EFFECT OF FRESHWATER INFLOW ON MACROBENTHOS PRODUCTIVITY IN THE GUADALUPE ESTUARY

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Final report to:

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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, Montagna 1989, 1999, 2000; Montagna et al. 2007; Montagna and Kalke 1992, 1995; Montagna and Li 1996, 2011; Montagna and Yoon 1991; Pollack et al. 2009). 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 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, while suspension feeders are reduced; thus there is a decrease in functional diversity when salinity is increased because of loss of a trophic guild. Within estuaries, the upstream benthic community is reduced by reduced inflow, whereas, the downstream community increases 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 demonstrates that freshwater inflow is important in to maintain secondary productivity and functional diversity in estuaries, which is required to maintain estuarine health and sustainability.

The ultimate goal of the current project 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). 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

Four stations were sampled for macrofauna and water quality in the Guadalupe Estuary (San Antonio Bay; Figure 1, Table 1). Sampling occurred four times: October 2009, and January, April, and July 2010.

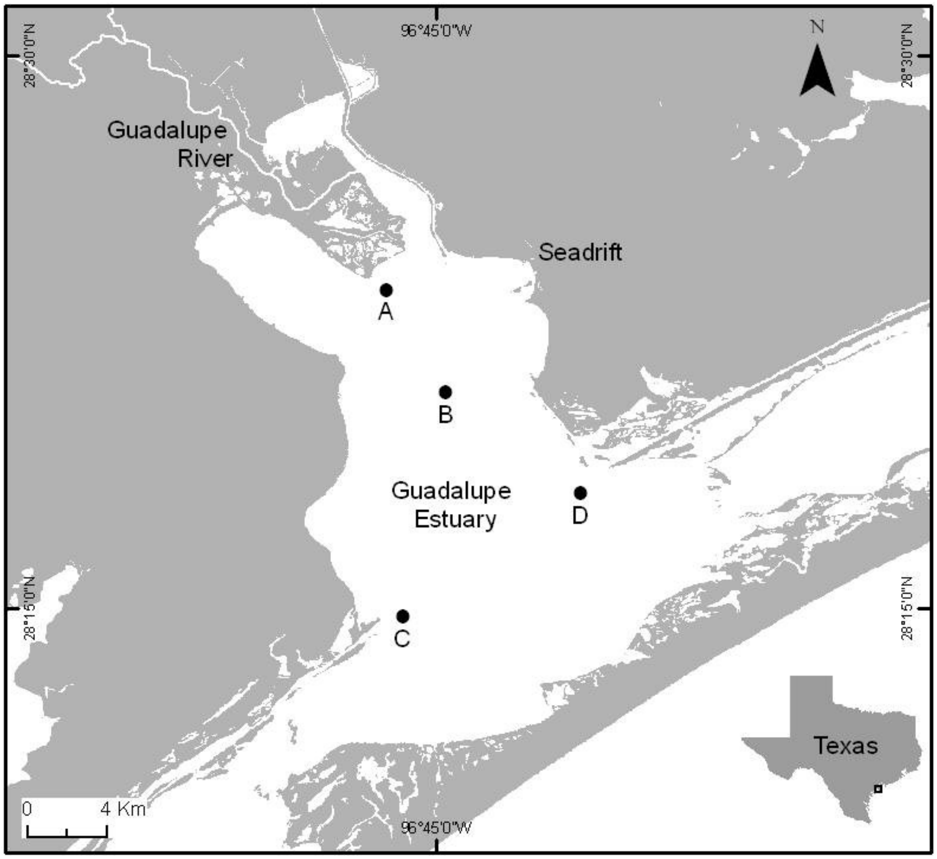

Figure 1. Map of sampling stations in Guadalupe Estuary / San Antonio Bay

Table 1. Station Locations.

Station	Latitude	Longitude
A	28.39352	-96.77240
B	28.34777	-96.74573
C	28.24618	-96.76488
D	28.30210	-96.68435

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 four stations on each 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 ºC), pH (± 0.1 units), dissolved oxygen (± 0.2 mg l^{-1}), depth (± 1 m), and salinity (ppt). Salinity is automatically corrected to 25 ºC.

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 specificed 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. 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 nonmetric multidimensional scaling (MDS) and cluster analysis using a Bray-Curtis similarity matrix. Prior to analysis, the data was log10 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

Principal Components Analysis explained 73 % of the variation within the water quality data set (Figure 2). Principal Component (PC) 1 explained 42 % of the variation while PC2 explained 31 % of the variation. PC1 represents seasonal changes in water quality with high temperatures and silicate concentrations being inversely proportional to pH and dissolved oxygen concentrations (Figure 2A and 2C). High temperatures and silicate concentrations occurred in October 2009, while the lowest temperatures and silicate concentrations occurred in January 2010 (Figure 2C). PC2 represents spatiotemporal changes in water quality. Along the PC2 axis, salinity is inversely proportional to Chlorophyll (Figure 2A). The lowest salinity values and highest chlorophyll concentrations occur in October 2009(Figure 2C).

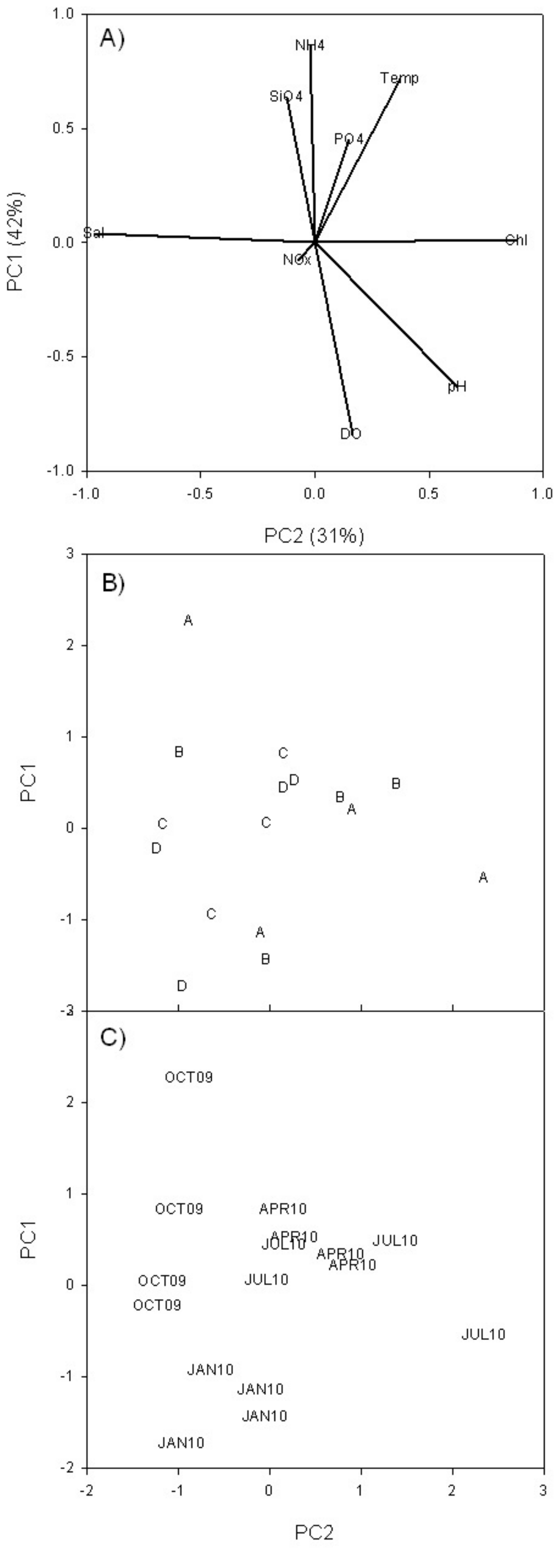

Figure 2. Principal Components Analysis of water quality. Variable loading plot (A) and station-scores labeled by station (B) and month(C) stating in October 2009 through to July 2010.

The lowest salinity and highest concentrations of silicate and nitrate+nitrite occur at Station A 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 all but one sampling date at Stations B and D, and for all dates at Station C. Mean chlorophyll concentrations are the highest and most stable at station B. Mean dissolved oxygen concentrations are also highest at station B, however they are more variable than any other station.

Table 2. Overall (for both top and bottom and over the sampling peirod) mean water quality values for each station. Standard deviation for all samples at each station are in parentheses.

	Station (n)				
Variables	**A(18)**	**B(23)**	**C(20)**	**D(20)**	**Mean**
DO (mg/l)	7.0(3.5)	7.5(2.6)	7.8(1.6)	7.4(2.0)	7.5
Salinity (psu)	8.1(9.8)	16.0(11.2)	17.5(9.2)	21.0(10.7)	15.7
Temperature (°C)	22.8(7.9)	20.7(8.0)	20.7(7.8)	21.8(7.5)	21.5
pH	8.4(0.3)	8.4(0.2)	8.3(0.2)	8.2(0.1)	8.3
NH4 (umol/L)	8.1(9.5)	4.7(3.8)	4.8(3.3)	2.4(1.7)	5.0
NOx (umol/L)	38.2(21.0)	15.4(11.1)	5.8(3.6)	5.6(7.4)	16.3
P04 (umol/L)	4.2(0.9)	2.5(0.8)	1.7(0.3)	1.8(1.0)	2.5
SI04 (umol/L)	113.1(63.3)	122.3(41.1)	76.4(24.0)	86.4(37.8)	99.5
Chlorophyll (mg/l)	9.2(6.5)	13.5(8.2)	5.0(2.1)	6.2(4.2)	8.5

The sampling year started off during a dry period and ended in a wet period and that is reflected by decreasing salinity throughout the year (Figure 3). In contrast average overall chlorophyll increased throughout the year.

The four stations (A through D) lie along a gradient from river to marine end at the Intracoastal Waterway and that is reflected in the differences in salinity among the stations as well (Figure 4A). Station A, closest to the river had the highest abundance (Figure 4B) and biomass (Figure 4C) indicating it also had the highest productivity. The other stations along the river-gradient had similar abundance and biomass. Typically, there is higher diversity in the more saline stations (Figure 4D), and this was true except for October 2009 when Station A and D had the same diversity values when salinity was the highest throughout the year. When salinity decreased during the wetter winter and spring period, abundance increased in all stations (Figures 4A and 4B).

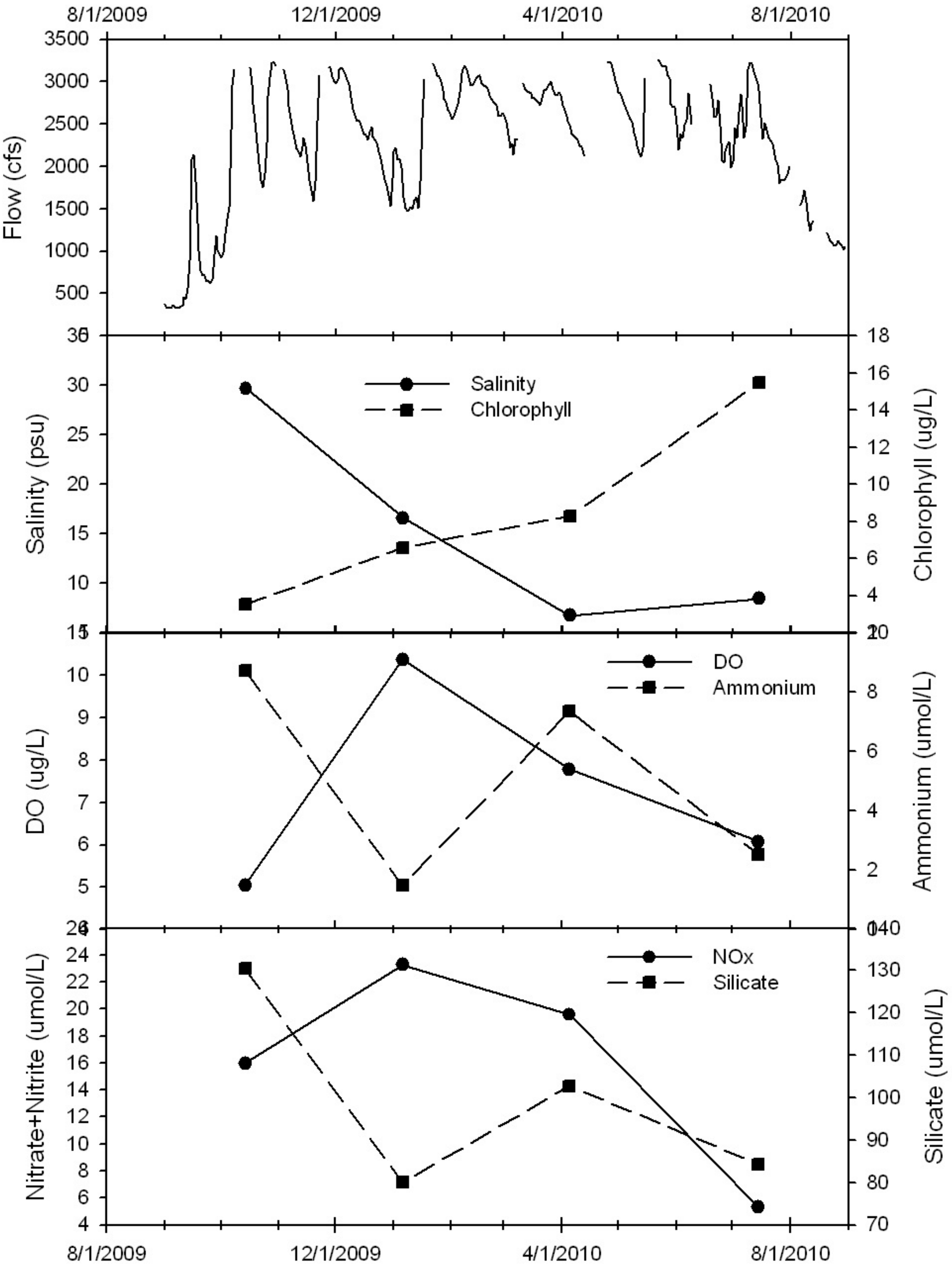

Figure 3. Flow and water quality during sampling year. Inflow at gage USGS 08188800 Guadalupe River near Tivoli, TX and water quality parameters during sampling periods.

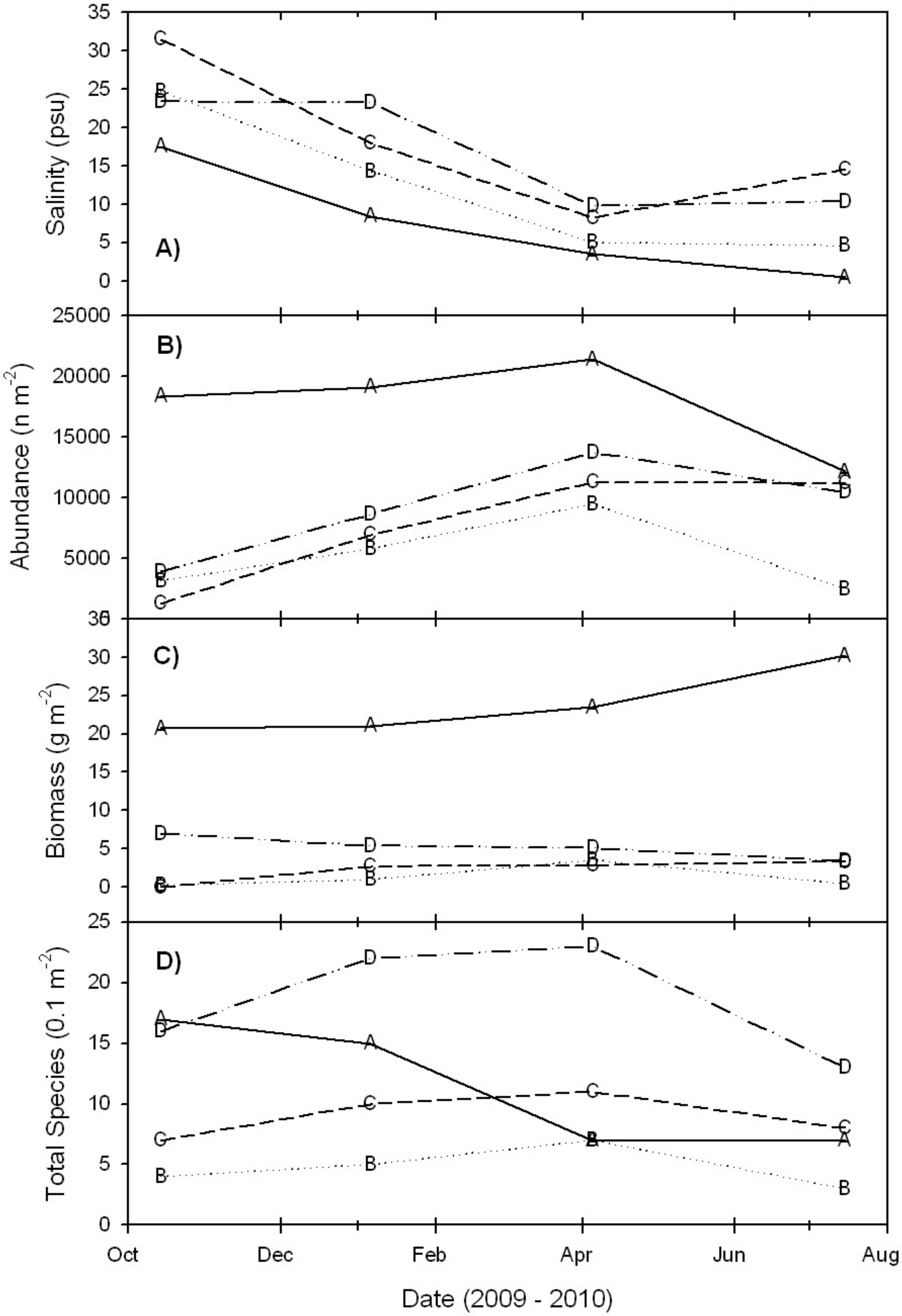

Figure 4. Macrofauna characteristics by station over the sampling period. Subfigures: A) Salinity, B) Abundance, C) Biomass, and D) Diversity.

There were a total of 53 species found over the year (Table 3). The capitellid polychaete *Mediomastus ambiseta* was the most abundant species overall and especially dominant at station A. However, it was not dominant at stations B and C, where the bivalve *Mulinia lateralis* was the most abundant. Overall, *M. ambiseta* made up 44 % of the total number of organisms found. *Mulinia* made up 20% of the organisms, and another polychaete *Streblospio benedicti* made up 15% of the organisms. Together the three most dominant species made up 79% of all organisms found. *Streblospio* was the second most abundant species at station A. The clam, *Rangia cuneata*, was rare, and only occurred in station A.

Macrofaunal 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. Macrofaunal communities at Station A in 2010 were significantly different from any other communities, but station A in Oct 2009 was similar to the transition communities. Three different macrofauna communities occur at Stations A in 2010 (left of MDS plot), Stations B and C (top-right of MDS plot), and Station D (bottom-right of MDS plot). During the sampling period, salinities were lower at Stations A, B, C, and D respectively. The inclusion of Station A in the transitional group in October 2009 is indicative of the dry period at the beginning of the sampling period. Station D in July 2010 was also included in the transition community group.

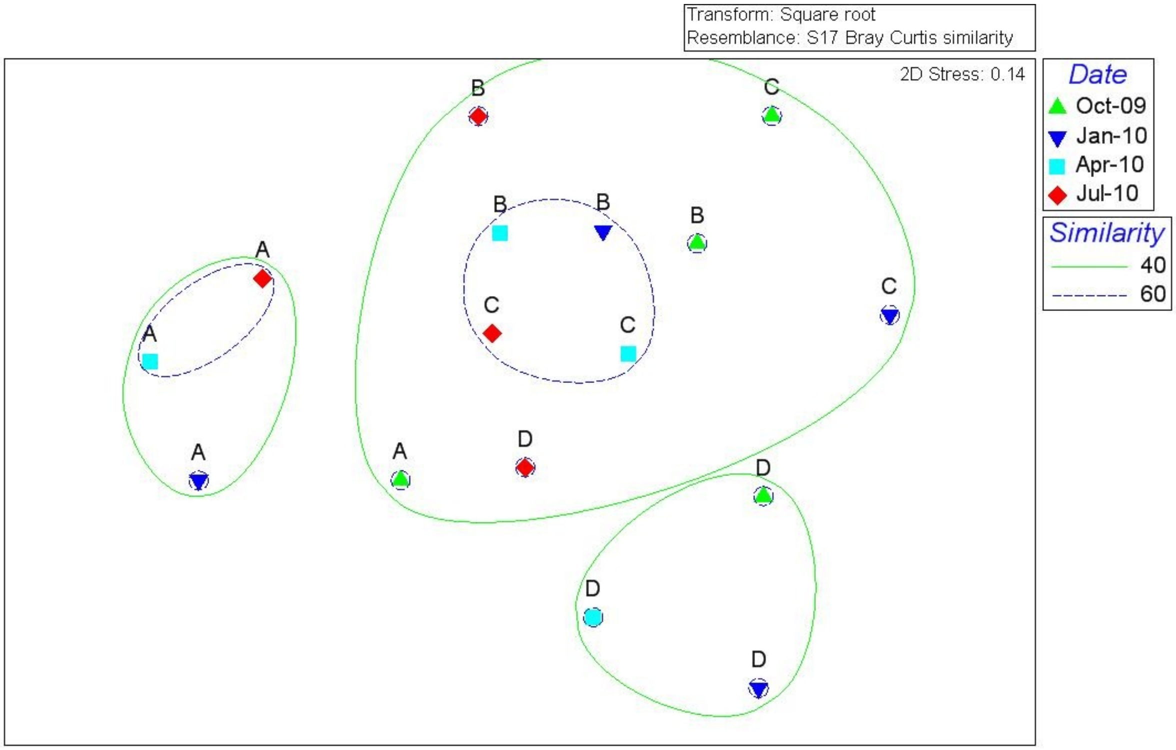

Figure 5. Multidimensional Scaling plot of macrofaunal community structure symbolized by date and labeled by station. Lines indicate percent similarity of samples from a cluster analysis.

Table 3. Species dominance and occurrence at stations in Guadalupe Estuary. Average abundance over time (n m^{-2}).

	Station				
Species Name	**A**	**B**	**C**	**D**	**Mean**
Mediomastus ambiseta	10,471	1,702	2,080	3,333	4,396
Mulinia lateralis	520	2,435	3,782	1,040	1,944
Streblospio benedicti	4,538	733	567	213	1,513
Ampelisca abdita	47	24	213	685	242
Parandalia ocularis	473	-	-	95	142
Glycinde solitaria	71	71	71	284	124
Spiochaetopterus costarum	-	-	24	449	118
Hemicyclops sp.	118	-	-	331	112
Hobsonia florida	425	-	-	-	106
Haploscoloplos foliosus	-	-	213	213	106
Nemertea unidentified	71	-	47	284	100
Clymenella torquata	-	-	-	378	95
Aligena texasiana	-	-	-	355	89
Paraprionospio pinnata	47	24	165	71	77
Macoma mitchelli	95	71	71	47	71
Acteocina canaliculata	-	95	71	95	65
Cyclaspis varians	-	-	95	165	65
Polydora caulleryi	-	-	-	213	53
Balanus eburneus	189	-	-	-	47
Gyptis vittata	-	24	71	47	35
Caprellidae unidentified	118	-	-	-	30
Rangia cuneata	118	-	-	-	30
Turbonilla sp.	-	-	-	118	30
Ischadium recurvum	95	-	-	-	24
Oxyurostylis sp.	-	-	71	24	24
Nuculana acuta	-	-	-	95	24
Oligochaeta unidentified	71	-	-	-	18
Eulimastoma sp.	-	-	71	-	18
Cossura delta	-	-	-	71	18
Polydora ligni	47	-	-	-	12
Texidina sphinctostoma	24	24	-	-	12
Pectinaria gouldii	24	-	24	-	12
Monoculodes sp.	24	-	-	24	12
Anthozoa unidentified	-	-	-	47	12
Capitella capitata	-	-	-	47	12
Ceratonereis irritabilis	-	-	-	47	12
Nereididae unidentified	-	-	-	47	12
Pinnixa sp.	-	-	-	47	12
Amygdalum papyrium	24	-	-	-	6
Cerapus tubularis	24	-	-	-	6

	Station				
Species Name	**A**	**B**	**C**	**D**	**Mean**
Corophium louisianum	24	-	-	-	6
Eupomatus protulicola	24	-	-	-	6
Grandidierella bonnieroides	24	-	-	-	6
Neanthes succinea	24	-	-	-	6
Allothyone mexicana	-	-	-	24	6
Cyclopoida commensal	-	-	-	24	6
Glycera americana	-	-	-	24	6
Isolda pulchella	-	-	-	24	6
Lyonsia hyalina floridana	-	-	-	24	6
Phoronis architecta	-	-	-	24	6
Sabellidae unidentified	-	-	-	24	6
Sarsiella texana	-	-	-	24	6
Sipuncula unidentified	-	-	-	24	6
Tellina sp.	-	-	-	24	6
Turbellaria unidentified	-	-	-	24	6
Xenanthura brevitelson	-	-	-	24	6
Number of species	26	10	16	40	56
Total	17,727	5,200	7,635	9,147	9,927

Benthic data has been collected in the Guadalupe Estuary since 1987 (Figure 6). The period from October 2009 through July 2010 was one of the drier periods in the record as indicated by high estuary-wide average salinities. The other periods when salinities were equally as high were 1988-1991, and 1997-1998. There has been a long-term decline in abundance over the entire range of sampling dates. Biomass has fluctuated, generally being high biomass during high salinity periods. The biomass was relatively average over the sampling period compared to the long-term trends. Diversity also fluctuates with salinity, being higher during high salinity periods.

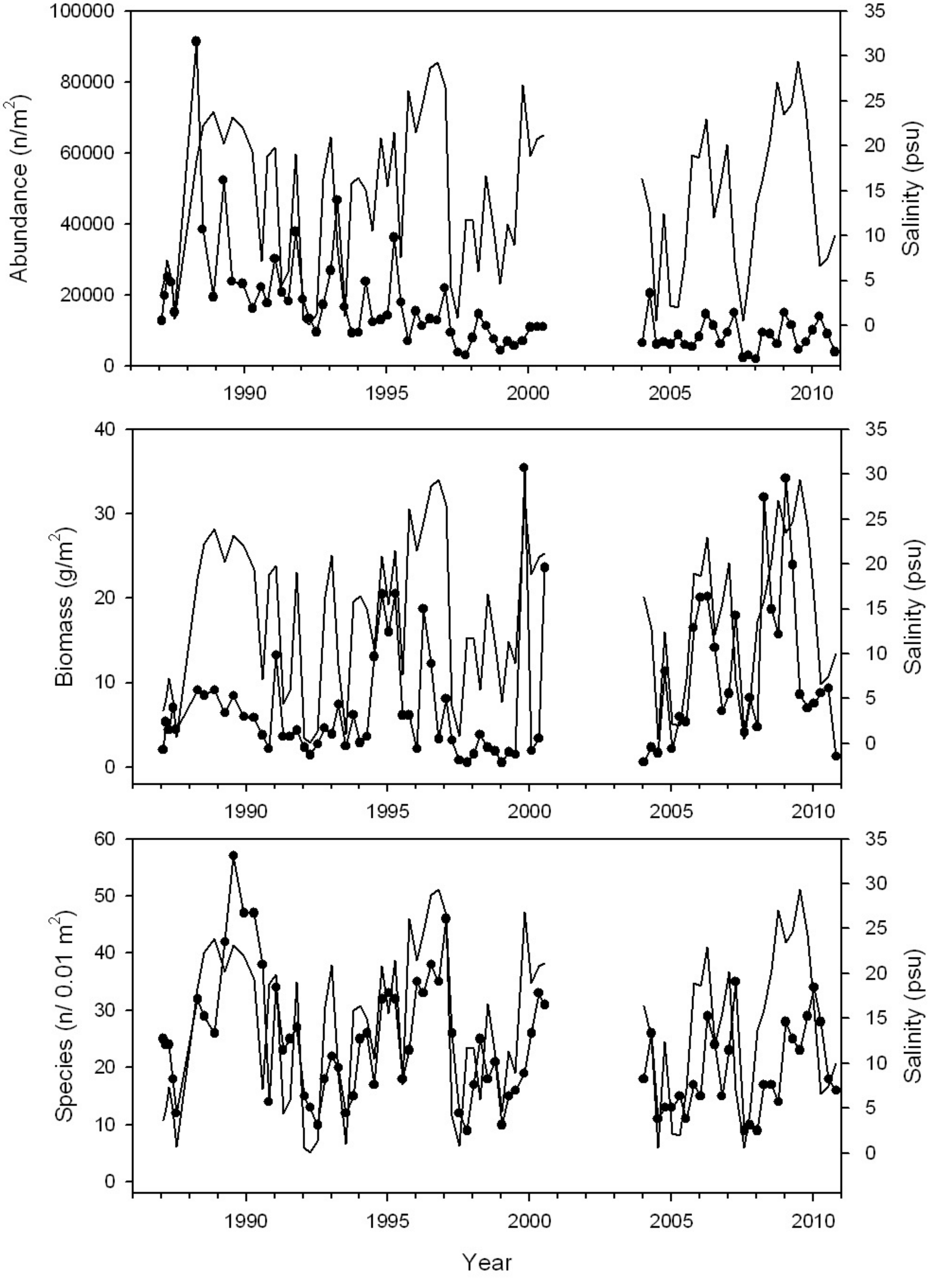

Figure 6. Long-term change in estuary-wide, average, biomass (with dots for each sample) and salinity (continuous line).

DISCUSSION

Overall water quality trends of station-date combinations separate stations both by season and by amount of freshwater inflow that each station receives (Figures 2 and 3). 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 dry period to a wet period.

There is a clear difference between macrofauna communities in environments with low salinities(Station A) and macrofaunal communities at stations with high salinities(Station D). In many years, there are gradients where Stations A and B are similar and Stations C and D are similar, but during the current period, Stations B and C represented a transition from river to marine influence. Freshwater inflow into Guadalupe Estuary travels southeast 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 4). The macrofauna community at station C is an intermediate community between the communities of the upper stations (A and B) and the community at station D because station C is located on the southwestern side of the estuary whereas station D is located on the southeastern side. This intermediate community occurs at station C despite station D being closer to the Guadalupe River mouth than station C.

It is also apparent that macrofauna abundance and biomass reacted positively to increases in inflow as it is indicated by decreases in salinity. The reaction of abundance to salinity over this October 2009 to April 2010 period is especially strong. Biomass increased only at Station A. Diversity typically increases during high salinity periods because of invasion by marine species, thus it decreases during fresher periods as indicated by the trend frm January 2010 to July 2010.

There has been a lot of interest lately in whether or not the bivalve *Rangia cuneata* can be used as indicator species of freshwater inflow. This is because *R. cuneata* usually occurs at lowers salinities (0- 15 psu; Montagna et al. 2008, Swingle and Bland 1974), but is known to tolerate salinities up to 33 psu in the laboratory (Bedford and Anderson 1972). In fact, *Rangia* occurrence in San Antonio Bay is nearly restricted to Station A, which has a long-term average salinity of 8.3 (Table 4). During early 2009 there was a very large cohort of *Rangia* clams at station A (Montagna and Palmer 2009). This cohort increased in size until January 2010, when a large flood event lowered dissolved oxygen to hypoxic conditions (0.9 mg/L at Station A) and they all died. This interaction between low salinities and low dissolved oxygen has the potential to confound responses of indicator species. However, over the long-term, *Rangia* abundances are very low (or zero) during times when salinity is high, and they bloom during wet periods (Figure 7).

Table 4. Average abundance (n/m^2)of *Rangia cuneata* from San Antonio Bay stations over the period January 1987 through July 2010.

	Abundance	Salinity	Temperature	D.O.
Station	Mean (STD)	Mean(STD)	Mean(STD)	Mean(STD)
A	389 (692)	8.3(7.7)	22.7(6.5)	8.3(2.0)
B	21 (82)	12.8(8.6)	22.2(6.7)	8.1(2.2)
C	6 (443)	17.3(9.6)	22.2(6.7)	7.9(1.8)
D	1 (11)	18.3(9.5)	22.3(6.5)	7.9(1.7)

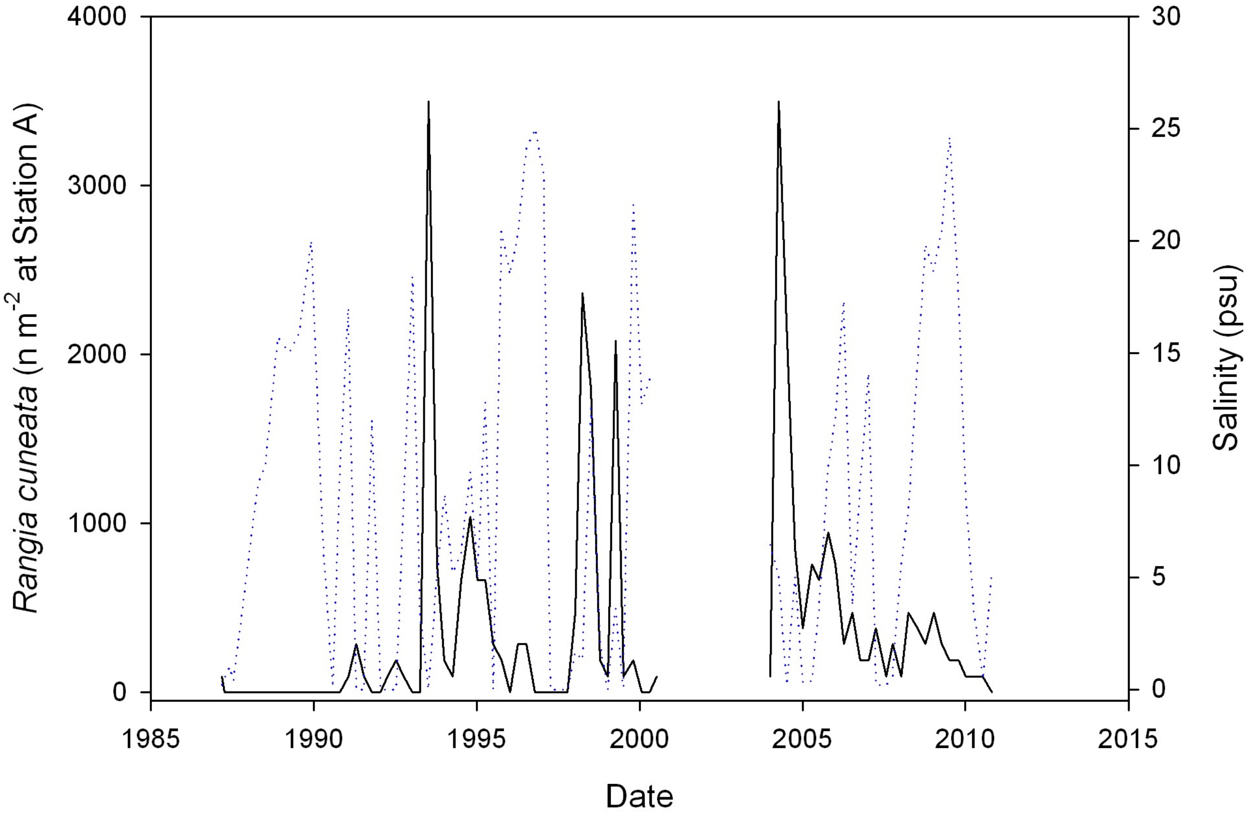

Figure 7. *Rangia cuneata* abundance at station A in San Antonio Bay over time (black solid line) and salinity over time at station A (blue dotted line).

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Texas Water
Development Board

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February 17, 2011

Paul A. Montagna, Ph.D.
Texas A&M University - Corpus Christi
Harte Research Institute for Gulf of Mexico Studies
6300 Ocean Drive, Unit 5869
Corpus Christi, Texas 78412

Re: Research Grant Contract between the Texas Water Development Board (TWDB) and the Texas A&M University at Corpus Christi (TAMU-CC); TWDB Contract No. 1004831015, Draft Report Comments

Dear Dr. Montagna:

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, the TAMU-CC will consider incorporating draft report comments from the EXECUTIVE ADMINISTRATOR as well as other reviewers into the final report. In addition, the 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. The 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

Effect of Freshwater inflow on macrobenthos productivity in the Guadalupe Estuary

P.I. Paul Montagna
Contract # 1004831015
TWDB comments to Draft Report

REQUIRED CHANGES

General Draft Final Report Comments:

This study scope of work focused on collecting and assessing benthic community data in the Guadalupe Estuary. The ultimate goal of this effort is to provide data for calibrating a benthic productivity model which will estimate biological productivity in this estuary as a function of freshwater inflow. Although model calibration was not part of this study, the data collection and continued information about benthic community trends, water quality data, and nutrient data in this estuary is valuable for use in long-term understanding of freshwater inflow effects on estuaries.

Specific Draft Final Report comments:

1. Introduction and Methods: The report aims to relate benthic community structure with freshwater inflow, but the study does not explicitly test against measures of freshwater inflow (*e.g.*, volume, *etc.*), but rather relates benthic structure to salinity and other nutrient parameters which indicate inflows. Please explain in the introduction and conclusion why freshwater inflow is not evaluated as an independent variable, either against the benthic data or the water quality and nutrient parameters, in analyses. Also, please be sure to present results in the same manner.

2. Introduction, page 1, 1st ¶: Please make the distinction that the Basin and Bay Area Expert Science Teams (BBEST) are the groups to establish environmental flow recommendations for bay and estuary inflows, and that the Basin and Bay Area Stakeholder Committees (BBASC) are charged with balancing environmental needs with the need for water for human uses.

3. Results, page 6, 2nd ¶: Please correct all references to Figures 4a-4d to read, Figures 3a-3d.

4. Results, page 6, 2nd ¶, 2nd sentence: Please correct that the four stations are A through D, not A through B.

5. Results, page 8, 1st ¶, 3rd sentence: Please add a space to change "Band C" to "B and C".

6. Discussion, page 12: The first statement of the discussion assumes water quality trends are related to freshwater inflow in the estuary, but the analyses in the report do not specifically test their relation to volumes of freshwater inflow. Instead, it is recommended to present the result as being a function of the proximity to the source of inflow or as a function of other measures which are related to freshwater inflow.

7. Discussion, page 12, 2nd ¶: Please provide a reference or other evidence to support the statement that the western portion of the estuary tends to be fresher than the eastern portion, based on bay circulation. Or, please present the results as providing support for this theory.

Figures and Tables Comments:

1. Results, page 6: Table 2. Please clarify the table caption to better explain whether the values in the table represent top or bottom samples at each station or if the value is a mean ± s.d. for each station. As written, the caption describing the standard deviation is confusing.

2. Results, page 13: Figure 5. It is unclear which line represents the biomass and salinity.

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1. Introduction, page 1: Consider expanding the Introduction to discuss how long-term hydrological cycles affect water quality and regulate benthic abundance, productivity, diversity, and community structure in terms of general trends as demonstrated by past studies.

2. Methods, page 3: Please consider explaining the logic behind the log transform chosen for the community structure data before the MDS.

3. Results, page 6, 2nd ¶, last sentence: It is stated that the wetter winter and spring period was correlated to increasing abundance and biomass in all stations; however, biomass does not appear to increase in stations B or D, and only very slightly at Station C. Please provide statistics that show an increasing and significant trend at these stations; otherwise, consider revising the statement.

4. Results, page 10: Please consider discussing the shift of Station D in July 2010 to be similar to the transition communities.