# MACROBENTHOS MONITORING IN MID-COASTAL ESTUARIES - 2012

by

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# INTRODUCTION

Since the early 1970's, Texas Water Development Board (TWDB) sponsored freshwater inflow studies focused on the major bay systems of the Texas coast. These bay systems, which are influenced primarily by river inflow and exchange with the Gulf of Mexico, are now subject to greater scrutiny because of recent legislative changes. In recognition of the importance that the ecological soundness of our riverine, bay, estuary, and riparian areas has on the economy, health, and well-being of our state, the 80th Texas Legislature enacted Senate Bill 3 in 2007, which calls for creation of Basin and Bay Area Expert Science Teams (BBEST) to establish environmental flow recommendations for bay and estuary inflows, and Basin and Bay Area Stakeholder Committees (BBASC) charged with balancing environmental needs with the need for water for human uses. In the past, the State methodology depended on modeling inflow effects on fisheries harvest in Texas estuaries (Longely 1994). SB 3 however, requires an ecosystem management approach to provide environmental flows “adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.” Thus, BBEST and BBASC groups will need information on freshwater inflow effects on water quality and biological indicator communities (Montagna et al. 2009, 2010).

Since 1986, researchers led by Dr. Montagna have been studying the effect of freshwater inflow on benthic communities and productivity (Kalke and Montagna 1991; Kim and Montagna 2009, 2012; Montagna 1989, 1999, 2000; Montagna et al. 2007; Montagna and Kalke 1992, 1995; Montagna and Li 1996, 2011; Montagna and Palmer 2009, 2010; Montagna and Yoon 1991; Pollack et al. 2009, 2011). These studies have demonstrated that long-term hydrological cycles affect water quality and regulate benthic abundance, productivity, diversity, and community structure. Benthos are excellent bioindicators of environmental effects because they are very abundant and diverse, are sessile, and long-lived relative to plankton (Montagna et al. 2010). Therefore, benthos are good biological indicators of freshwater inflow effects because they integrate changes in temporal dynamics of ecosystem factors over long time scales and large spatial scales.

The benthic studies performed as part of the long-term monitoring of benthos (i.e., those listed above) have elucidated some general trends. The Texas estuaries lie in a climatic gradient where those in the northeast receive more rainfall than those in the southwest. Consequently, freshwater inflow and nutrient loading decreases along the climatic gradient and salinity increases. In addition there is year-to-year variation in rain and inflow that results in wet and dry years. This combination of the climatic gradient and temporal variability drives variability in estuarine communities and secondary production. Among Texas estuaries, increased salinity (and thus decreased inflow) benefits deposit feeders (increased abundance and species richness), while suspension feeders are reduced (decreased abundance and species richness); thus there is a decrease in functional diversity when salinity is increased because of loss of a trophic guild. Within estuaries, the abundance and biomass of the upstream benthic community is reduced by reduced inflow, whereas, the downstream community increases in abundance and biomass with reduced inflow and higher salinities. This is because lower salinity regimes are required to support food production for suspension feeders, and polyhaline deposit feeding species increase during marine conditions. Overall, these studies demonstrate that freshwater inflow is important in to maintain secondary productivity and functional diversity in estuaries, which is required to maintain estuarine health and sustainability (Montagna et al. 2013).

The ultimate goal of the long-term benthic data collection is to use the data to assess ecosystem health as it relates to change in freshwater inflow by assessing benthic habitat health, and benthic productivity. However, inflow itself does not affect ecosystem dynamics; it is the change in estuarine condition primarily salinity, nutrients, and chlorophyll, which drives change in biological resources (SAC 2009). Thus, the goal is to relate changes in water column dynamics with change in benthic dynamics. The benthic data set has proven useful to date. For example, it has been used to model productivity based on seven years (1988 – 1995) of data in four Texas estuaries: Lavaca-Colorado, Guadalupe, Nueces, and Laguna Madre (Montagna and Li 1996, 2010). The model was used to support inflow criteria development for Matagorda Bay in the Lavaca-Colorado Estuary (Kim and Montagna 2009). Recently, the adjusted model was rerun on 20 years (1988 - 2008) of benthic and water column data and it was shown that salinity and nutrient changes (which are caused by inflow changes) drives benthic productivity and functional diversity (Kim and Montagna 2010; 2012). In order to perform similar analyses and provide an understanding of the long-term ecosystem dynamics the San Antonio Bay system, data is needed, and the data collected during this study will support these efforts.

# METHODS

Sampling was performed in three estuaries in the Texas mid-coastal zone: Nueces, Guadalupe, and Lavaca-Colorado Estuaries (Figure 1). The study area is ideal to answer questions related to altered hydrology and climate variability occurring temporal scales (e.g., seasonal, annual, multi-annual), and spatial scales of inflow along climatic (among estuary) and estuarine (within estuary) gradients (Figure 1).

Stations were located in primary bays closer to the Gulf of Mexico exchange point, and in secondary bays closer to the freshwater inflow sources (Table 1). Four stations were sampled for macrofauna and water quality in the Guadalupe Estuary, six in the Lavaca-Colorado Estuary, and five in the Nueces Estuary.

Water column and sediment samples were collected at all stations in all estuaries. However, benthic samples were analyzed only in the Guadalupe Estuary and the benthic samples from the Nueces and Lavaca-Colorado estuaries were archived for future analysis. Only the benthos from the Guadalupe Estuary are described and discussed in this report.

Sampling occurred seven times: October 2011; January, April, July and October 2012; and January and April 2013.

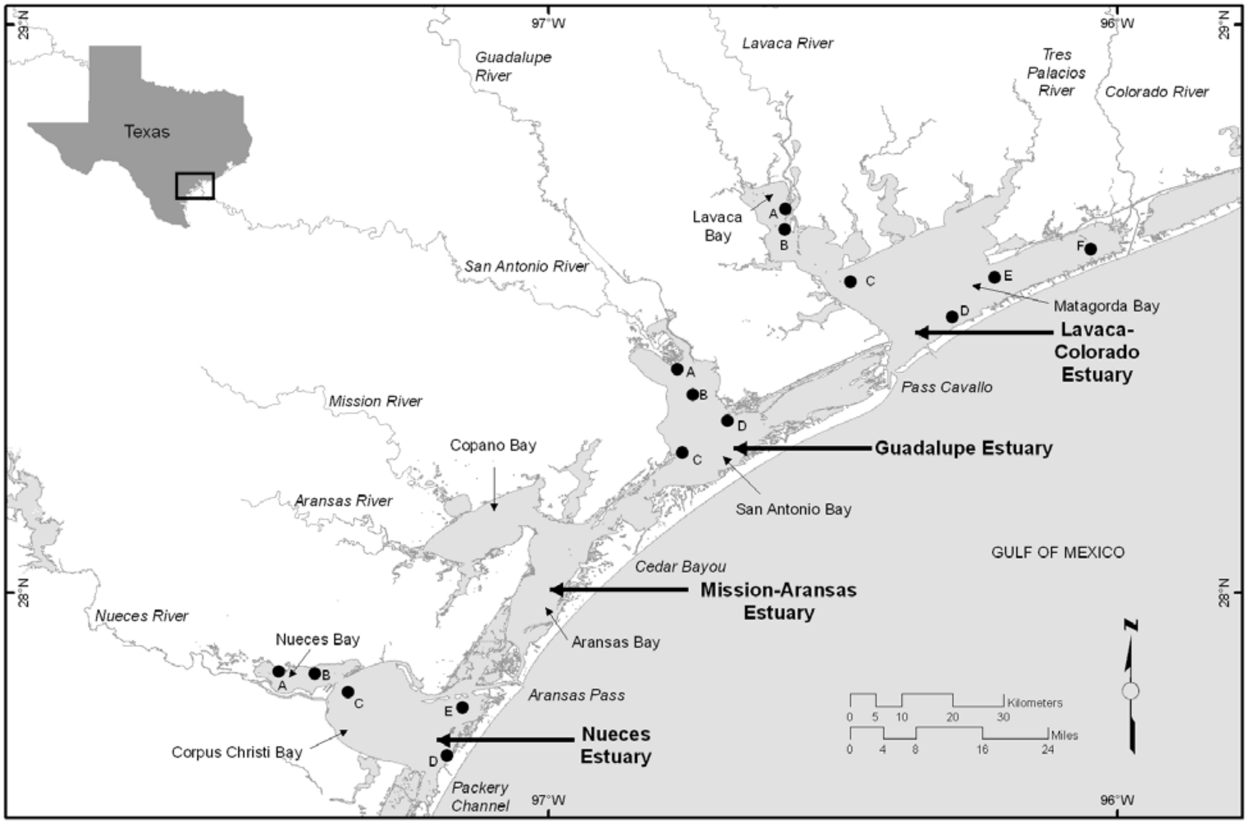

**Figure 1. The three Texas Coastal Bend estuaries sampled. Station locations are along a climatic (among estuaries) and estuarine (within estuaries) gradients. Mission-Aransas estuary not** sampled.

**Table 1. Locations of stations within the Guadalupe (GE), Lavaca-Colorado (LC), and Nueces (NC) estuaries.**

| Estuary | Bay | Station | Latitude | Longitude |
|---|---|---|---|---|
| GE | San Antonio | A | 28.39352 | -96.77240 |
| GE | San Antonio | B | 28.34777 | -96.74573 |
| GE | San Antonio | C | 28.24618 | -96.76488 |
| GE | San Antonio | D | 28.30210 | -96.68435 |
| LC | Lavaca | A | 28.67467 | -96.58268 |
| LC | Lavaca | B | 28.63868 | -96.58437 |
| LC | Matagorda | C | 28.54672 | -96.46894 |
| LC | Matagorda | D | 28.48502 | -96.28972 |
| LC | Matagorda | E | 28.55450 | -96.21550 |
| LC | Matagorda | F | 28.60463 | -96.04600 |
| LC | Matagorda | 15 | 28.65307 | -96.59498 |
| NC | Nueces | A | 27.86069 | -97.47358 |
| NC | Nueces | B | 27.85708 | -97.41025 |
| NC | Corpus Christi | C | 27.82533 | -97.35213 |
| NC | Corpus Christi | D | 27.71280 | -97.17872 |
| NC | Corpus Christi | E | 27.79722 | -97.15083 |

### *Water Quality*

Physical water quality measurements in addition to chlorophyll and nutrients were sampled in duplicate just beneath the surface and at the bottom of the water column at all stations on every sampling date.

Hydrographic measurements were made at each station with a YSI 6600 multi parameter instrument. The following parameters were read from the digital display unit (accuracy and units): temperature (± 0.15 °C), pH (± 0.1 units), dissolved ox4ygen (± 0.2 mg $l^{-1}$ ), depth (± 1 m), and salinity (ppt). Salinity is automatically corrected to 25 °C.

Chlorophyll samples were filtered onto glass fiber filters and placed on ice (<4.0 °C). Chlorophyll is extracted overnight and read fluorometrically on a Turner Model 10-AU using the non-acidification technique (Welschmeyer, 1994; EPA method 445.0).

Nutrient samples were filtered to remove biological activity (0.45 µm polycarbonate filters) and placed on ice (<0.4 °C).Water samples were analyzed at the Harte Research Institute using a OAI Flow-4 autoanalyzer with computer controlled sample selection and peak processing.Chemistries are as specified by the manufacturer and have ranges as follows: nitrate+nitrate (0.03-5.0 µM; Quikchem method 31-107-04-1-A), silicate (0.03-5.0 µM; Quikchem method 31-114-27-1-B), ammonium (0.1-10 µM; Quikchem method 31-107-06-5-A) and phosphate (0.03-2.0 µM; Quikchem method 31-115-01-3-A.

Multivariate analyses were used to analyze how the physical-chemical environmental changes over time.The water column structure was each analyzed using Principal Component Analysis (PCA).PCA reduces multiple environmental variables into component scores, which describe the variance in order to discover the underlying structure in a data set (Clarke and Warwick 2001).In this study, only the first two principal components were used.

### *Macrofauna*

Sediment samples were collected using cores deployed from small boats.The position of all stations is established with a Global Positioning System (GPS) with an accuracy of ±3 m.Macrofauna were sampled with a 6.7-cm diameter core tube (35.4 $cm^2$ area).The cores were sectioned at 0-3 cm and 3-10 cm depths to examine vertical distribution of macrofauna. Three replicates are taken per station. Organisms are enumerated to the lowest taxonomic level possible, and biomass is determined for higher taxonomic groupings.

Community structure of macrofauna species was analyzed by non-metric multidmensional scaling (MDS) and cluster analysis using a Bray-Curtis similarity matrix (Clarke 1993, Clarke and Warwick 2001). Prior to analysis, the data was $\log_{10}$ transformed. Log transformations improve the performance of the analysis by decreasing the weight of the dominant species. MDS was used to compare numbers of individuals of each species for each station-date combination. The distance between station-date combinations can be related to community similarities or differences between different stations. Cluster analysis determines how much each station-date combination resembles each other based on species abundances. The percent resemblance can then displayed on the MDS plot to elucidate grouping of station-date combinations. The group average cluster mode was used for the cluster analysis.

# RESULTS

*Guadalupe Estuary During the Study Period*

Principal Components Analysis explained 73 % of the variation within the water quality data set (Figure 2). Principal Component (PC) 1 explained 43 % of the variation while PC2 explained 30 % of the variation. PC1 represents temporal changes in water quality and represents seasonal changes in water quality with high temperatures being inversely proportional to low dissolved oxygen concentrations (Figure 2A and 2C). Along the PC1 axis, high temperature is correlated with chlorophyll, phosphate, and silicate concentrations (Figure 2A). PC2 represents an inflow gradient because the lowest salinity values are inversely correlated to the highest ammonia and Nitrite+Nitrate (NOx) concentrations, which occur in Stations A and B nearest the Guadalupe River mouth (Figure 2C).

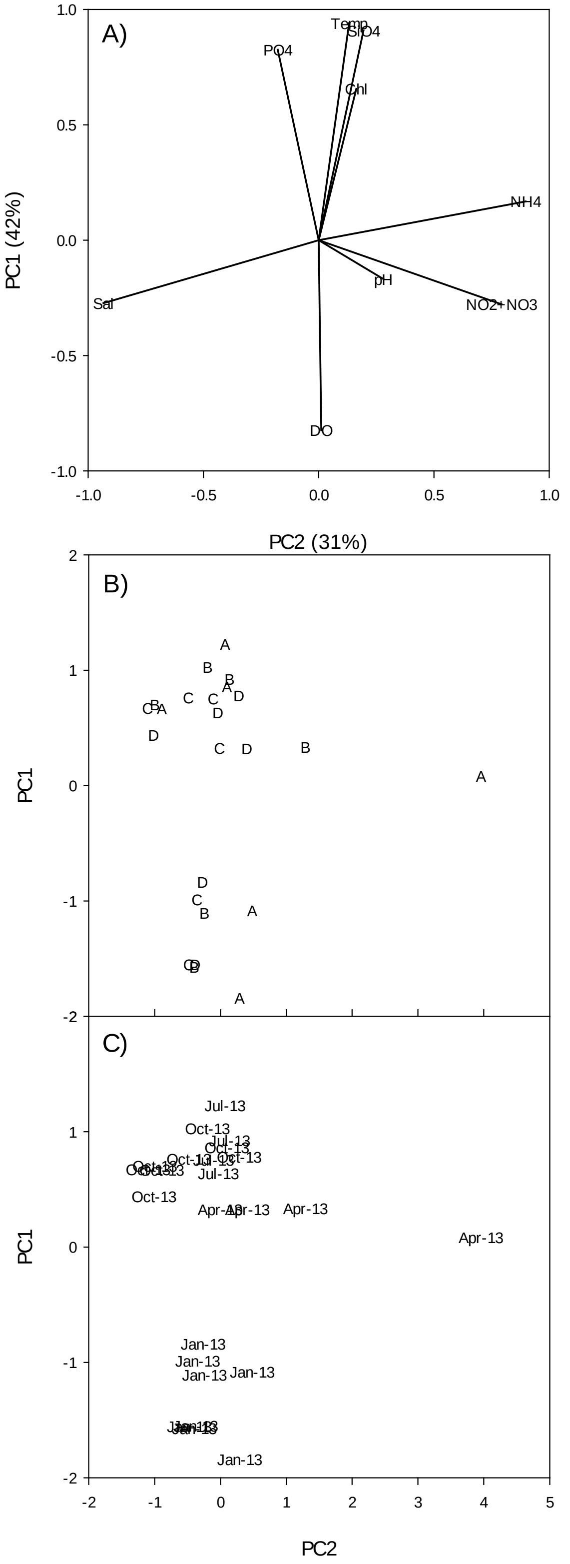

**Figure 1. Principal Components Analysis of water quality. Variable loading plot (A) and station scores labeled by station (B) and month (C) from October 2011 through to January 2013.**

The lowest average salinity and highest average concentrations of all nutrients (silicate, phosphate, ammonia, and nitrate+nitrite), and chlorophyll concentrations occur at Stations A and B, and this is an indicator of river flow from the Guadalupe River into San Antonio Bay (Table 2).Ammonium concentrations are below detection limits for many samples, so the overall average is only near 1 umol/L. Mean chlorophyll concentrations are the highest at stations A and B, and decrease along the salinity gradient from station C to Station D. Mean dissolved oxygen concentrations are also highest at station A, and decline along the salinity gradient.

**Table 2. Overall (for both top and bottom and over the sampling period) mean water quality values for each station. Standard deviation for all samples at each station are in parentheses. Abbreviations: NH4=ammonium, NOx=nitrate+nitrite, PO4=phosphate, SiO4=silicate, and Chl=chlorophyll**

| | Station (number of samples) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable (units)** | **A** | **(27)** | **B** | **(28)** | **C** | **(24)** | **D** | **(33)** |
| DO (mg/l) | 9.59 | (3.37) | 9.30 | (2.17) | 8.13 | (1.59) | 7.85 | (0.79) |
| Salinity (psu) | 17.84 | (9.36) | 22.64 | (8.65) | 27.81 | (5.97) | 26.06 | (7.39) |
| Temperature (C) | 22.19 | (5.61) | 21.71 | (5.88) | 21.78 | (6.14) | 21.80 | (5.71) |
| NH4 (umol/L) | 1.89 | (2.34) | 0.87 | (0.81) | 0.59 | (0.36) | 0.98 | (0.87) |
| NOx (umol/L) | 13.56 | (19.27) | 1.36 | (1.70) | 0.23 | (0.35) | 0.34 | (0.63) |
| P04 (umol/L) | 1.63 | (1.03) | 1.22 | (0.95) | 1.06 | (0.60) | 1.05 | (0.75) |
| Si04 (umol/L) | 133.06 | (90.89) | 111.11 | (71.61) | 76.72 | (49.83) | 82.25 | (54.79) |
| Chl (mg/l) | 16.12 | (6.31) | 16.28 | (9.95) | 10.39 | (5.64) | 8.73 | (6.29) |
| pH | 8.37 | (0.17) | 8.35 | (0.17) | 8.22 | (0.12) | 8.18 | (0.15) |

The sampling year was characterized by extremely dry conditions in the fall of 2011, and periodic flows from January 2012 to May 2012, followed by decreasing and more discontinuous inflows from June 2012 to December 2012 (Figure 3). The initial fall was a very dry period overall, which is reflected by high salinities (Figure 3). Then salinities dropped to near zero in winter 2012, and continued to rise throughout the rest of the year. Chlorophyll dropped in winter 2012 and then rose through October 2013, when it dropped again. Nutrient behavior was complex, for example silicate first declines from October 2011 to near zero in January 2012 and then rises. Nitrate+Nitrite increases toward the end of the study period from October 2012 to January 2013.

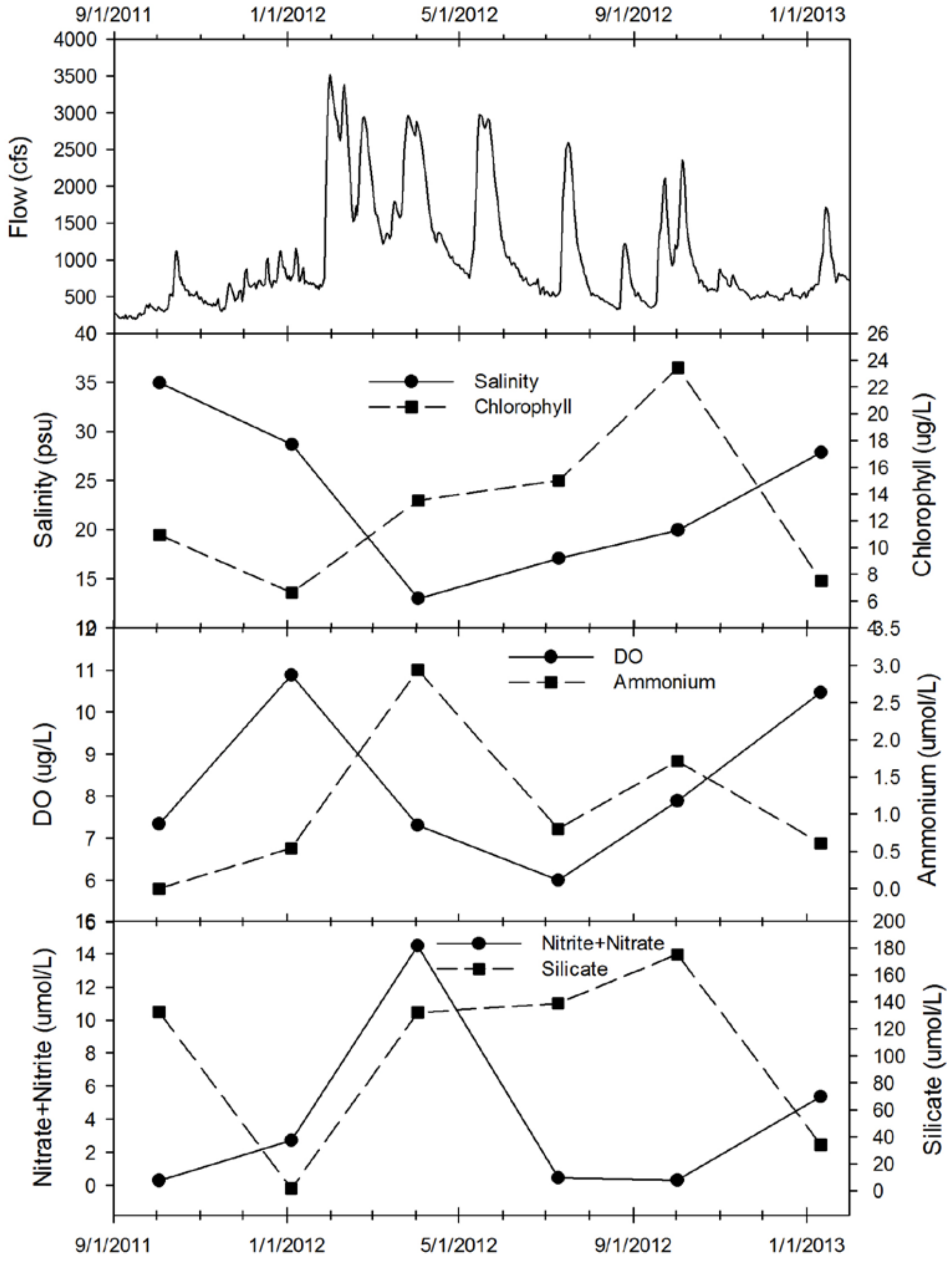

**Figure 3. Flow and water quality during sampling year. Inflow at gage USGS 08188800 Guadalupe River near Tivoli, TX and mean estuary-wide water quality parameters during sampling periods.**

The four stations (A through D) in San Antonio Bay lie along a gradient from river to marine end at the Gulf Intracoastal Waterway (Figure 1) and that is reflected in the differences in salinity among the stations as well where salinity increases from A to B, B to C, and C to D (Figure 4A). However, analysis of variance and Tukey post hoc multiple comparison tests showed that the stations were all significantly different for salinity (Table 3).

Station A, closest to the river, and station D (closest to Gulf influence) had the highest macrofauna abundance (Figure 4B), biomass (Figure 4C) and diversity (Figure 4D). Stations and A and D were not significantly different for abundance, but these were different from stations B and C, which were the same (Table 3). Abundance, biomass, and diversity were similar, and always low, in stations B and C. During the dry fall 2011, abundance, biomass, and diversity were low and began to rise when salinities decreased in 2012. When salinity increased during the drier spring and summer, abundance, biomass, and diversity decreased at all stations (Figure 4). However, there was a recovery of abundance, biomass, and diversity in January 2013. There was an unusual bloom of 15 large polychaetes that weighed 658 mg (that extends to 186.5 $g/m^2$) in January 2013, but only in one replicate that was in the 3 – 10 cm deep section.

**Table 3. Analysis of salinity, abundance, biomass, and diversity in the Guadalupe estuary during the study period. A 2-way analysis of variance (ANOVA) and Tukey multiple comparisons test for station (STA) differences where letter group and lines designate non-significance.**

**Salinity(psu)**

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Date | 5 | 2655.06 | 531.011757 | 233.63 | <.0001 |
| Station | 3 | 749.654 | 249.884569 | 109.94 | <.0001 |
| Date*Station | 15 | 209.115 | 13.94101 | 6.13 | <.0001 |
| Error | 24 | 54.5488 | 2.272865 | | |
| Corrected Total | 47 | 3668.38 | | | |

**Tukey Test Group**

| | Mean | STA |
|---|---|---|
| A | 27.00 | C |
| B | 26.23 | D |
| C | 22.23 | B |
| D | 17.72 | A |

**Abundance (nm2)**

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Date | 5 | 3.50E+09 | 7.00E+08 | 36.34 | <.0001 |
| Station | 3 | 4.58E+09 | 1.53E+09 | 79.35 | <.0001 |
| Date*Station | 15 | 1.63E+09 | 1.09E+08 | 5.64 | <.0001 |
| Error | 48 | 9.24E+08 | 1.93E+07 | | |
| Corrected Total | 71 | 1.06E+10 | | | |

**Tukey Test Group**

| | Mean | STA |
|---|---|---|
| A | 23,763 | A |
| A | | |
| A | 20,091 | D |
| B | 7,186 | B |
| B | | |
| B | 5,295 | C |

**Biomass (gm2)**

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Date | 5 | 5787 | 1157 | 2.22 | 0.0675 |
| Station | 3 | 5601 | 1867 | 3.58 | 0.0204 |
| Date*Station | 15 | 5240 | 349 | 0.67 | 0.7998 |
| Error | 48 | 25024 | 521 | | |
| Corrected Total | 71 | 41652 | | | |

**Tukey Test Group**

| | | Mean | STA |
|---|---|---|---|
| | A | 23.39 | D |
| | A | | |
| B | A | 9.11 | A |
| B | | | |
| B | | 2.48 | C |
| B | | | |
| B | | 1.15 | B |

**Diversity (S)**

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Date | 5 | 455 | 91 | 17.34 | <.0001 |
| Station | 3 | 1745 | 582 | 110.79 | <.0001 |
| Date*Station | 15 | 153 | 10 | 1.94 | 0.0425 |
| Error | 48 | 252 | 5 | | |
| Corrected Total | 71 | 2605 | | | |

**Tukey Test Group**

| | Mean | STA |
|---|---|---|
| A | 16.22 | D |
| B | 8.00 | A |
| C | 4.28 | B |
| C | | |
| C | 4.06 | C |

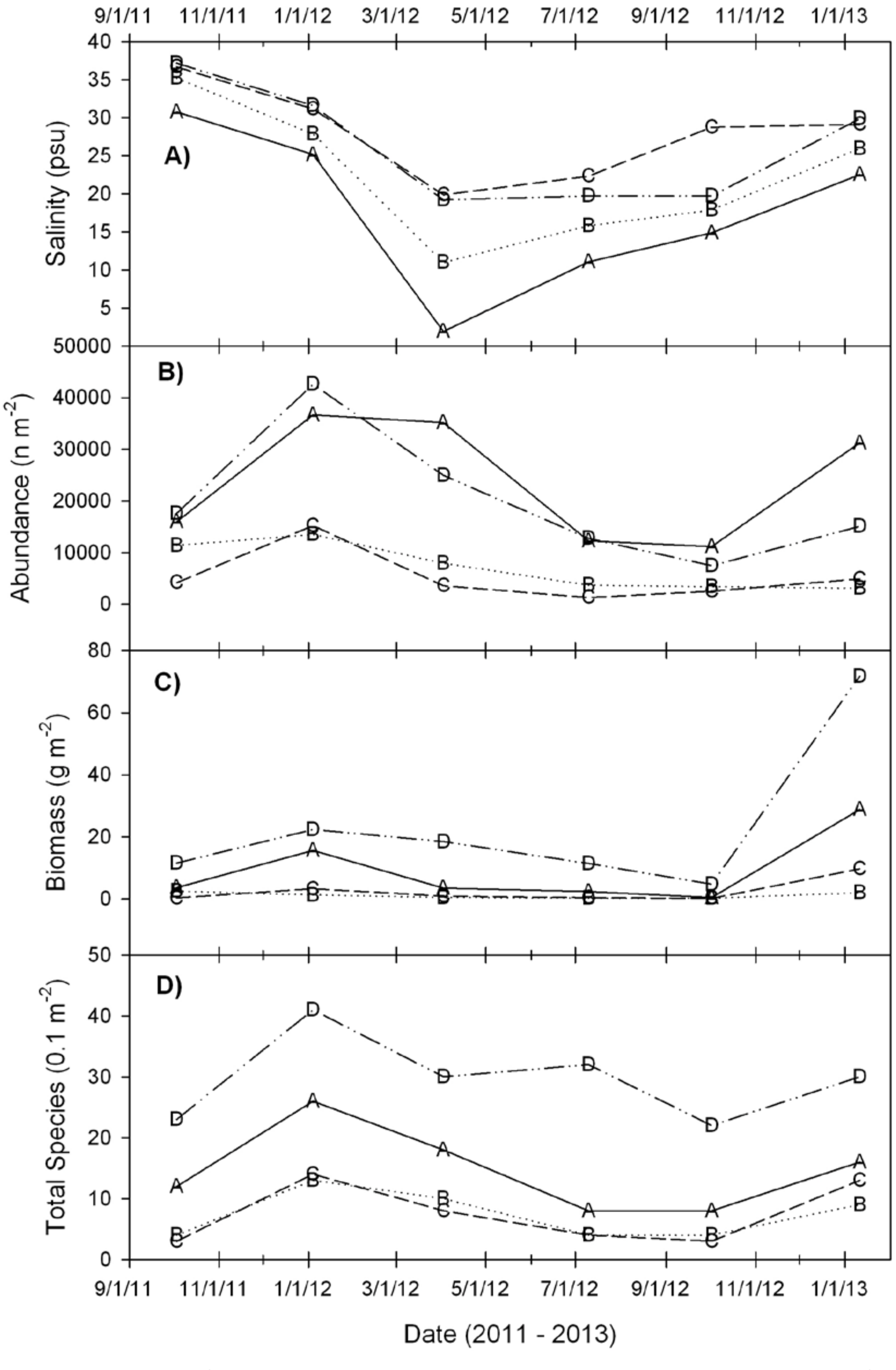

**Figure 4. Macrofauna characteristics by station over the sampling period. Subfigures: A) Salinity, B) Abundance, C) Biomass, and D) Diversity.**

There were a total of 84 species found over the year (Table 4). The capitellid polychaete *Mediomastus ambiseta* was the most abundant species overall and was especially dominant at station A. Overall, *M. ambiseta* made up about 56 % of the total number of organisms found. Another polychaete *Streblospio benedicti* was the second most dominant species and it made up about 7% of the organisms. Two more polychaete worms, *Axiothella* and *Mediomastus californiensis* made up about 6% or the community each. The bivalve *Mulinia lateralis* was the fifth most abundant species, but made up only about 4% of organisms found. In contrast, *M. lateralis* made up 20% of the organisms during a wetter period in 2009-2010 (Montagna and Palmer 2011). Together the seven most dominant species made up 80% of all organisms found. Only 13 species occur at all four stations. The high diversity found in San Antonio Bay is made up of rare organisms or organisms found primarily in the marine parts of the bay, especially stations C and D. For example 16 species were found only once in all the samples, and 4 species were found only twice. Together this is 24% of all species found.

**Table 4. Species abundance and occurrence at stations in Guadalupe Estuary. Average abundance (n $m^{-2}$) over the period October 2011 to October 2012 period.**

| | Station | | | | | Mean % |
|---|---|---|---|---|---|---|
| **Species Name** | **A** | **B** | **C** | **D** | **Mean** | **of Total** |
| Mediomastus ambiseta | 18,090 | 5,011 | 2,821 | 5,720 | 7,910 | 56.15% |
| Streblospio benedicti | 1,812 | 1,087 | 378 | 552 | 957 | 6.80% |
| Mediomastus californiensis | 47 | 47 | 32 | 3,152 | 819 | 5.82% |
| Axiothella sp. A | - | 32 | 32 | 2,836 | 725 | 5.15% |
| Mulinia lateralis | 142 | 378 | 1,229 | 252 | 500 | 3.55% |
| Clymenella torquata | - | - | - | 930 | 232 | 1.65% |
| Cossura delta | - | 79 | 32 | 536 | 162 | 1.15% |
| Polydora caulleryi | - | - | - | 630 | 158 | 1.12% |
| Molgula manhattensis | 552 | - | - | 47 | 150 | 1.06% |
| Glycinde solitaria | 173 | 79 | 173 | 142 | 142 | 1.01% |
| Nemertea (unidentified) | 110 | 32 | 63 | 362 | 142 | 1.01% |
| Acteocina canaliculata | 268 | 63 | 32 | 173 | 134 | 0.95% |
| Polydora ligni | 504 | - | - | - | 126 | 0.89% |
| Aligena texasiana | - | - | - | 473 | 118 | 0.84% |
| Texidina sphinctostoma | 441 | - | - | - | 110 | 0.78% |
| Euclymene sp. B | - | - | - | 441 | 110 | 0.78% |
| Gyptis vittata | 16 | 16 | 32 | 347 | 102 | 0.73% |
| Hemicyclops sp. | 32 | - | - | 362 | 98 | 0.70% |
| Paraprionospio pinnata | 16 | 32 | 95 | 252 | 98 | 0.70% |
| Cyclaspis varians | 158 | 95 | - | 95 | 87 | 0.62% |
| Haploscoloplos foliosus | 16 | 32 | 126 | 63 | 59 | 0.42% |
| Parandalia ocularis | 79 | - | - | 142 | 55 | 0.39% |
| Mysella planulata | 16 | - | - | 205 | 55 | 0.39% |
| Melinna maculata | - | - | - | 189 | 47 | 0.34% |
| Lyonsia hyalina floridana | 110 | 16 | 32 | 32 | 47 | 0.34% |
| Capitella capitata | 158 | - | - | 16 | 43 | 0.31% |
| Corophium louisianum | 95 | - | - | 63 | 39 | 0.28% |
| Diopatra cuprea | 79 | - | - | 79 | 39 | 0.28% |
| Branchioasychis americana | - | - | - | 158 | 39 | 0.28% |
| Tellina texana | 32 | 32 | 16 | 63 | 35 | 0.25% |
| Eulimastoma sp. | 16 | 63 | 16 | 47 | 35 | 0.25% |
| Notomastus latericeus | - | - | - | 142 | 35 | 0.25% |
| Turbellaria (unidentified) | 16 | - | 32 | 79 | 32 | 0.22% |
| Caprellidae (unidentified) | 126 | - | - | - | 32 | 0.22% |
| Periploma margaritaceum | - | - | - | 126 | 32 | 0.22% |

| Species Name | Station A | B | C | D | Mean | Mean % of Total |
|---|---|---|---|---|---|---|
| Monoculodes sp. | 32 | 16 | - | 47 | 24 | 0.17% |
| Nuculana acuta | - | 16 | 16 | 63 | 24 | 0.17% |
| Pandora trilineata | - | - | 32 | 63 | 24 | 0.17% |
| Amphiodia atra | - | - | 16 | 79 | 24 | 0.17% |
| Ceratonereis irritabilis | - | - | - | 95 | 24 | 0.17% |
| Turbonilla sp. | - | - | - | 95 | 24 | 0.17% |
| Ampelisca abdita | 63 | - | - | 16 | 20 | 0.14% |
| Rictaxis punctostriatus | 47 | - | - | 32 | 20 | 0.14% |
| Eteone heteropoda | 32 | - | - | 47 | 20 | 0.14% |
| Microprotopus sp. | - | 32 | 32 | 16 | 20 | 0.14% |
| Listriella barnardi | - | - | - | 79 | 20 | 0.14% |
| Texidina barretti | - | - | - | 79 | 20 | 0.14% |
| Paleanotus heteroseta | - | - | - | 79 | 20 | 0.14% |
| Batea catharinensis | 63 | - | - | - | 16 | 0.11% |
| Crepidula plana | 63 | - | - | - | 16 | 0.11% |
| Pectinaria gouldii | 63 | - | - | - | 16 | 0.11% |
| Lumbrineris parvapedata | - | - | - | 63 | 16 | 0.11% |
| Neanthes succinea | 47 | - | - | - | 12 | 0.08% |
| Oligochaeta (unidentified) | 47 | - | - | - | 12 | 0.08% |
| Scoloplos texana | 32 | 16 | - | - | 12 | 0.08% |
| Hobsonia florida | 32 | - | 16 | - | 12 | 0.08% |
| Polydora socialis | 32 | - | - | 16 | 12 | 0.08% |
| Armandia maculata | 16 | - | - | 32 | 12 | 0.08% |
| Cyclopoida (commensal) | 16 | - | - | 32 | 12 | 0.08% |
| Spiochaetopterus costarum | 16 | - | - | 32 | 12 | 0.08% |
| Hauchiella sp. | - | - | - | 47 | 12 | 0.08% |
| Neosamytha gracilis | - | - | - | 47 | 12 | 0.08% |
| Vitrinella floridana | - | - | - | 47 | 12 | 0.08% |
| Xenanthura brevitelson | - | - | - | 47 | 12 | 0.08% |
| Haploscoloplos fragilis | - | - | 16 | 16 | 8 | 0.06% |
| Apoprionospio pygmaea | - | - | - | 32 | 8 | 0.06% |
| Megalomma bioculatum | - | - | - | 32 | 8 | 0.06% |
| Scolelepis texana | - | - | - | 32 | 8 | 0.06% |
| Chironomidae (larvae) | 16 | - | - | - | 4 | 0.03% |
| Edotea montosa | 16 | - | - | - | 4 | 0.03% |
| Grandidierella bonnieroides | 16 | - | - | - | 4 | 0.03% |
| Melita nitida | 16 | - | - | - | 4 | 0.03% |
| Oxyurostylis sp. | 16 | - | - | - | 4 | 0.03% |
| Pseudodiaptomus pelagicus | - | 16 | - | - | 4 | 0.03% |
| Leucon sp. | - | - | 16 | - | 4 | 0.03% |
| Malmgreniella taylori | - | - | 16 | - | 4 | 0.03% |
| Ampharetidae (unidentified) | - | - | - | 16 | 4 | 0.03% |
| Amphilochus sp. | - | - | - | 16 | 4 | 0.03% |
| Brania furcelligera | - | - | - | 16 | 4 | 0.03% |
| Chione cancellata | - | - | - | 16 | 4 | 0.03% |
| Cymadusa compta | - | - | - | 16 | 4 | 0.03% |
| Ninoe nigripes | - | - | - | 16 | 4 | 0.03% |
| Schizocardium sp. | - | - | - | 16 | 4 | 0.03% |
| Sigambra bassi | - | - | - | 16 | 4 | 0.03% |
| Total | 23,778 | 7,186 | 5,295 | 20,091 | 14,087 | 100.00% |

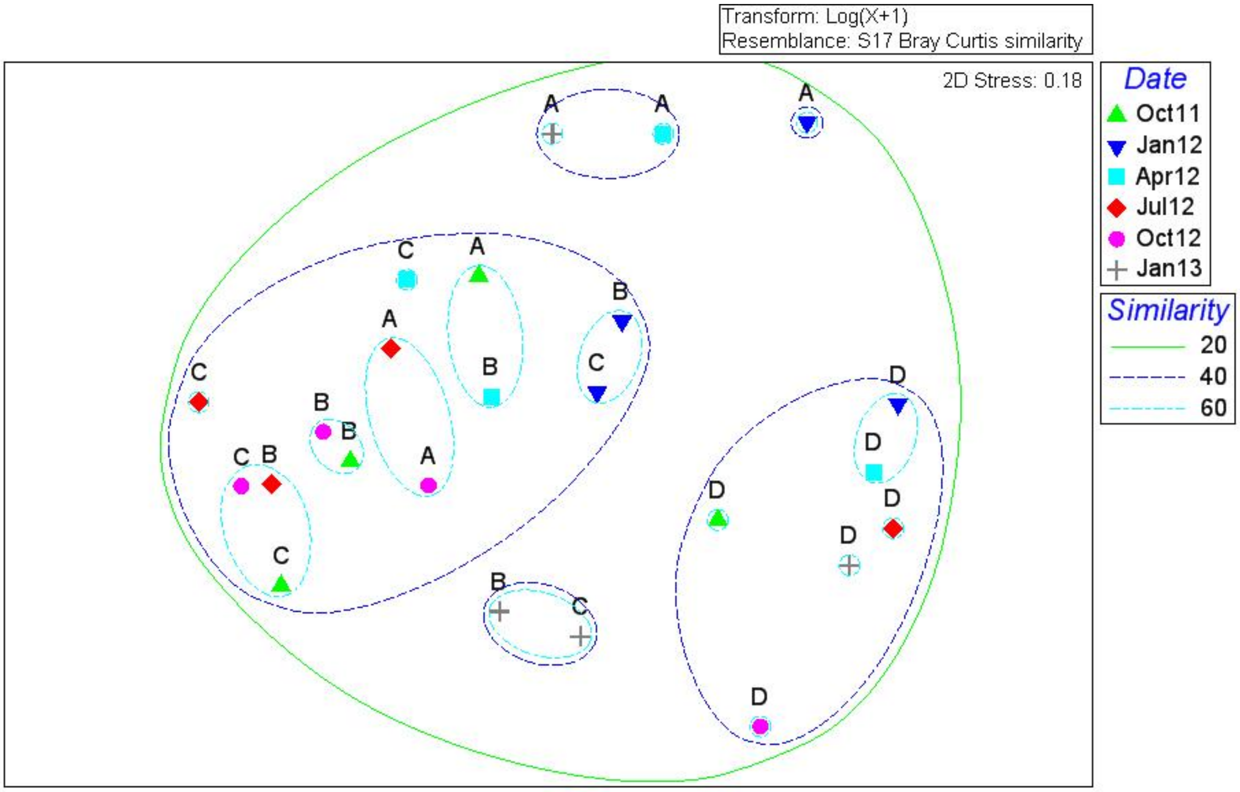

**Figure 5. Multidimensional Scaling plot of macrofaunal community structure symbolized by date and labeled by station. Lines indicate percent similarity of samples from a cluster analysis**

Macrofauna communities for each station-date combination were depicted in a multidimensional scaling plot (MDS, Figure 5). Significant clustering of communities are represented by similarity contours that are overlaid on the MDS plot. Macrofauna communities at Station A in January and April 2012, when salinities were very low, were significantly different from any other communities. In general, there is a gradation of communities from the fresher stations A during dry times, and B and C all the time, from the bottom right to the saltier station D to the upper left. Three macrofauna communities occur at 40% similarity level. These represent changes in salinity over time and space.

*Long-term Analyses of the Guadalupe Estuary*

Benthic data has been collected in the Guadalupe Estuary since 1987 (Figure 6). The period October 2011 was the driest period in the record as indicated by The highest estuary-wide average salinity, reaching an average of 35 psu among all stations (Figure 6). The other months when salinity was also high were October 1988 (25 psu), October 1996 (29 psu), October 1999 (25 psu), October 2008 (27 psu), and July 2009 (29 psu). So, prior to 2011, the highest recorded average salinity was 6 psu less than observed that October. There has been a long-term decline in abundance over the entire range of sampling dates, and this continued during the current sampling period. Biomass has fluctuated, generally being high biomass during high salinity periods. The biomass was relatively low over the sampling period compared to the long-term trends. Diversity fluctuates with salinity, being higher during high salinity periods.

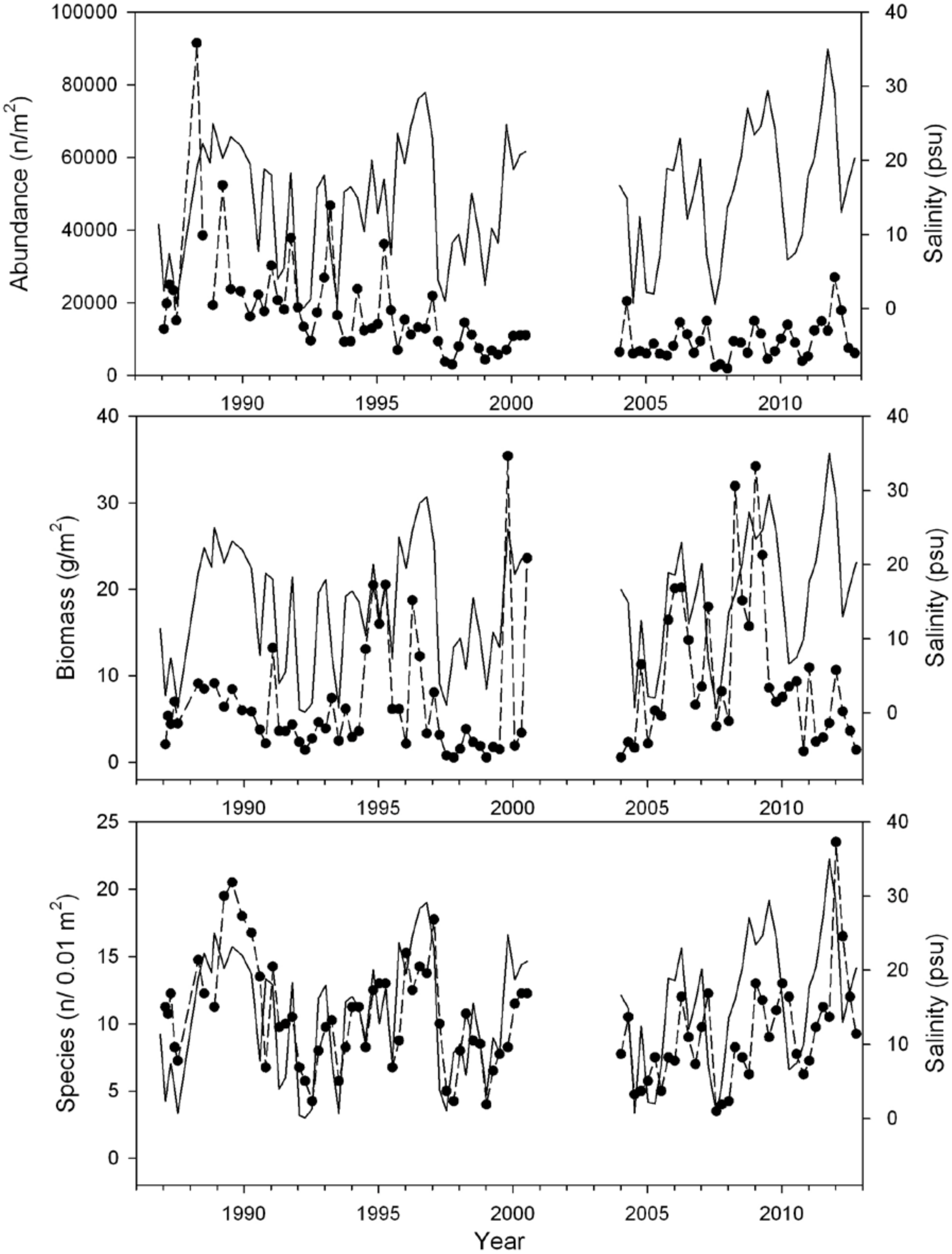

**Figure 6. Long-term change in estuary-wide, average, abundance (top), biomass (middle), and diversity (bottom) with dots dashed lines and salinity with a continuous line and no markers.**

### *Water Column Conditions in Mid-Coastal Estuaries*

Water quality measurements were made in the Nueces and Lavaca-Colorado Estuary. The salinity change over time is largely parallel among the three estuaries (Figure 7). The wet period in April 2012 can be seen as lower salinities in all three estuaries. For the period October 2011 to January 2013, the Guadalupe Estuary has the lowest mean salinity 23.6 psu, the Lavaca-Colorado Estuary has an average salinity of 30.1 psu, and the Nueces Estuary had the highest average salinity 38.5 psu.

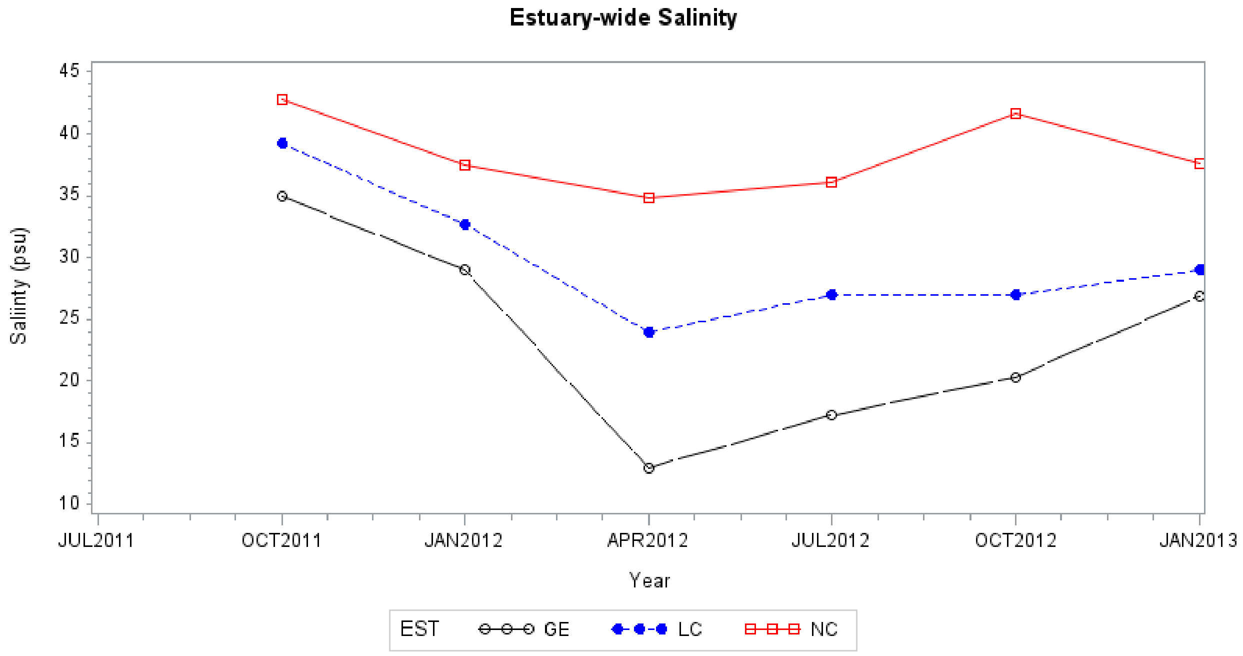

**Figure 7. Average salinity estuary-wide at each sampling period in three mid-coast estuaries.**

Salinity at stations generally follows the expected gradient of lower values near the freshwater input source relative to the point of exchange with the Gulf of Mexico. In the Guadalupe Estuary, station C was higher than D in July and October 2012 (Figure 8). The Nueces Estuary is a “reverse estuary” with highest salinities at stations A and B near the mouth of the Nueces River during dry periods (Figure 9). The Nueces River was running in July 2012 so salinities were lower at stations A and B during that time. The Lavaca-Colorado Estuary has two river sources the Lavaca River (near stations A and B) and the Colorado River (near station E) (Figure 1), consequently station F sometimes takes on characteristics of stations A and B (Figure 10).

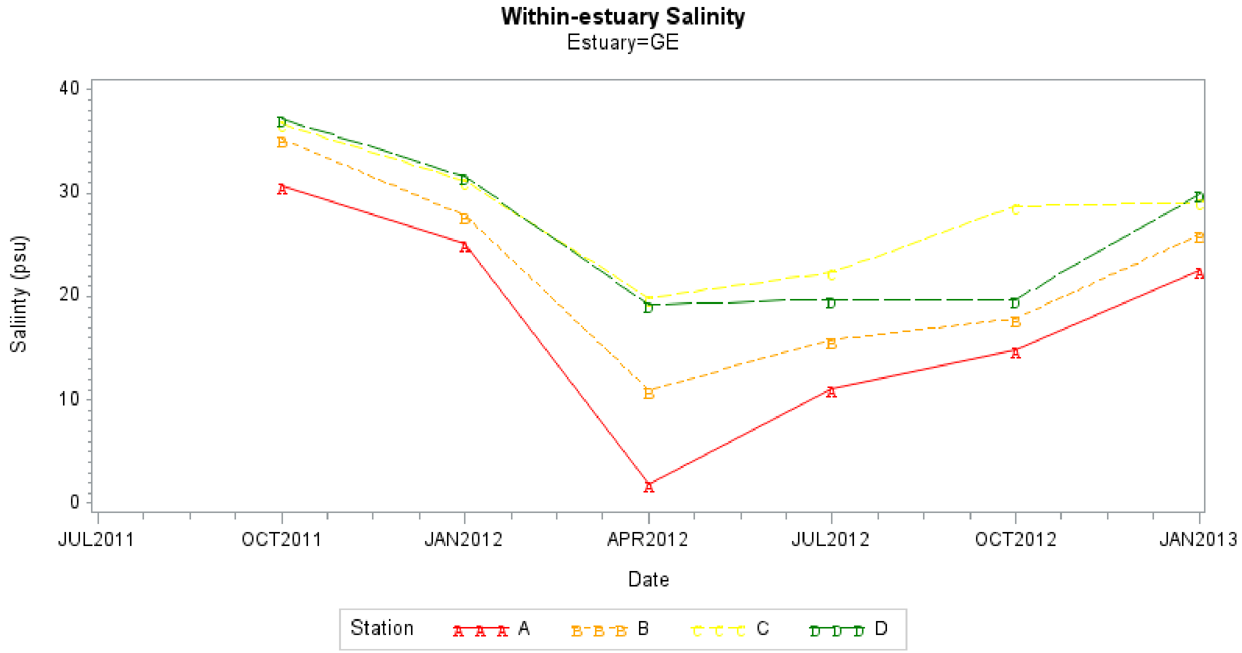

**Figure 8. Salinity at stations within the Guadalupe Estuary.**

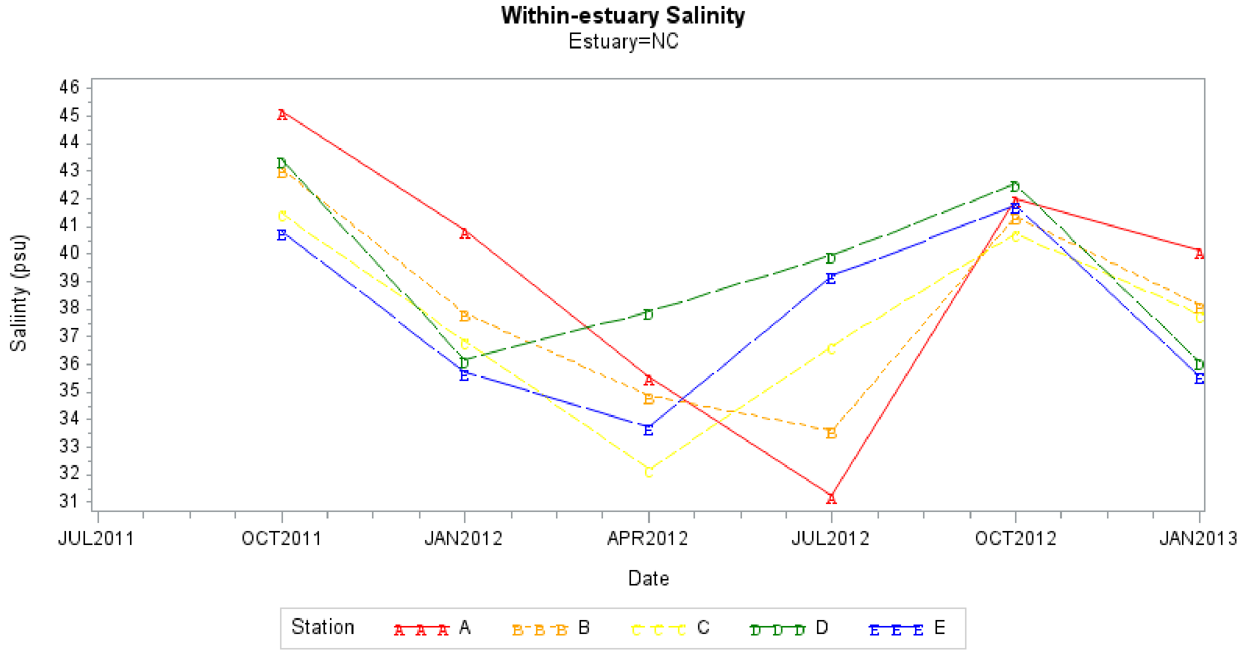

**Figure 9. Salinity at stations within the Nueces Estuary.**

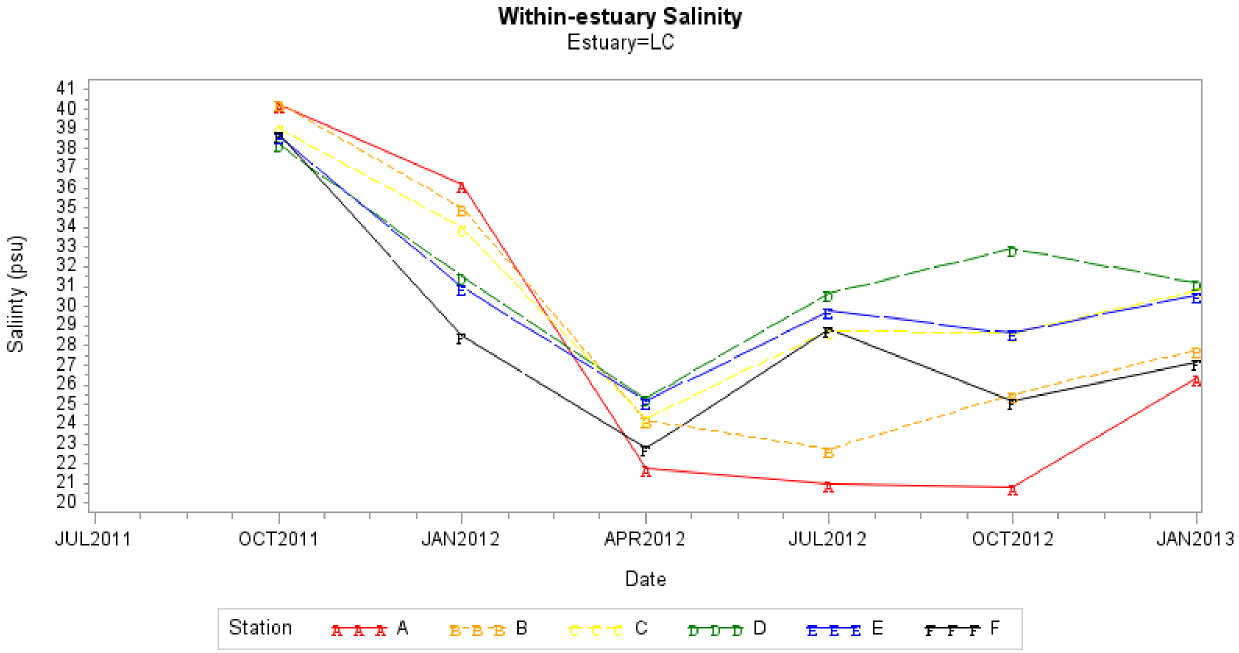

**Figure 10. Salinity at stations within the Lavaca-Coloradao Estuary.**

There is a relationship between the overall average salinity and nutrient concentrations during the study period, because the Guadalupe Estuary had the lowest average salinity and the highest average nitrate+nitrite ($NO_x$), phosphate ($PO_4$), and silicate ($SiO_4$) concentrations (Table 5). Concomitantly, chlorophyll a (Chl) concentrations were highest in the Guadalupe Estuary as well. These trends are true over the long-term, i.e., Guadalupe has lowest salinity (15.95 psu) and highest chlorophyll (12.30 ug/L), and Nueces has highest salinity (30.89 psu) and lowest chlorophyll (5.82 ug/L) (Table 6).

**Table 5. Estuary-wide average concentrations for water quality variables for the period October 2011-January 2013. Number station-date combinations: LC=36, GE=24, NC=30. Abbreviations: Est=estuary, LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces, DO=dissolved oxygen, Temp=temperature, $NH_4$=ammonium, NOx=nitrate+nitrite, PO4=phosphate, SiO4=silicate, and Chl=chlorophyll.**

| Est | DO (mg/L) | Salinity (psu) | Temp (°C) | $NH_4$ (µmol/L) | $NO_x$ (µmol/L) | $PO_4$ (µmol/L) | $SiO_4$ (µmol/L) | Chl (µg/L) | pH |
|---|---|---|---|---|---|---|---|---|---|
| LC | 7.8 | 30.1 | 21.6 | 1.89 | 1.47 | 0.63 | 46.2 | 6.3 | 8.156 |
| GE | 8.3 | 23.6 | 21.9 | 1.10 | 3.94 | 1.27 | 102.4 | 12.8 | 8.277 |
| NC | 7.0 | 38.5 | 22.2 | 0.95 | 0.56 | 0.56 | 53.9 | 7.2 | 8.123 |

**Table 6. Long-term, estuary-wide, average concentrations for water quality variables. Period of record: Lavaca-Colorado (LC) Estuary= April 1988 – January 2103, Guadalupe (GE) Estuary = November 1986 – January 2013, Nueces (NC) Estuary = October 1987 – January 2013. Note there are 6 stations in LC, 4 in GE, and 5 in NC, thus unbalanced number (n) of observations. There are also many missing values in the data set. Abbreviations: Est=estuary, DO=dissolved oxygen, Temp=temperature, NOx=nitrate+nitrite, PO4=phosphate, SiO4=silicate, and Chl=chlorophyll.**

| | Lavaca-Colorado | | | | | Guadalupe | | | | | Nueces | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable (unit)** | **N** | **Mean** | **Std Dev** | **Min** | **Max** | **N** | **Mean** | **Std Dev** | **Min** | **Max** | **N** | **Mean** | **Std Dev** | **Min** | **Max** |
| DO (mg/l) | 2182 | 7.26 | 1.74 | 0.12 | 16.36 | 385 | 7.95 | 2.03 | 0.91 | 14.87 | 1910 | 6.83 | 1.85 | 0.22 | 12.11 |
| Salinity (psu) | 2766 | 22.71 | 9.30 | 0.00 | 40.35 | 1117 | 15.95 | 9.98 | 0.00 | 37.19 | 2406 | 30.89 | 7.45 | 0.74 | 45.17 |
| Temperature (C) | 2764 | 22.30 | 6.27 | 2.99 | 32.13 | 1117 | 22.66 | 6.32 | 8.29 | 32.38 | 2406 | 22.38 | 6.45 | 2.85 | 32.23 |
| NH4 (umol/L) | 2420 | 2.39 | 4.80 | 0.00 | 91.71 | 933 | 3.36 | 15.44 | 0.00 | 191.35 | 2208 | 1.59 | 2.60 | 0.00 | 25.74 |
| NOx (umol/L) | 2442 | 3.73 | 10.44 | 0.00 | 186.00 | 950 | 12.32 | 23.66 | 0.00 | 283.70 | 2237 | 1.21 | 2.43 | 0.00 | 21.95 |
| P04 (umol/L) | 2446 | 1.45 | 4.65 | 0.00 | 108.49 | 924 | 2.15 | 2.18 | 0.00 | 18.55 | 2199 | 1.00 | 1.00 | 0.00 | 8.18 |
| SiO4 (umol/L) | 2462 | 66.71 | 57.55 | 0.00 | 398.13 | 916 | 122.50 | 100.41 | 1.05 | 1230.32 | 2208 | 68.06 | 62.88 | 0.00 | 442.17 |
| Chl (mg/l) | 1843 | 7.97 | 6.70 | 0.00 | 66.20 | 668 | 12.30 | 11.87 | 0.29 | 87.16 | 1594 | 5.82 | 5.22 | 0.05 | 44.68 |
| pH | 2629 | 8.12 | 0.39 | 6.42 | 12.53 | 981 | 8.26 | 0.33 | 6.54 | 10.93 | 2254 | 8.12 | 0.24 | 6.62 | 10.49 |
| Turbidity (NTU) | 229 | 13.48 | 13.26 | 0.00 | 60.30 | 142 | 19.72 | 19.37 | 0.00 | 121.10 | 155 | 16.06 | 32.22 | 0.00 | 161.00 |

Over the period of the current study period, ammonia concentrations generally had parallel responses in all stations within an estuary, except for when large inflow events occurred (Figure 11). Large inflow events occurred in January through April 2012, which caused spikes in concentrations at Station A in the Guadalupe and A and B in the Nueces. The large peak in ammonia found in station A of the Gaudalupe estuary in April 2012 was replicated in Stations A and B of the Nueces estuary, but not in the Lavaca-Colorado estuary. In the Lavaca-Colorado estuary, the highest peaks of ammonia occurred in July 2012 in stations A and B near the Lavaca River mouth, and stations E and F near the Colorado River mouth. Typically ammonia is highest near river sources in all estuaries.

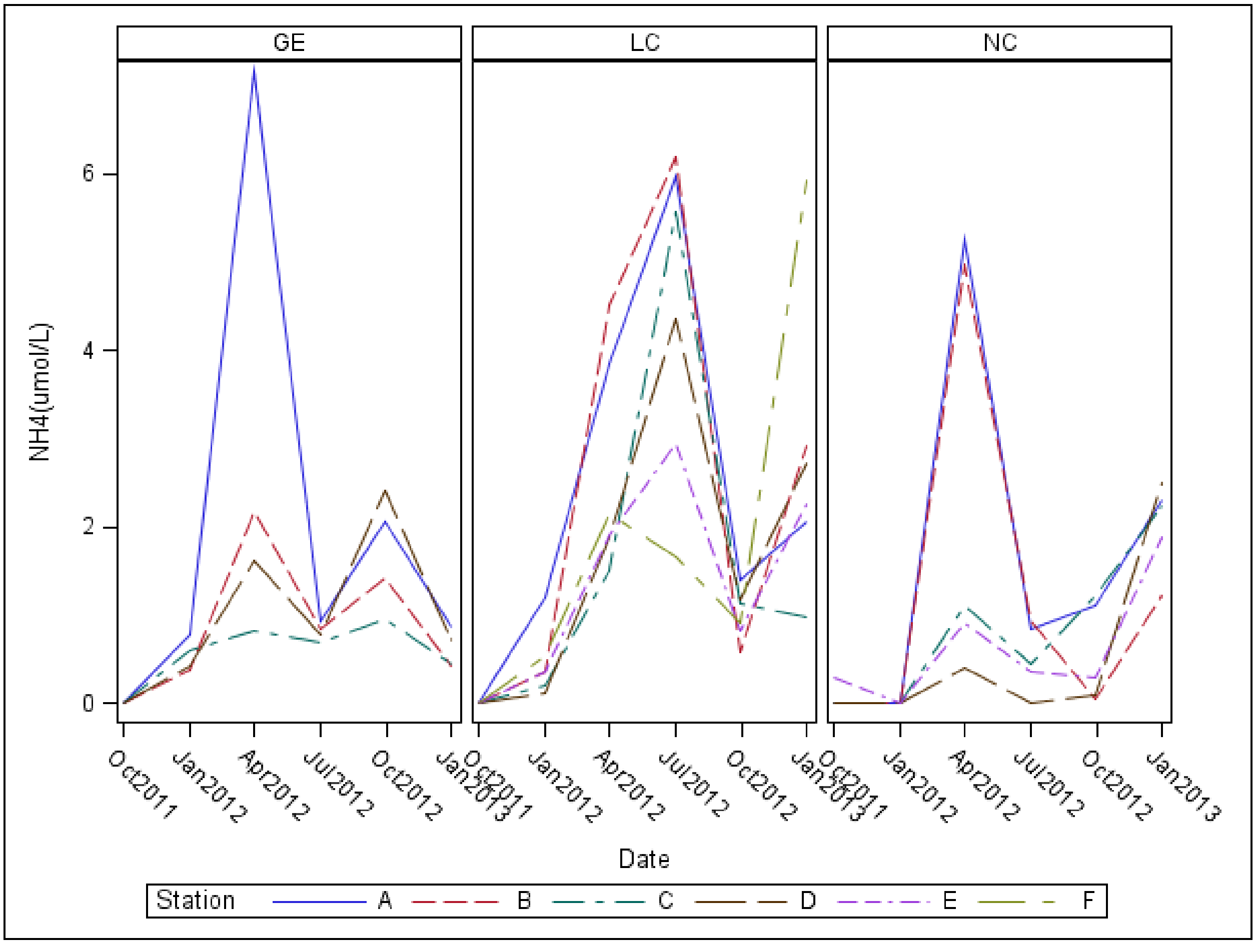

**Figure 11. Ammonia concentrations in three estuaries over time. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

There was a large inflow events in January through April 2012, which caused spikes in nitrate+nitrite concentrations at Station A in the Guadalupe Estuary (Figure 12a). There was a second large spike for Station A in the Guadalupe Estuary in January 2013. However, except for this spike, over time, nitrate+nitrite concentrations generally had parallel responses in all stations within an estuary (Figure 12b). There were no consistent patterns of nitrate+nitrite among the estuaries (Figure 12b).

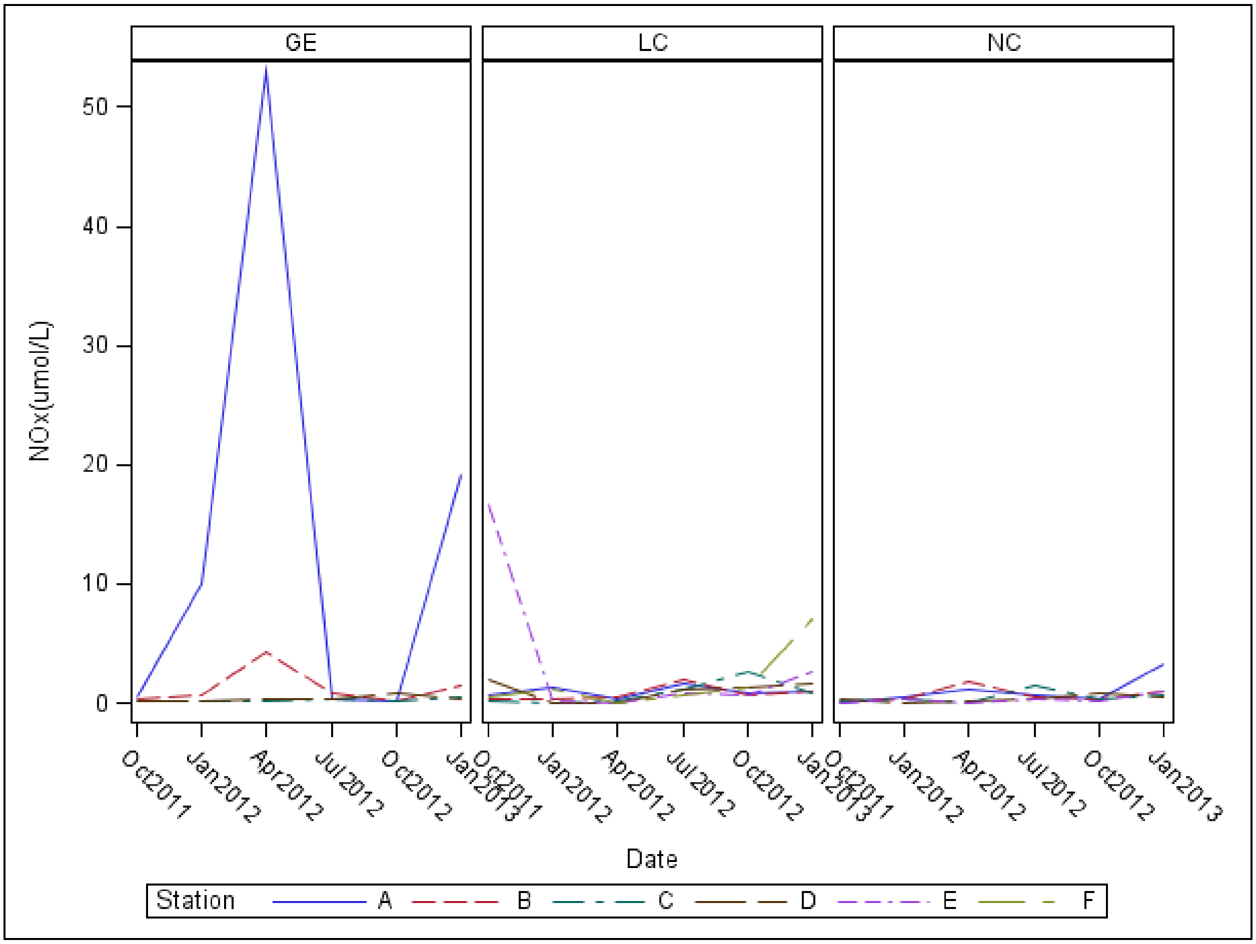

**Figure 12a. Nitrate+Nitrite concentrations in three estuaries over time. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

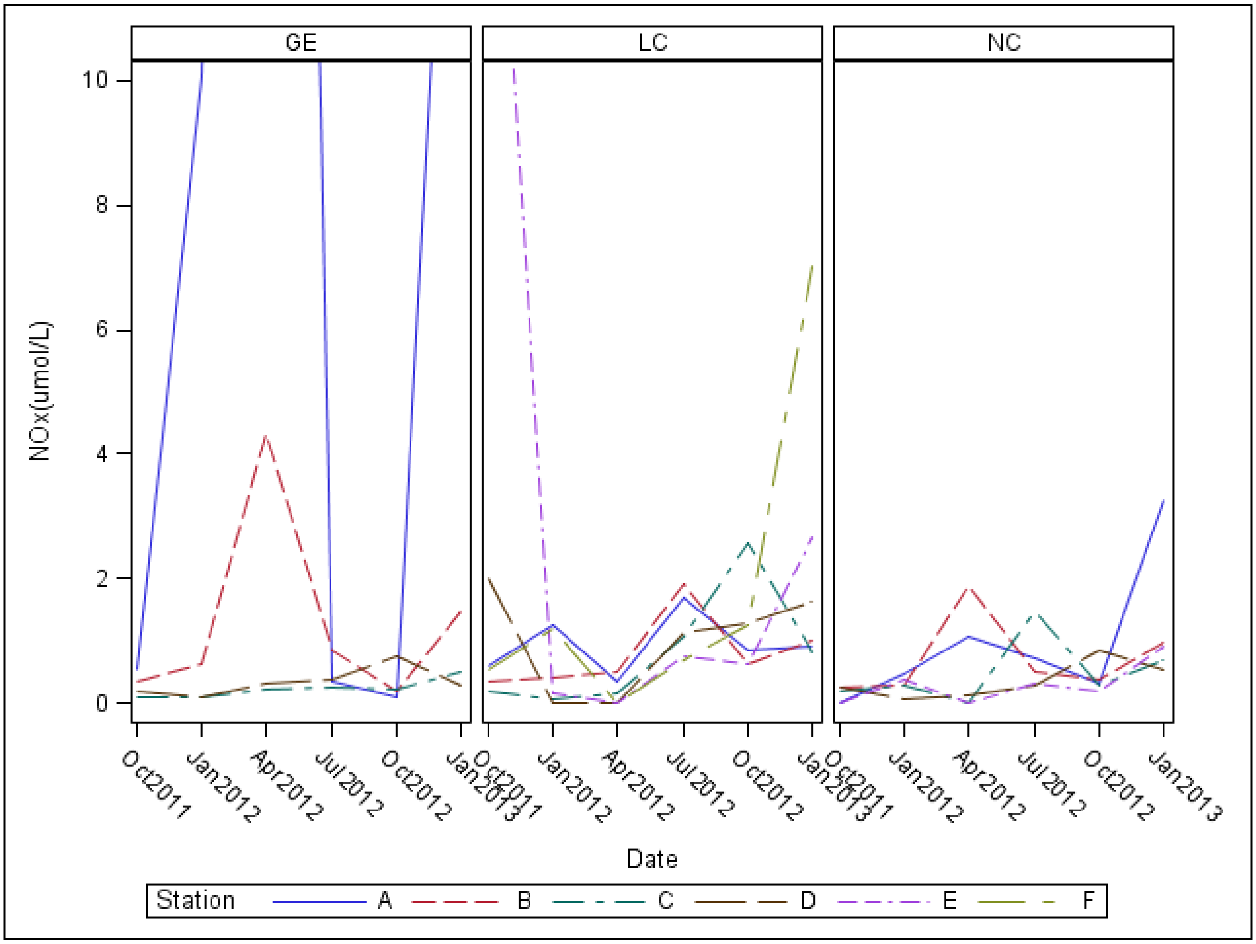

**Figure 12b. Nitrate+Nitrite concentrations in three estuaries over time. Concentration maximum is 10 umol/L to show detail for low concetrations. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

Over time, phosphate concentrations generally had parallel responses in all stations within an estuary (Figure 13). The parallel responses were especially evident in the Guadalupe estuary. In the Nueces Estuary, there were distinct station differences with A and B higher than C and D. In the Lavaca-Colorado estuary, the highest phosphate concentrations were found in station F, closest to the Colorado River mouth. While station A near the Lavaca River mouth generally had the second highest concentration, it was the third highest in October 2012 because Station E had a higher concentration.

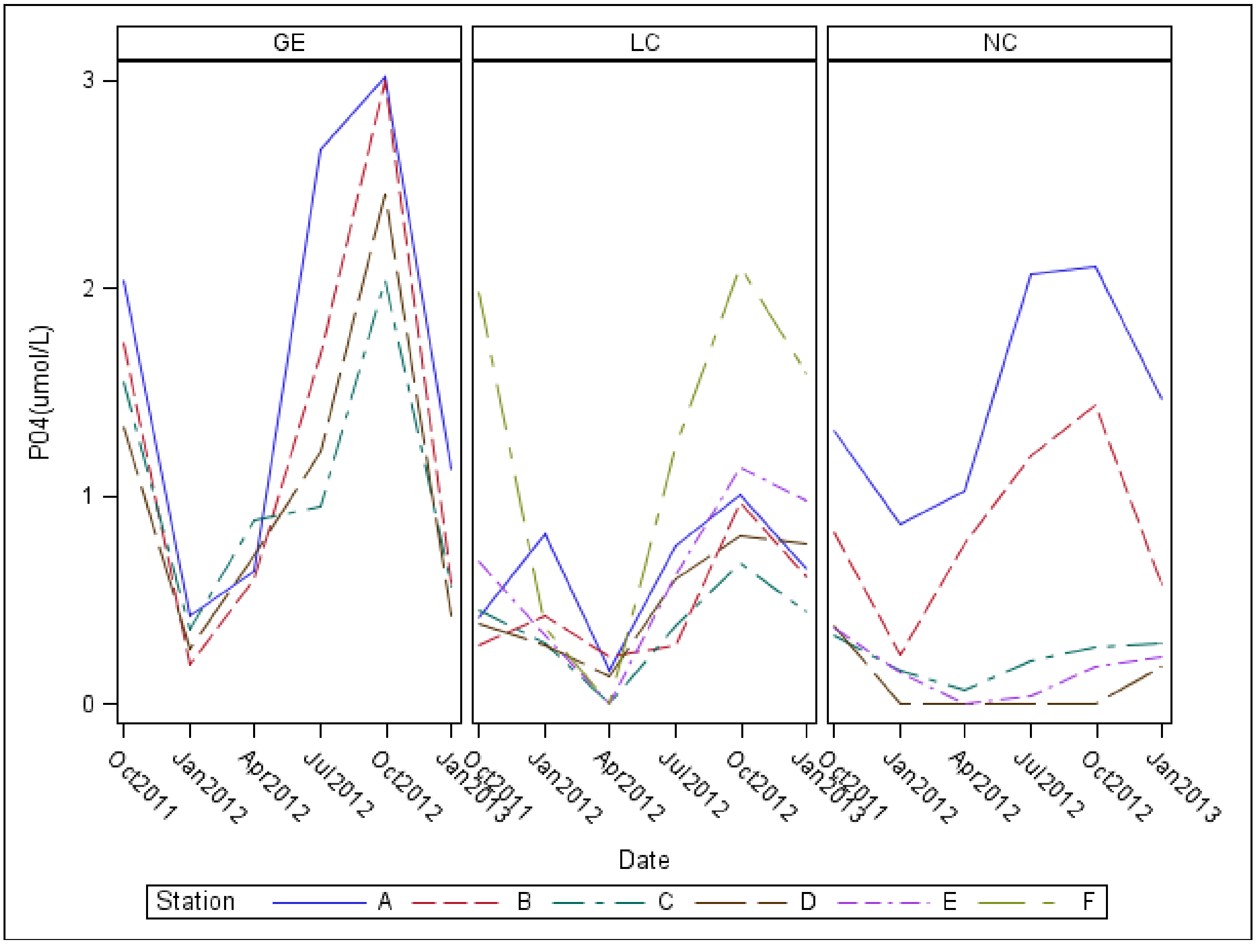

**Figure 13. phosphate concentrations in three estuaries over time. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

Over time, silicate concentrations generally had parallel responses in all stations within an estuary (Figure 14). Concentrations at Stations A and B in the Nueces were higher than C and D. The pattern of silicate was very similar in all estuaries, because all estuaries had the lowest value in January 2012 and higher values in July and October 2012.

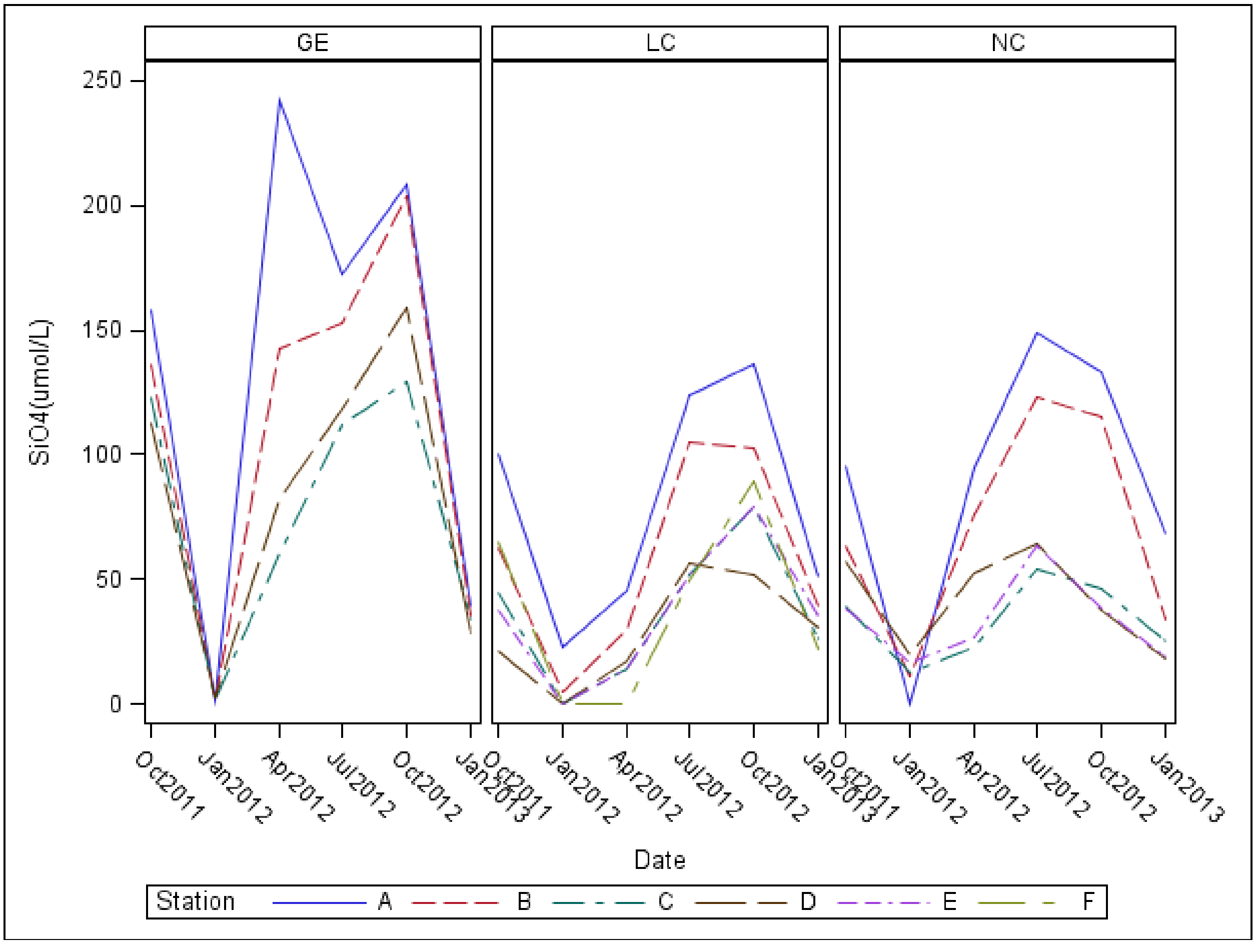

**Figure 14. Silicate concentrations in three estuaries over time. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

Over time, chlorophyll concentrations generally had parallel responses in all stations within an estuary (Figure 15). Low values were recorded in January 2012 and 2013 and higher values were recorded in April, July and October in all estuaries. In the Guadalupe estuary, stations A and B had the highest concentrations, but this was true only once, but at different times in the Lavaca-Colorado and Nueces estuaries.

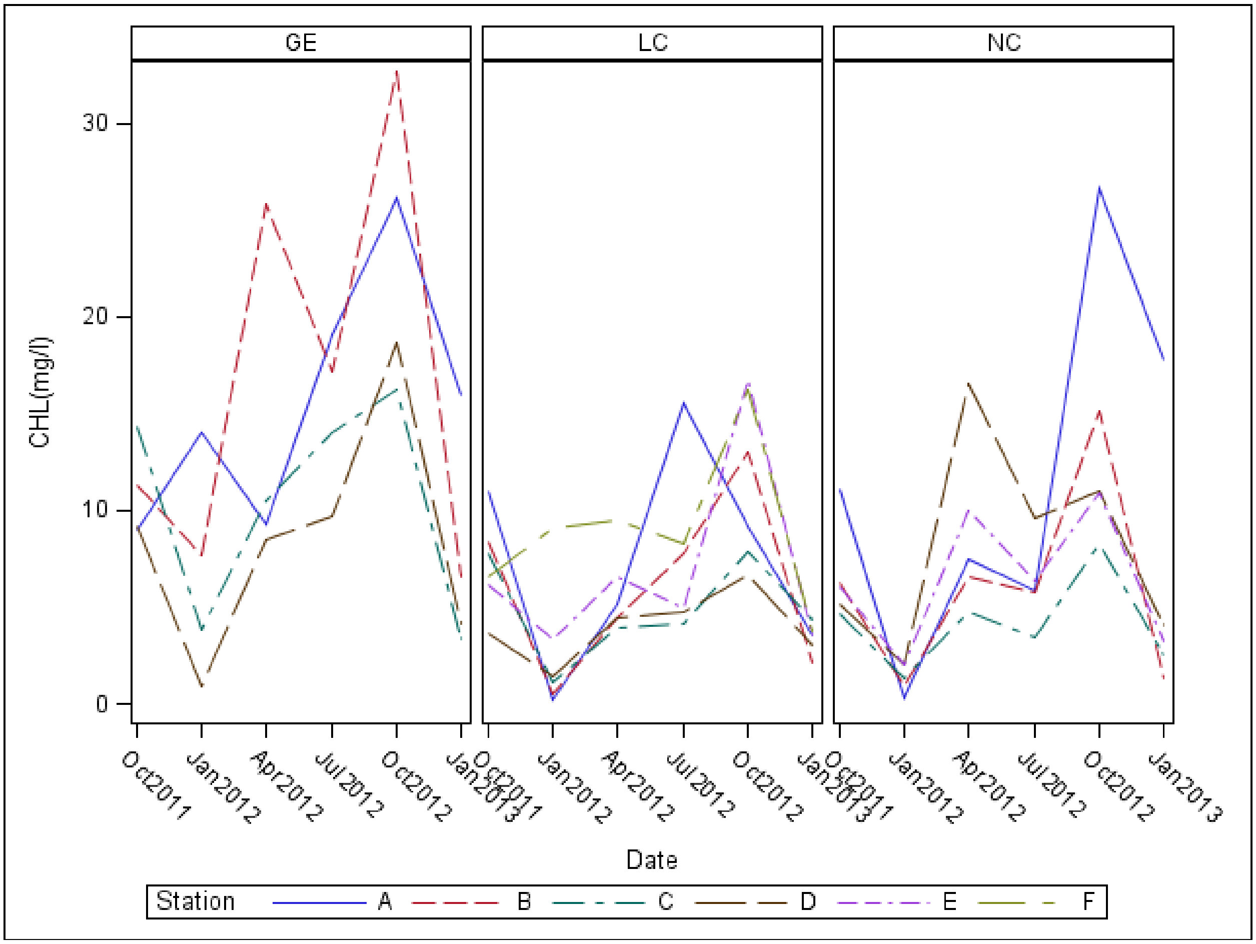

**Figure 15. Chlorophyll a concentrations in three estuaries over time. Abbreviations: LC=Lavaca-Colorado, GE=Guadalupe, NC=Nueces.**

Because stations typically have the same patterns, the estuary-wide average concentrations were calculated and plotted for each variable at each time point for all three estuaries (Figures 16-18). A common pattern is decrease in salinity, increases in nutrients followed by increases in chlorophyll.

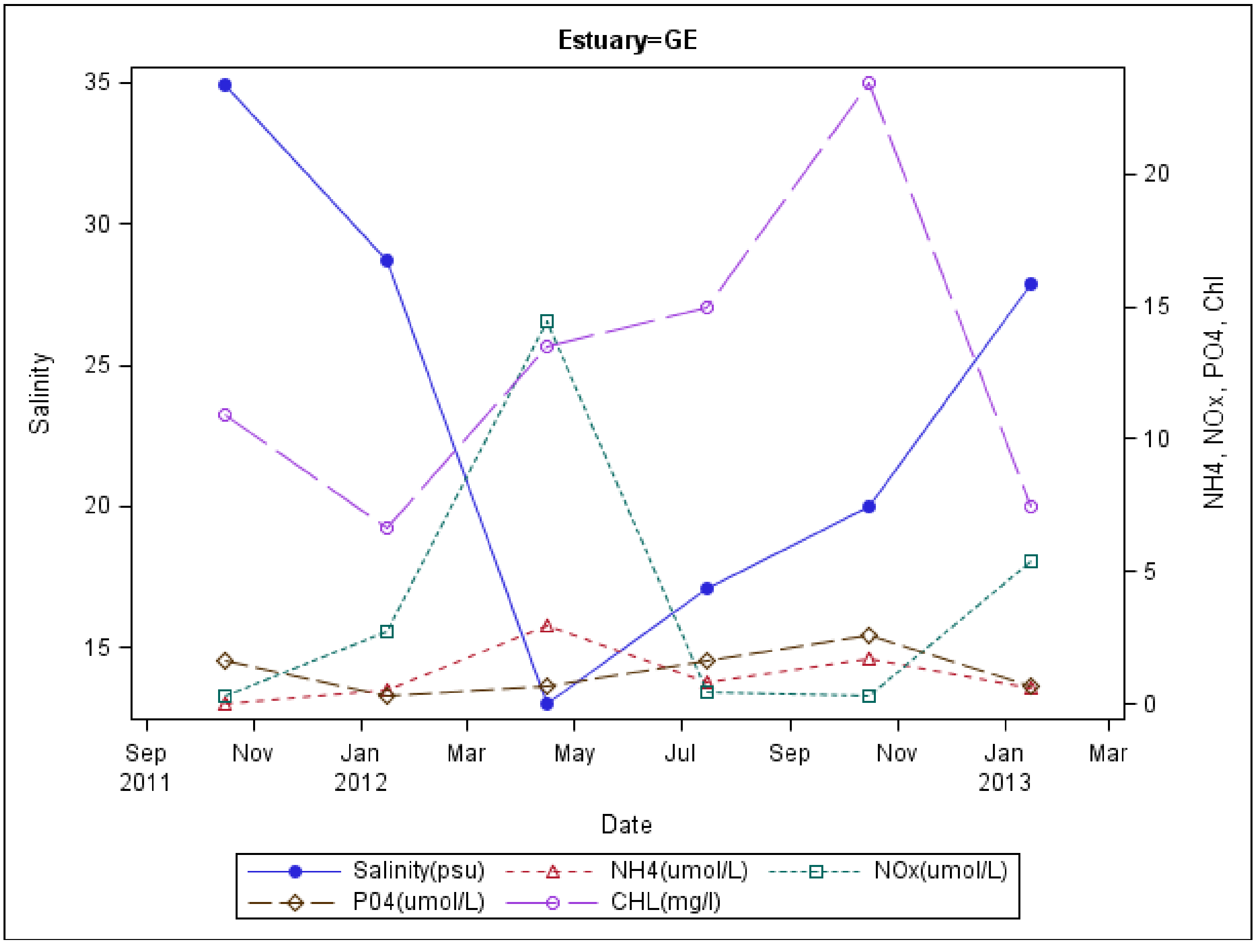

**Figure 16. Estuary-wide average water quality variables in the Guadalupe Estuary (GE) over the study period.**

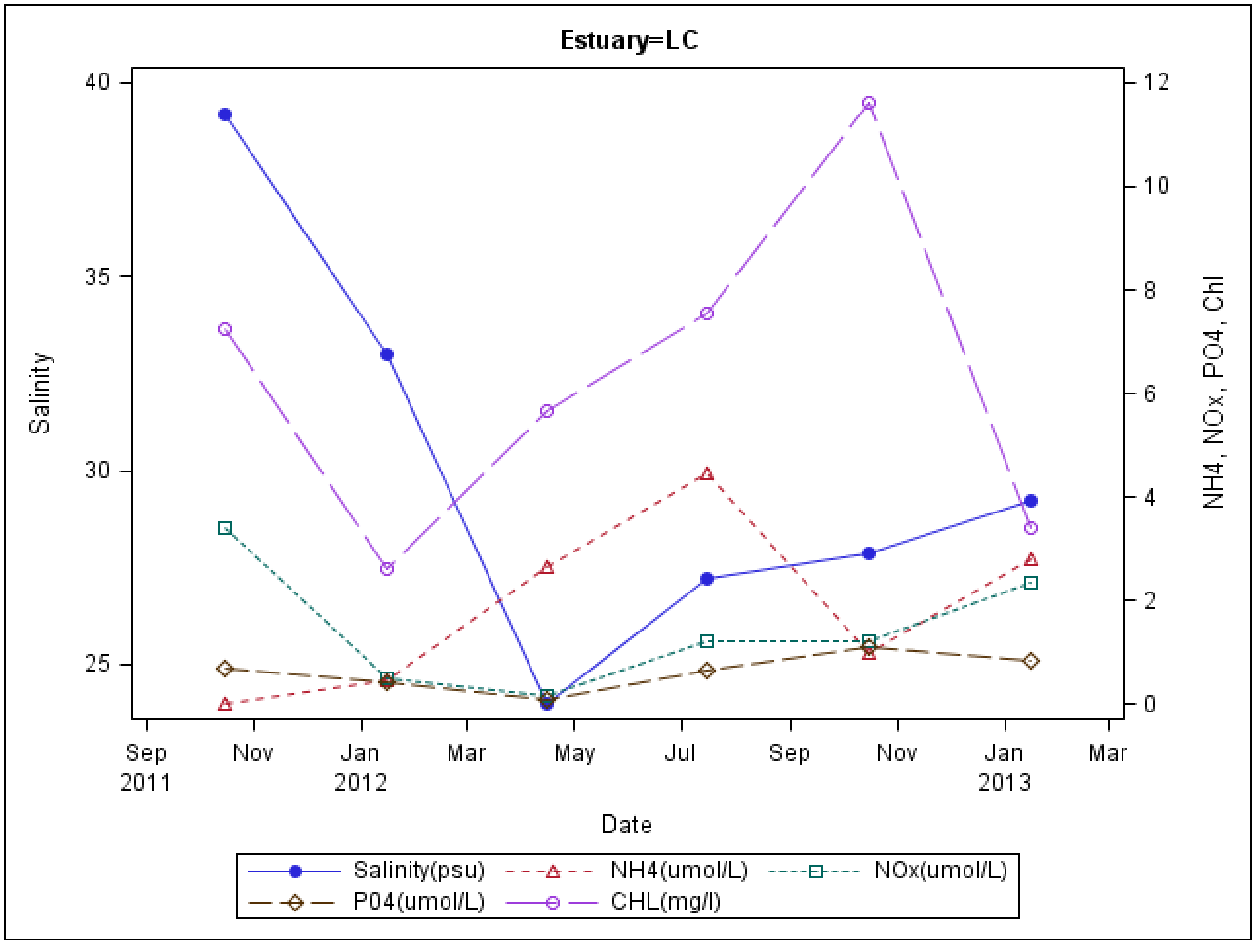

**Figure 17. Estuary-wide average water quality variables in the Lavaca-Colorado Estuary (LC) over the study period.**

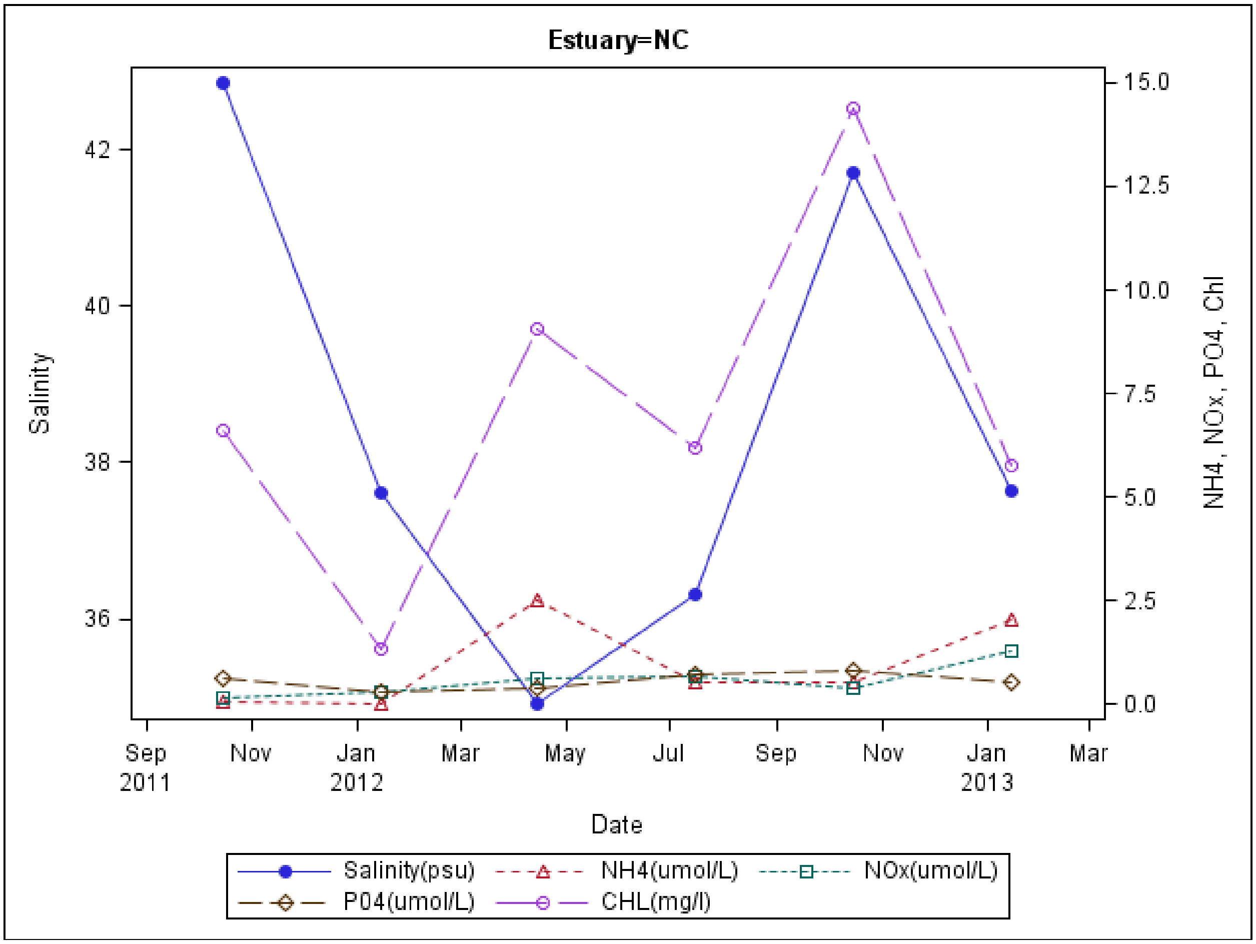

**Figure 18. Estuary-wide average water quality variables in the Nueces Estuary (NC) over the study period.**

# DISCUSSION

*Guadalupe Estuary*

Overall water quality trends of station-date combinations separate stations both by season and by amount of freshwater inflow that each station receives (Figures 2b and 2c). Temperature is inversely proportional to dissolved oxygen and the separation of the station-date combinations along this gradient represents seasonal changes in water quality. The spatial difference in freshwater inflow that each station receives is represented by the inverse relationship between salinity and nutrients. Station A is the closest of the stations to the Guadalupe River mouth so had the highest nutrient concentrations and lowest salinity values. The most important trend during the current sampling period was a transition from a wet period in January 2012 to a dry period in January 2013.

Macrofauna communities have characteristics that are both multivariate (i.e., species differences as presented in Table 4 and Figure 5), and univariate (i.e., summary values of abundance, biomass and diversity as presented in Figures 4 and 6). There is a clear difference between macrofauna communities in environments with high and low salinities because samples from Station D always cluster together, and are distinct from other stations (Table 4 and Figure 5). Stations B and C are similar all of the time. However, Station A can be like C and B, as it was in October 2011, July 2012, and October 2012, or it can be distinct as it was in January 2012, April 2012, and January 2013. Freshwater inflow into Guadalupe Estuary travels southwest along the western side of the estuary allowing lower salinities on the southwestern side to be lower than salinities on the northeastern side resulting in long-term lower salinities at station C than D (Table 7). The period studied here (October 2011 – January 2013) was unusual in that average salinity at station C (28.0 psu) was higher than at station D (26.2). Regardless, the macrofauna community at Station D still has more marine characteristic species present than Station C.

**Table 7. Long-term average salinities at four stations in San Antonio Bay. Period from November 1986 to January 2013.**

| **Station** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Salinity | 9.0 | 13.4 | 18.3 | 19.1 |

It is also apparent that macrofauna abundance and biomass reacted positively with lowered salinity after the freshwater event in October 2011. When salinities rose from July 2012 through January 2013, the abundance, biomass and diversity decreased.

There has been a decline in macrofauna abundance since 1987, but it does not appear that there is an associated decrease in macrofauna biomass or species richness (Figure 6). Diversity follows a pattern of increasing when salinity increases and decreasing when salinity decreases, and this is because of the expansion of a more diverse marine fauna that invades San Antonio Bay during dry periods. A similar decline in benthic abundance, but also biomass and diversity, in the Lavaca-Colorado estuary has been observed over the past 21 years (Pollack et al. 2011). However we do not know if this decline is a result of natural, long-term population or community cycles that span multiple decades and will reverse, or if it is due to a permanent state-shift..

Biomass does not exhibit a clear trend, sometimes following salinity patterns, but sometimes not following salinity patterns (Figure 6). Biomass did increase following drops in salinity on six occasions: January 1991 following a 1 psu drop, October 1994 following 5 psu drop, April 1996 following a 4 psu drop, April 2007 following a 13 psu drop, and July 2009 following a 4 psu drop. However, biomass increased following a rise in salinity on six occasions: April 1995 following a 4 psu rise, October 1999 following a 16 psu rise, October 2004 following a 11 psu rise, April 2006 following a 5 psu rise, April 2008 following a 3 psu rise, and January 2011 following a 7 psu rise.

Mean estuary-wide salinity in October 2011 (35 psu) was the highest it has ever been and is 2.3 times the long-term average salinity of 14.8 psu (Figure 6). Some of the benthic metrics are much lower than average. Average abundance in October 2011 was 12,291 n/m$^2$, which is 82% of the long-term average abundance of 14,899 n/m$^2$. Average biomass in October 2011 was 4.53 g/m$^2$, which is a little more than half (55%) of the long-term average biomass of 8.23 g/m$^2$. Average species richness is about the same, because in October 2011 it was 10.5 species/0.01 m$^2$, which is 4% more than the long-term average richness of 10.1 species/0.01 m$^2$.

### *Mid-Coastal Estuaries*

The three Texas mid-coast estuaries share a connection via large lagoons. Matagorda Bay is connected to San Antonio Bay via Espiritu Santo Bay. San Antonio Bay is connected to Corpus Christi Bay via Aransas Bay and Lydia Ann Channel. The Intracoastal Waterway enhances these connections and further facilitates water exchange among these Texas lagoons. However, because of the strong climatic gradient along the Texas coast, the three estuaries have different inflow regimes and consequently different patterns in water quality.

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**Texas Water Development Board**

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.texas.gov
Phone (512) 463-7847, Fax (512) 475-2053

August 15, 2013

Mayra A. Hough, Ed.D.
Director of Sponsored Programs
Texas A&M University – Corpus Christi
6300 Ocean Drive, Unit 5844
Corpus Christi, Texas 78412-5844

Re: Research Contract between the Texas Water Development Board (TWDB) and Texas A&M University – Corpus Christi (TAMU-CC); TWDB Contract No. 1248311357, Draft Report Comments

Dear Dr. Hough:

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

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. **Please further note, that in compliance with Texas Administrative Code Chapters 206 and 213 (related to Accessibility and Usability of State Web Sites), the digital copy of the final report must comply with the requirements and standards specified in statute. For more information, visit http://www.sos.state.tx.us/tac/index.shtml.** If you have any questions on accessibility, please contact David Carter with the Contract Administration Division at (512) 936-6079 or David.Carter@twdb.texas.gov

TAMU-CC shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

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

Sincerely,

Robert E. Mace, Ph.D., P.G.
Deputy Executive Administrator
Water Science and Conservation

Enclosures

c: Carla Guthrie, Ph.D., TWDB

Our Mission

To provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas

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Attachment I

***Macrobenthos Monitoring in Mid-Coastal Estuaries***
P.I. Paul Montagna
Contract # 1248311357
TWDB comments to Final Report

## REQUIRED CHANGES

### General Draft Final Report Comments:

This study scope of work focused on collecting benthic community and associated water quality data in the mid-Coastal zone of Texas, including the Lavaca-Colorado, Guadalupe, and Nueces estuaries. In addition, the scope of work included processing samples and analyzing data collected from the Guadalupe Estuary. The goal of this effort is to relate changes in water column dynamics with changes in benthic community dynamics. The continued data collection and information about benthic community trends, water quality data, and nutrient data in this estuary will allow for the analysis of estuarine productivity and understanding of long-term ecosystem dynamics in the San Antonio Bay system, particularly with respect to freshwater inflow. In addition, by supporting long-term data collection in the Lavaca-Colorado and Nueces estuaries analyses can be conducted at a future point in time to assess those ecosystems.

Please check the document for grammar, spelling, typographical errors, and randomly dispersed symbols.

Please ensure that all of the citations listed in the References section are cited in the body of the document or are removed from the References section if not applicable.

Please be sure that the report meets new accessibility requirements as noted in TWDB's cover letter.

### Specific Draft Final Report comments:

1. Introduction, page 2 1st ¶: The first sentence mentions the ultimate goal of the "*current project*". One suggestion is to replace "*the current project*" with "*long-term benthic data collection*" as it is the long-term effort to collect data across multiple estuaries which allows for an assessment of ecosystem health.

2. Introduction, page 1, 3rd ¶: Please clarify which aspect of the community (diversity or some other measure) is being referred to in the following statement, "*Within estuaries, the upstream community is reduced by reduced inflow, whereas, the downstream community increases with reduced inflow and higher salinities.*"

3. Methods, page 3, 3rd ¶: Please better clarify that benthic samples collected in the Guadalupe Estuary were the only samples processed and analyzed for discussion in this report, but that water quality conditions in all three estuaries are reported on and that the benthic samples from the other two estuaries will be archived for future analysis.

4. Methods, *Water Quality*, page 4, 1st ¶: The description of water quality data collected references sampling at "four stations". If, however, sampling occurred at all stations, please correct the text.

5. Results, *Guadalupe Estuary During the Study Period*, page 8, 2nd ¶: Please clarify the observed trends in the data. It is stated that salinity and chlorophyll dropped in winter 2012 and then rose throughout the rest of the year, but chlorophyll actually begins to decrease in October 2012. The last sentence states that average nutrients increased and then decreased throughout the year, but this trend is not observed for all nutrients as reported in Figure 3. For example, silicate first declines from October 2011 to zero in January 2012 before following the stated trend. Also, nitrite+nitrate increases towards the end of the study period, from October 2012 to January 2013.

6. Results, *Guadalupe Estuary During the Study Period*, page 8, 3rd ¶: In the second to last sentence, it is stated that "During the dry fall of 2011, abundance, biomass, and diversity were low and began to rise when salinities decreased in 2013." Please correct this statement to reflect that salinities decreased in **2012**.

7. Results, *Long-Term Analyses*, page 13, 1st ¶: The outline of the report might benefit by changing the subheading to read "*Long-Term Analyses of the Guadalupe Estuary*", since only this estuary is discussed in this section. Additionally, the text describes October 2012 as having the highest estuary-wide salinity for the Guadalupe Estuary, with a salinity of 35 psu, but does not reference any figures or tables of data. However, Figure 7 shows salinity in the Guadalupe Estuary being near 35 psu in October 2011 and ~20 psu in October 2012. Please verify the statement against the presented data. In addition, please verify the "other periods" when salinity was high by first specifying what values constitute a "high" salinity for this estuary and then double-checking the corresponding years. The last sentence discusses diversity but Figure 6 refers to abundance and species – diversity is not clarified.

8. Results, *Water Column Conditions in Mid-Coastal Estuaries*, page 15, 1st ¶: The text states that lower salinities occurred in all three estuaries between January and April 2012, but lower salinities also were present in July 2012. Also, mean estuary-wide salinities are stated in the text, but it is not clear if these values represent mean salinity during the study period (October 2011 to January 2013) or for the full period of record since 1987. Salinity for the Lavaca-Colorado Estuary as stated in the text does not match the salinity reported in Table 4. Please clarify which value is correct.

9. Results, *Water Column Conditions in Mid-Coastal Estuaries*, page 17: Please clarify whether these results are specific to the study period or are representative of the full period of record since 1987. Additionally, a reference is made to a relationship that exists between the overall average salinity and nutrient concentrations in Table 4, but there are no correlation statistics in this table that make the relationship explicitly clear. Although the relationship is described for the Guadalupe Estuary, the other two estuaries reported in the table are not discussed. Please clarify the nature of the relationship mentioned in the first sentence and how the results in Table 4 support the claim.

10. Results, *Water Column Conditions in Mid-Coastal Estuaries*, page 18: The statement that nitrate+nitrite concentrations had parallel responses in all stations seems misrepresentative given that this was not the case in the Guadalupe Estuary and results were too close to zero to distinguish in for the remaining two estuaries.

11. Results, *Water Column Conditions in Mid-Coastal Estuaries*, page 20: The statement that a common pattern shows decreasing salinity, increasing nutrients which is then followed by increasing chlorophyll for all estuaries is misrepresentative. For all three estuaries, there is no lag time for increases in chlorophyll.

12. Discussion, *Guadalupe Estuary*, page 22, 1st ¶: The first sentence refers to figures 2 and 3; however, figure 3 does not support the statement because it shows an estuary-wide average as opposed to station-by-station results. Please consider referencing Figure 2 and Table 2 instead. Additionally, please add dates to the last sentence to clarify the period of transition between "wet" and "dry".

13. Discussion, *Guadalupe Estuary*, page 22, 2nd ¶: According to Figure 4, stations A and D do not exhibit a clear difference in abundance, biomass, or total species, but rather these two stations are more similar to one another while stations B and C are more similar to each other. Please clarify this statement or refer to the supporting evidence as well as clarify the characteristics that led all stations to be classified as having "marine" influences. Additionally, Table 2 (and Figure 4) does not support the statement that station C has a lower salinity than station D – at least during the study period. This statement needs to be revised and perhaps placed into the context of long-term patterns previously documented.

14. Discussion, *Guadalupe Estuary*, page 22, 2nd ¶: According to Figure 5, stations A, B, and C tend to be similar to one another, and station D is distinctive. Station C does not appear to be intermediate between A/B and D during this study period. Please reconsider the statements made in the discussion.

15. Discussion, *Guadalupe Estuary*, page 22, 4th ¶: Figure 6 does not support the statement that macrofauna biomass and species "richness" show a long-term declining pattern. (In addition, the report does not clarify whether species richness or species diversity is being reported; please clarify.) Please provide a citation for the statement that salinity was more sporadic before 2005 and has been less so after 2005. The last sentence which references Pollack et al. 2011 and mentions observed declines in biomass and diversity may not be as relevant to the Guadalupe Estuary as to other monitored estuaries.

**Figures and Tables Comments:**

1. Figure 3, page 9: Please clarify in the figure or caption if the water quality data presented are an estuary-wide average from all stations or some other value.

2. Figure 6, page 14: The figure caption states that biomass (middle image) and salinity (all images) are presented but fails to mention abundance (top image) and species (bottom image) are also shown for 1987 to 2012 for the Guadalupe Estuary. The caption also fails to mention if species richness or diversity is shown in the bottom image. Please clarify the information being shown in the figures.

3. Figure 7, page 15: The figure caption fails to describe the acronyms used in the figure legend. Please define the use of GE, LC and NC in this and all other figures and tables.

4. Table 4, page 17: Please define all acronyms either in the table header or in the table caption. Please verify whether mean salinity for the Lavaca-Colorado Estuary is 30.16 psu as reported in this table or is 29.8 as reported in the text on page 15.

5. Figures 16 -18, pages 20 - 21: Please add markers to the plot lines to indicate the sampling events or change the date axes to show sampling events. As presented, the data appears to have been collected monthly, and it is hard to know which values were recorded and which values are interpreted.

## SUGGESTED CHANGES

### Specific Draft Final Report Comments:

1. Results, *Water Column Conditions in Mid-Coastal Estuaries*, pages 18-20: Please consider describing the actual nutrient responses within each estuary, including similarities or differences between estuaries.
2. Discussion, *Guadalupe Estuary*, page 22: Please consider commenting on why the benthic communities seemed to differ during this study period as compared to previous years.
3. Discussion, *Mid-Coastal Estuaries*, page 22: Please consider commenting on some of the similarities and differences in the patterns of water quality among the three mid-coastal estuaries, referencing previous studies if necessary.
4. Discussion, *Guadalupe Estuary*, page 22: Please re-consider the assertion that the drought was "broken" in October 2011 unless supporting evidence can be provided. Defining the beginning and ending of a drought is difficult, especially in aquatic environments and given that long-term droughts may include some precipitation events.