EFFECT OF SALINITY CHANGES ON THE MACROFAUNA SPECIES OF THE UPPER RINCON BAYOU, TX

A Thesis

By

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Abstract

EFFECT OF SALINITY CHANGES ON THE MACROFAUNA COMMUNITY OF UPPER RINCON BAYOU, TX

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Decreased freshwater inflow due to damming of the Nueces and Frio Rivers has increased salinity in Nueces Bay, caused Rincon Bayou to become a reverse estuary, and disturbed the overall hydrology of Corpus Christi Bay. Adaptive management began in 1994 and continues today in an effort to restore historical hydrology. The objectives of this study are to determine to what extent salinity fluctuates within Rincon Bayou and what effects these fluctuations have on estuary health. Benthic macrofauna are ideal indicators of ecological effects because of their relative immobility and longevity in contrast with plankton of comparable size. Samples were collected from the upper Rincon Bayou near Corpus Christi, TX and analyzed alongside archived samples. One historical station was sampled biweekly. Conductivity, temperature, and salinity were monitored continuously. Additional water quality measurements were taken during sampling events. Macrofauna biomass, abundance, and diversity were measured. Large and haphazard salinity fluctuations resulted in a frequently disturbed system populated by pioneer species, such as *Streblospio benedicti*, during Mesohaline and Euhaline+Hyperhaline conditions. These results indicate that further changes need to be made to the Rincon Bayou restoration and management programs in order to reestablish a reasonably undisturbed ecosystem.

Table of Contents

List of Figures

List of Tables

Introduction

The Wesley Seale Dam was built on the Nueces River in 1958 and the Choke Canyon Dam was built on the Frio River in 1982 (Figure 1) (Montagna et al. 2002). Stream flow to the Nueces Delta has decreased by 99% since the building of the Wesley Seale Dam (Asquith et al. 1997). Decreased flow has increased salinity in Nueces Bay and Rincon Bayou resulting in a reverse estuary, where salinity is higher upstream than downstream, disturbing the overall hydrology of the estuary (Palmer et al. 2002). The Nueces Overflow Channel and Rincon Overflow Channel were built in 1995 by the U.S. Bureau of Reclamation in an effort to restore ecological value to the bayou by allowing increased freshwater inflows to the area (Montagna et al. 2002). The channels were intended to reduce the flooding threshold from the Nueces River to Rincon Bayou from 1.64 meters above sea level to zero (Palmer 2002). The Nueces Overflow Channel was closed in September 2000, but reopened in October 2001 (Ward et al. 2002).

Only one inflow event in September of 1998 restored normal a salinity gradient to the estuary. During this event $5{,}092 \times 10^6 \mathrm{m}^3$ of freshwater runoff was diverted through the Rincon Overflow Channel. The effects of the altered freshwater inflows on benthos via the channels reached six kilometers downstream, but failed to restore natural freshwater and salinity patterns to the lower reaches of the bayou or in Nueces Bay (Palmer et al. 2002). However, within the affected area, organismal response to moderate inflow was positive, producing higher abundance, diversity, and biomass of benthic macrofauna (Montagna et al. 2002). Following floods, pioneer species, such as *Streblospio benedicti*, were found in high abundance indicating that Rincon Bayou is likely an area of high disturbance following floods (Palmer et al. 2002, Ritter et al. 2005, Connell and Slayter

1977). In fact, Rincon Bayou is likely in a constant state of early to intermediate succession because of the highly variable environmental conditions, including artificial freshwater inflows (Ritter et al. 2005). This would indicate that Rincon Bayou is in a constant state of disturbance.

Reduced diversity and an increase in smaller pioneering species is an indicator of early stages of disturbance (Rhoads et al. 1978, Pearson and Rosenberg 1978). Thus one would expect that a graphical representation where species rank (i.e., dominance) is related to high biomass would also represent the early stages of succession, and this is what the abundance, biomass comparison (ABC) method attempts to portray (Clarke and Warwick 1994). The ABC graph is a combination of two k-dominance curves, biomass and abundance, in which the log of species rank is plotted against cumulative ranked abundance or biomass, expressed as a percentage of the total abundance or biomass. The ABC method, therefore, provides a greater depth of understanding than a simple diversity index by retaining species specific data (Clarke 1990).

It is possible that reducing the great fluctuation in flow could help improve the ecological state of Rincon Bayou. The Calallen Saltwater Barrier Dam, and its resulting reservoir the Calallen Pool, were constructed in 1898 to prevent tidal salt water from in the fresh water of the Nueces River (Barajas 2011, Sugarek 2003). To improve hydrological conditions in Rincon Bayou, a pipeline, running from the Calallen Pool to Rincon Bayou, and pumping station were completed in fall 2008 but first used in fall 2009. The pumping provides additional freshwater inflows into Rincon Bayou that do not depend upon overflow from the Calallen Saltwater Barrier Dam (Adams and Tunnell 2010). Salinity and benthos were monitored for one year after initial pumping began, but that study was performed during a relatively wet period; average salinity was 17 psu from between 28 September 2009 and 11 August 2010 (Barajas 2011). Because salinity did not vary much during this study period, there was little correlation between abundance and species composition to salinity. Thus, the optimal pumping strategy to produce salinity ranges that would improve the ecology of Rincon Bayou and the surrounding systems is unknown.

The purpose of the current study is to determine the effect of salinity changes on benthic macrofauna. Benthic organisms have been especially useful in environmental research for several reasons:

> 1) benthos are usually the first organisms affected by pollution, 2) because of gravity, everything ends up in bottom sediments, 3) materials from watersheds and freshwater will be transported downstream to the coastal sea bottoms, 4) everything dies and ends up in the detrital food chain, which is utilized by the benthos, 5) pollutants are usually tightly coupled to organic matrices, therefore benthos have great exposure through their niche (food) and habitat (living spaces) to pollutants, 6) benthos are relatively long-lived and sessile, so they integrate pollutants effects of over long temporal and spatial scales, 7) benthic invertebrates are sensitive to change in environmental conditions and pollutants in particular, thus biodiversity loss is an excellent indicator of environmental stress, and 8) bioturbation and irrigation of sediments by benthos effect the mobilization and burial of xenobiotic materials (Montagna et al. 2013).

The approach used here is to relate samples of water quality and benthic macrofauna response to salinity and inflow.

Freshwater inflows into Rincon Bayou dilute saline water and reduce salinity, but pumping only occurs as a required pass-through when freshwater is available to flow into the bay system. Salinity decreases in Rincon Bayou within days when the river flows or pumping begins (Adams and Tunnell 2010, Barajas 2011), so salinity is a proxy for inflow. Thus the focus here is to use salinity, which changes with total inflow into Rincon Bayou (i.e., pumping events plus natural inflows), as a driver of benthic community dynamics.

Disturbance and succession theory predicts that diversity is lower in disturbed systems. This will be tested using the ABC method, which is a variant of the k-dominance method for detecting disturbance. New samples were collected for one year from the upper Rincon Bayou and added to a time series of archived samples. The relationship between salinity and benthic metrics were analyzed to determine the effects of salinity changes on the abundance, biomass and diversity of benthic macrofauna. Biomass was measured at the species level so that species-specific responses could be observed and evaluated using ABC curves.

Materials and Methods

Site Description

The study took place in Rincon Bayou near Corpus Christi, Texas, USA (Figure 1). Rincon Bayou flows east from the Nueces River to Nueces Bay and is the main stem of the Nueces Marsh. The two main sources of freshwater input to Rincon Bayou are the Nueces River Overflow channel and the Calallen pump station that pumps water from the Calallen Pool directly into Rincon Bayou. Station C (27.89878° N, -97.60417° W), sampled since 1994 (Montagna et al. 2002), was sampled for this study (Figure 1).

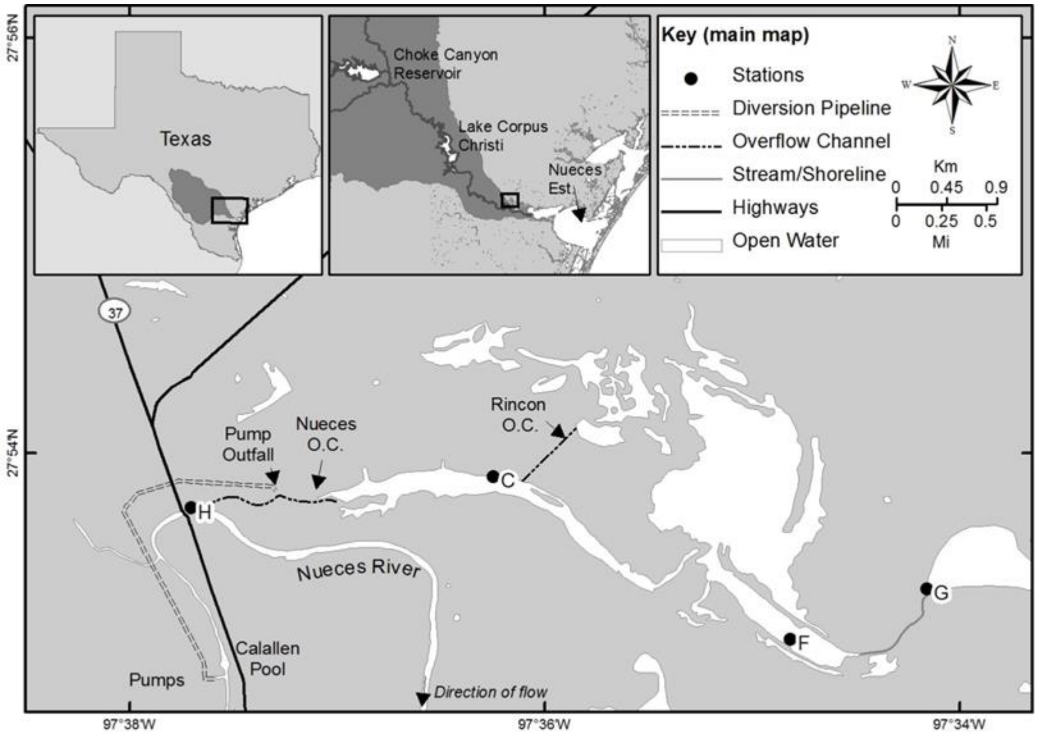


Figure 1. Map of study area.

Station C is near to the pump outfall and overflow channel in the upper Rincon Bayou and has been shown to be the most affected by previous attempts to restore freshwater inflow to the area (Palmer et al. 2002). The site is surrounded by dense shrubbery and grasses that grow to the shoreline. Clay and mud dominate the substrate.

Sampling Methods

Macrofauna samples were collected using a 6.7-cm diameter benthic core (area=35.23 cm^2). Three replicates were taken by hand at each station. The cores were divided into 0-3 cm and 3-10 cm vertical sections and preserved in 5% buffered formalin. Samples were washed through a 500 micron steel sieve and sorted under a dissecting microscope to the lowest taxonomic level possible. Specimens were stored in 75%

ethanol until biomass measurements were performed. Organisms were grouped by species and placed on pre-weighed aluminum pans and dried in an oven for a minimum of 24 hours at 55 °C. Weight was recorded to the nearest 0.01 mg. Specimens weighing less were assigned a weight of 0.01 mg. Weights were divided by number of organisms to obtain individual weights. Mollusk shells were dissolved in 1 N HCL prior to biomass measurements.

Archived Samples

Archived benthic samples from previous collections in Rincon Bayou were used in addition to new samples collected during the present study period. A total of 21 archived samples (i.e., 3 replicates for 7 sampling dates) from Station C were processed for the following dates: May 2010, June 2010, January 2011, April 2011, July 2011, July 2012, and October 2012. These samples were analyzed using the previously described method.

New Samples

Samples were taken biweekly from 25 October 2013 through 27 April 2015 at station C. Benthic samples have been collected at different sampling frequencies since 1994 (Table 1). The original method was to take samples quarterly and measure biomass by major taxa level only (Montagna et al. 2002). For the purposes of the current study, biomass was measured at the species level, or lowest taxonomic level possible. This species level biomass measurement was performed on the archived samples and samples collected since October 2012.

Table 1
Sampling periods and protocol differences for archived and new samples.

Study Period	Period Between Observations	Biomass Method
Oct 1994 – Oct 2008	Quarterly	Taxa
Jan 2009-Sept 2010	Monthly	Taxa
Oct 2010-Oct 2013	Quarterly	Taxa
Nov 2013-present	Biweekly	Species

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 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 : temperature, pH, dissolved oxygen, depth, and salinity (psu). Conductivity, temperature, and salinity were measured hourly from 10 December 2013 to 27 April 2015, using two YSI 600LS sondes. One sonde was deployed at a time and replaced during biweekly sampling. The sondes were mounted on frames constructed from PVC pipe and deployed at the site so that the sonde sensors were approximately seven centimeters above the substrate. Recovered sondes underwent post-deployment calibrations and cleaning upon returning to the lab. Calibrations were made using known standards for pH, conductivity, salinity, depth, turbidity, and dissolved oxygen (DO) concentration and percent saturation.

Chlorophyll samples were filtered onto glass fiber filters and placed on ice (<4.0 EC). Chlorophyll was extracted overnight and read fluorometrically on a Turner Model 10-AU using the non-acidification technique (Welschmeyer, 1994).

Nutrient samples were filtered to remove biological activity (0.45 µm polycarbonate filters) and placed on ice. Water samples were analyzed at the Harte Research Institute using a OAI Flow-4 autoanalyzer with computer controlled sample selection and peak processing.

Data Analysis

Database programming, calculations, and statistical analyses were performed using SAS 9.4 software (SAS Institute Inc. 2013, SAS Institute Inc. 2010) and PRIMER-e software (Clarke and Gorley 2006). Diversity was calculated using Hill's N1 diversity (Hill 1973), which is a measure of the effective number of species in a sample, and indicates the number of abundant species. It is calculated as the exponential form of the Shannon diversity index, H'. As diversity decreases N1 will tend toward 1. H' is the average uncertainty per species in an infinite community made up of species with known proportional abundances (Shannon and Weaver 1948). Richness is an index of the number of species present, which is simply the total number of all species found in a sample regardless of their abundances. Hill (1973) named the richness index N0. Evenness was calculated using Pielou’s evenness index (Pielou 1975) which indicates the how numerically equal the species are within the community.

Correlations were calculated using the Pearson product-moment correlation which determines the strength of linear relationships between variables. PROC CORR was used to calculate the Pearson product-moment correlation coefficients and probabilities for Hill’s N1 diversity, Pielou’s evenness index, biomass, and abundance.

Multivariate analyses were used to analyze how the physical-chemical environment changes over time. The water quality variables were 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.

Benthic community structure of macrofauna species was analyzed in PRIMER-e software by non-metric multidmensional scaling (MDS) and cluster analysis using a Bray-Curtis similarity matrix (Clarke and Warwick 1994). Prior to analysis, the data was natural logarithm 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 date. The distance between station-date combinations can be related to community similarities or differences between different dates. 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.

The abundance/biomass comparison (ABC) method was used to assess community response during different salinity periods. This method allows for the comparison of ranked species abundance and biomass versus an environmental variable, such as salinity, despite differing units of measurement (Clarke and Warwick 1994).

Table 2
The Venice System for salinity classification. a) Coastal modifiers are used in the marine and estuarine systems. b) Inland modifiers are used in the riverine, lacustrine, and palustrine systems. c) The term "Brackish" should not be used for inland wetlands or deepwater habitats.

Coastal Modifiers[a]	**Inland Modifiers**[b]	**Salinity (‰ or psu)**	**Specific Conductance (µMhos at 25°C)**
Fresh	Freshwater (Limnetic)	<0.5	<800
Oligohaline	Oligosaline	0.5-5.0	800-8,000
Mesohaline	Mesosaline	5.0-18.0	8,000-30,000
Polyhaline	Polysaline	18.0-30.0	30,000-45,000
Euhaline	Eusaline	30.0-40.0	45,000-60,000
Hyperhaline	Hypersaline	>40.0	>60,000
Mixohaline (Brackish)	Mixosaline[c]	0.5-30.0	800-45,000

Only species specific biomass data can be used. First the salinity data for the entire period from January 2009 to April 2015 was classified into four classes based on a modified Venice System (Table 2, Cowardin et al. 1979, Venice 1959). Attemepts to use the unmodified Venice System produced inconclusive results. The modified Venice classes represent Fresh+Oligohaline, Mesohaline, Polyhaline, and Euhaline+Hyperhaline conditions, and were applied to the data using PROC RANK. Then, the overall average abundance and biomass was calculated for each species for each class. The cumulative abundance and biomass were then ranked by species dominance using SAS programming and PROCRANK. The ABC plots for each salinity period were created using PROC SGPLOT.

While the ABC method can be helpful in clarifying diversity data it cannot be relied upon as the sole analysis. Dominance curves rely heavily on the ranking of the most dominant species and may fail to accurately represent secondary and succeeding dominant species (Clarke 1990). However, because the total number of species in Rincon Bayou is so low, all the species were used in the ABC analyses presented here.

Results

There were a total of 80 hydrographic sample dates between January of 2009 and April of 2015 (Table 3). Salinity ranged from fresh (0.34 psu) to hyperhaline (57.27 psu). Dissolved oxygen (DO) was never hypoxic (less than 2 mg/L). Water depth ranged from 13 cm to 50 cm.

Several relationships among water quality variables are observed when comparing temporal variations in water quality at Station C (Figure 2). Salinity and chlorophyll concentrations are inversely related to nutrient concentrations (ammonium, nitrate+nitrite, silicate, phosphate) and depth. This salinity-nutrient relationship represents an inflow gradient along principal component axis one (PC1). The PC1 axis represents 35.5% of the variation in water quality among dates. Dissolved oxygen concentrations are inversely correlated to water temperature and pH. This relationship represents seasonal changes and lies along the PC2 axis. The PC2 axis represents 20.3% of the variation in water quality among dates.

Table 3
Summary of all hydrographic measurements using the YSI 6600 at Station C from January 2009 to April 2015 collected during macrofauna sampling.

Variable	N	Mean	Std Dev	Minimum	Maximum
Salinity (psu)	80	14.26	17.11	0.34	79.66
Temperature (°C)	79	22.81	6.36	8.08	32.44
DO (mg/L)	78	8.71	2.26	4.11	17.57
pH	79	8.40	0.27	7.73	9.25
Depth (m)	80	0.18	0.13	0.01	0.50
Turbidity (NTU)	40	111	139	0	750

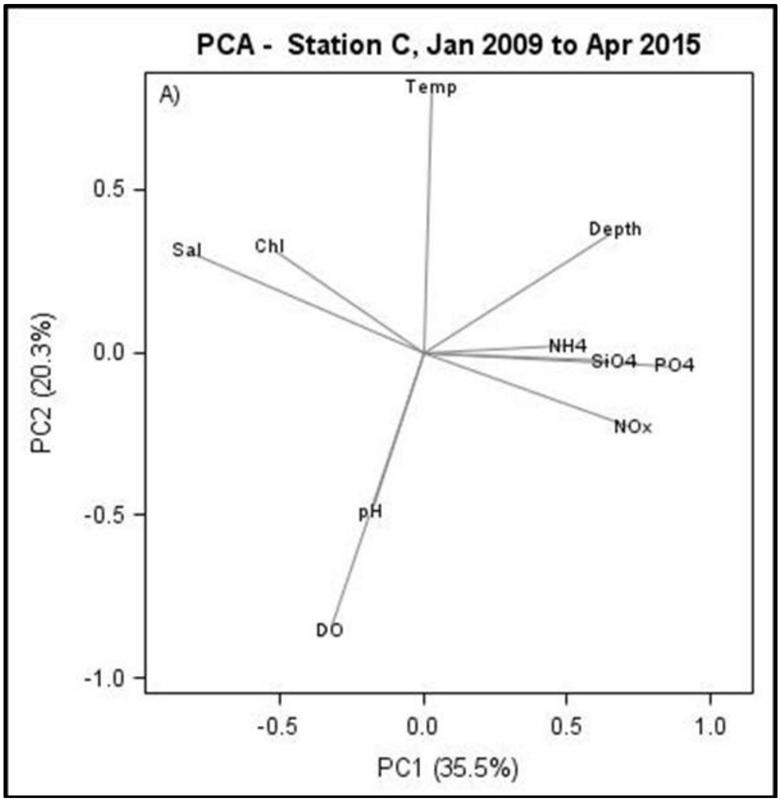


Figure 2. Principal Components Analysis (PCA) of water quality variables from Station C in Rincon Bayou with variable loads.

Pearson correlations of infaunal abundance, biomass and diversity with salinity, and principal components one and two (PC1 and 2) for December 2009 to April 2015. Principle components are derived from principle components analysis (Figure 2).

<table>
<tr><th rowspan="2">Benthic Metrics</th><th colspan="3">Pearson Correlation Coefficients
Prob > |r| under H_0: Rho=0</th></tr>
<tr><th>Salinity</th><th>PC1</th><th>PC2</th></tr>
<tr><td>Abundance (n/m^2)</td><td>0.49368</td><td>-0.36082</td><td>0.05142</td></tr>
<tr><td></td><td><0.0001</td><td>0.0138</td><td>0.7343</td></tr>
<tr><td>Biomass (gm/m^2)</td><td>0.27209</td><td>-0.25759</td><td>-0.33509</td></tr>
<tr><td></td><td>0.0190</td><td>0.0839</td><td>0.0228</td></tr>
<tr><td>Diversity (N1)</td><td>-0.27840</td><td>-0.18337</td><td>0.04751</td></tr>
<tr><td></td><td>0.0163</td><td>0.2225</td><td>0.7538</td></tr>
</table>

Macrofaunal abundance (from December 2009 and April 2015) was positively correlated with salinity and inversely correlated to PC1, the inflow axis (Figure 2, Table 4). This means that macrofaunal abundances were lowest with the highest inflows. Salinity was also positively correlated with macrofaunal biomass and negatively correlated with N1 diversity. PC2, the seasonal axis, was negatively correlated with biomass, meaning that higher biomass was found in cooler months.

Table 5

Correlations between physical and biological variables over 74 sampling periods. Bold values are significant at the 0.05 level.

Pearson Correlation Coefficients

Prob > |r| under H0: Rho=0

Biological Variable

Physical Variable	**R (Total Species)**	**n/m^2 (Abundance)**	**H' (Shannon's Diversity Index)**	**N1 (Hill's Diversity)**	**J' (Pielou's Evenness Index)**	**gm/m^2 (Biomass)**
Depth(m)	-0.2061	-0.25017	-0.10775	-0.15186	0.04536	-0.2958
	0.0781	**0.0316**	0.3608	0.1965	0.7011	0.0105
Temperature(°C)	-0.38558	-0.11545	0.04887	0.04098	0.2903	-0.3242
	0.0007	0.3273	0.6793	0.7289	0.0121	**0.0048**
Salinity(psu)	-0.04418	0.49368	-0.32245	-0.2784	-0.35963	0.27209
	0.7086	**<0.0001**	**0.0051**	**0.0163**	**0.0016**	**0.019**
DO(mg/L)	0.30572	-0.18095	0.21517	0.19673	0.06188	0.07267
	0.0085	0.1255	0.0675	0.0953	0.603	0.5412

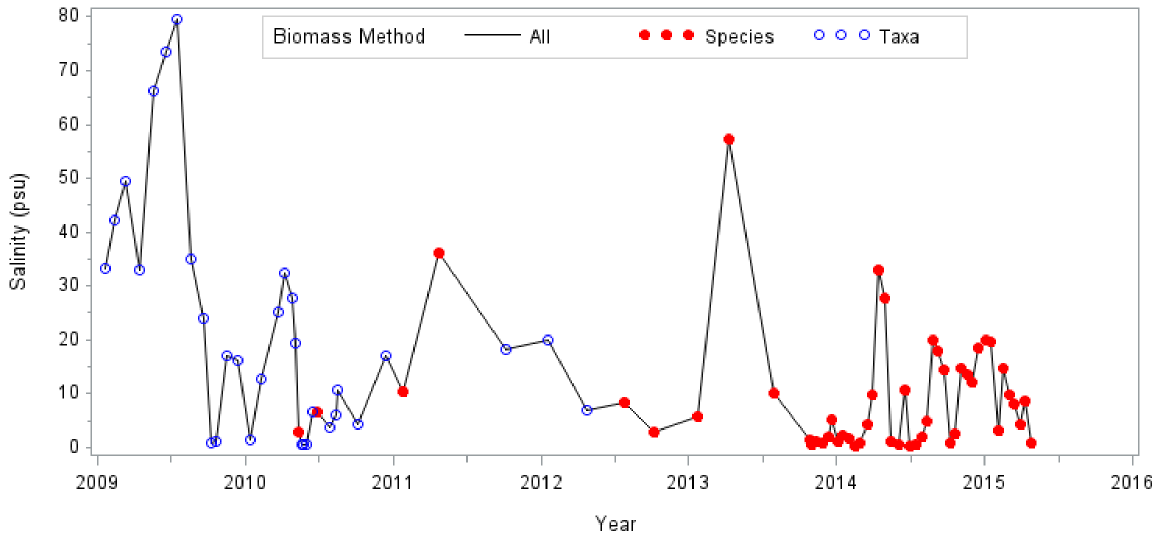


Figure 3. Salinity change in grab samples at Station C over the study period. Red dots are when biomass was measured at the species level, blue circles when biomass was measured at taxa level.

Table 6

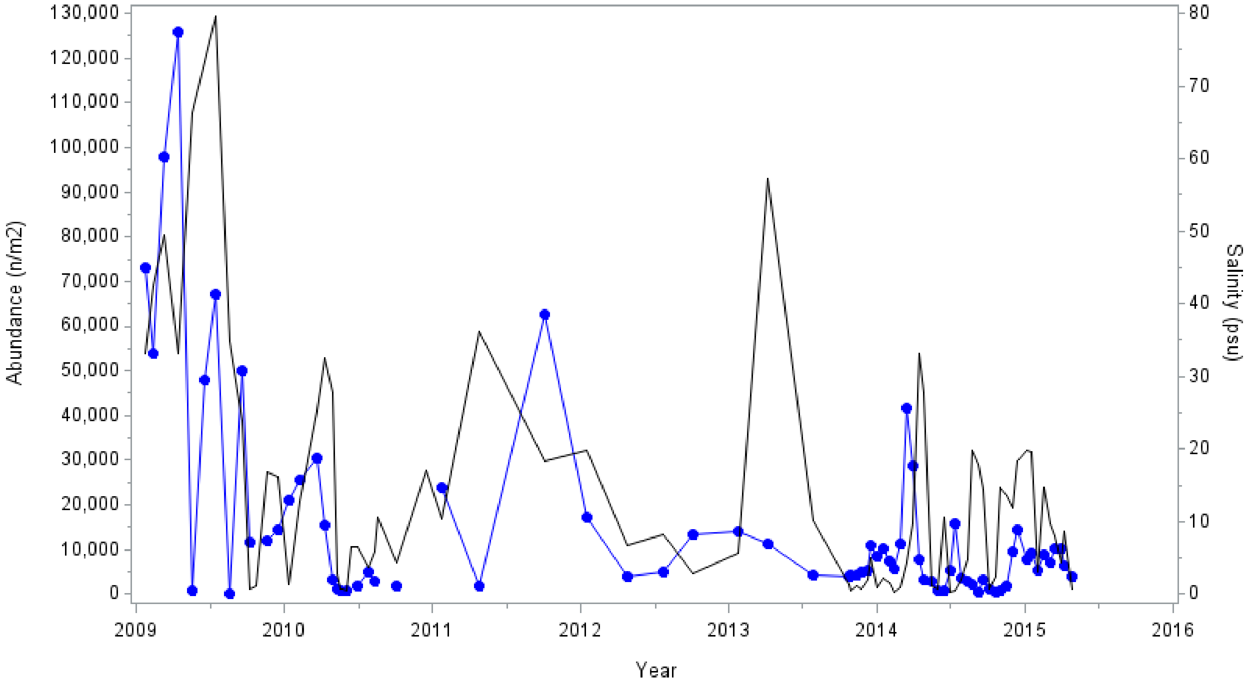
Summary of the mean benthic parameters over 74 sampling periods at all stations.

Variable	Mean	Std Dev	Minimum	Maximum
Abundance (n/m2)	15,081	23,035	284	125,936
Total Species (R)	3.51	1.67	1	10
Diversity (N1)	1.76	0.57	1	3.03
Evenness (J')	0.44	0.29	0	0.99
Biomass (g DryWt/m2)	1.02	1.29	0.02	7.45

Salinity fluctuated over short time frames (i.e., days to weeks) and long time frames (i.e., interannually and seasonally) (Figure 3). Salinity ranged from 0.34 psu to 79.66 psu over the study period (Table 3). Salinity was low with nearly freshwater conditions during eight periods during the study: October 2009, January 2010, May to June 2010, October to November 2013, February 2014, June to July 2014, October 2104, and April 2015. Salinity was very high with hypersaline conditions during three periods: February to March 2009, May to July 2009, and April 2013. An alternation between generally wet and generally dry periods occurred in 2009 to 2010, 2010 to 2011, 2011 to 2013, 2013 to 2014, and in late 2014. Biomass was measured at the species level during a mix of wet, dry and average periods, but not at the most extreme hypersaline conditions in 2009. Salinity within sample dates reached a maximum of 57.27 psu (Figure 3).

The time series of abundance, biomass, diversity, and evenness show that there is a great fluctuation over time for all the metrics of benthic biological response (Figure 4). The benthic abundances in Rincon Bayou are high (Figure 4A), but the biomass (Figure 4B), diversity (Figure 4C) and evenness (Figure 4D) values are relatively low (Table 6).

A)



B)

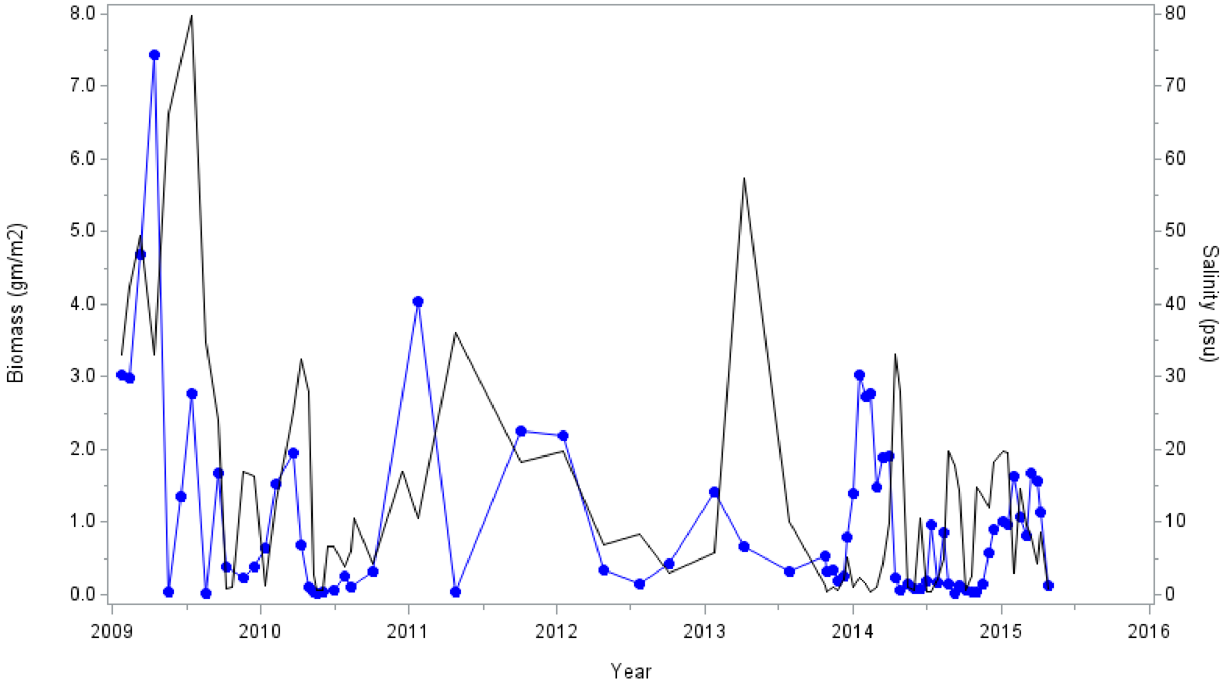
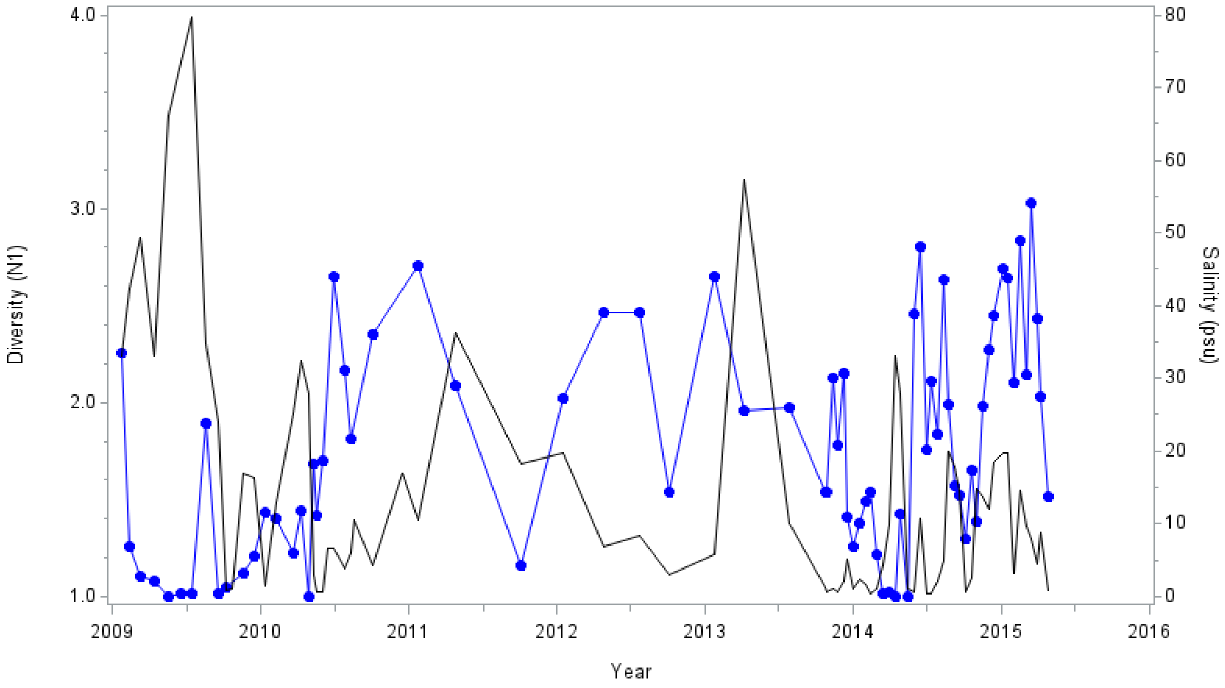


Figure 4. Time series data at Station C with salinity as black line. A) Abundance (n/m^2), B) Biomass (gm/m^2), C) Diversity (N1), D) Evenness (J').

C)



D)

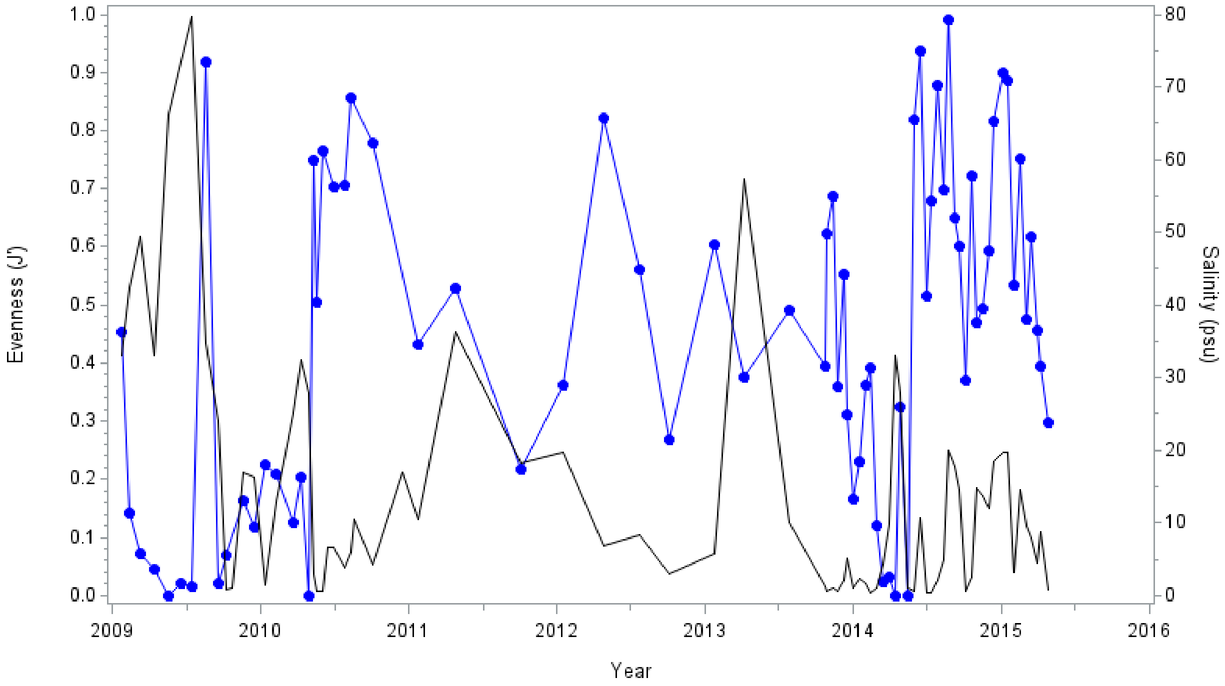


Figure 4. Continued. Time series data at Station C with salinity as a black line. A) Abundance (n/m^2), B) Biomass (gm/m^2), C) Diversity (N1), D) Evenness (J')

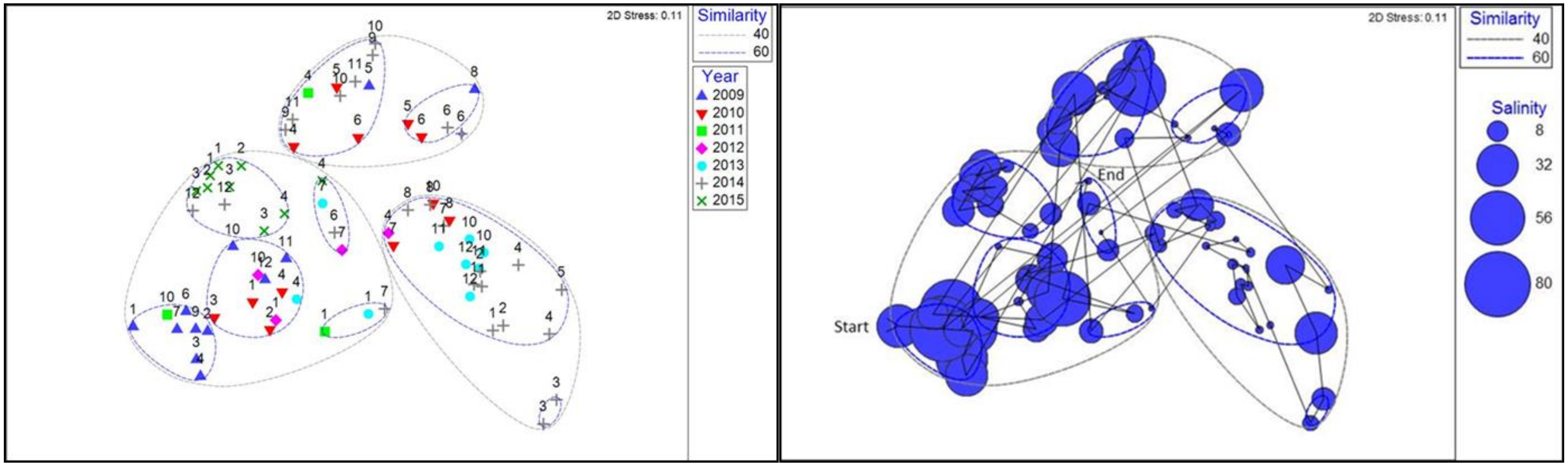


Figure 5. Multidimensional scaling plot of community structure change over time at station C. Left: Symbol labels are months. Right: As it relates to salinity with order trajectory.

Table 7
Modified Venice System values for Station C.

Modified Venice Zones	Number of Samples	Mean Salinity	Standard deviation	Minimum Salinity	Maximum Salinity
Total	49	9.29	11.15	0.34	57.27
Fresh+Oligohaline	24	1.79	1.36	0.34	4.87
Mesohaline	17	10.6	3.53	5.1	17.83
Polyhaline	5	21.1	3.82	18.35	27.84
Euhaline+Hyperhaline	3	42.2	13.2	33.09	57.27

Community structure at station C changed over time (Figure 5). Community structure was 60% similar in most of the years, such as 2009, 2013, 2014, and 2015. These were predominantly high salinity years (Figure 3). When abrupt salinity changes occurred there was abrupt community structure change, such as between August (symbol upper right) and September (symbol lower left) of 2009 when salinity decreased by 44.8 psu (Figure 5). The year 2014 was the most variable because symbols are scattered over the entire MDS space. The spring of 2014 was largely in the lower right, the summer moves to the center, the fall moves to the top.

All of the salinity values from grab samples (Figure 3) were divided into four bins based on a modified Venice System (Table 7). The four salinity periods were: Fresh+Oligohaline with a mean salinity of 9.29 psu, Mesohaline with a mean salinity of 10.6 psu, Polyhaline with a mean salinity of 21.1 psu, and Euhaline+Hyperhaline with a mean salinity of 42.2 psu (Table 7).

The ABC method was applied to the four salinity groups. In Fresh+Oligohaline conditions, biomass and abundance were very similar, indicating moderately disturbed conditions (Figure 6). In Mesohaline conditions, abundance was greater than biomass, suggesting extreme disturbance. In Polyhaline conditions, biomass was greater than abundance, indicating relatively undisturbed conditions. In Euhaline+Hyperhaline conditions, abundance is greater than biomass, as in Mesohaline conditions, indicating extreme disturbance (Warwick 1986).

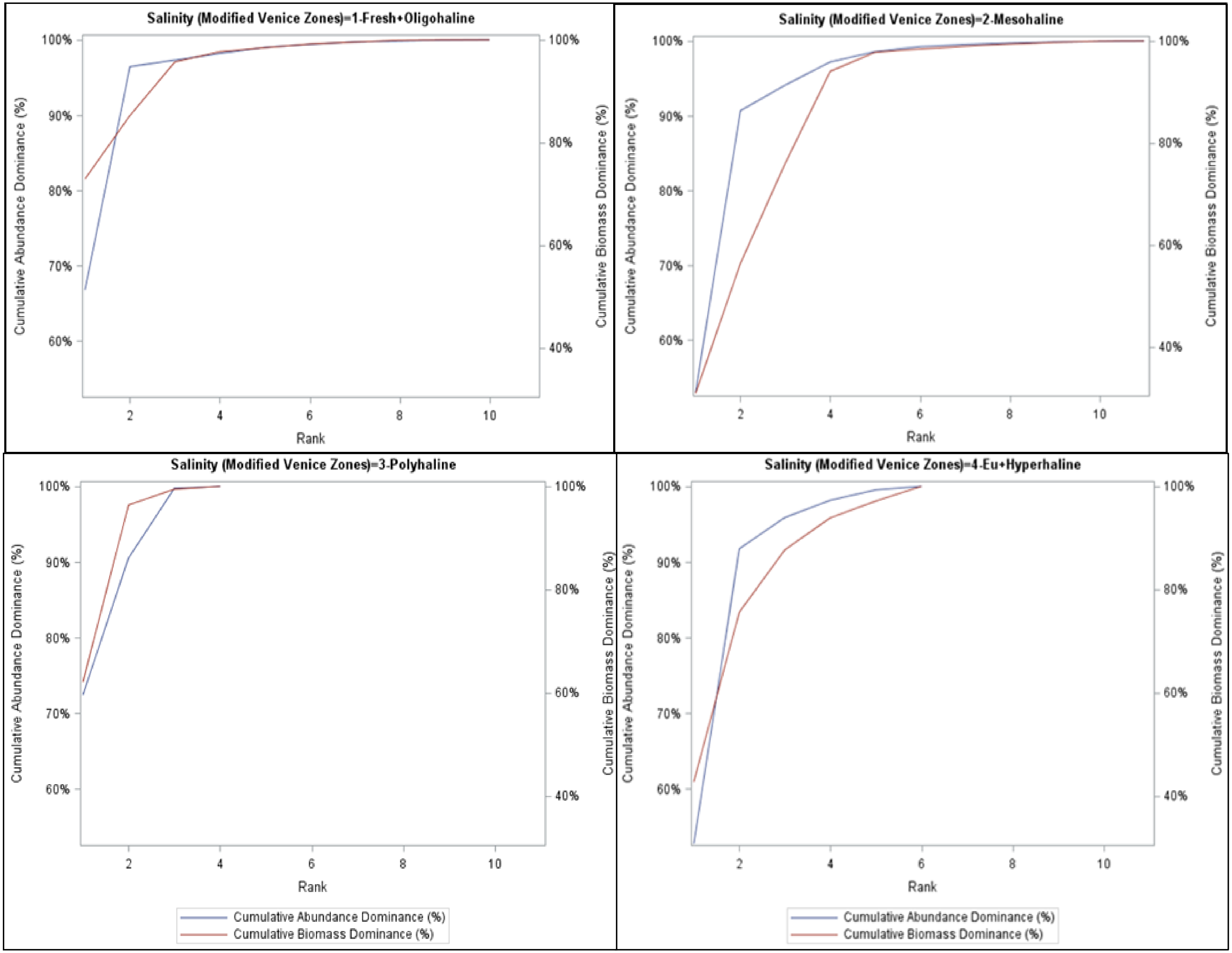


Figure 6. ABC curves for four salinity ranges. Top left: Fresh+Oligohaline, top right: Mesohaline, bottom left: polyhaline, bottom right: euhaline+hyperhaline.

Table 8

Species contributions to total abundance for three salinity ranks used in ABC analysis.

	Total Abundance n/m²			
Species	**Fresh+Oligohaline**	**Mesohaline**	**Polyhaline**	**Euhaline+Hyperhaline**
Chironomidae (larvae)	4798	3064	662	2679
Streblospio benedicti	2131	4310	5219	3624
Laeonereis culveri	63	250	1305	0
Mediomastus ambiseta	63	56	0	284
Nemertea (unidentified)	59	111	0	32
Hobsonia florida	28	0	0	0
Ceratopogonidae (larvae)	24	11	0	0
Oligochaeta (unidentified)	8	278	0	0
Mulinia lateralis	8	22	0	158
Ostracoda (unidentified)	4	17	19	95
Americamysis almyra	0	6	0	0
Farfantepenaeus setiferus	0	6	0	0
Total	7186	8131	7205	6872

Table 9

Species contributions to total biomass for three salinity ranks used in ABC analysis.

	Total Biomass gm/m²			
Species	**Fresh+Oligohaline**	**Mesohaline**	**Polyhaline**	**Euhaline+Hyperhaline**
Chironomidae (larvae)	0.64457	0.26150	0.01872	0.10180
Laeonereis culveri	0.10932	0.16685	0.21141	0
Streblospio benedicti	0.09230	0.21673	0.38178	0.13205
Nemertea (unidentified)	0.01789	0.03165	0	0.00882
Mediomastus ambiseta	0.00697	0.00345	0	0.01922
Mulinia lateralis	0.00611	0.00200	0	0.03750
Ceratopogonidae (larvae)	0.00347	0.00300	0	0
Hobsonia florida	0.00303	0	0	0
Oligochaeta (unidentified)	0.00067	0.00462	0	0
Ostracoda (unidentified)	0.00004	0.00539	0.00340	0.01008
Farfantepenaeus setiferus	0	0.15289	0	0
Americamysis almyra	0	0.00039	0	0
Total	0.88437	0.84847	0.61531	0.30947

Chironomidae (larvae) and *Streblospio benedicti* were the most abundant species for all four salinity classes (Table 8). Chironomid larvae show a marked decrease during Polyhaline conditions, nearly a quarter of their next lowest abundance. *Streblospio benedicti* had the highest abundance for all but the Fresh+Oligohaline class. *Laeoneris culveri* made a significant contribution to abundance during Polyhaline conditions. Chironomid (larvae) had the highest biomass for Fresh+Oligohaline and Mesohaline conditions, although biomass in Mesohaline conditions are roughly a third of those in Fresh+Oligohaline conditions (Table 9). *Streblospio benedicti* was always one of the top five biomass contributors and had the highest biomass for Polyhaline and Euhaline+Hyperhaline conditions. *Laeoneris culveri* made a significant contribution to biomass during Polyhaline condtions. The greatest overall biomass occurs during periods of Fresh+Oligohaline and Mesohaline conditions while the greatest overall abundance occurs during Mesohaline and Polyhaline conditions.

Discussion

In Rincon Bayou, salinity fluctuations were seen throughout the duration of the study period. Salinity variability has been characterized as a disturbance in Texas estuaries (Van Diggelin 2014, Montagna et al. 2002), so the wide range of salinity observed in this study is likely disturbing the benthic macrofaunal community. Organisms have a specific range of conditions in which they can be successful, surviving and reproducing; as environmental parameters change only some organisms will survive. Organisms that are mobile (i.e., mobile epifauna, nekton, and plankton) are likely to migrate from the area resulting in a lower diversity following a disturbance. Sessile organisms and infauna, unable to leave the affected area, remain. Sessile organisms will suffer severe mortality if they are not adapted to a sufficiently broad range of salinity conditions to survive. Their inability to retreat from the disturbance puts sessile organisms at a higher risk of being affected by a disturbance event (Menge and Sutherland 1987).

Benthic invertebrates have been used as indicators of estuarine health in the Texas Coastal Bend area for over two decades (Mannino and Montagna 1997, Kim and Montagna 2009, Montagna and Palmer 2011). Numerous studies have shown benthic invertebrates are ideal indicators of freshwater inflow effects because of their sessile nature (Kalke and Montagna 1991, Montagna and Yoon 1991, Montagna and Kalke 1992). Benthic macrofaunal communities respond to long-term hydrological cycles (e.g. droughts) with reduced diversity just as they respond to reduced freshwater inflow on shorter time scales (MacKayet al. 2010, Palmer et al. 2011, Palmer and Montagna 2015). The ABC plots from the present study indicate extremely disturbed conditions during Mesohaline and Euhaline+Hyperhaline conditions, moderately disturbed conditions during Fresh+Oligohaline conditions, and a relatively undisturbed community during Polyhaline conditions. This would suggest that salinities between 18-30 psu are ideal for the resident macrofaunal community and that both extremely fresh and saline conditions may act as a disturbance to this community. It is worth noting that both the Polyhaline and Euhaline+Hyperhaline conditions had relatively low sample counts, five and three samples respectively. With such low sample numbers, further study would be necessary to confirm the results seen here.

In the current study, the ABC plots showed higher biomass than abundance during Mesohaline and Euhaline+Hyperhaline conditions indicating the presence of pioneer species (Figure 6) (Warwick 1986). Species contributions to both biomass and abundance do indicate that a known pioneer species, *Streblospio benedicti,* was present throughout the study in high abundances. While chironomids (a freshwater species) dominate Station C during Fresh+Oligohaline conditions, *S. benedicti* (a marine species and known pioneer species) dominates during all other conditions. This is the same pioneer species seen in other studies of inflow restoration to Rincon Bayou (Palmer et al. 2002, Ritter et al. 2005).

Areas affected by frequent disturbance are likely to have low diversity as a result of being consistently dominated by pioneer species (Sousa 1979, Ritter et al. 2005, McFarland et al. 2013, Teuber et al. 2013). The Intermediate Disturbance Hypothesis (IDH) predicts the effects of disturbance frequency on system will be a bell-like curve where species diversity changes with differing frequencies of disturbance (Teuber et al. 2013, Sousa 1979). A similar pattern, a bell-like curve with low abundance and biomass at the extremes and highest in the middle, was seen in a 2002 study of Rincon Bayou (Montagna et al. 2002). It has been shown that frequent salinity disturbances in Rincon Bayou caused domination by pioneer species, *Streblospio benedicti* adapted to higher salinities than other species within the system (Ritter et al. 2005).

A 2011 study of the Lavaca-Colorado Estuary in Texas found chironomid larvae only during flood events but suggested that this distribution may change if the salinity gradient were altered in the future (Pollack et al. 2011). The 2011 study, and several others, found higher abundances of *Streblospio benedicti* in lower salinity areas in contrast with the current study (Chollett and Bone 2007, Mannino and Montagna 1997, Pollack et al. 2011). A 2007 Venezuelan study showed increased spionids following heavy rains, however, while the ensuing salinity levels were relatively low for the area the 25 psu values fall squarely in the Polyhaline range for the current study (Chollett and Bone 2007). It may be possible that the extreme dominance of chironomid larvae will occur only when nearly fresh conditions, salinities < 1, occur and that *S. benedicti* is a more cosmopolitan species that can be present in a wider range of salinities and fill a higher salinity niche than seen in other areas of the Texas coast.

The current study proves the usefulness of species specific biomass data in assessing estuary health. In contrast, past benthic studies in Rincon Bayou assessed biomass by major taxa only. Future studies should endeavor to create longer time series of biomass data to capture more interannual variability. This could inform changes to the Rincon Bayou inflow management and restoration programs. Although the species may change, estuary programs for areas exhibiting similar functional groups and freshwater influences may also be improved with this knowledge.

Conclusion

By Texas law, beneficial inflow means a salinity, nutrient, and sediment loading regime that adequately maintains an ecologically sound environment in the receiving bay and estuary system that is necessary for the maintenance of productivity of economically important and ecologically characteristic sport and estuarine life upon which such fish and shellfish are dependent (Texas Water Code §11.147(a)). In Rincon Bayou, inflow is partially dependent on pumped inflows required by the 2001 Agreed Order from the Texas Commission on Environmental Quality. This agreement requires the city of Corpus Christi to "pass through" inflows no less than 151,000 acre-feet to the Nueces Estuary each year. However, monthly inflows required are dependent on season, rainfall, stored levels of the reservoir system, and salinity levels in Nueces Bay (Montagna, Hill, and Moulton 2009). The pump system has been active since 2009, but it is used during high inflow periods only because that is when pass-throughs are required. This means that pumped flows in addition to natural flooding enter Rincon Bayou and lower salinities even further than they would have naturally. It also means that there is no relief when salinities are high and the fresh water is needed the most. It is clear from this study that the large swings from fresh to hypersaline conditions maintains this habitat in a constant disturbed state with negative consequences on the community. Therefore there are two recommendations to ameliorate the disturbed state of the community: 1) pump when salinities are high, i.e., over 25 psu; and 2) use one pump only to move the fresh water into Rincon Bayou in a slow trickle rather than a flood. These changes to the pumping regime should improve environmental conditions in Rincon Bayou.

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