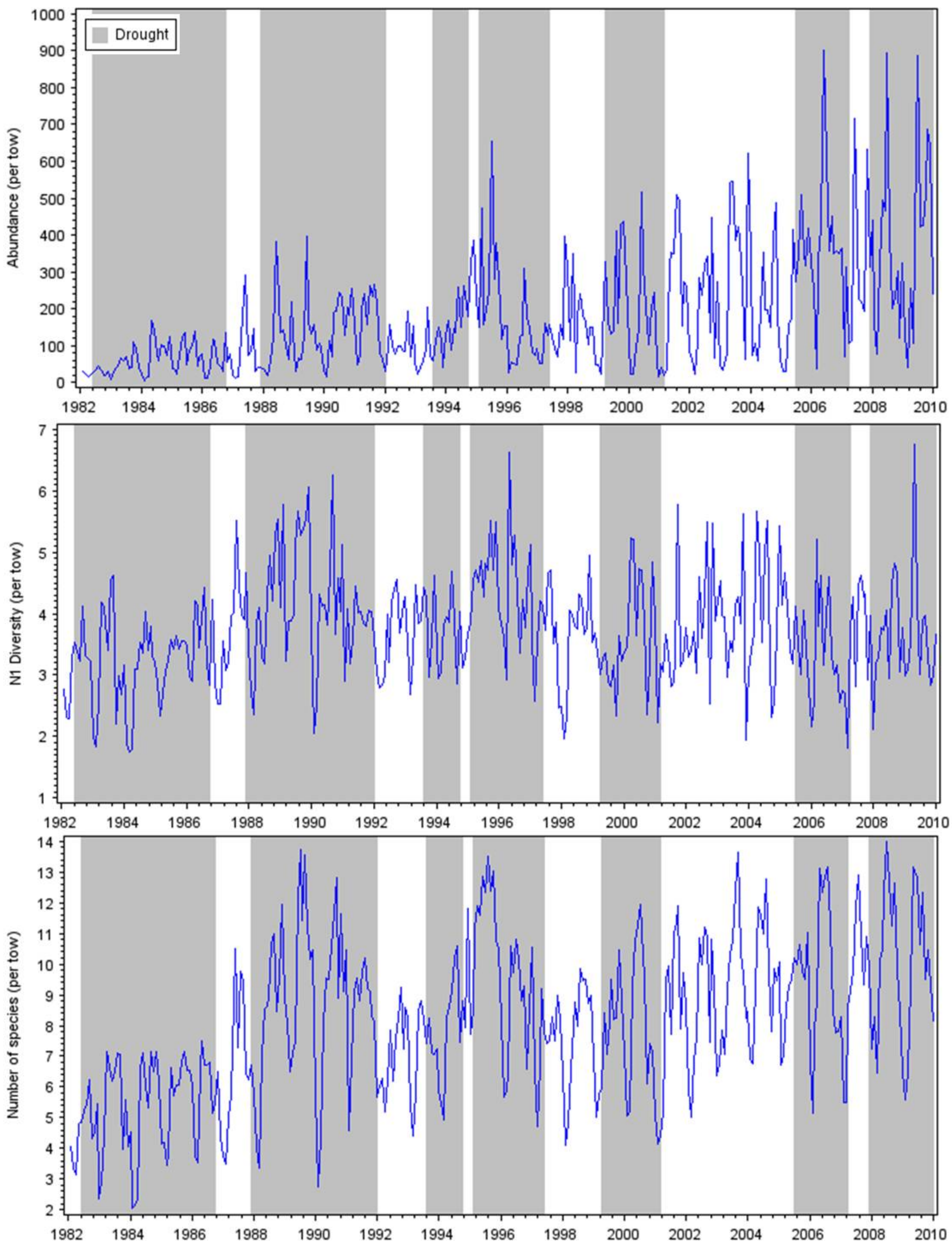

Figure 21. Mean monthly epifaunal abundance, N1 diversity, and species richness in Guadalupe Estuary

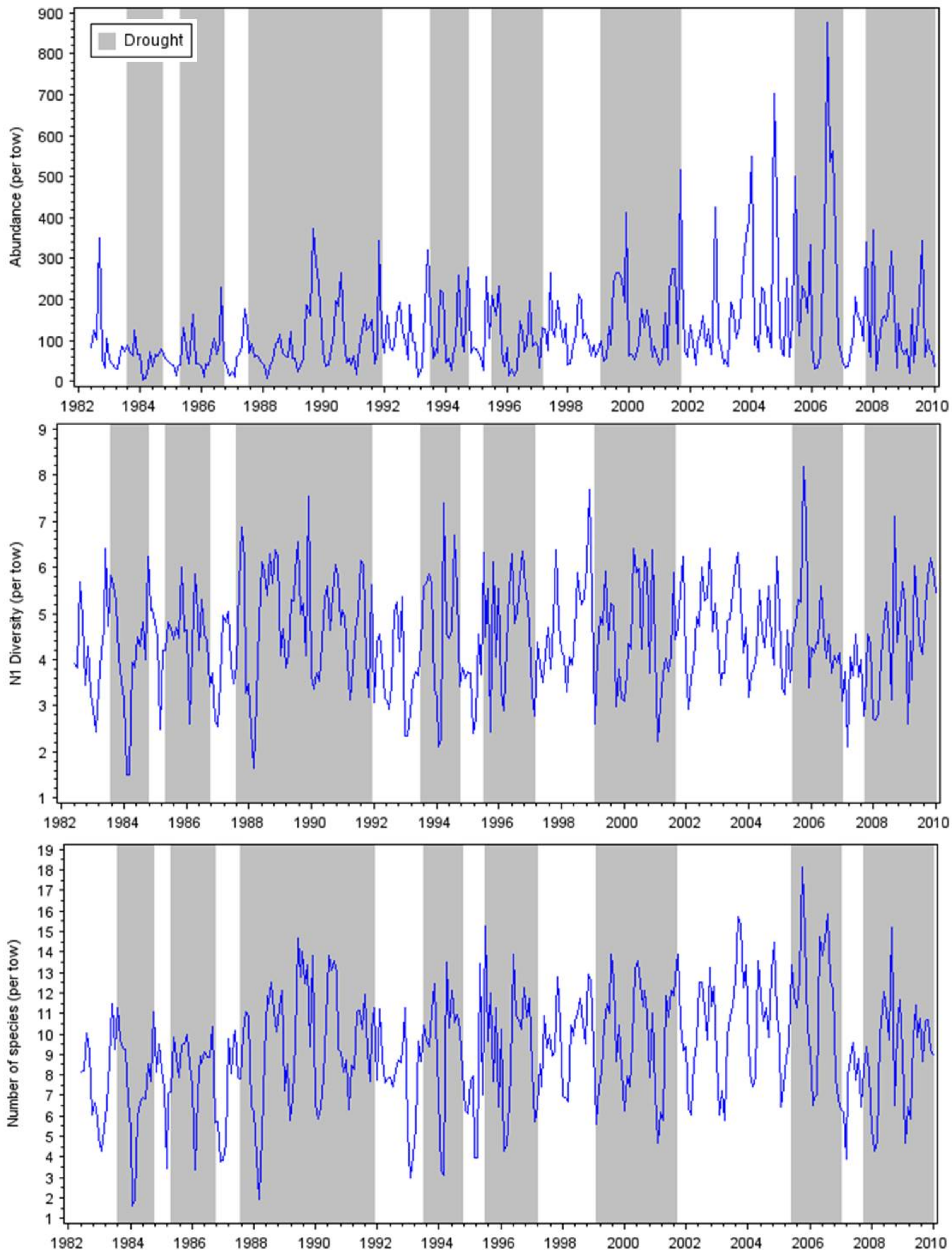

Figure 22. Mean monthly epifaunal abundance, N1 diversity, and species richness in Lavaca-Colorado Estuary

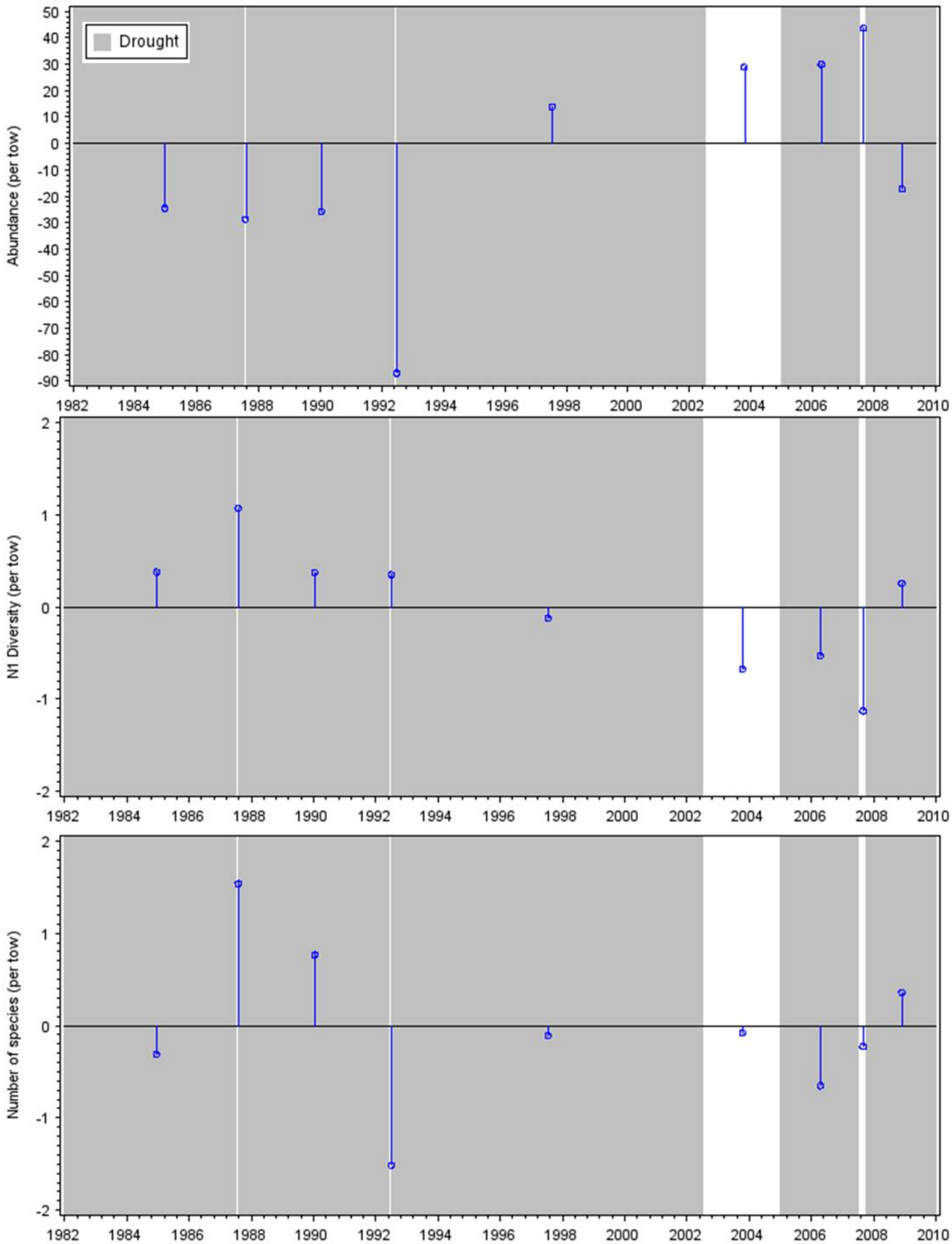

Figure 23. Differences from long-term mean epifaunal abundance, N1 diversity and species richness among wet and dry periods in Nueces Estuary (Method One).

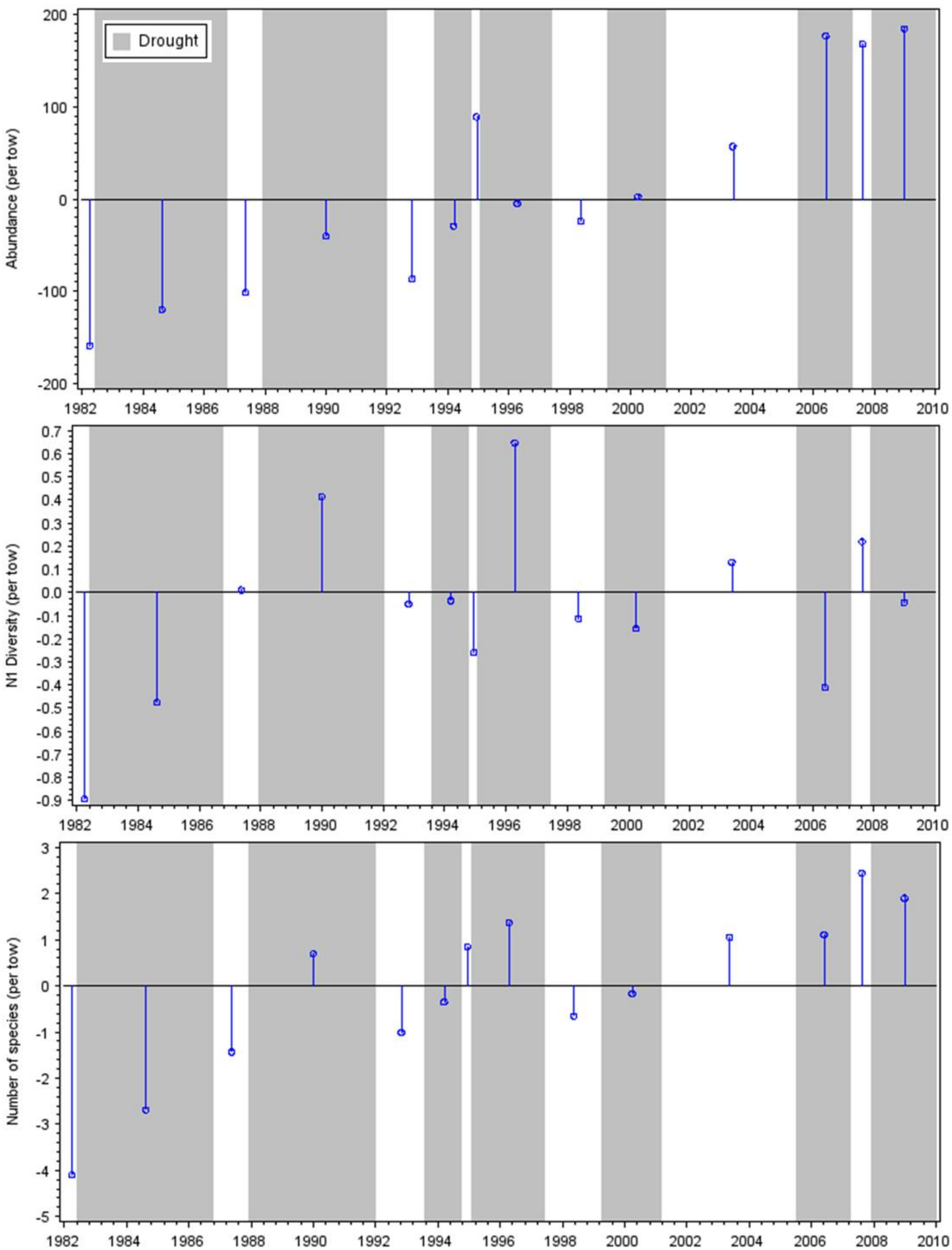

Figure 24. Differences from long-term mean epifaunal abundance, N1 diversity and species richness among wet and dry periods in Guadalupe Estuary (Method One).

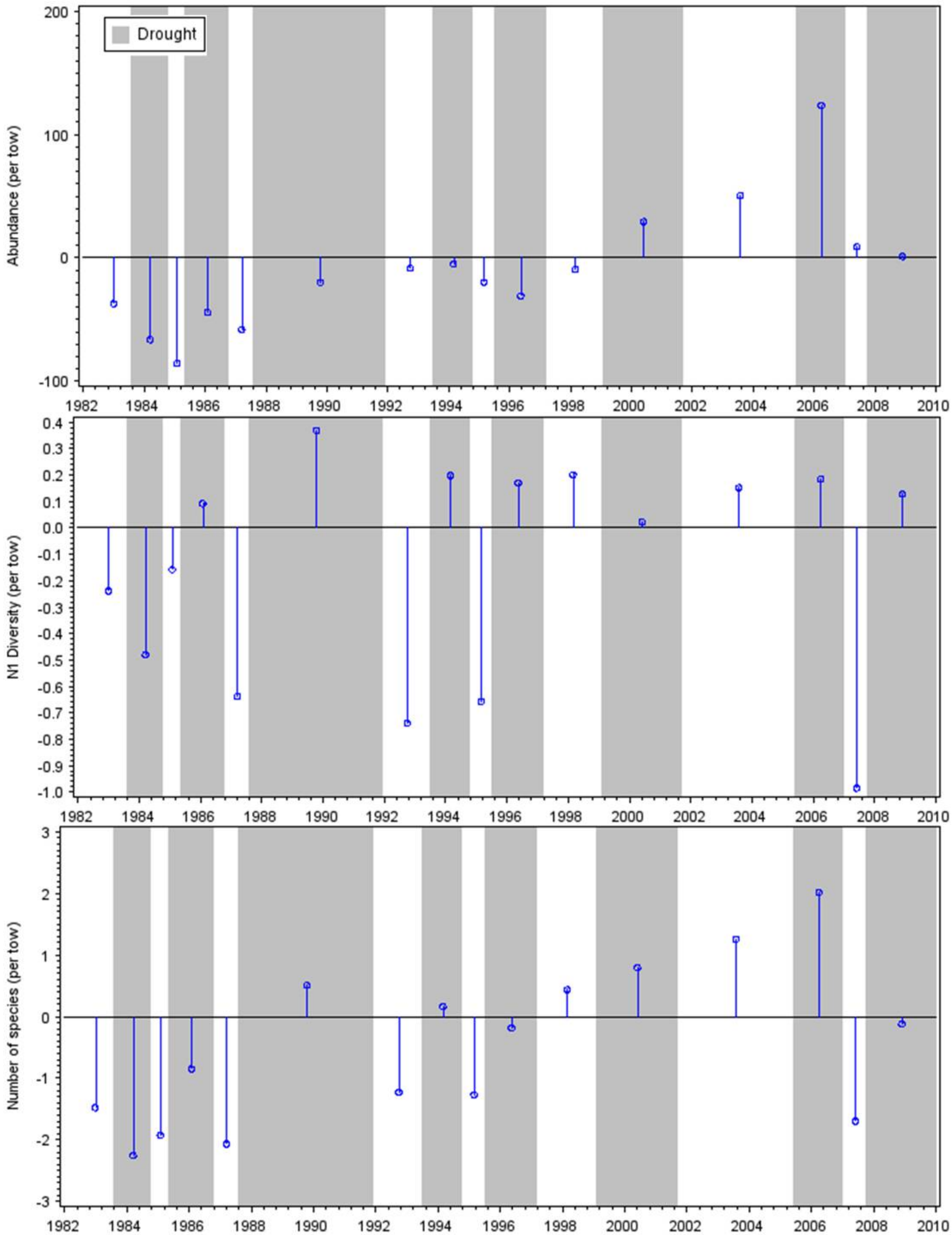

Figure 25. Differences from long-term mean epifaunal abundance, N1 diversity and species richness among wet and dry periods in Lavaca-Colorado Estuary (Method One).

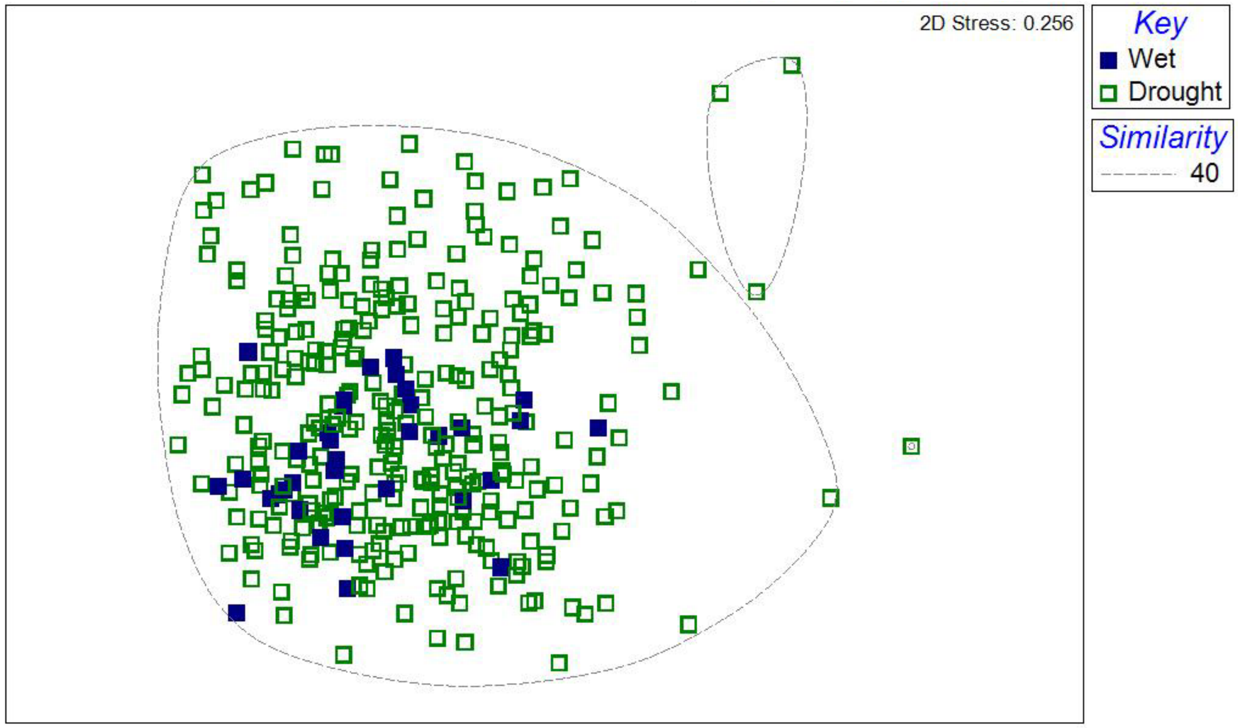

Figure 26. Wet and dry monthly macrofauna community composition in the Nueces Estuary (Method One).

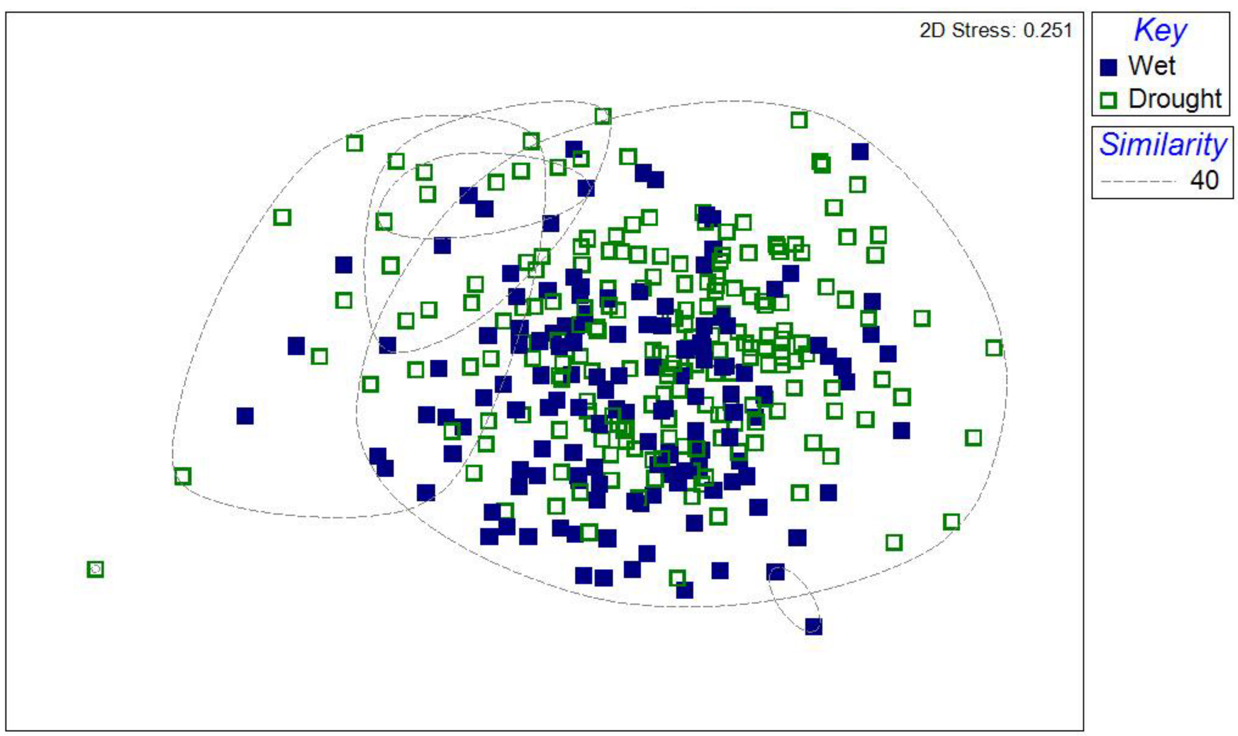

Figure 27. Wet and dry monthly epifaunal community composition in the Guadalupe Estuary (Method One).

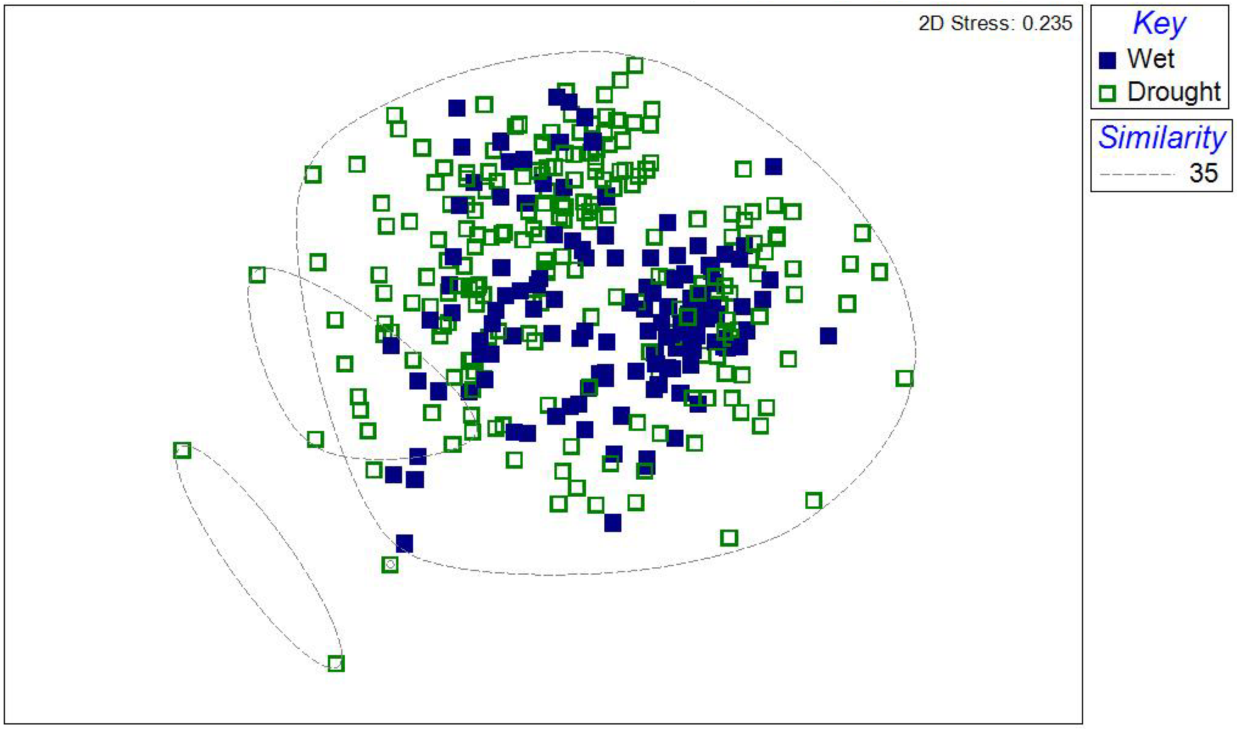

Figure 28. Wet and dry monthly epifaunal community composition in the Lavaca-Colorado Estuary (Method One).

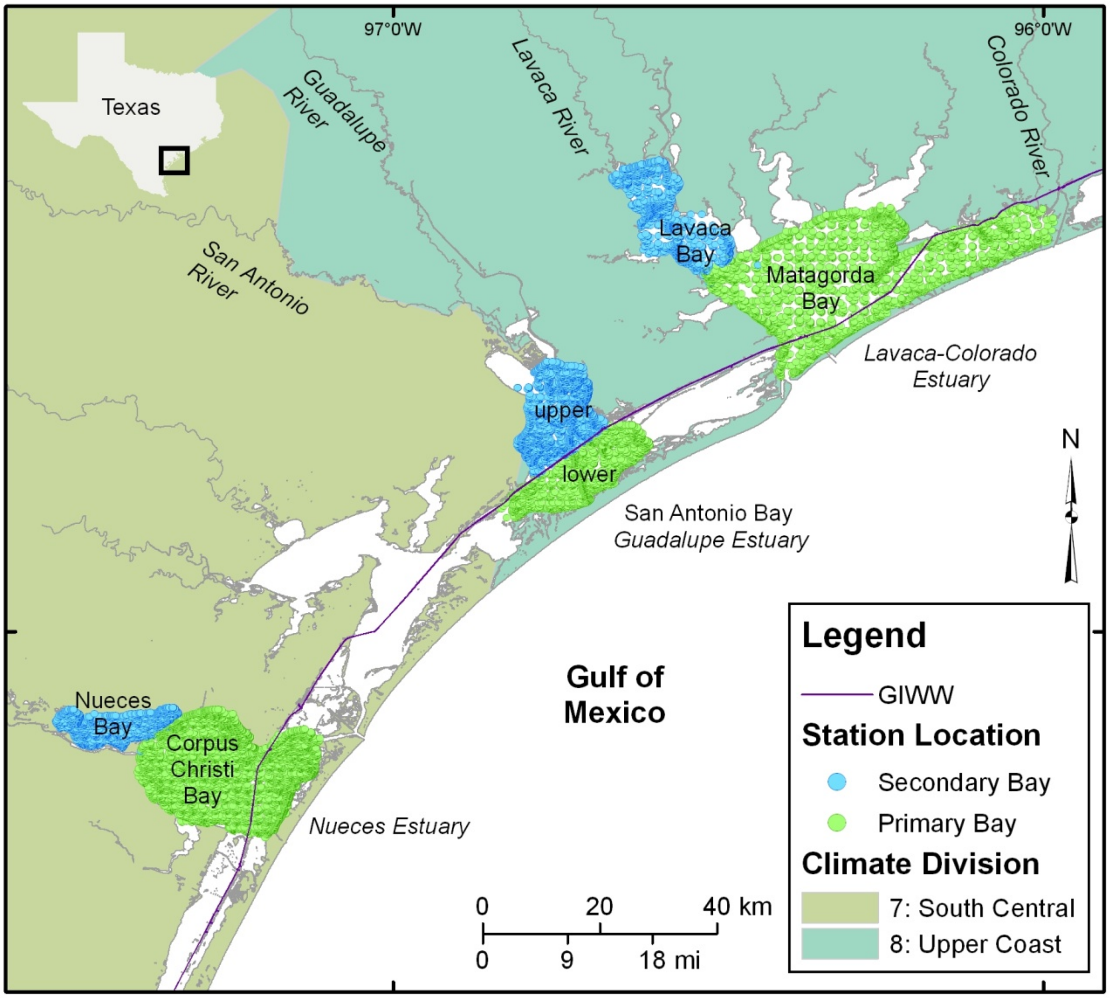

Figure 29. Map of TPWD sampling stations in each bay and NOAA climatological divisions.

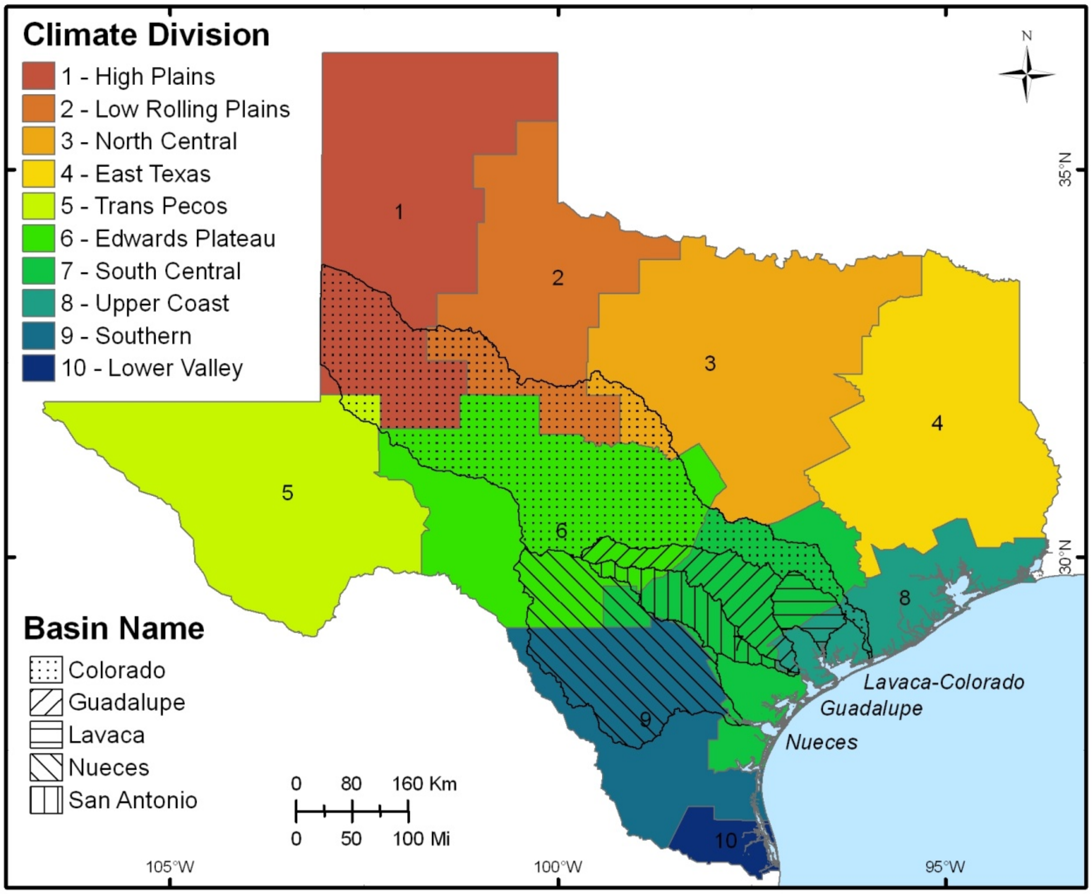

Figure 30. Texas climatological divisions and selected estuary basins.

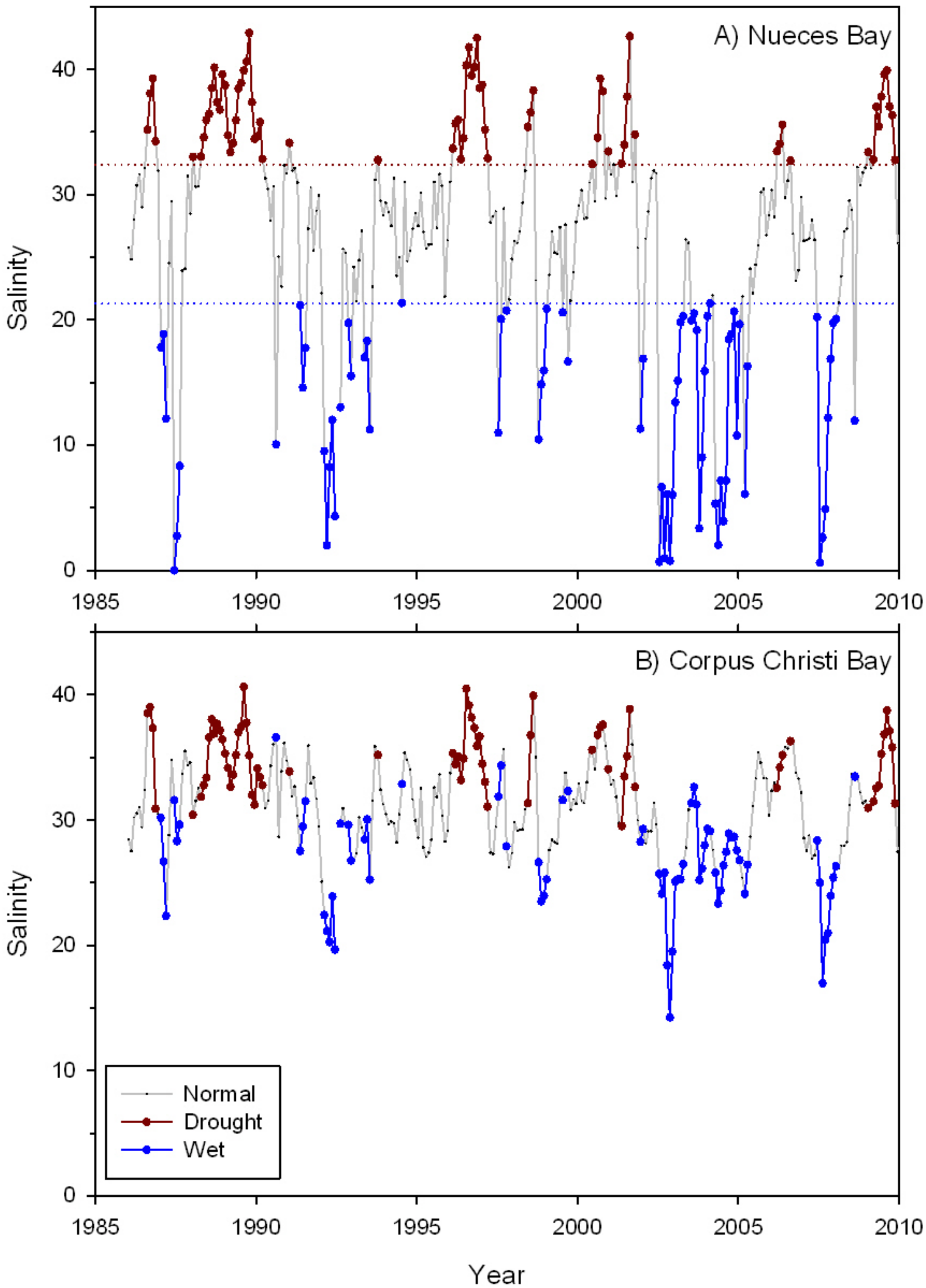

Figure 31. Monthly salinity over time in Nueces and Corpus Christi Bays labeled by drought, normal and wet periods (Method Two).
Drought and wet months are defined by the upper (red dotted line) and lower quartiles (blue dotted line) of salinity in Nueces Bay respectively.

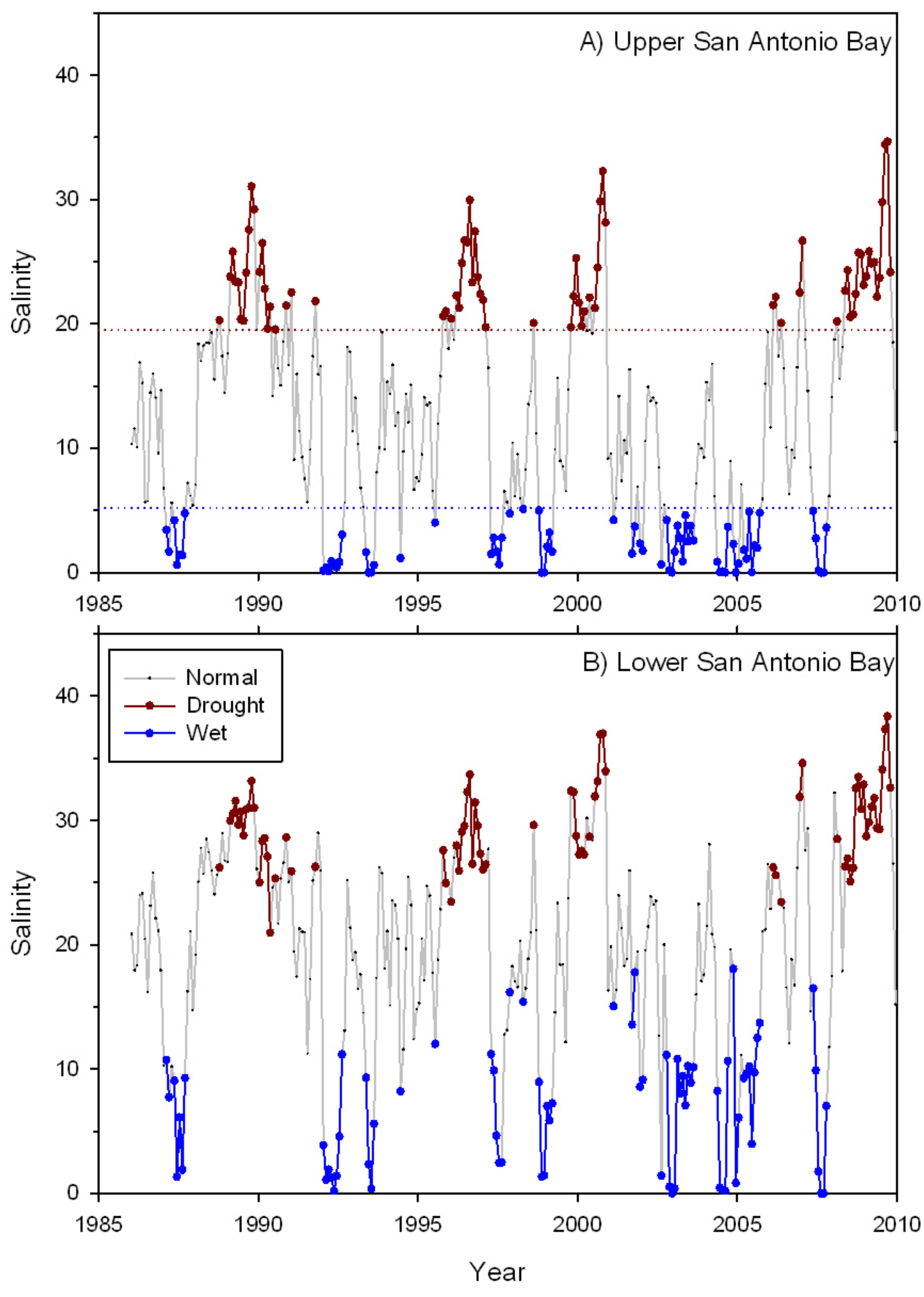

Figure 32. Monthly salinity over time in upper and lower San Antonio Bay labeled by drought, normal and wet periods (Method Two).
Drought and wet months are defined by the upper (red dotted line) and lower quartiles (blue dotted line) of salinity in upper and lower San Antonio Bay respectively.

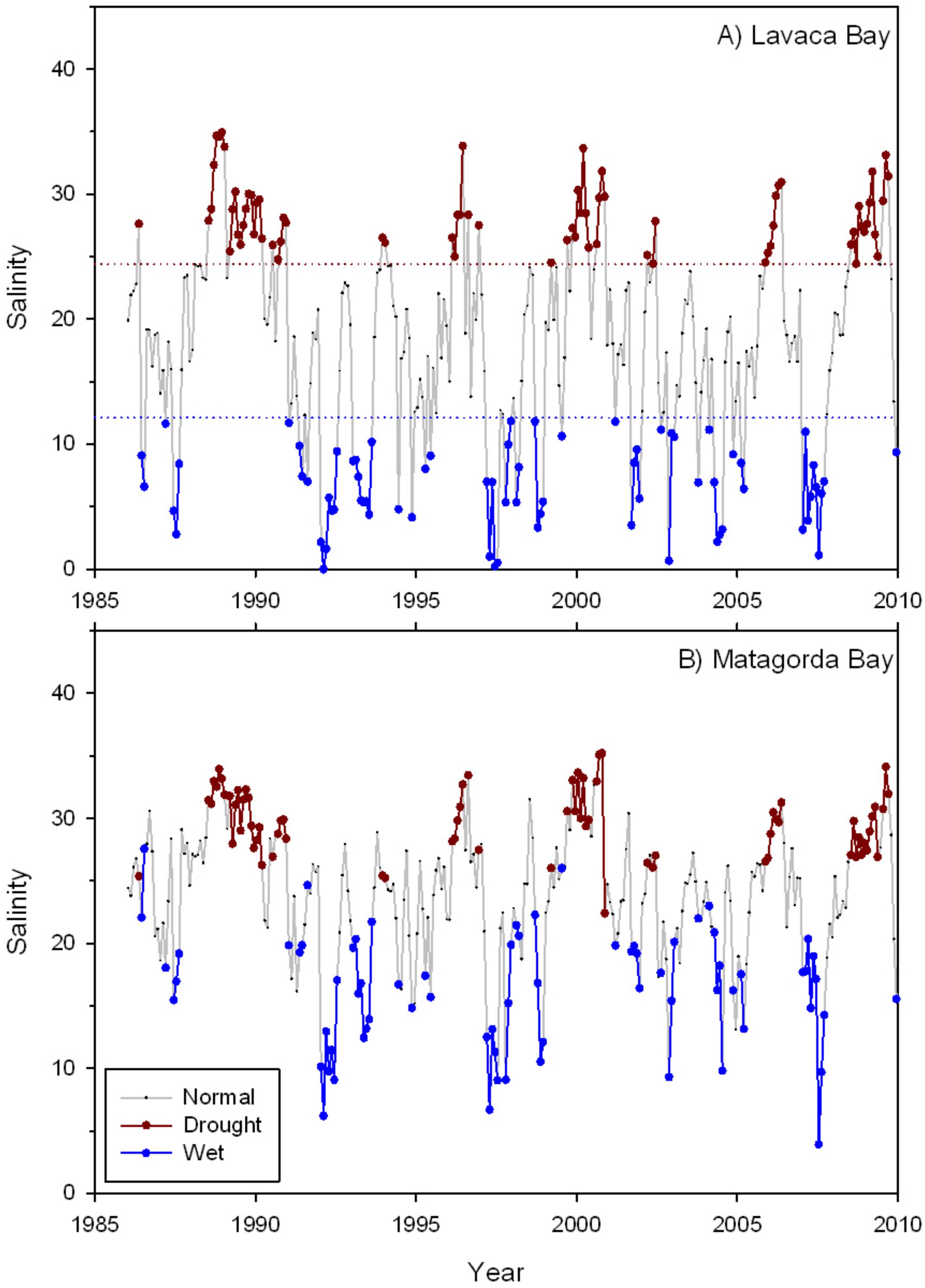

Figure 33. Monthly salinity over time in Lavaca and Matagorda Bays labeled by drought, normal and wet periods (Method Two).
Drought and wet months are defined by the upper (red dotted line) and lower quartiles (blue dotted line) of salinity in Lavaca and Matagorda Bays respectively.

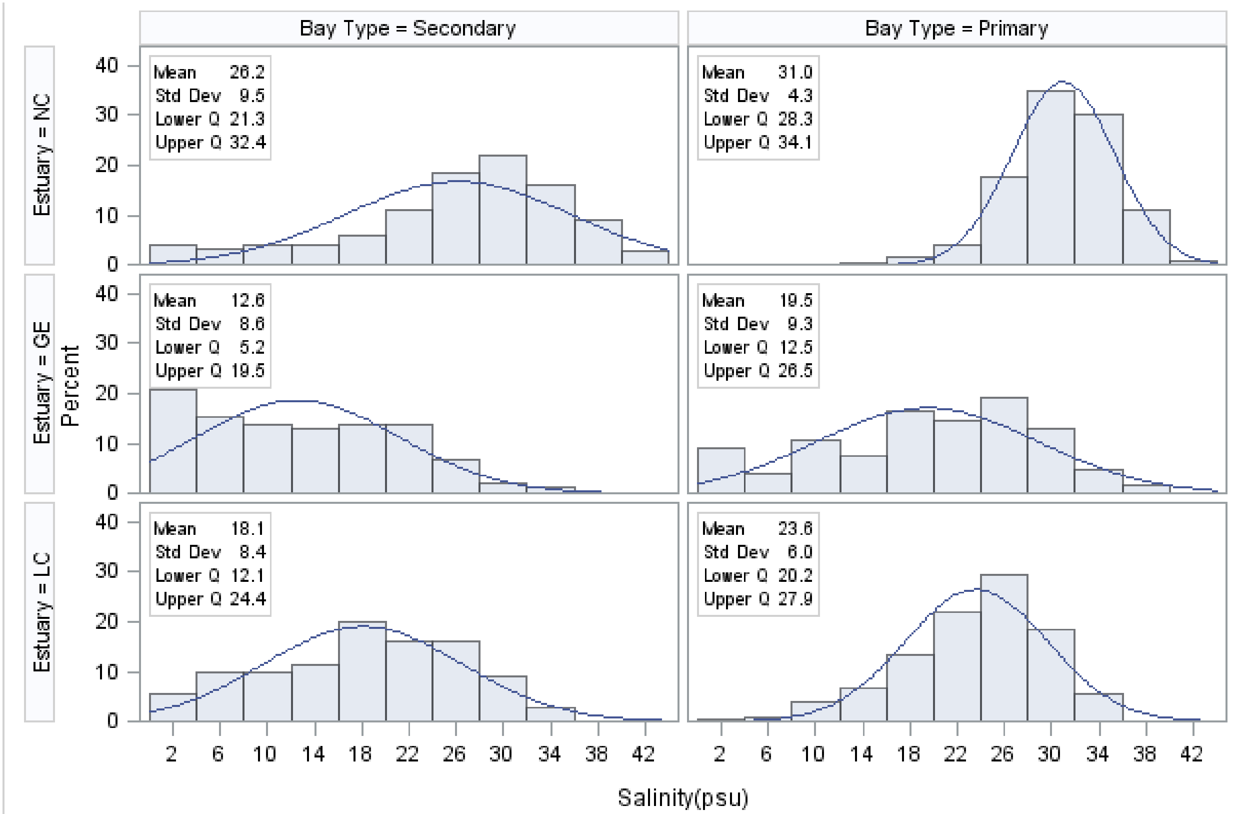

Figure 34. Frequencies of monthly salinity in each bay.

NC=Nueces, GE=Guadalupe, LC=Lavaca-Colorado. N=287 or 288 for all bays.

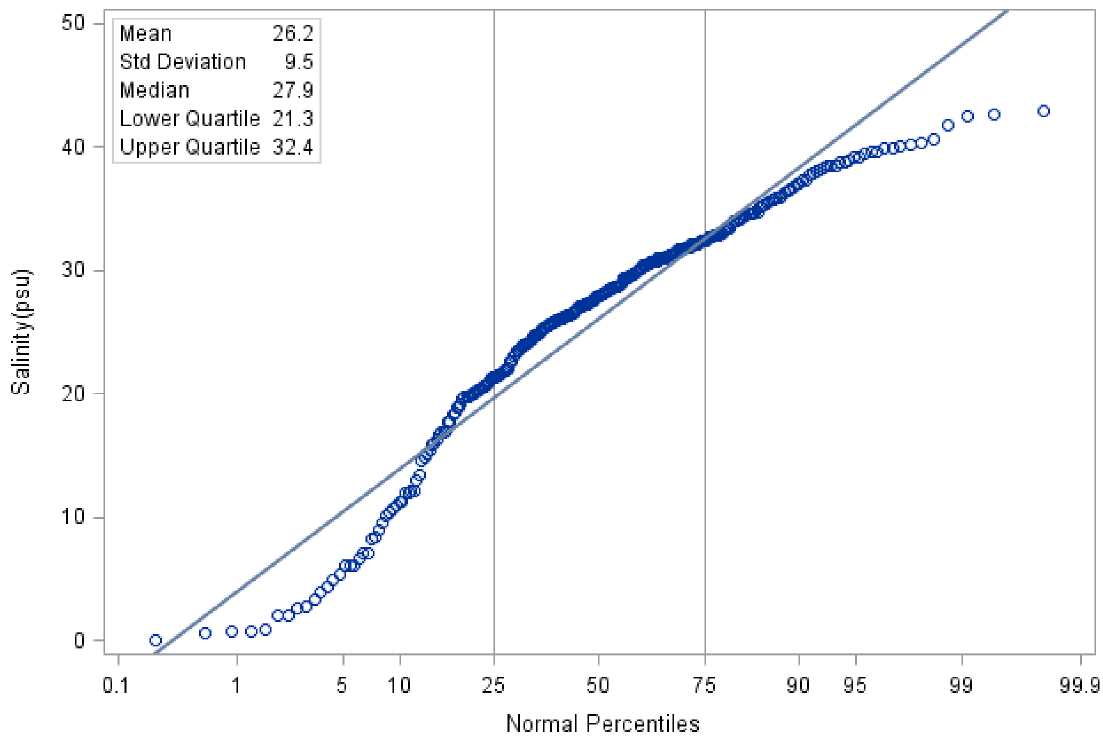

Figure 35. Probability Plot of monthly salinity in Nueces Bay.

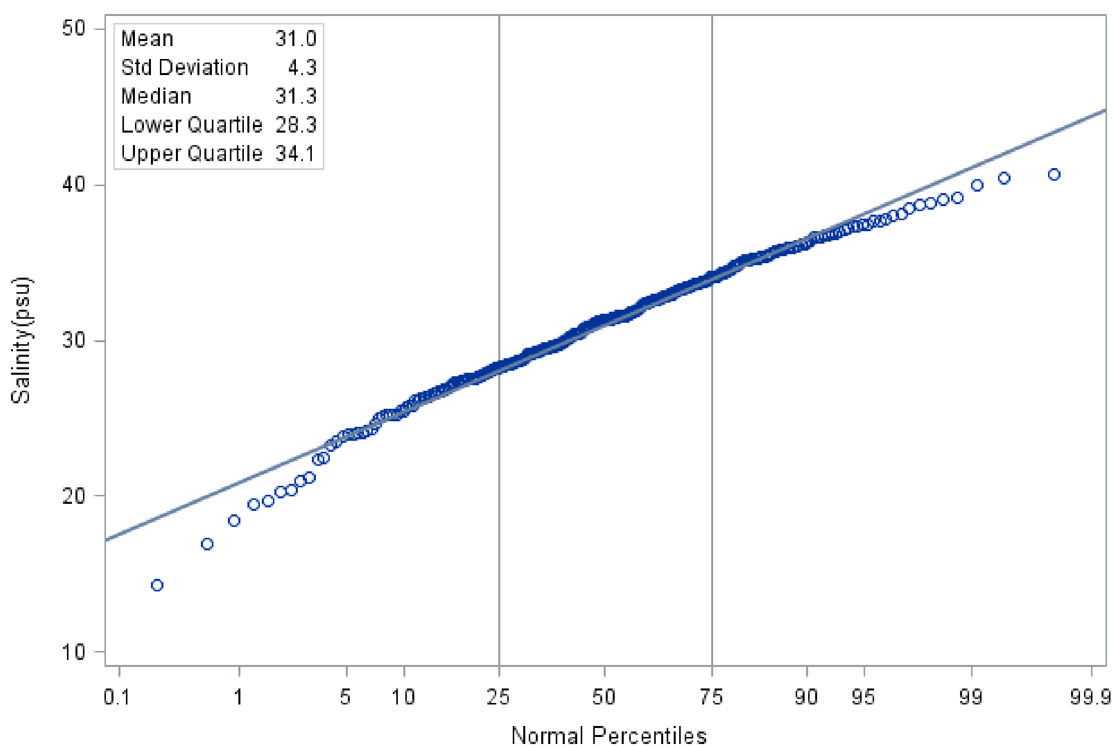

Figure 36. Probability Plot of monthly salinity in Corpus Christi Bay.

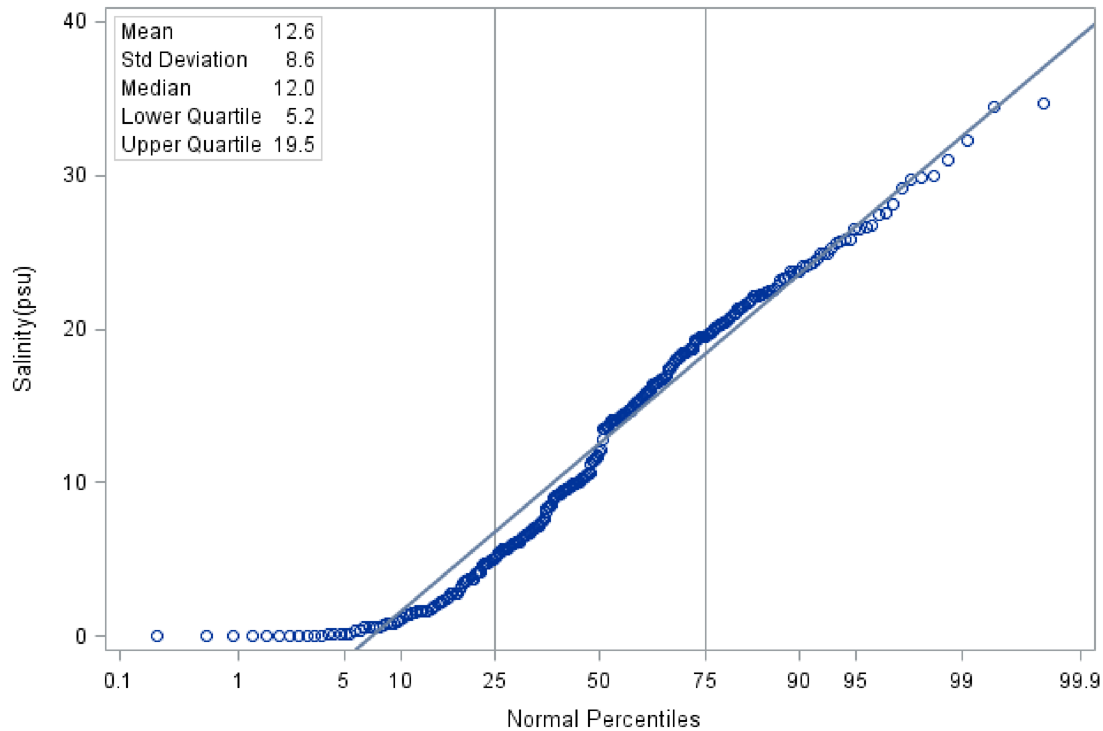

Figure 37. Probability Plot of monthly salinity in upper San Antonio Bay.

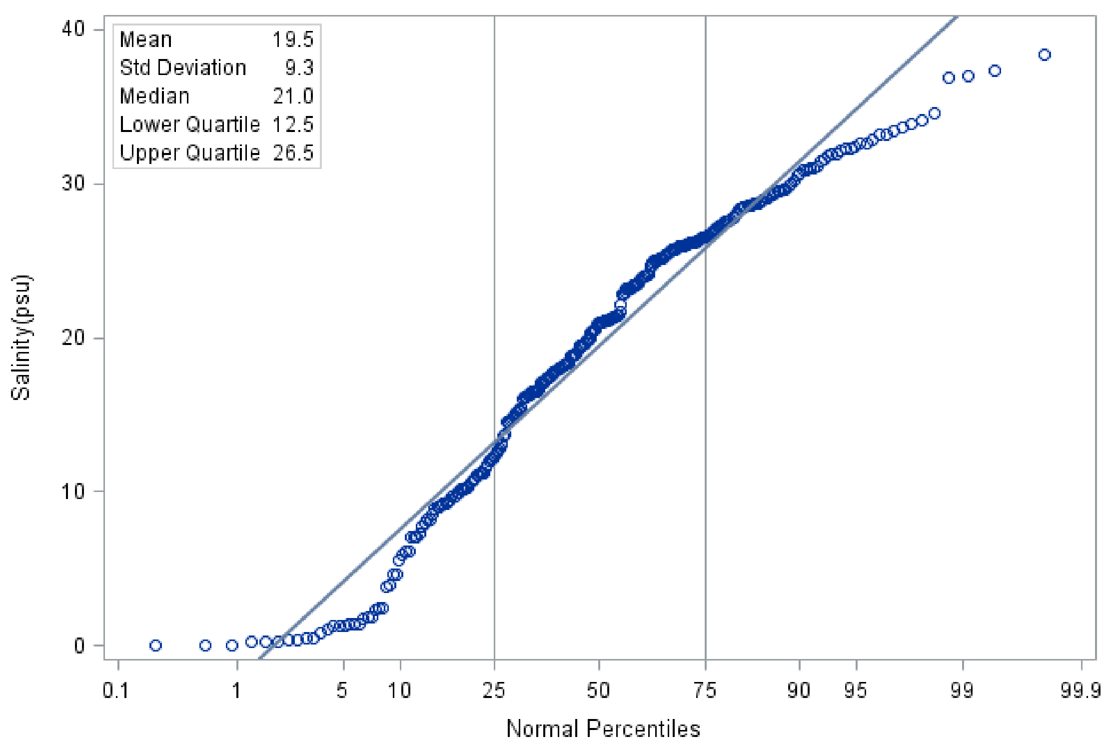

Figure 38. Probability Plot of monthly salinity in lower San Antonio Bay.

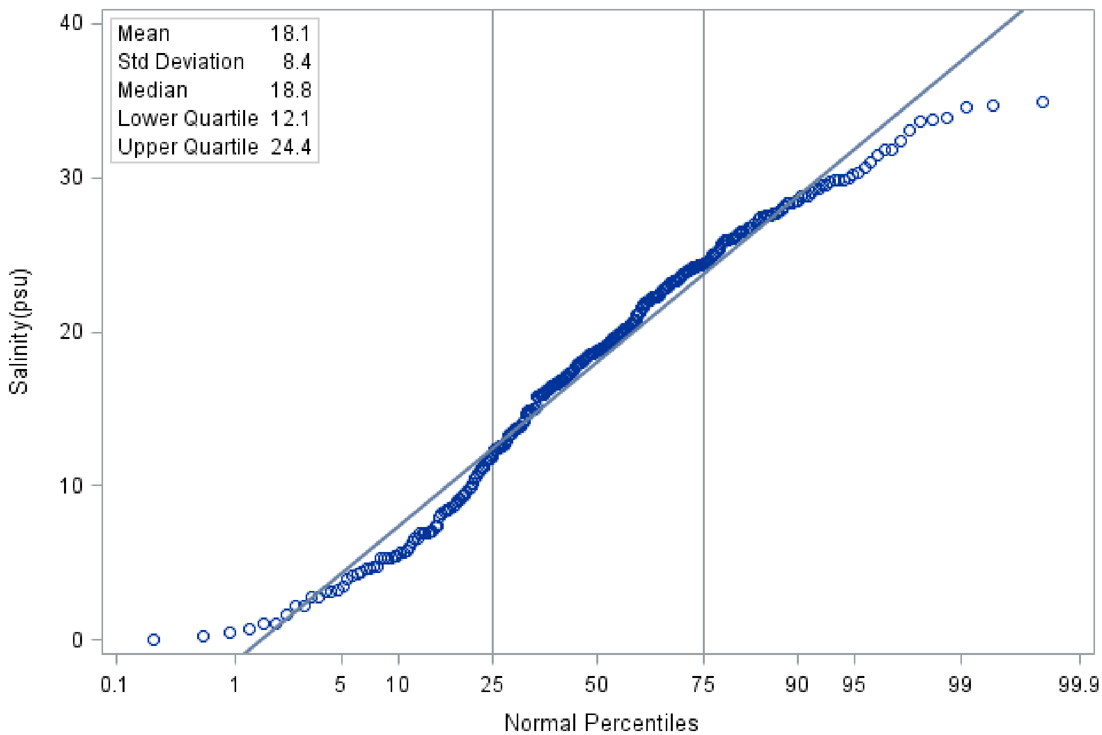

Figure 39. Probability Plot of monthly salinity in Lavaca Bay.

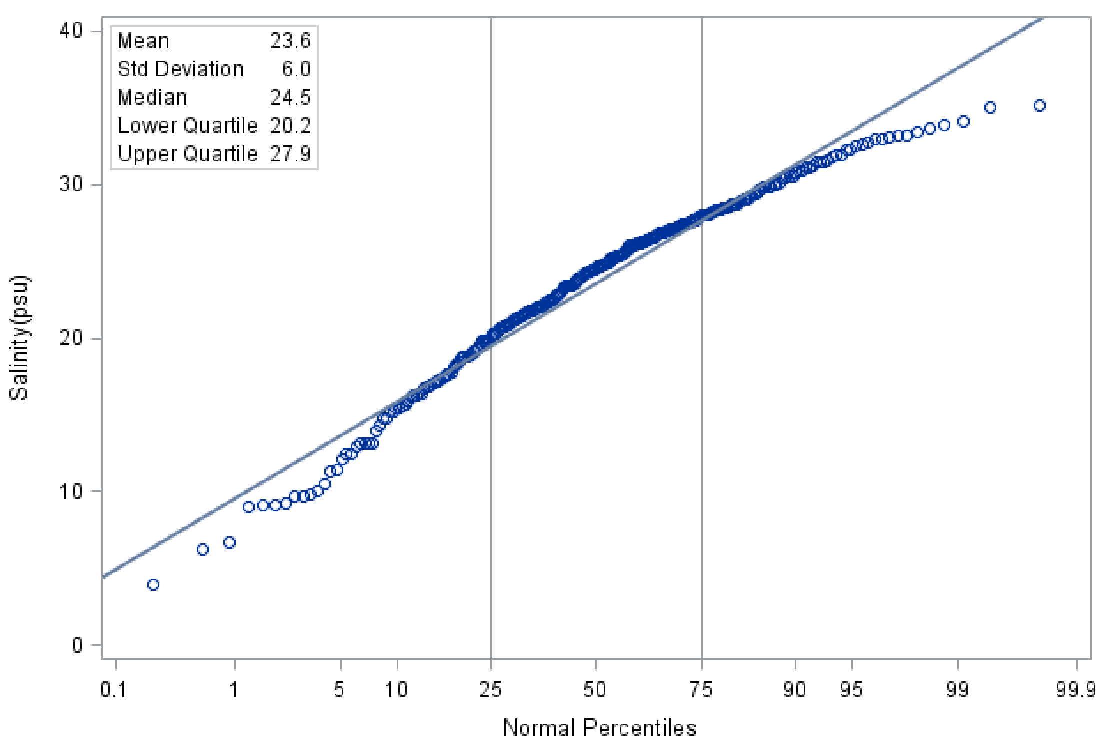

Figure 40. Probability Plot of monthly salinity in Matagorda Bay.

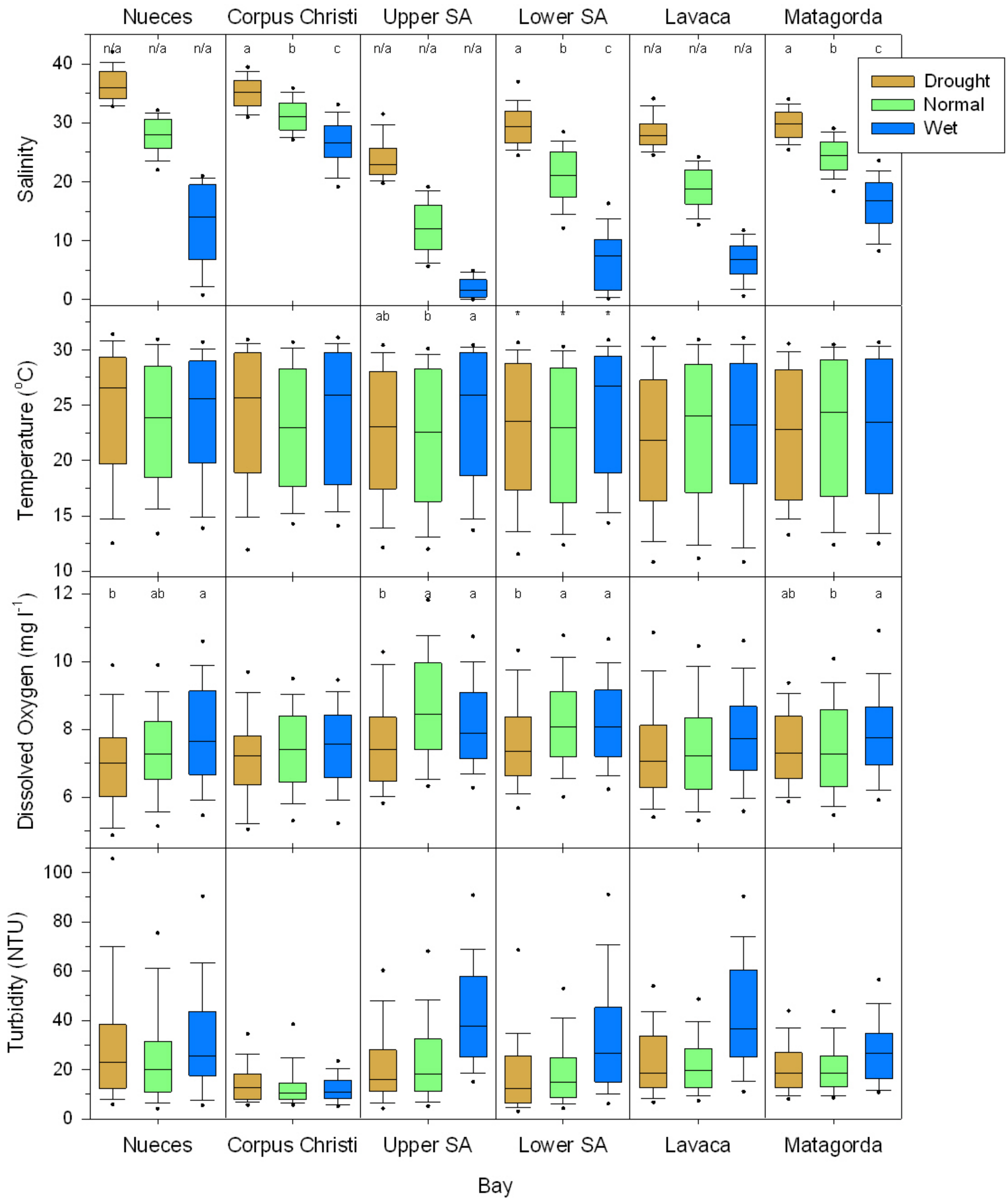

Figure 41. Box plots of salinity, temperature, dissolved oxygen and turbidity for each bay during drought, normal and wet periods (Method Two) - data from TPWD monthly averages. Significant Tukey-Kramer groupings among periods within bays are denoted by letters at the top of each plot.

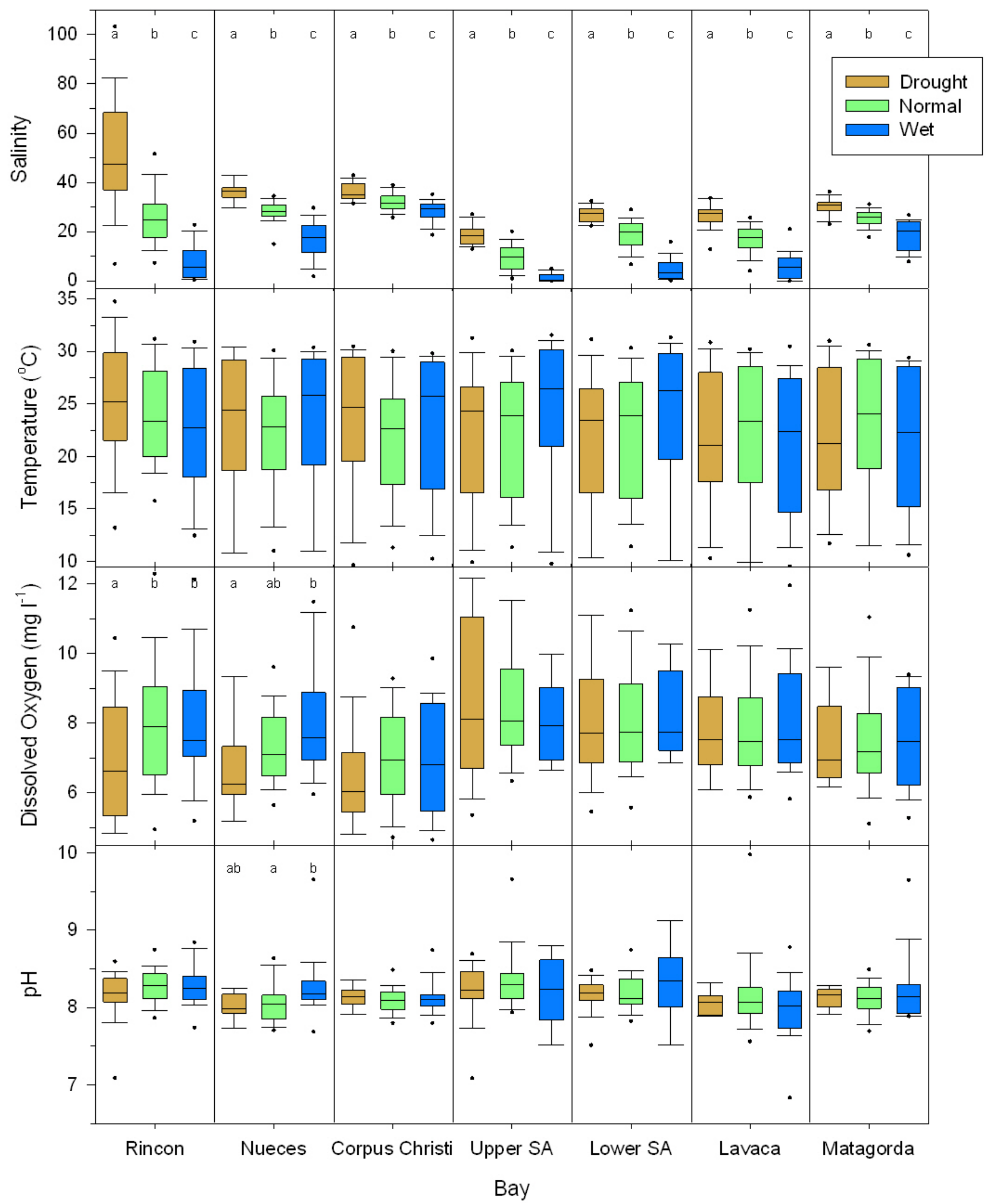

Figure 42. Box plots of salinity, temperature, dissolved oxygen and pH from each bay during drought, normal and wet periods (Method Two) - data from HRI quarterly sampling. Significant Tukey-Kramer groupings among periods within bays are denoted by letters at the top of each plot.

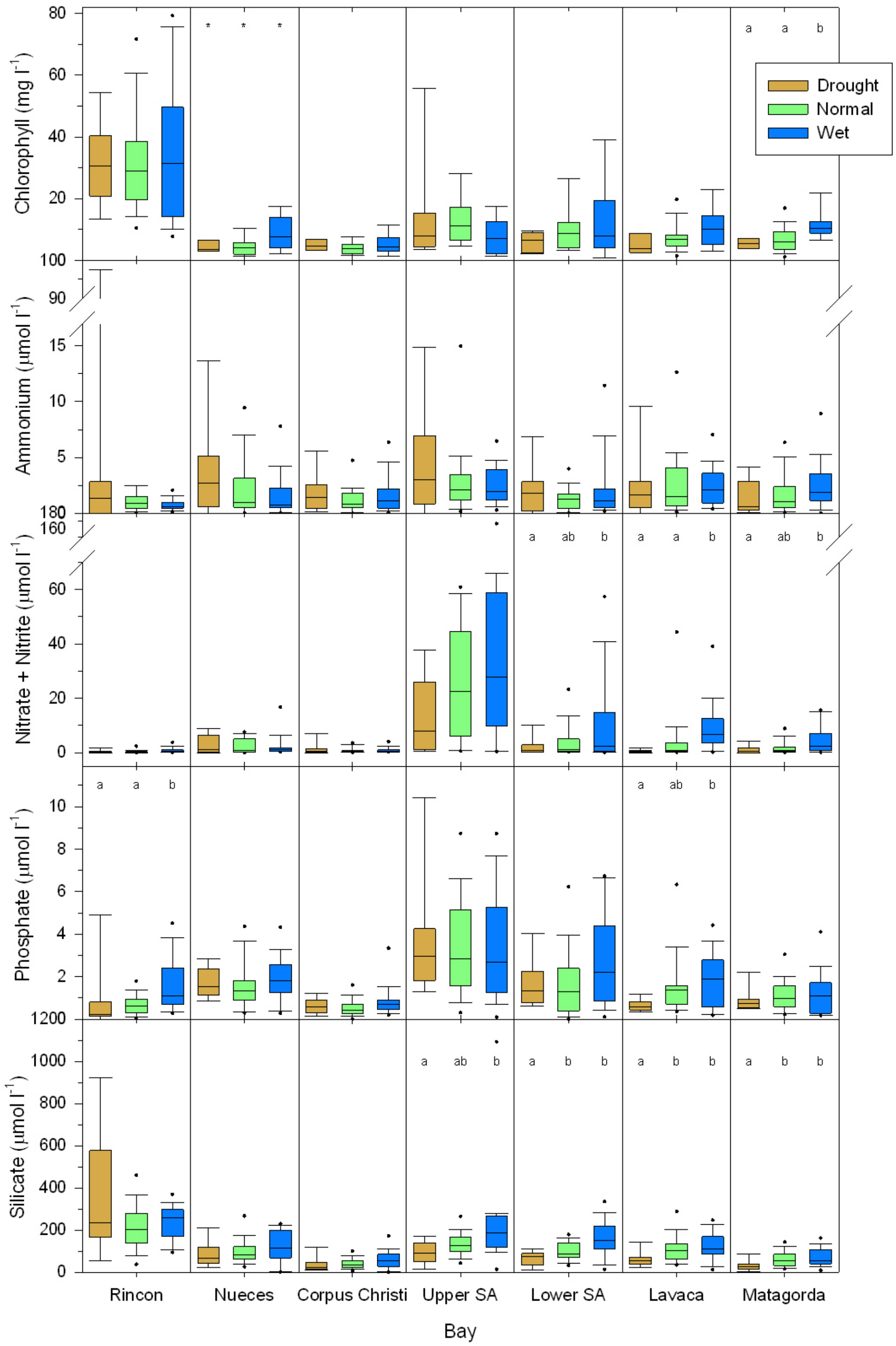

Figure 43. Box plots of nutrients and chlorophyll in each bay during drought, normal and wet periods (Method Two).
Significant Tukey-Kramer groupings among periods within bays are denoted by letters at the top of each plot. A letter 'x' indicates significant differences in ANOVA but not Tukey-Kramer test.

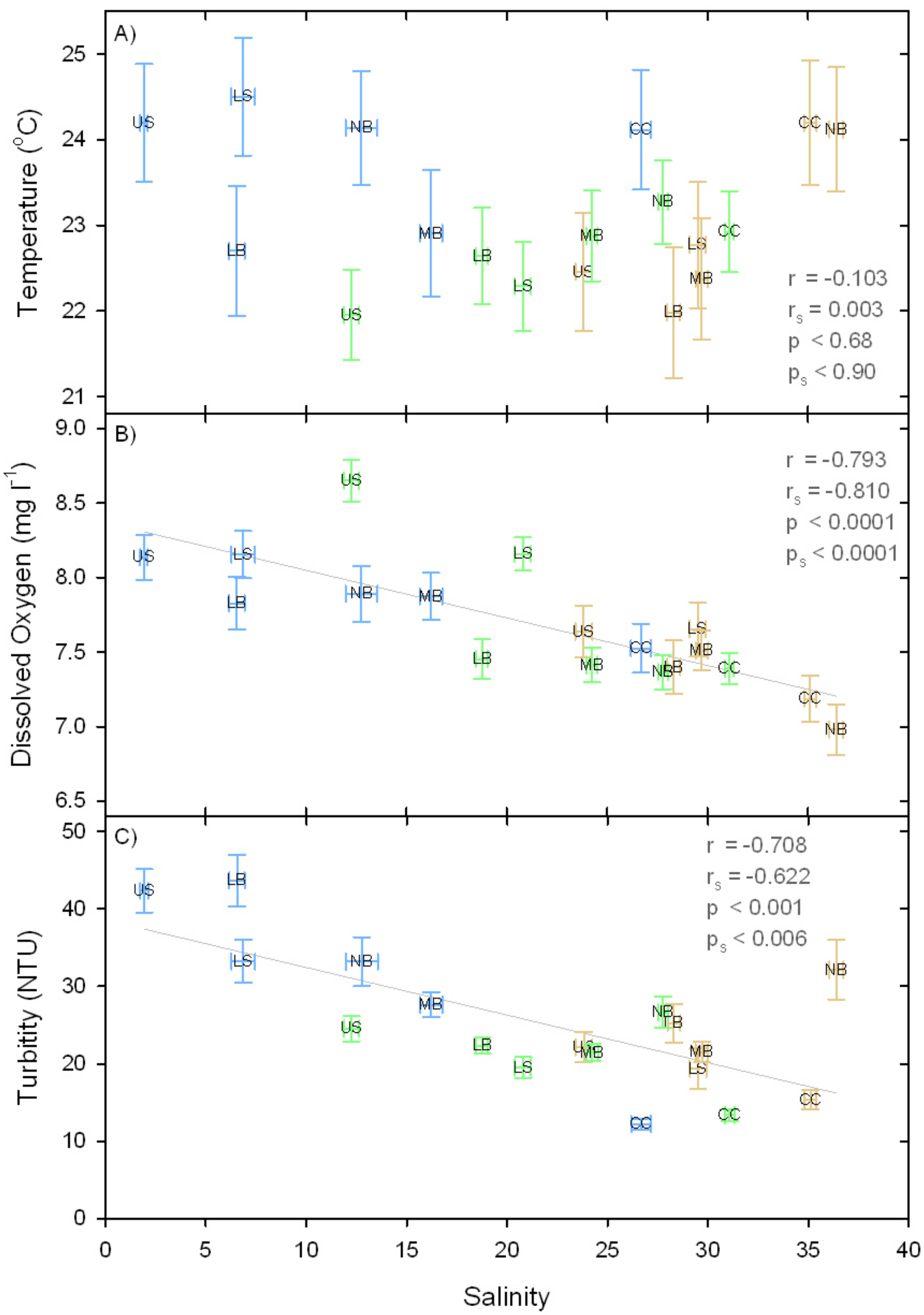

Figure 44. Correlations of temperature, dissolved oxygen and turbidity with salinity among bay-condition combinations (Method Two).

Bars represent standard errors about the mean. Significant correlations among all bays are portrayed with a gray line. No subscript = Pearson correlation coefficient, s subscript = Spearman Rank Order correlation coefficient. Data shown was collected by TPWD.

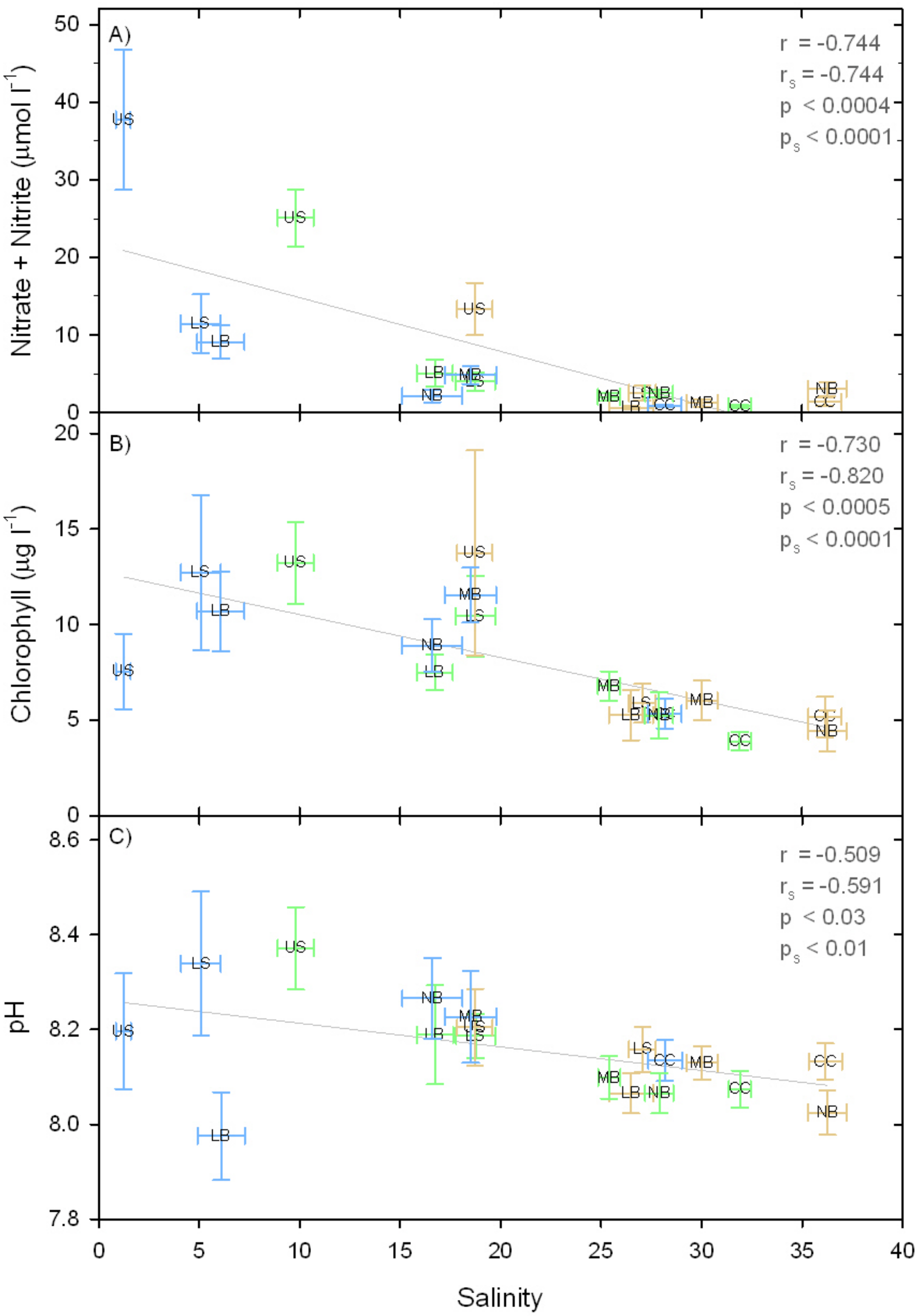

Figure 45. Correlations of nitrate plus nitrite, chlorophyll and pH with salinity among bay-condition combinations (Method Two).
Bars represent standard errors about the mean. No subscript = Pearson correlation coefficient, s subscript = Spearman Rank Order correlation coefficient. Significant correlations among all bays are portrayed with a gray line. Data shown was collected by HRI.

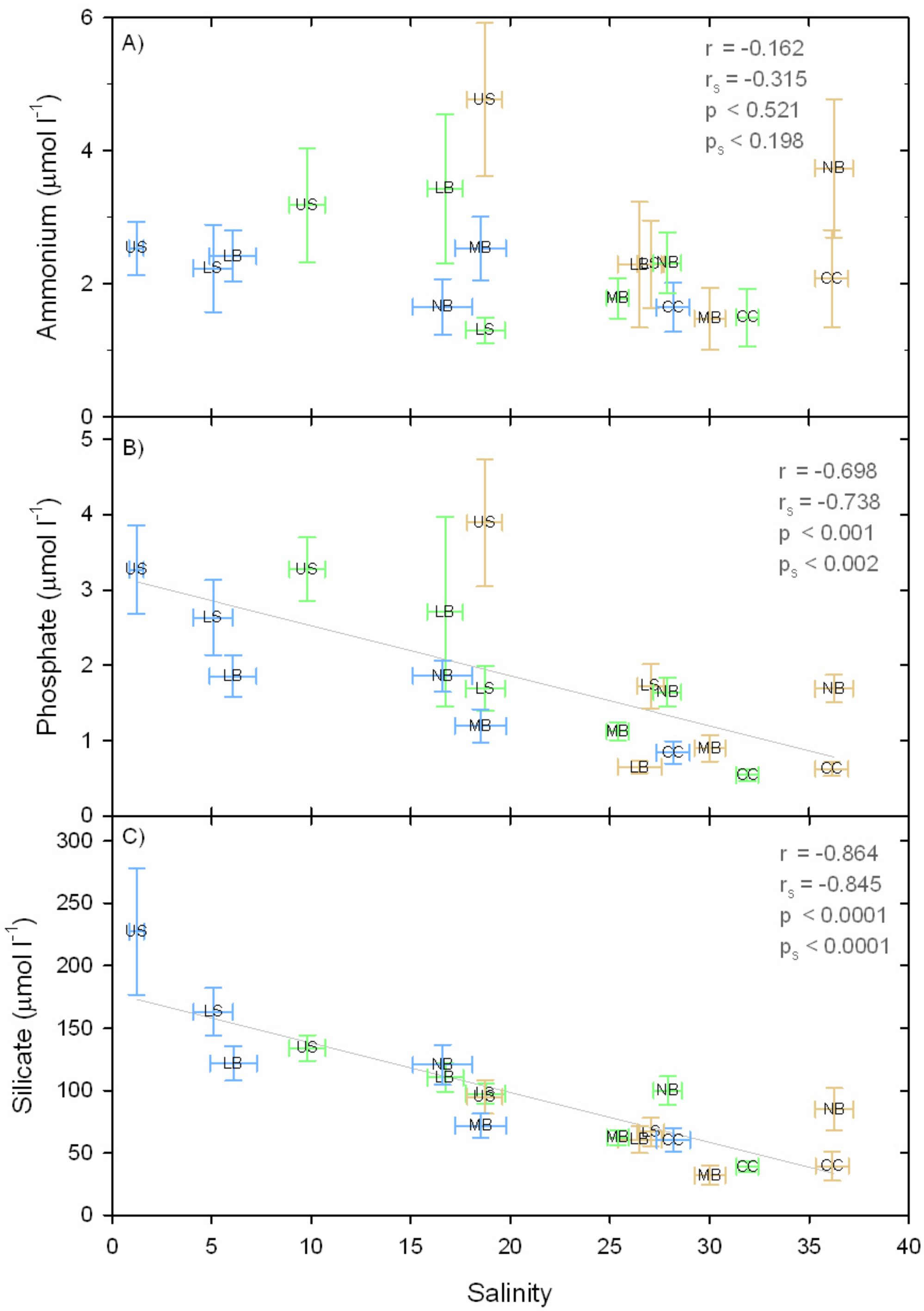

Figure 46. Correlations of ammonium, phosphate and silicate with salinity among bay-condition combinations (Method Two).

Bars represent standard errors about the mean. Significant correlations among all bays are portrayed with a gray line. Data shown was collected by HRI.

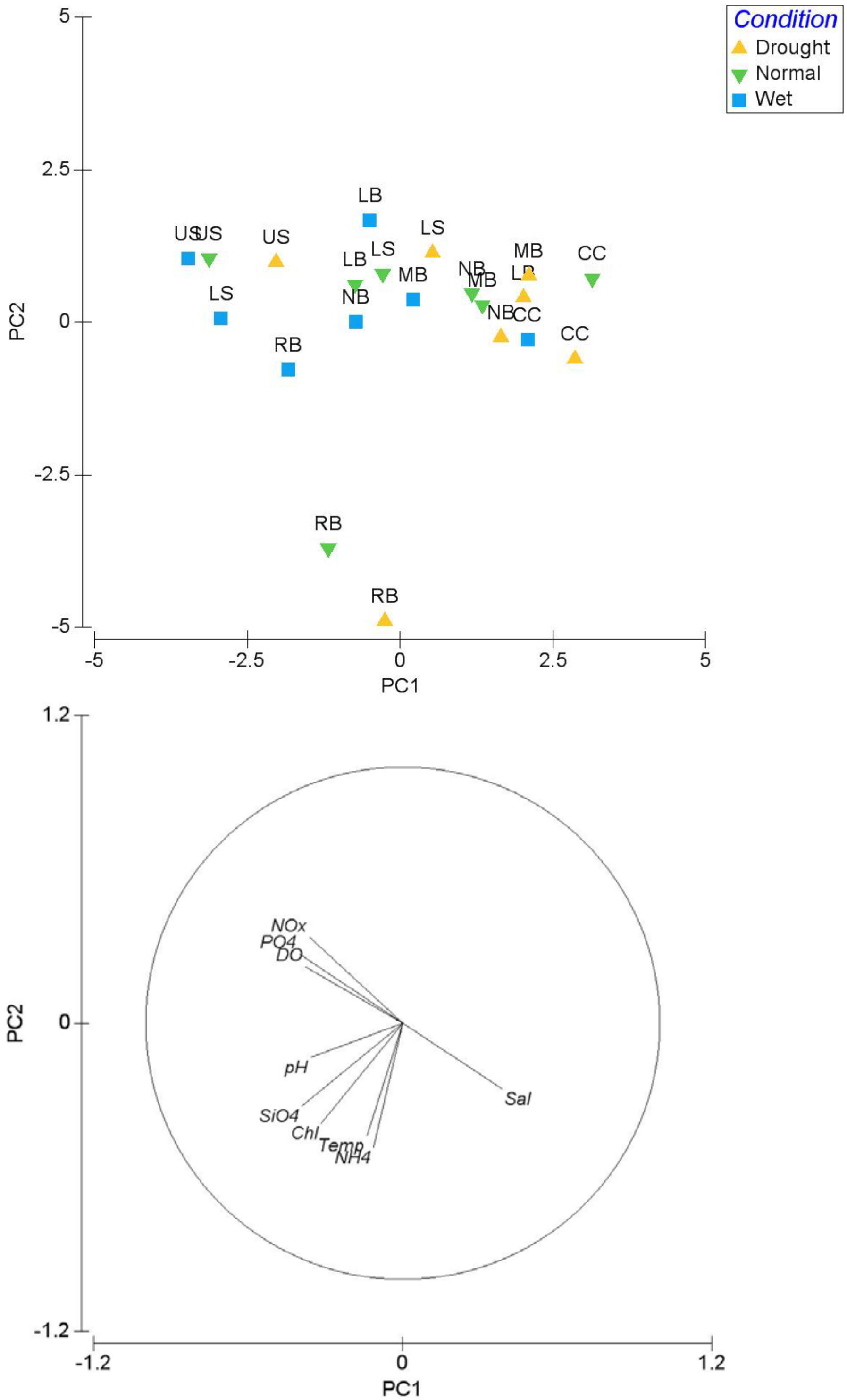

Figure 47. Plots of loading scores (top) and eigenvectors (bottom) from Principal Components Analysis of water quality using HRI-collected data (Method Two).
PC1 and PC2 account for 43.2 and 27.1 % of total variation respectively (total 70.3 %).

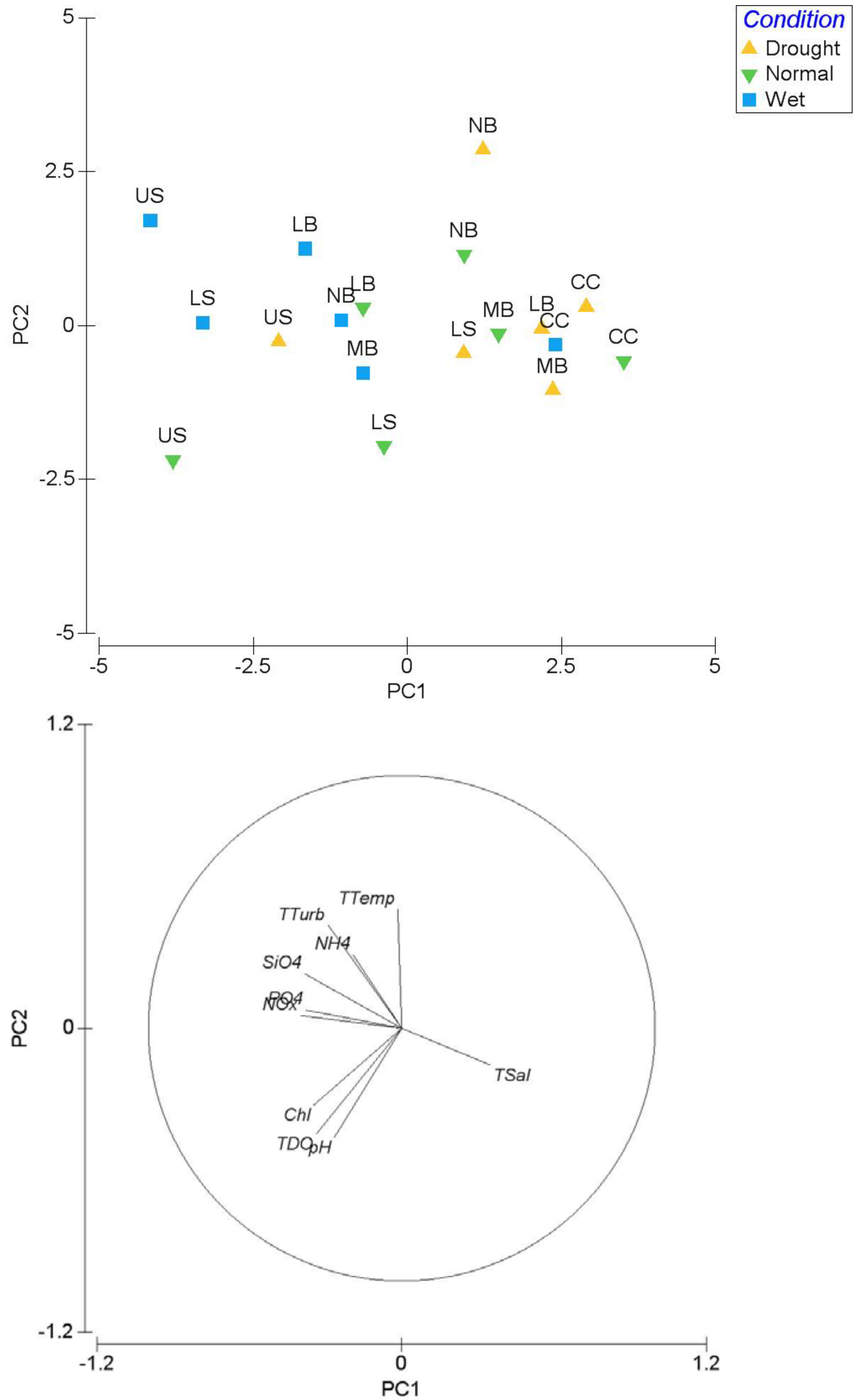

Figure 48. Plots of loading scores (top) and eigenvectors (bottom) from Principal Components Analysis of water quality (no Rincon Bayou) using TPWD-collected ('T' prefix) and HRI-collected nutrient data (no prefix).
PC1 and PC2 account for 55.6 and 14.8 % of total variation respectively (total 70.4 %).

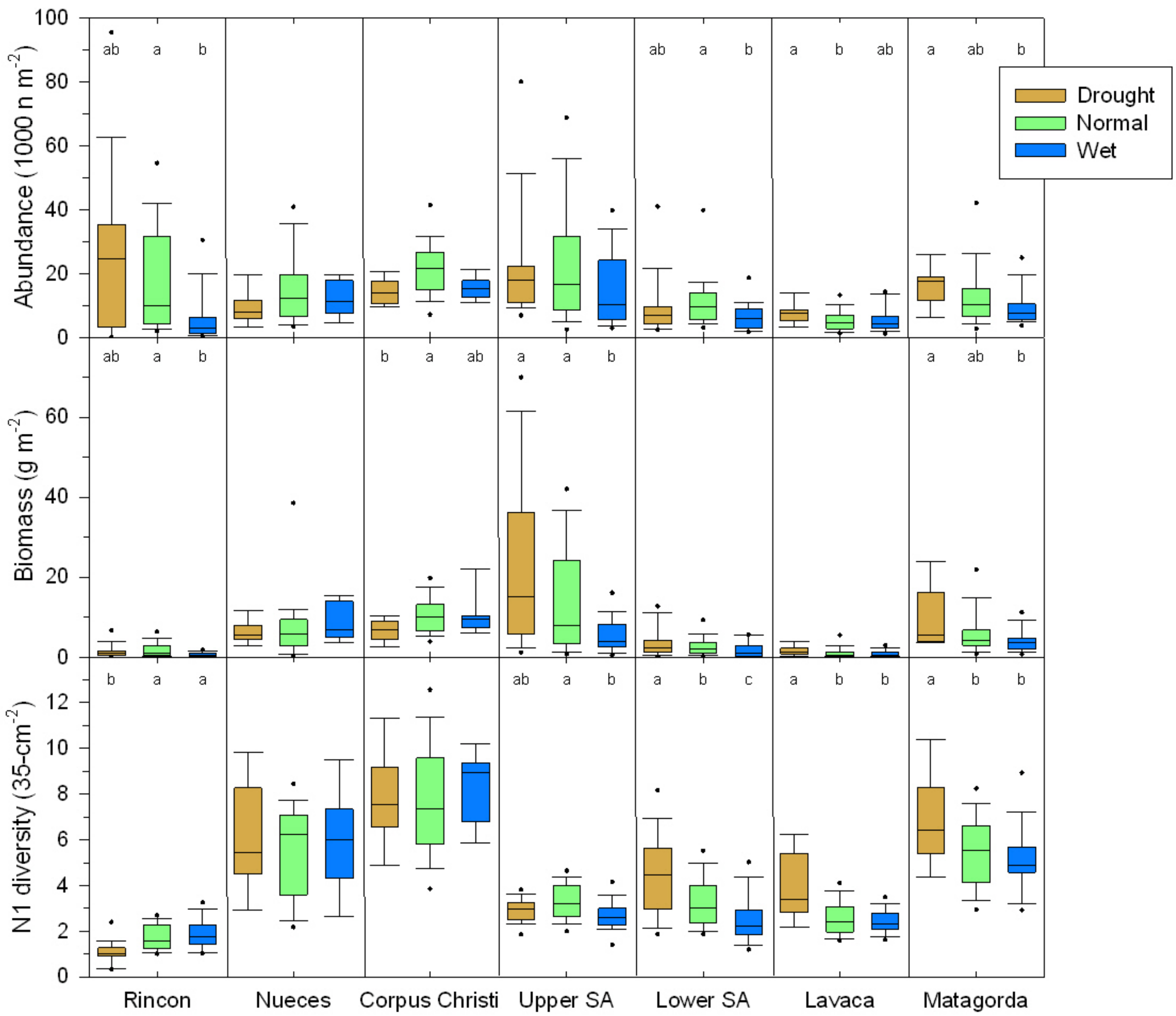

Figure 49. Box plots of macrofauna descriptors among bays and climatic conditions (Method Two).
Significant Tukey groupings among periods within bays are denoted by letters at the top of each plot.

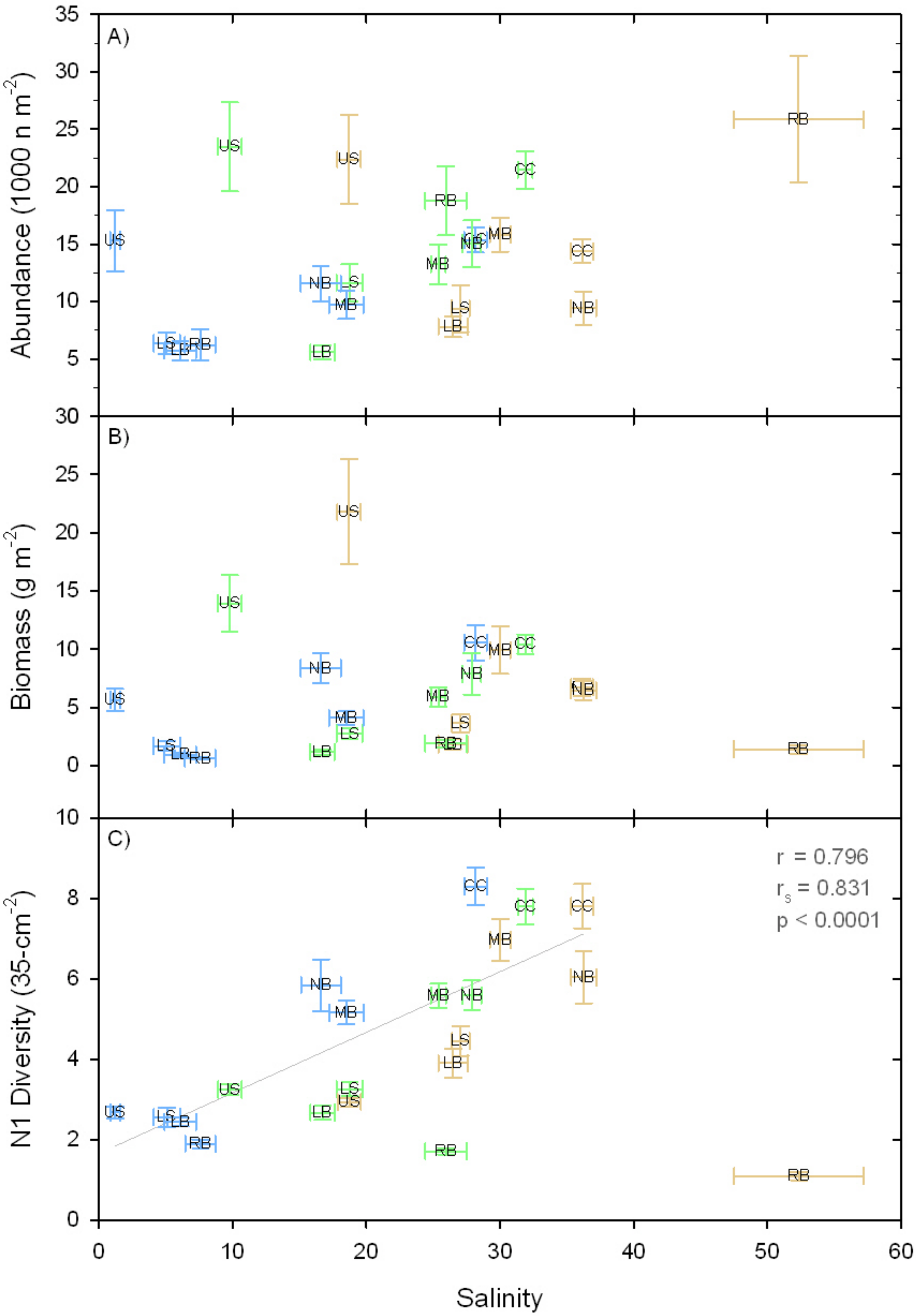

Figure 50. Corelations of univariate macrofauna qualities and salinity (Method Two). Bars represent standard errors about the mean. Significant correlations among all major bays (not Rincon Bayou) are portrayed with a gray line. All data was collected by HRI.

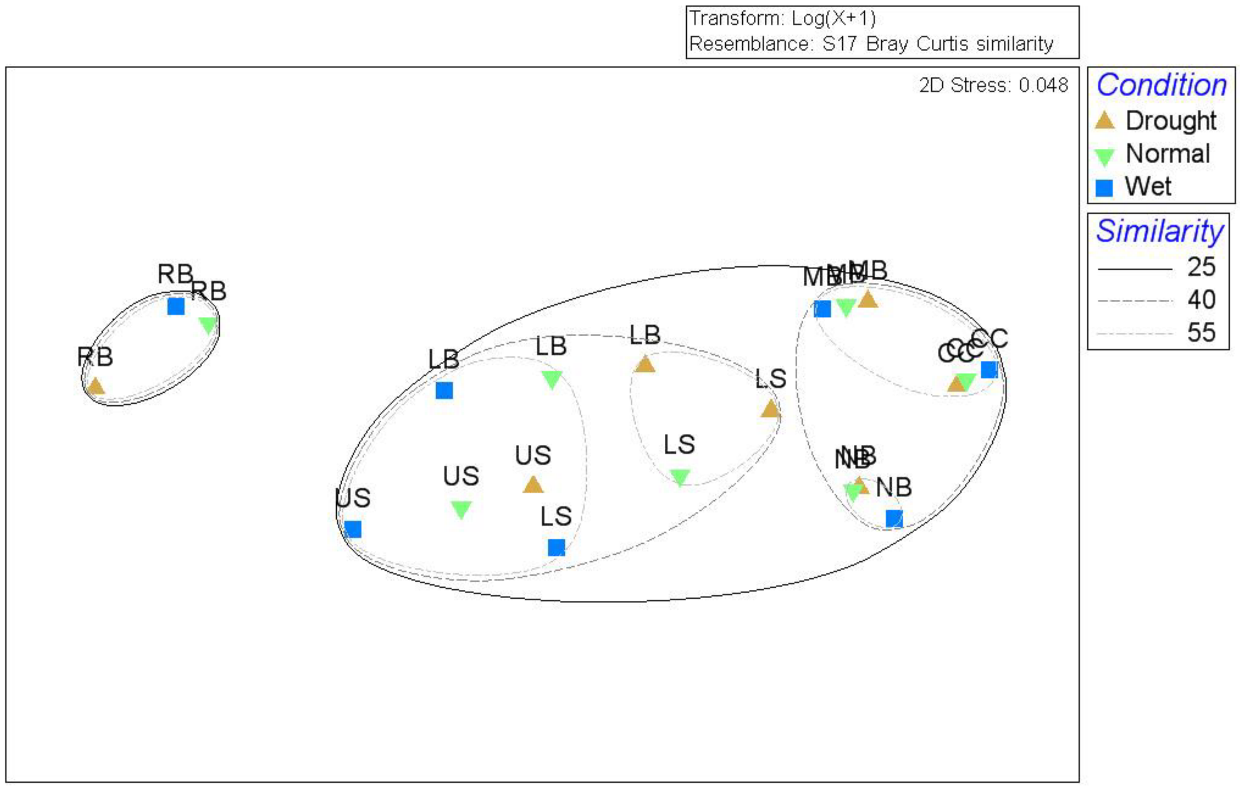

Figure 51. Multi-dimensional scaling plot of macrofauna community composition in each bay under drought, normal and wet conditions (Method Two).

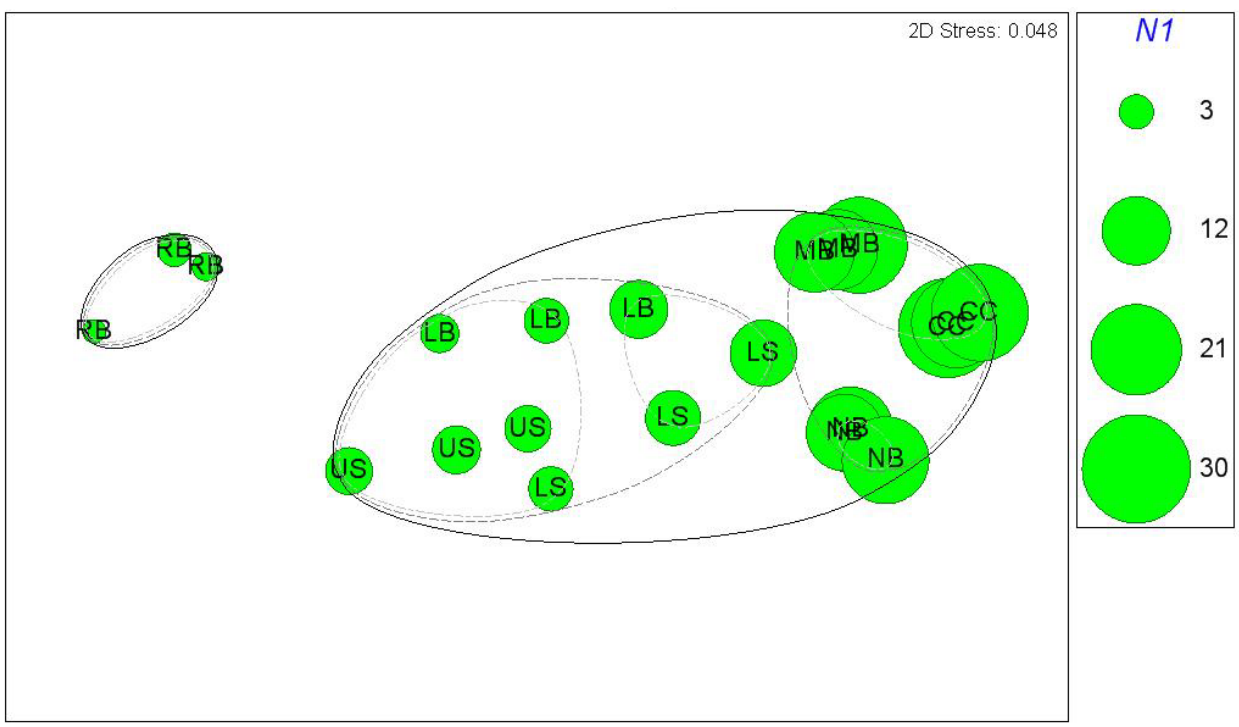

Figure 52. MDS plot of macrofauna communities (Figure 51) overlaid with N1 diversity.

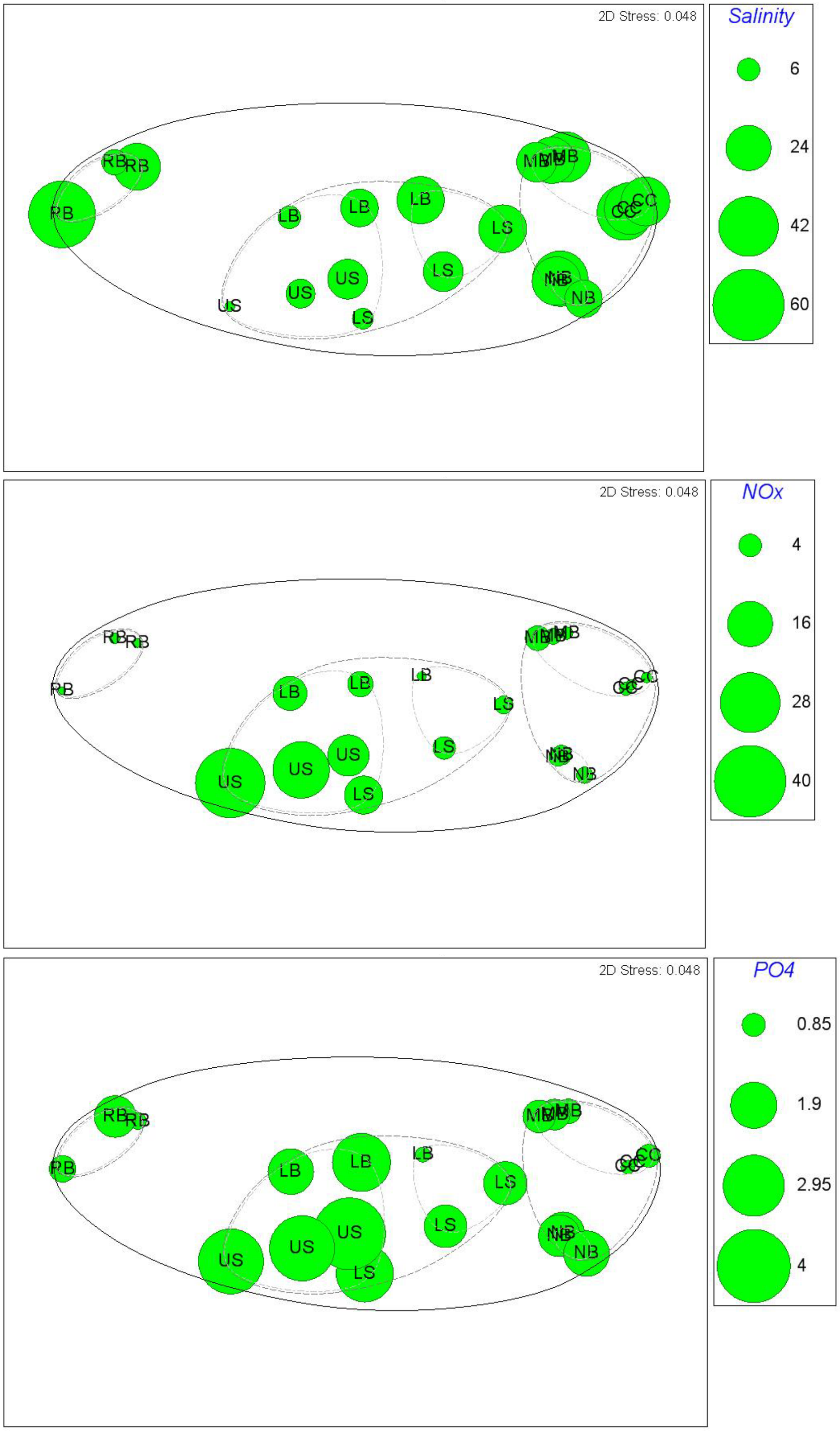

Figure 53. MDS plot of macrofauna community structure (Figure 51) overlaid with salinity, nitrate + nitrite and phosphate.

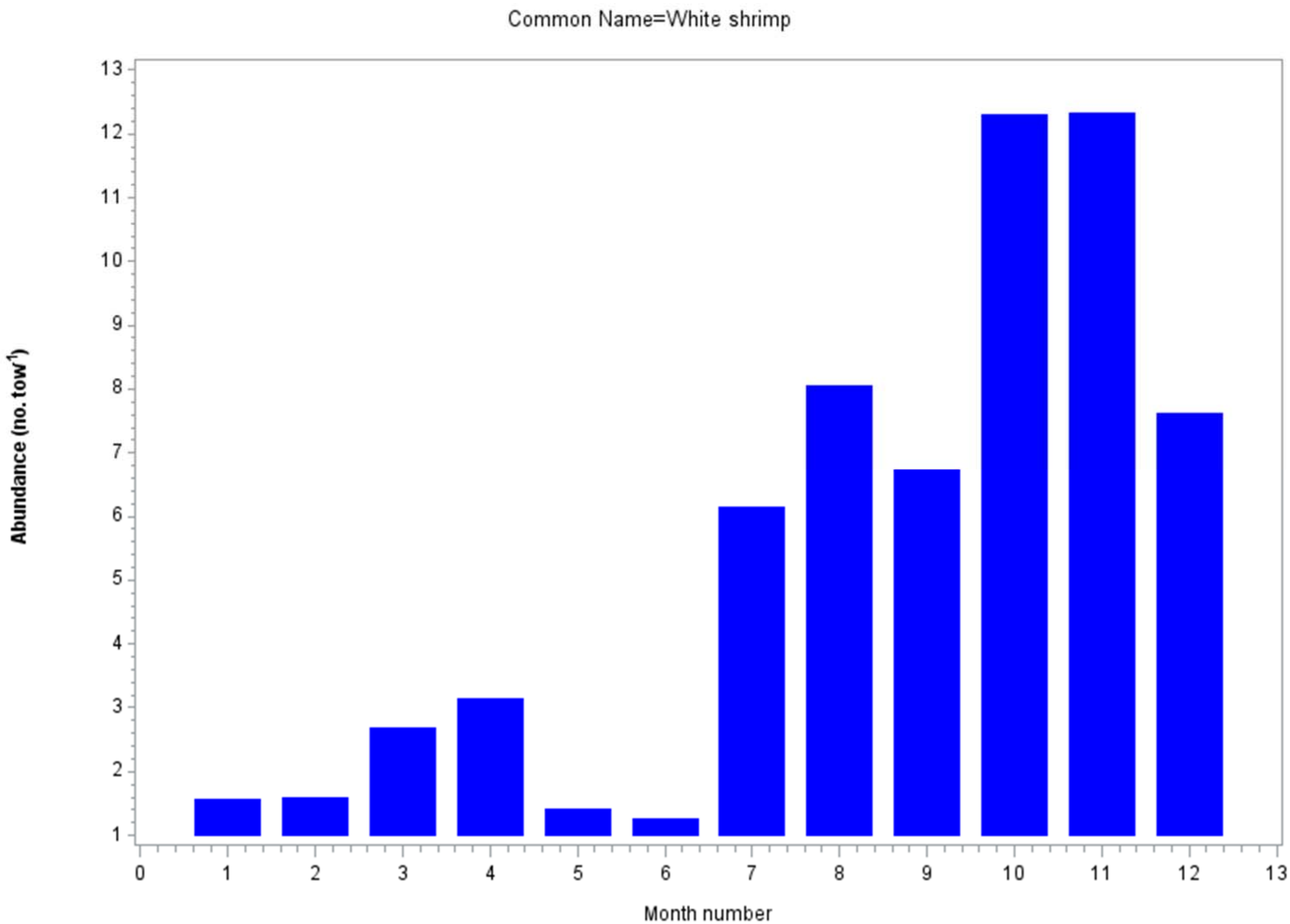

Figure 54. Abundance of white shrimp for each month in Texas estuaries.

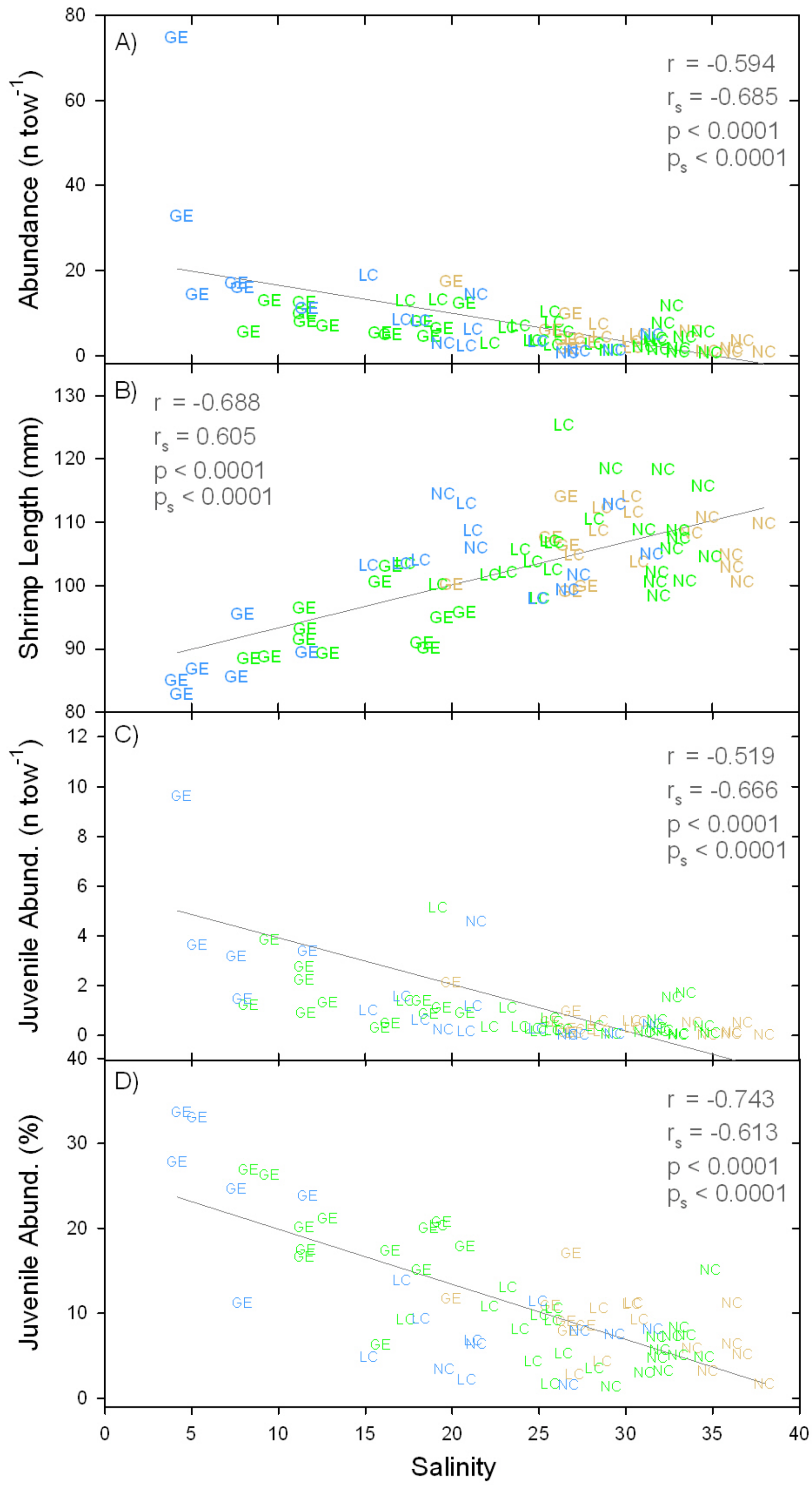

Figure 55. Scatter plots of yearly salinity (Jun-Dec) versus yearly white shrimp (Jul-Dec) characteristics.

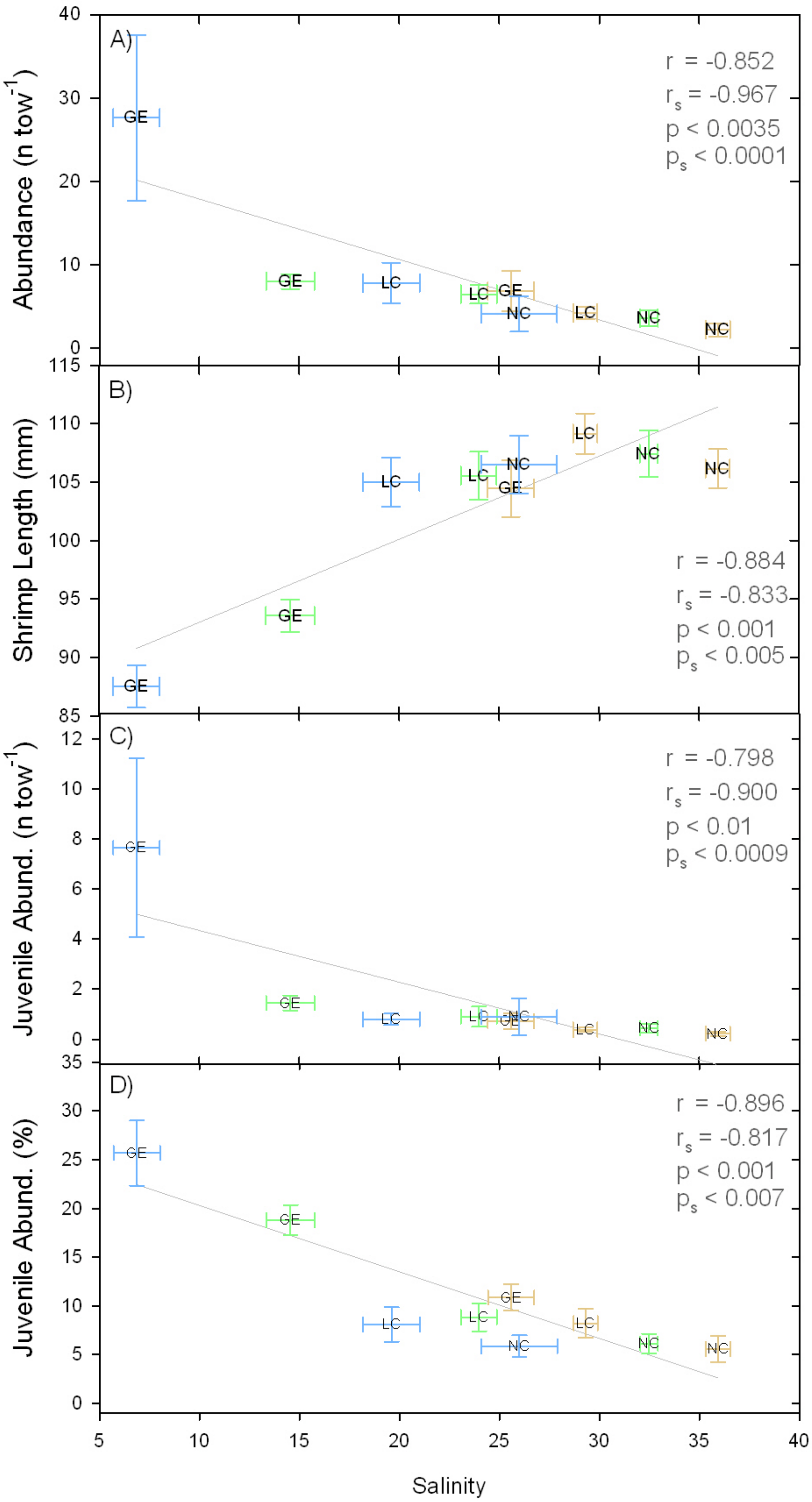

Figure 56. Mean white shrimp characteristics (± standard error) of each estuary under each condition versus salinity (Method Two).

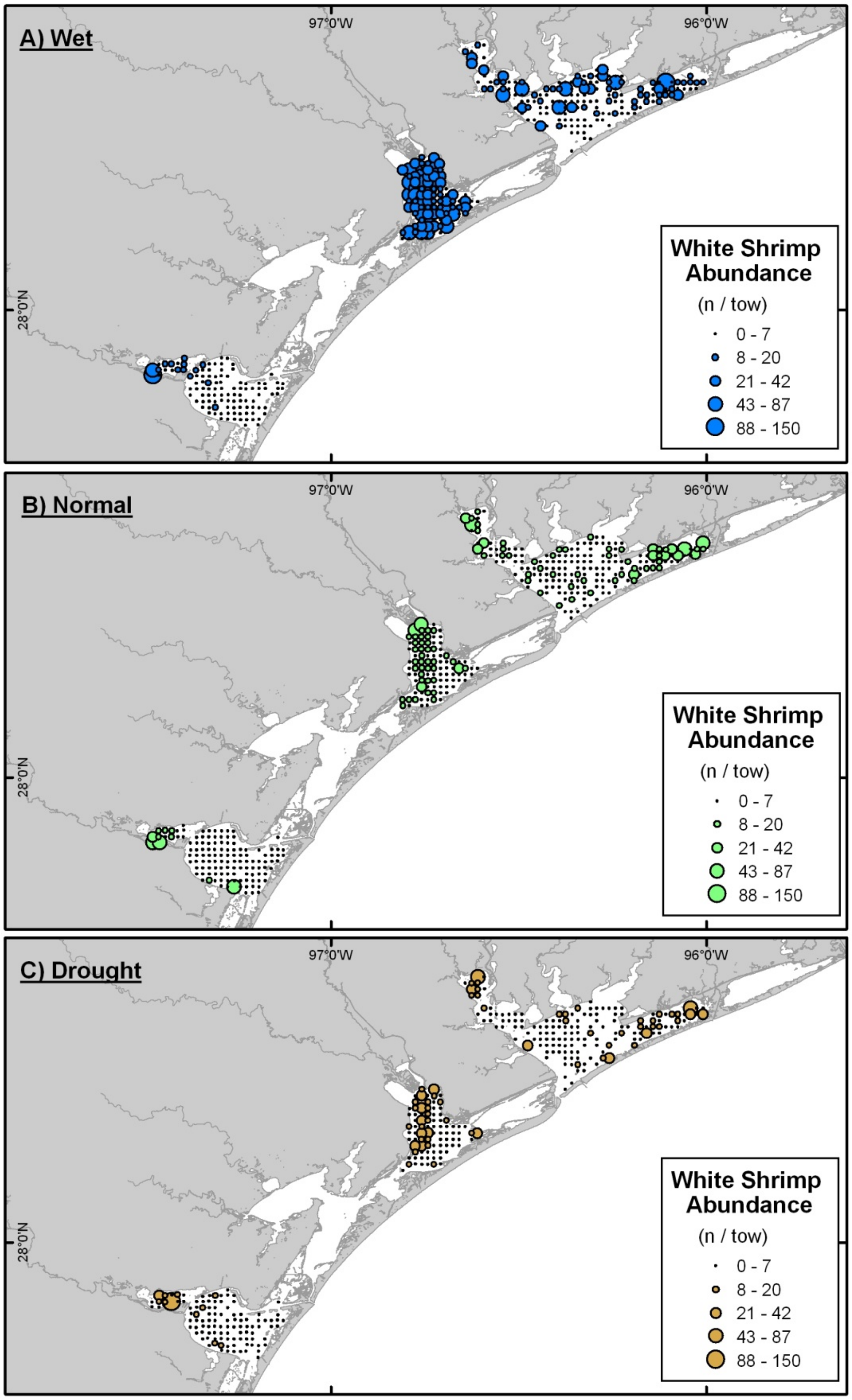

Figure 57. Spatial distribution of white shrimp abundances in drought, normal and wet years (Method Two).

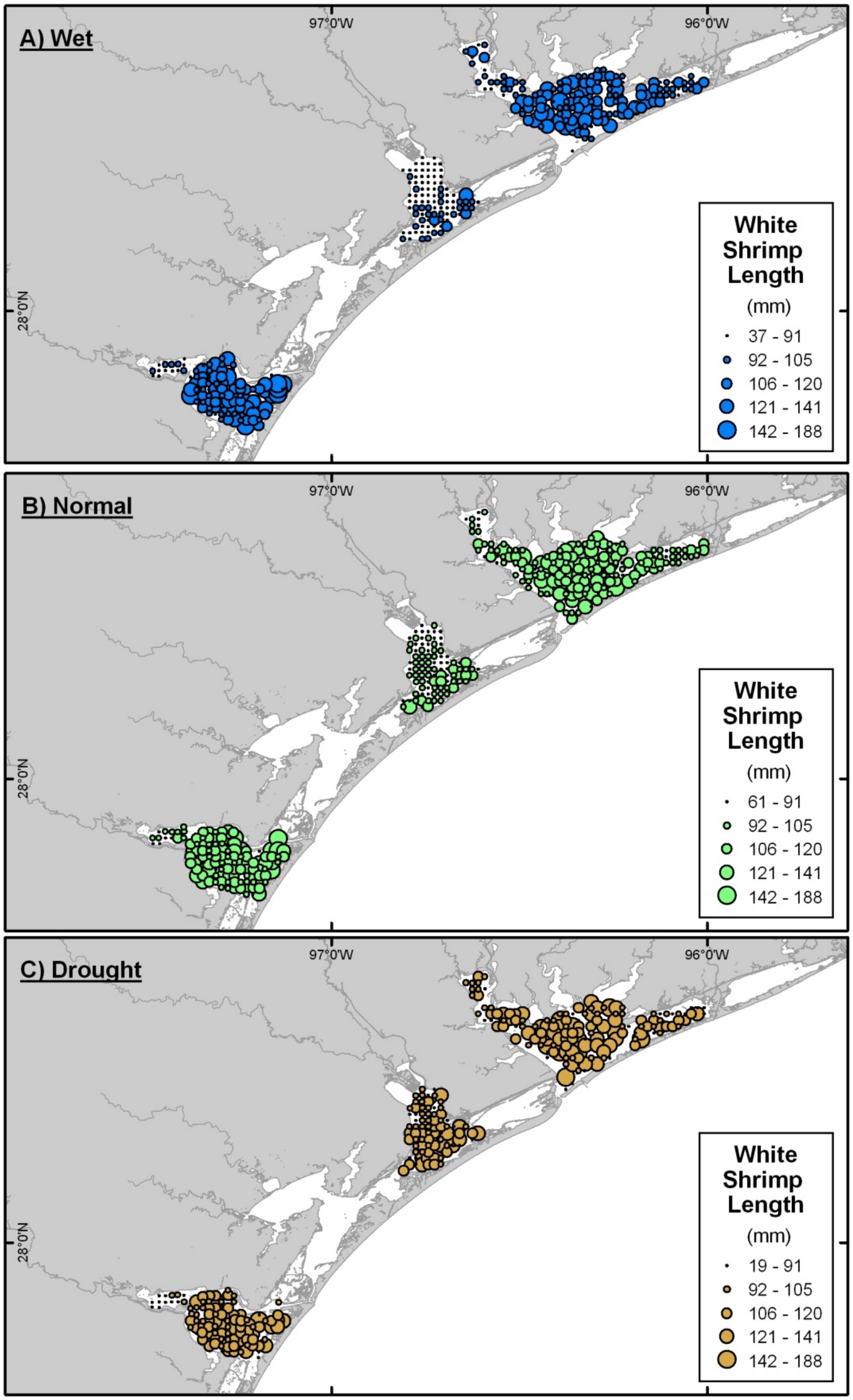

Figure 58. Spatial distribution of white shrimp lengths in drought, normal and wet years (Method Two).

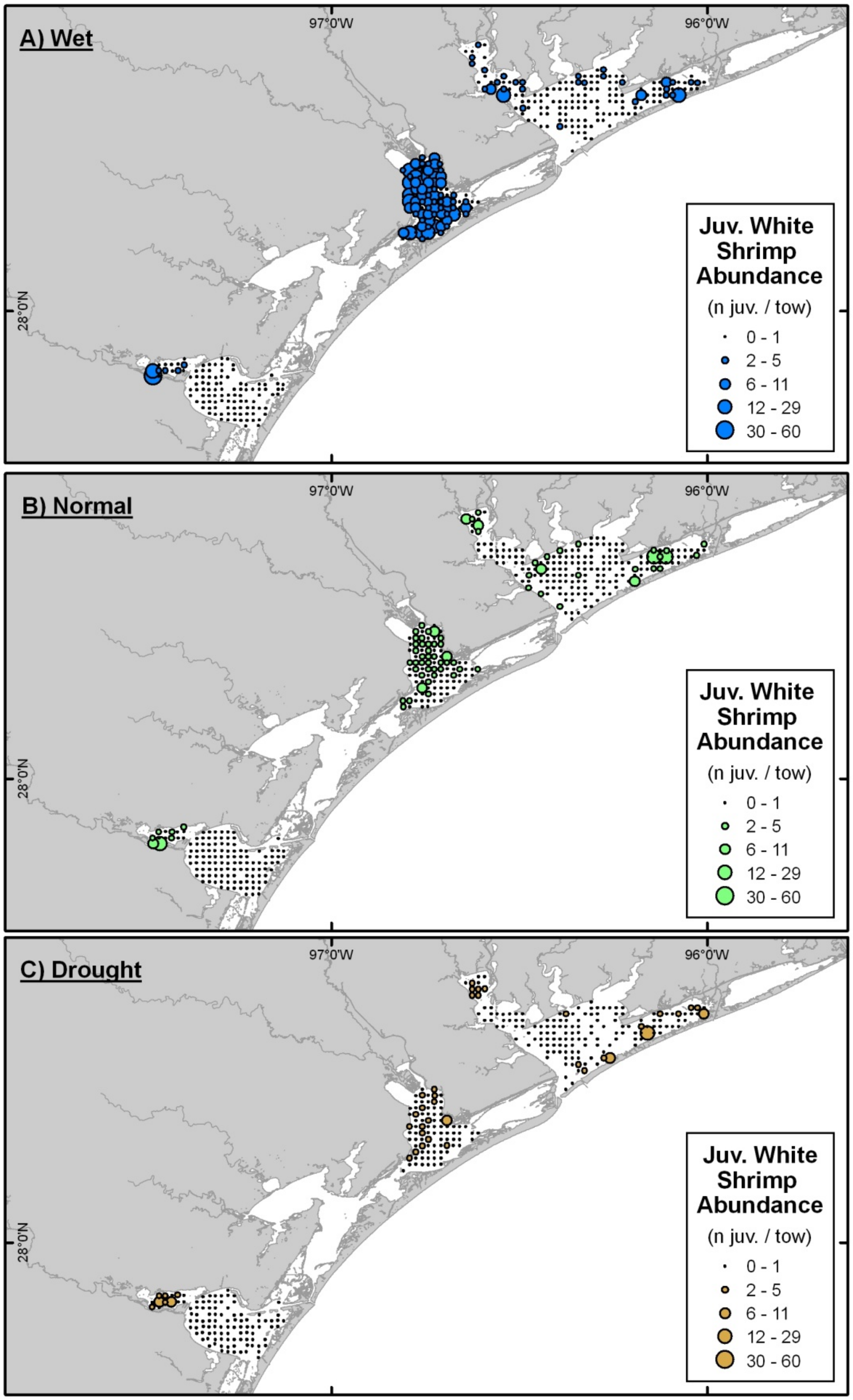

Figure 59. Spatial distribution of juvenile white shrimp (< 76 mm (3")) abundances in drought, normal and wet years (Method Two).

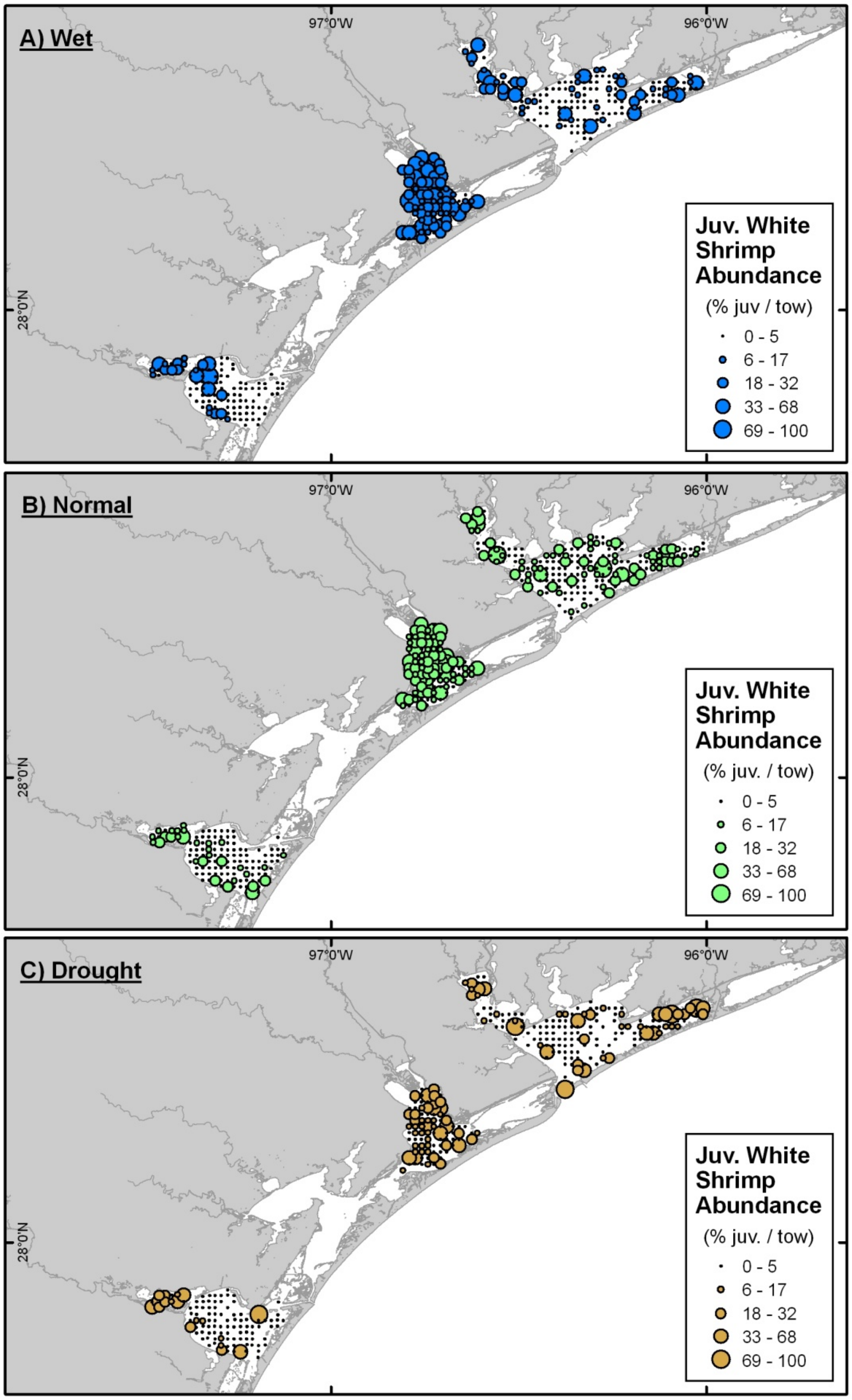

Figure 60. Spatial distribution of percentages of juvenile white shrimp (< 75 mm (3")) in drought, normal and wet years (Method Two).

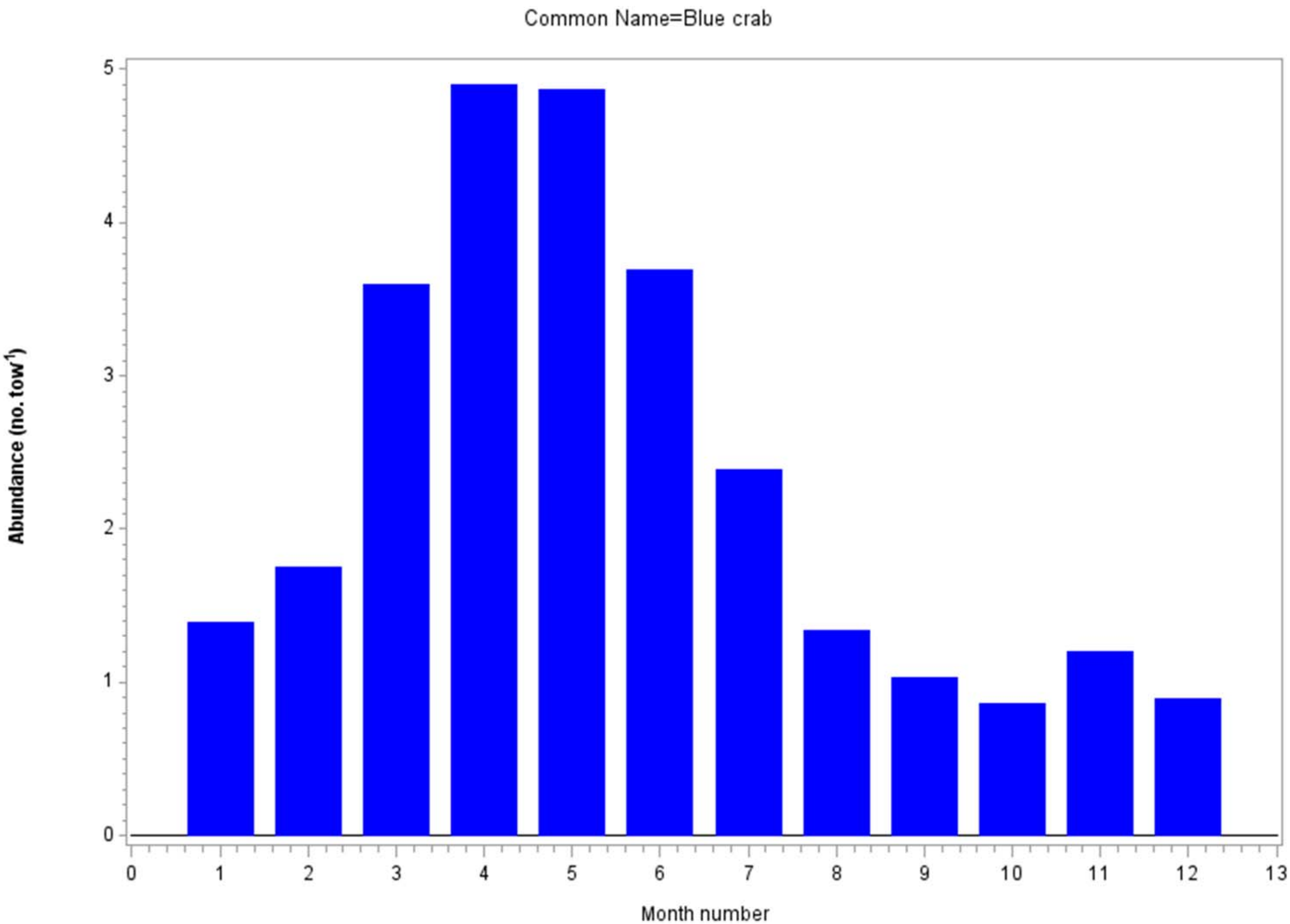

Figure 61. Abundance of blue crab for each month in Texas estuaries.

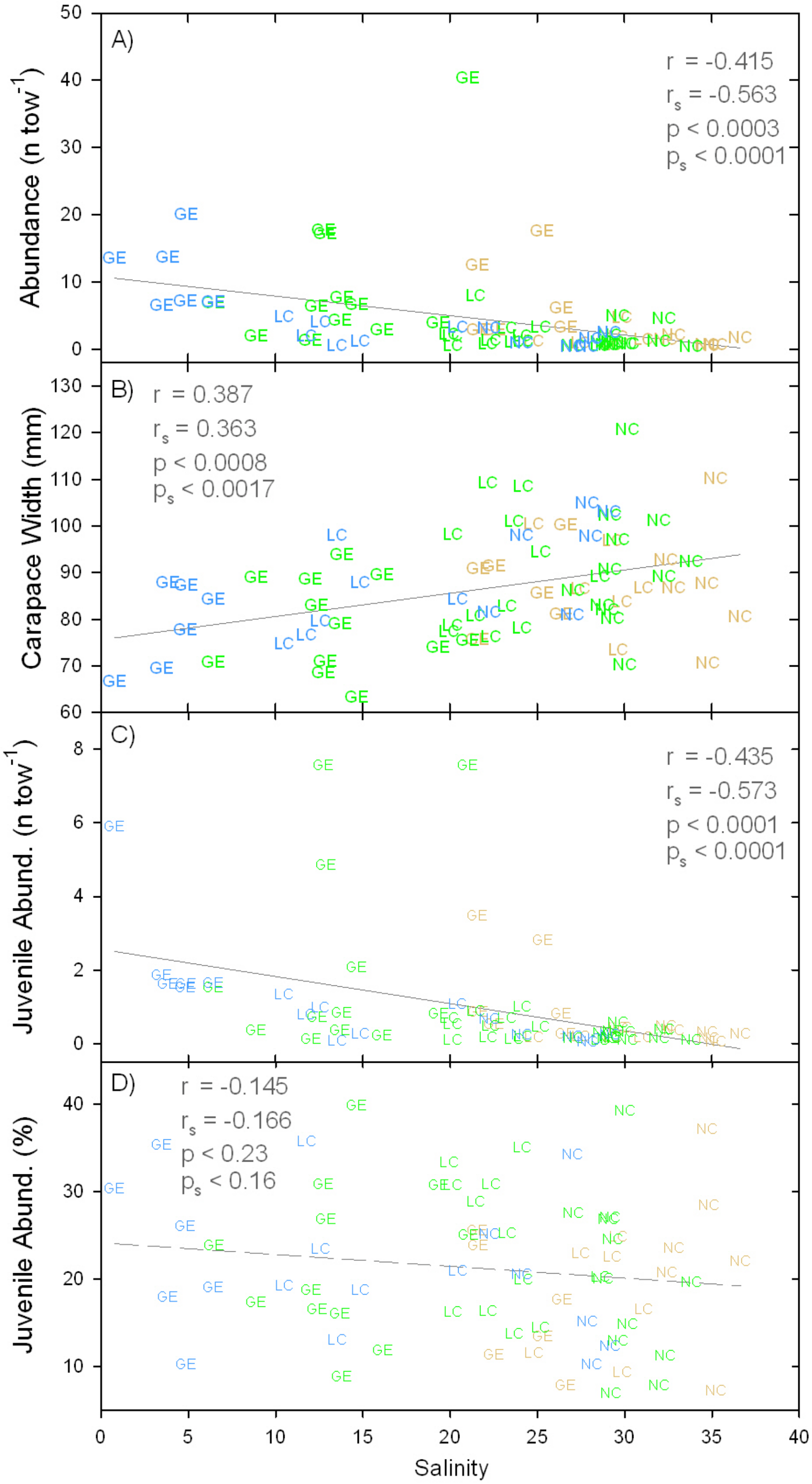

Figure 62. Scatter plots of yearly salinity (Feb-Jul) versus yearly blue crab (Mar-Jul) characteristics.

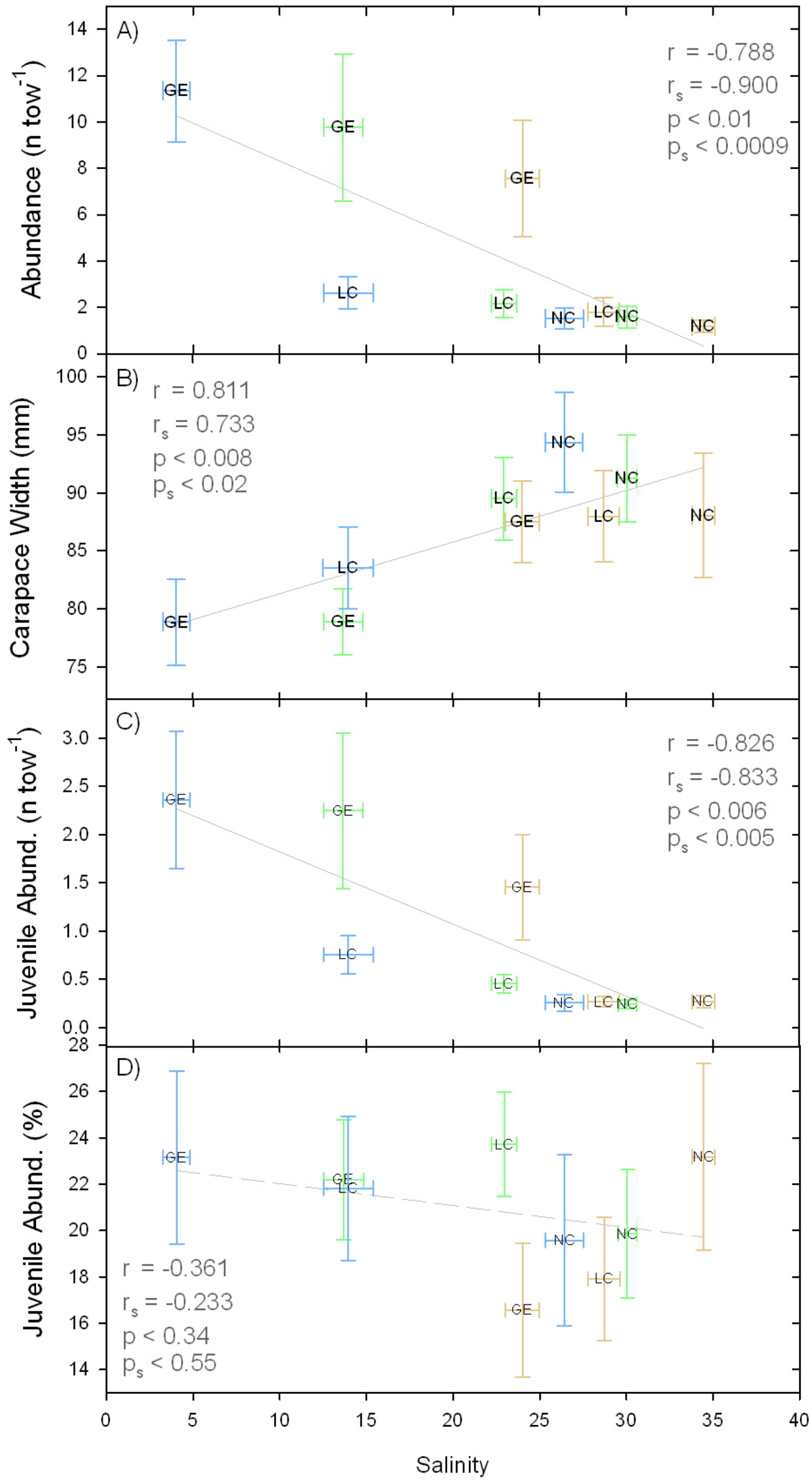

Figure 63. Mean blue crab characteristics (± standard error) of each estuary under each condition versus mean salinity (Method Two).

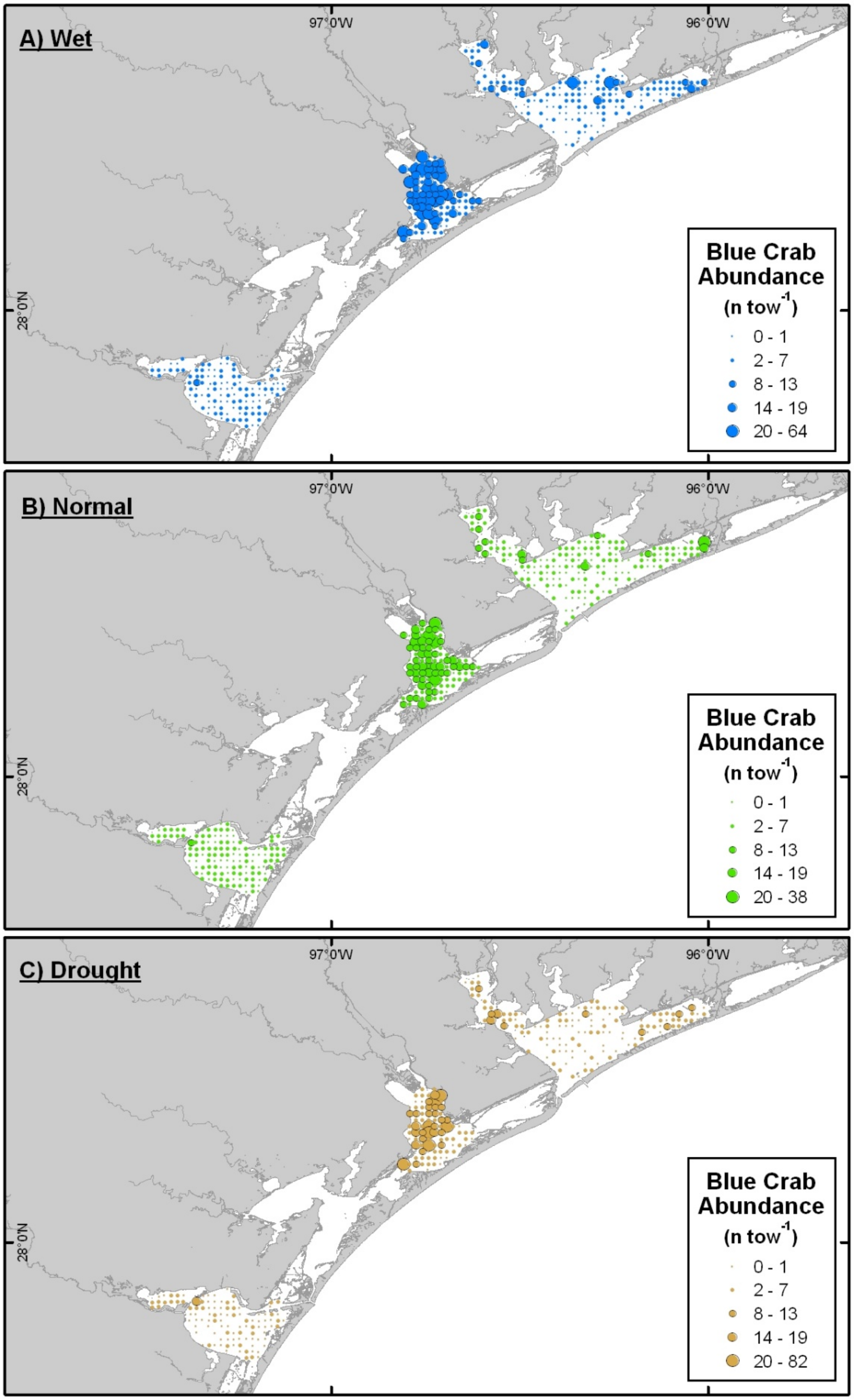

Figure 64. Spatial distribution of blue crab abundances in drought, normal and wet years (Method Two).

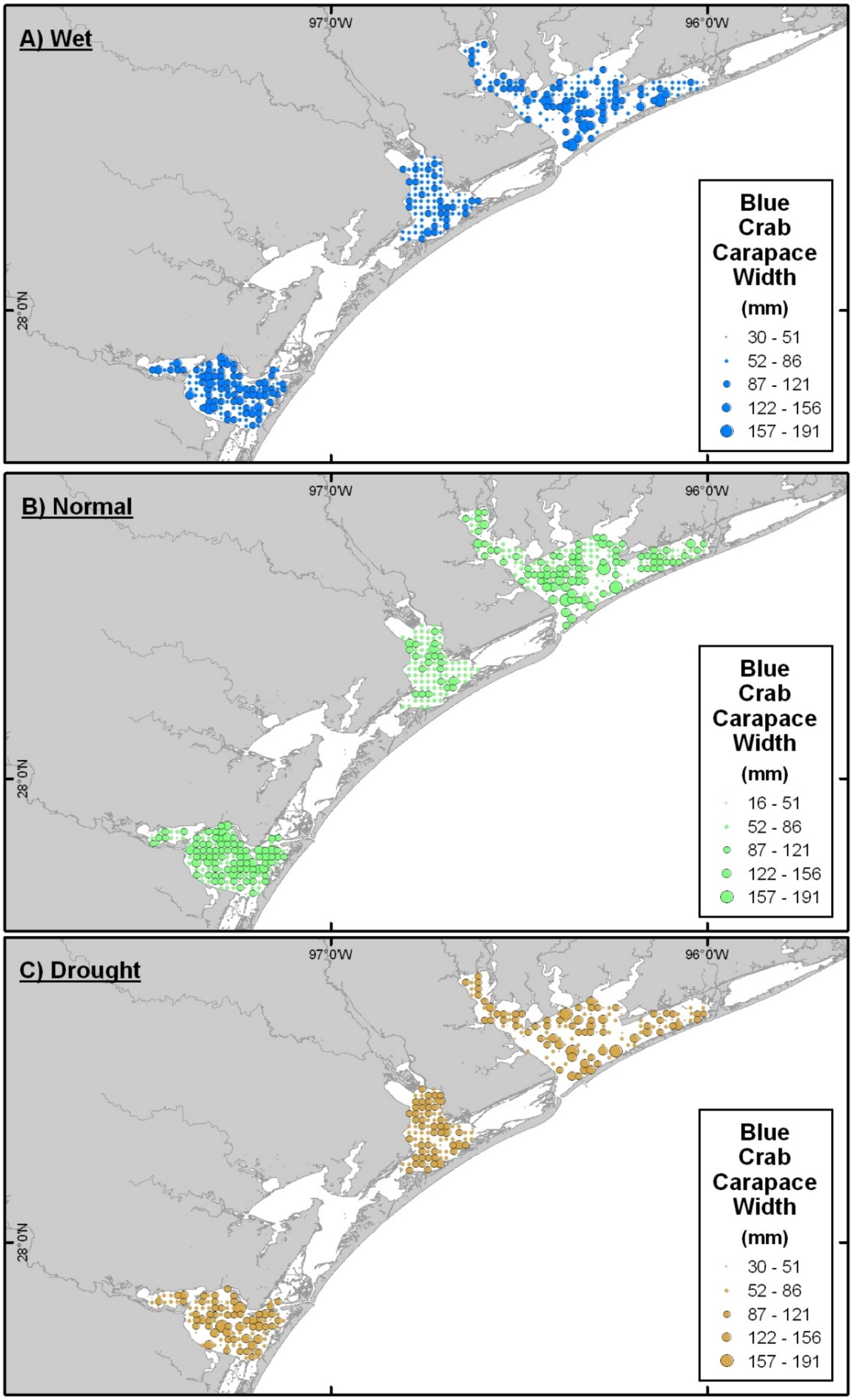

Figure 65. Spatial distribution of blue crab widths in drought, normal and wet years (Method Two).

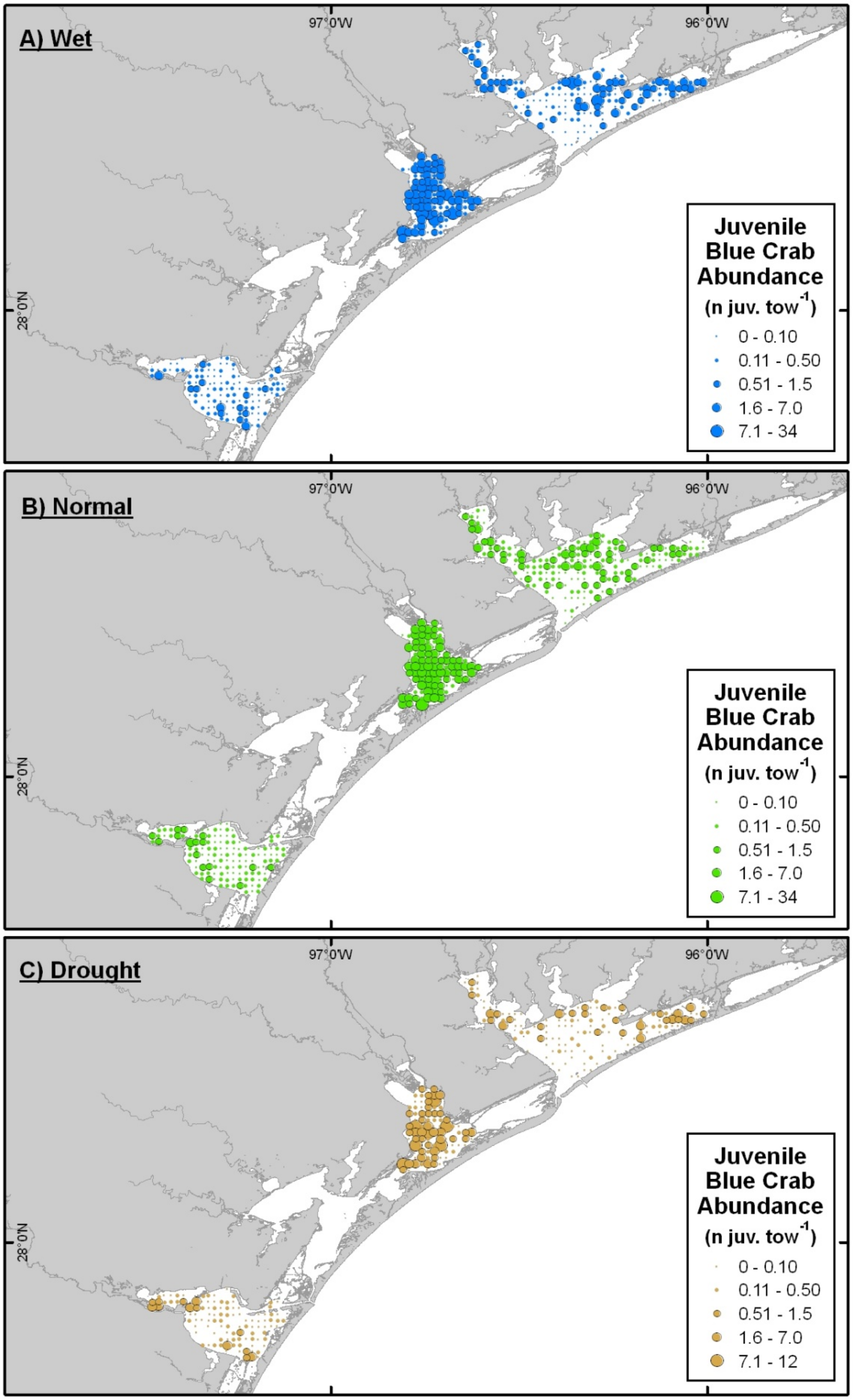

Figure 66. Spatial distribution of juvenile blue crab (< 51 mm (2")) abundances in drought, normal and wet years (Method Two).

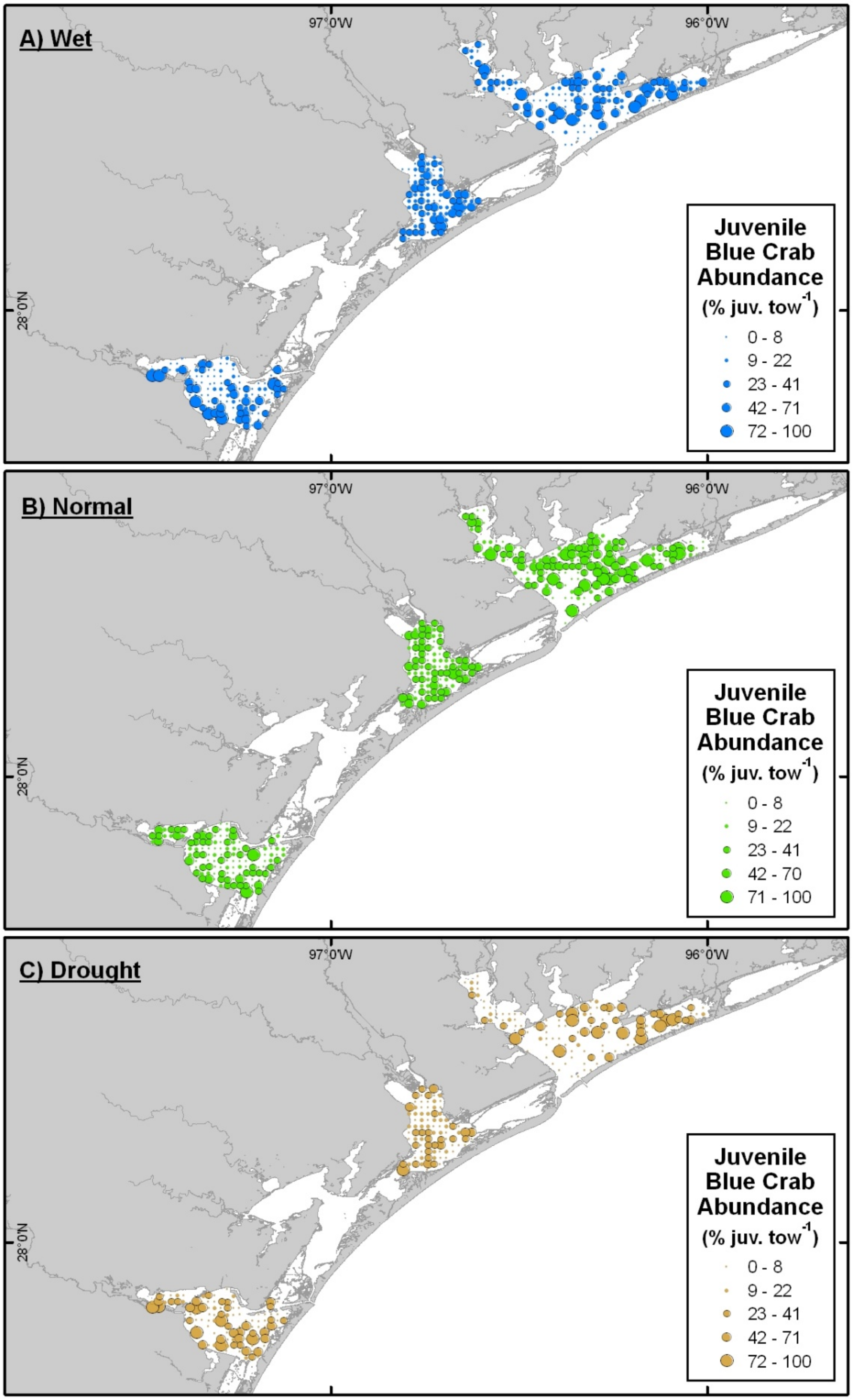

Figure 67. Spatial distribution of the percentage of juvenile blue crabs (< 51 mm (2")) abundances in drought, normal and wet years (Method Two).

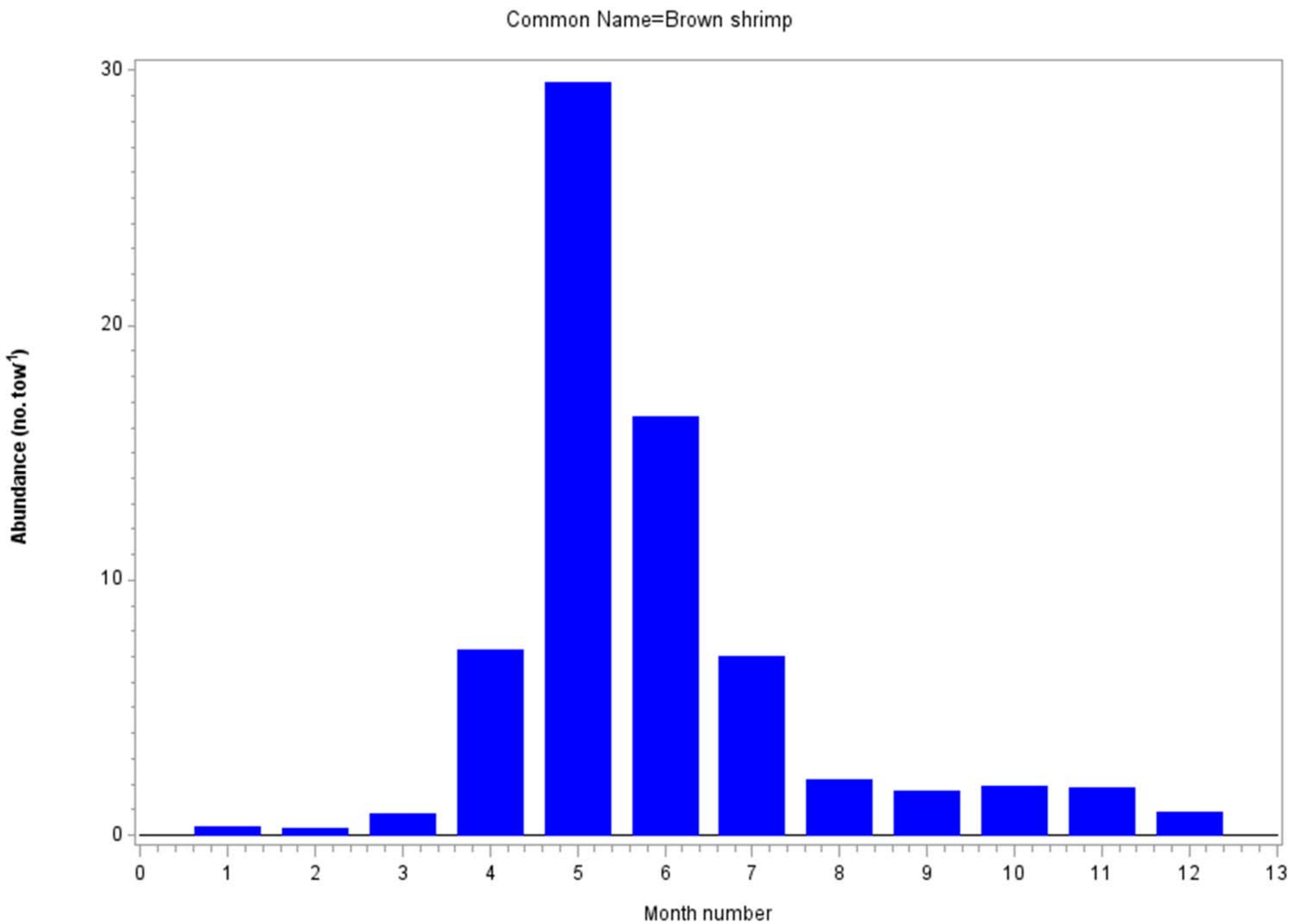

Figure 68. Abundance of brown shrimp for each month in Texas estuaries.

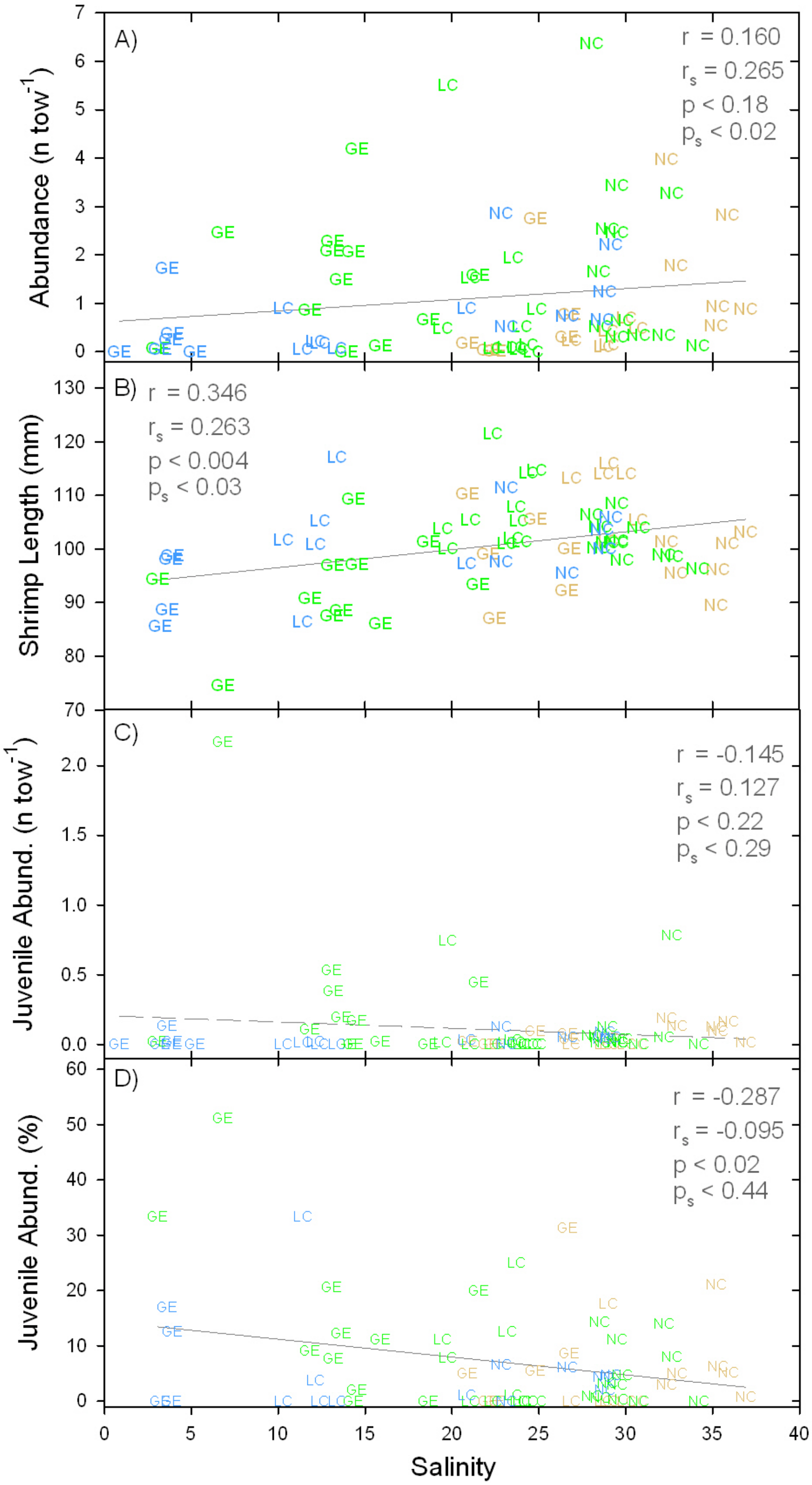

Figure 69. Scatter plots of yearly salinity (Mar-Jul) versus yearly brown shrimp (Apr-Jul) characteristics.

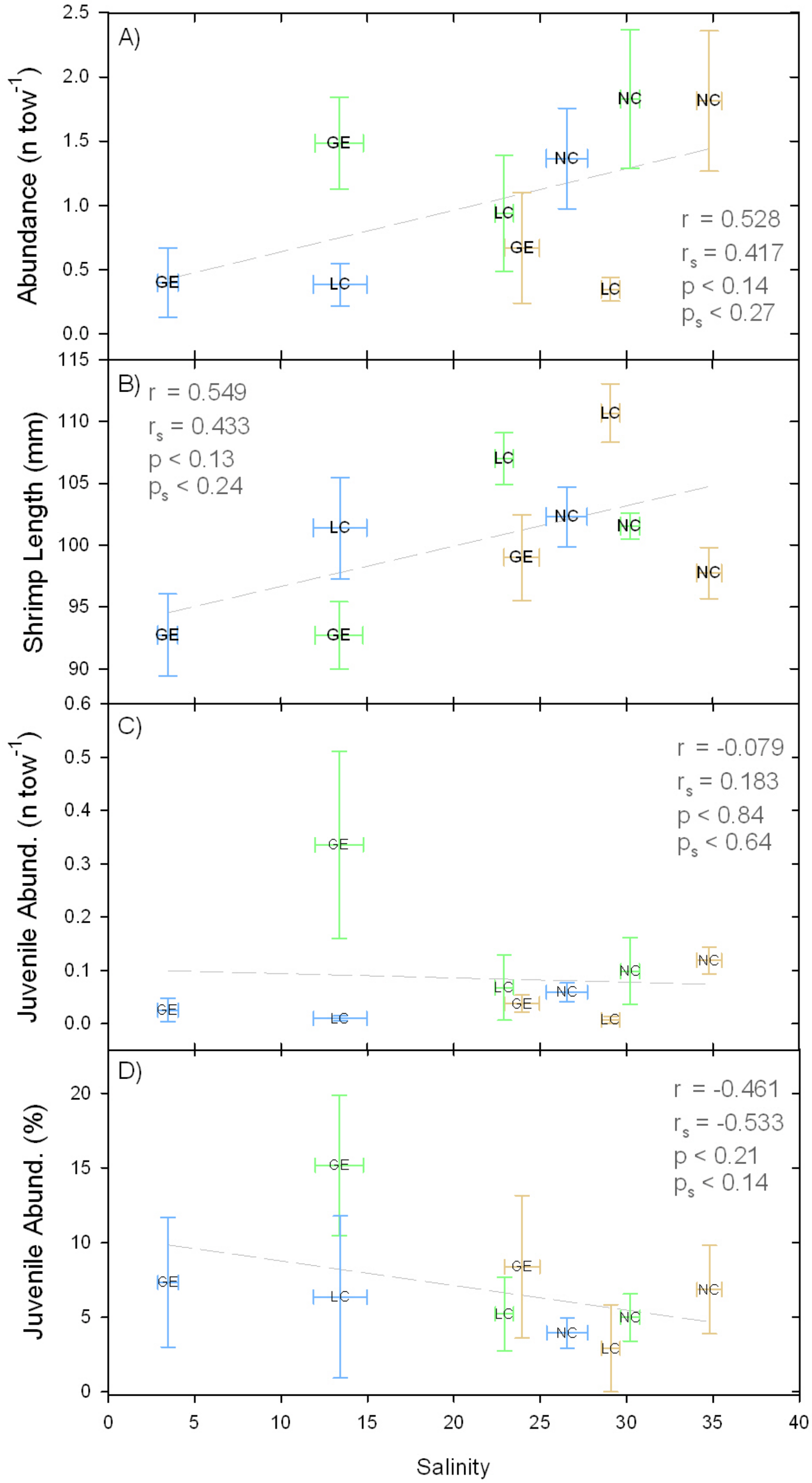

Figure 70. Mean brown shrimp characteristics (± standard error) of each estuary under each condition versus mean salinity (Method Two).

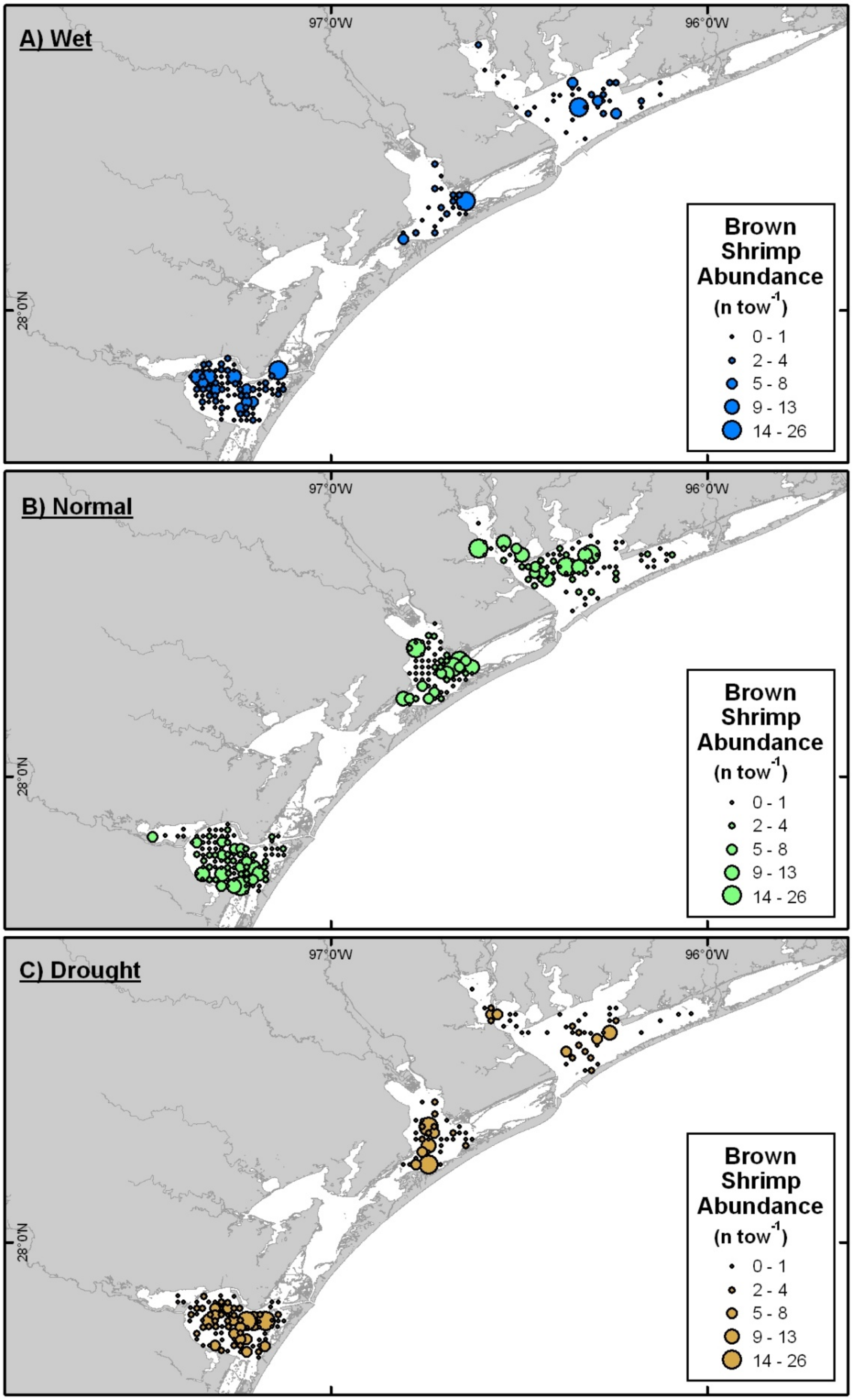

Figure 71. Spatial distribution of brown shrimp abundances in drought, normal and wet years (Method Two).

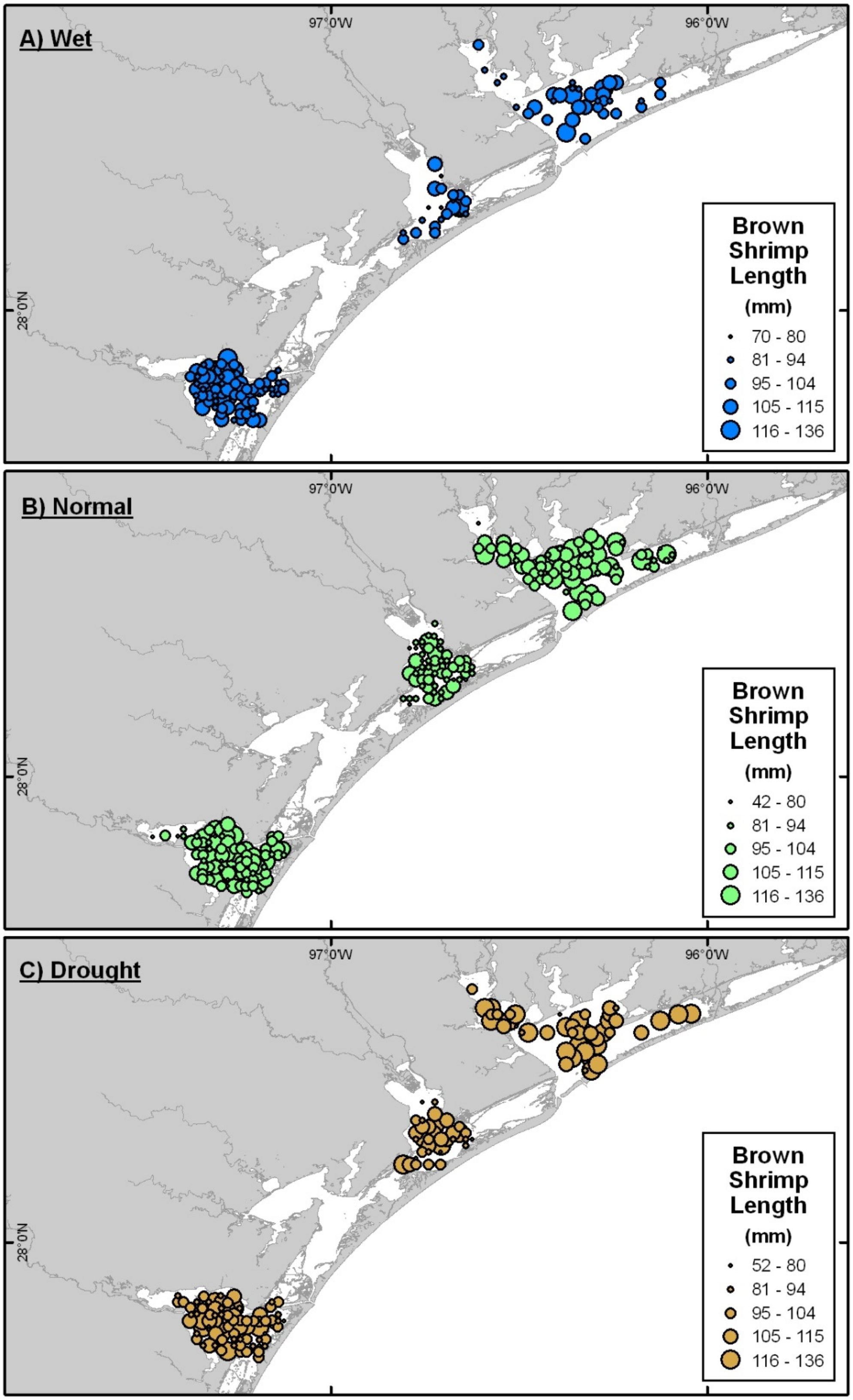

Figure 72. Spatial distribution of brown shrimp lengths in drought, normal and wet years (Method Two).

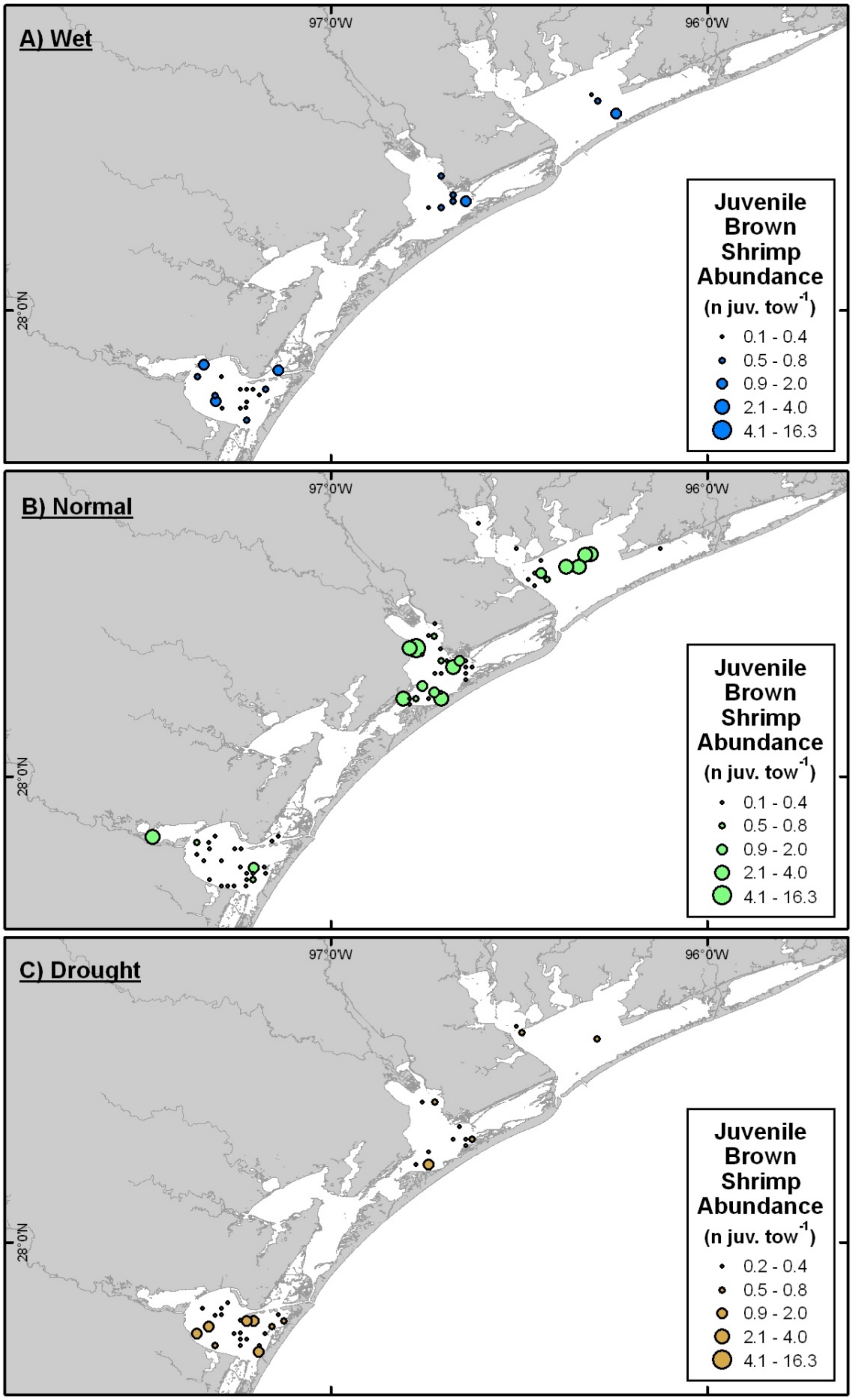

Figure 73. Spatial distribution of juvenile brown shrimp (< 75 mm (3")) in drought, normal and wet years (Method Two).

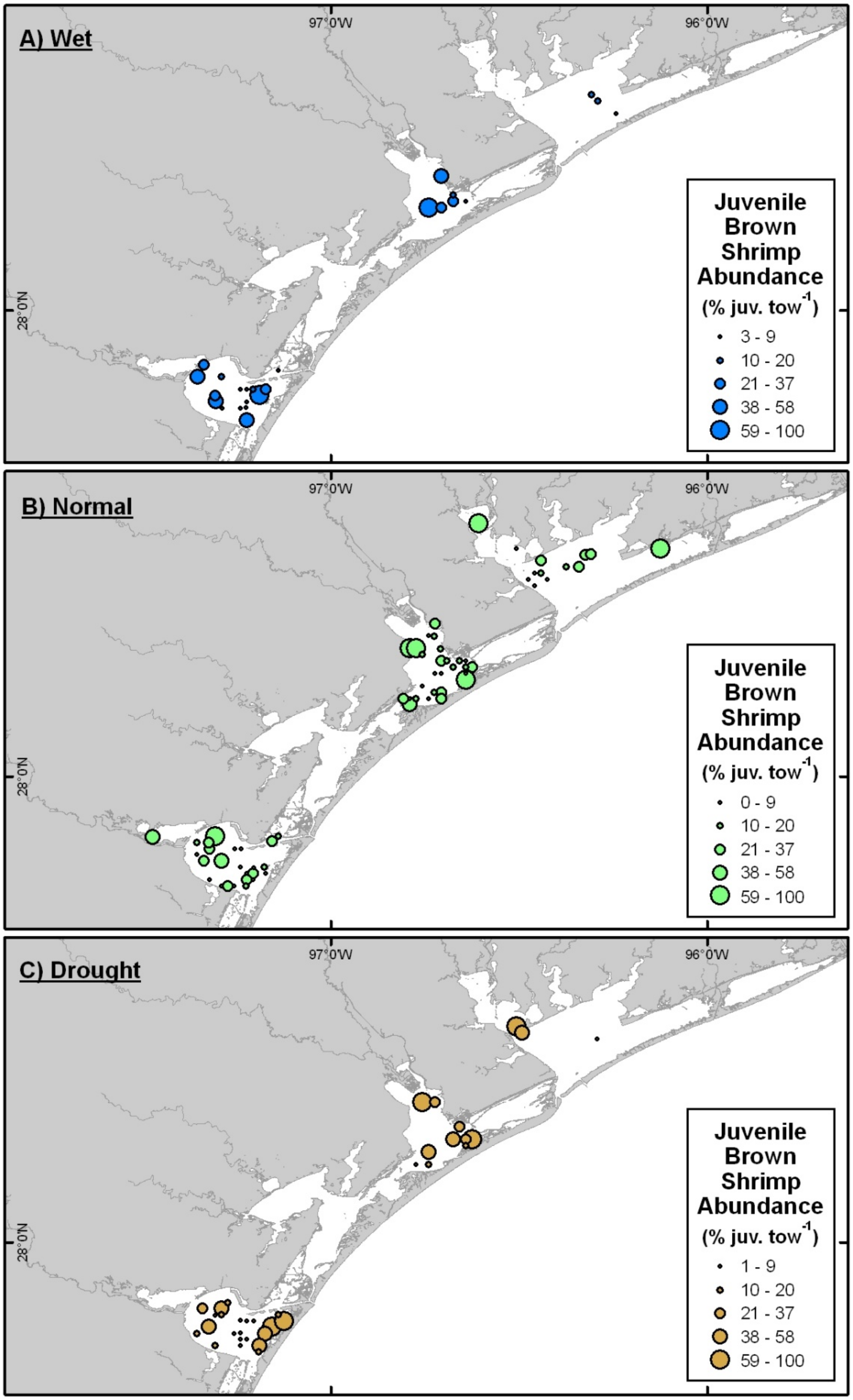

Figure 74. Spatial distribution of percentages of juvenile white shrimp (< 75 mm (3”)) in drought, normal and wet years (Method Two).