Management Strategies for the Rincon Bayou Pipeline

Final Report
CBBEP Publication – 128
Project Number -1817
January 2019

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Cite as:

Montagna, P.A. 2019. Management Strategies for the Rincon Bayou Pipeline. Final Report to the Coastal Bend Bays & Estuaries Program for Project # 1817, CBBEP Publication – 128. Harte Research Institute, Texas A&M University-Corpus Christi, Corpus Christi, Texas, 45 pp.

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Acknowledgements

This project was funded in part by U.S. Environmental Protection Agency (EPA) Cooperative Agreement Numbers: C6-480000-54, EPA Q-TRAK# - 18-387. We thank Sharon R. Coleman, Texas Commission on Environmental Quality (TCEQ); Terry Mendiola, EPA; Cory Horan, TCEQ; Curry Jones, EPA; and Kerry Niemann, TCEQ for reviewing and approving the Quality Assurance Project Plan. The work was overseen at the Coastal Bend Bays & Estuaries Program by Leo Trevino and Rae Mooney, who provided helpful guidance and oversight to complete the project.

Abstract

Decreased inflow due to damming of the Nueces and Frio rivers has resulted in increasing salinity in Nueces Bay and caused Rincon Bayou to become a reverse estuary disturbing the overall hydrology of the adjacent Corpus Christi Bay. Adaptive management to perform hydrological restoration began in 1994 and continues today. The objective of the present study is to develop a set of recommendations and implementation strategy for management of environmental flows delivered to upper Rincon Bayou by the Rincon Bayou Pipeline. This information is needed to improve the environmental effectiveness of pumped flow deliveries to Rincon Bayou and the Nueces marsh. Change in water quality and benthic community structure were used as indicators of ecological effects. High inflow reduces salinity and introduces nutrients. Large and haphazard salinity fluctuations result in an often disturbed system populated by pioneer species, such as chironomid larvae and the polychaete *Streblospio benedicti*, during especially low and high salinity periods. Epifaunal organisms are mobile and capable of escaping unsuitable conditions, so the more immediate results of fluctuations in water quality is the lack of higher trophic marine organisms following pumping events. Results of time lags indicated that variance in diversity variables in response to changes in salinities occurred within the first few weeks after pumping. Immediate responses to salinity were not identified in abundance and biomass. Positive relationships between abundance and biomass, in response to salinity fluctuations, were evident after 6 to 8 weeks. A little bit of water pumped during dry times can have positive environmental benefits, and too much water pumped during wet times can have a negative influence and act as an ecological disturbance. The results of the infaunal and epifaunal analyses indicate that further changes need to be made to the Rincon Bayou restoration and management programs in order to reestablish a reasonably undisturbed ecosystem.

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Introduction

The purpose of the current project is to develop a set of recommendations and implementation strategy for management of environmental flows delivered to upper Rincon Bayou by the Rincon Bayou Pipeline. This information is needed to improve the environmental effectiveness of pumped flow deliveries to Rincon Bayou and the Nueces marsh. This new project is a logical follow-up to recently completed field and modeling studies, funded by the CBBEP and Texas Water Development Board (TWDB) respectively, that identified the ecological impacts of pumped flows (Montagna et al. 2016a, 2016b, 2015, Montagna and Herdender 2015). We now know that a little bit of water pumped during dry times can have positive environmental benefits, and too much water pumped during wet times can have a negative influence and act as an ecological disturbance (Montagna et al. 2018). The next step is to formulate a series of recommendations for managing pumped flows and determine the policy and regulatory processes and steps needed to enable these recommendations to be implemented. This study provides the scientific basis for these policy recommendations.

The project is composed of five (5) tasks:

1) Create a Quality Assurance Project Plan (QAPP).
2) Literature review and synthetic analysis of available long-term data.
3) Create a science-based recommendation for pipeline operations based on the synthesis.
4) Create a stakeholder team willing to advise and participate in developing an implementation plan. Conduct stakeholder meetings.
5) Investigate implementation, management, or regulatory options to implement the new operation plan.

Task 1, the QAPP was approved by the TCEQ on May 22, 2018, submitted to the EPA on May 16, 2018, and approved by EPA on June 7, 2018 (Montagna 2018). The remainder of this report is dedicated to reporting on Tasks 2 – 5.

Literature Review and Analysis of Long-Term Data

Literature Review

The Nueces River System has been highly modified to provide fresh water resources for human uses. 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 (Montagna et al. 2002). As part of the permit to build the Choke Canyon Reservoir, the City of Corpus Christi was required to provide not less than 151,000 ac-ft (185 10^6 m^3) of fresh water per year to the Nueces Estuary to maintain ecological health and productivity of living marine resources. However, no releases were made and Nueces Bay became hypersaline during the drought of 1988 - 1990. After public complaints, the Texas Water Commission issued a series of orders beginning in May 1990 requiring the City to meet the special conditions contained in their water right permit that required provision of freshwater inflows to the estuary. However, there were many questions that needed to be answered. What was the right quantity? What were the most effective ways to provide the water? And, what was the role of stakeholders? This led to the creation of the Nueces Estuary Technical Advisory Committee in June 1990, which is composed of stakeholders, and is now commonly referred to as NEAC. NEAC was charged with overseeing the adaptive management process to manage environmental flows to Nueces Bay.[1]

The Corpus Christi Bay National Estuary Program commissioned a series of studies in the early 1990's to characterize the state of the Nueces Estuary. One finding was that by 1996, stream flow to the Nueces River had decreased by 55% since the building of the Wesley Seale Dam and the Choke Canyon Dam compared to the pre-1983 era (Asquith et al. 1997). In the same period, flow from the Nueces River to the Nueces Delta via Rincon Bayou decreased 99% (Irlbeck and Ward 2000, Ward et al. 2002). 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).

A series of adaptive management activities were undertaken with a goal to enhance or restore environmental flows into the Nueces Marsh. The Nueces Overflow Channel was 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 (Bureau of Reclamation 2000, Montagna et al. 2002, Ward et al. 2002). The channel was closed in 2000, but reopened in 2002 (Palmer et al. 2002). In 2009, a pipeline and pumping station was constructed to pump freshwater from the Calallen Pool to Rincon Bayou so that inflow would not rely on overflowing the Calallen Dam (Montagna et al. 2009).

Monitoring studies have also been completed to determine the effects of the management activities. The initial monitoring was to determine the effectiveness of construction of the Nueces River Overflow channel that was built in 1994. The monitoring between 1994 and 2000

[1] The NEAC process was so successful that it became a model for the Bay and Basin Expert Science Teams (BBEST) created for all the Texas basins, rivers, and bays by Senate Bill 3 in 2007.

was supported by the U.S. Bureau of Reclamation, between 2001 and 2009 by the City of Corpus Christi, and between 2010 and 2016 by the CBBEP. The effects on benthos of the altered freshwater inflows via the channel reached six kilometers downstream, but failed to affect restoration in 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 (Palmer et al. 2002, Ritter et al. 2005, Herdener 2015). The presence of pioneer species indicates that Rincon Bayou is likely an area of high disturbance following floods (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 (Ritter et al. 2005).

To determine the effects of pumping, the upper and central Rincon Bayou have been monitored for water quality and benthic macrofauna between 2009 and 2016. Hydrologically, Rincon Bayou is still a reverse estuary that occasionally exhibits hypersaline conditions (Montagna et al. 2016, 2018). The salinity can fluctuate from fresh to hypersaline, and hypersaline to fresh in very short time periods. Pumping from the Calallen Pool into Rincon Bayou occurs only when there is also natural inflow because that is the only time when pass-through is required. Nutrients are high when salinity is low. The diversity of macroinfauna and macroepifauna is low. There are very high fluctuations of abundance and biomass related to fluctuations in inflow. The low diversity and population fluctuations indicate the ecosystem is still disturbed. To improve the marsh, salinity should be maintained between 6 and 18 psu, minimum water depth should be between 0.2 m to 0.3 m, and to improve ecological stability inflows should be a continuous trickle, not a pulsed flood. Therefore, inflows from pumping should be continuous and not haphazard, and not dependent on pass-through requirements.

It is possible that reducing the great fluctuation in flow could help improve the ecological state of Rincon Bayou. To improve hydrological conditions in Rincon Bayou, a pipeline and pumping station was completed in fall 2008, but first used in 2009, from the Calallen Pool to Rincon Bayou. The pumping facilitates additional freshwater inflows that do not depend upon overflow from the Calallen Dam (Adams and Tunnell 2010). The salinity and benthos were monitored for one year after initial pumping began, but that study was during relatively wet periods; average salinity was 17 psu from between 28 September 2009 and 11 August 2010 (Barajas 2011). Because salinity did not vary much during that study period, there was little correlation between abundance and species composition to salinity (Barajas 2011). In contrast, from October 2013 through December 2015, Rincon Bayou was in a constant state-shift between the extremes of droughts and floods, being persistently disturbed, with salinity playing a major role in structuring the benthic community as a disturbed community (Chaloupka 2016). The frequent disturbances were identified because of the dominance by pioneer species, *Streblospio benedicti*, during Mesohaline and Euhaline+Hyperhaline conditions (Herdener 2015).

Data Analysis

Given that the goal of this project is to determine a pumping strategy to maintain ecological health, the basic assumption of the study is that the effects of salinity changes on benthic macrofauna will guide selection of a pumping regime and how the pipeline should be operated to enhance or maintain estuary health. Salinity decreases within days when the river flows or pumping begins (Adams and Tunnell 2010, Barajas 2011), so salinity is a proxy for inflow. The independent variables of the study are space and time. Different volumes of freshwater inflow will have different effects downstream (Palmer et al. 2002), thus it is important to examine the spatial extent of inflow effects with pumping strategies. There is natural temporal variability with precipitation, and thus inflow, over time (Del Rosario and Montagna 2018), therefore it is important to examine temporal variation. Macrofauna are ideal indicator organisms of habitat quality and ecosystem health because of their relative immobility and longevity in contrast with plankton of comparable size (Diaz et al. 2004, Montagna et al. 2013). Thus the dependent variables that indicate ecosystem health are benthic metrics such as abundance, biomass and diversity.

Spatial Sampling

The focus of this data analysis study is Rincon Bayou near Corpus Christi, Texas, USA. Rincon Bayou flows east from the Nueces River to Nueces Bay and is the main stem of the Nueces Marsh (Figure 1). 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. The historical stations, C (27.89878° N, -97.60417° W) and F (27.87760 °N, -97.57873 °W) sampled since October 1994 (Montagna et al. 2002), and an additional station G (27.88992°N, -97.56910 °W) sampled from October 2002 to February 2017 (Figure 1). Station C is nearest 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 and Montagna 2002). Station C is also known as 466C, F as 400F, and G as 463G (Montagna et al. 2009). The sites are surrounded by dense shrubs and marsh grasses that grow to the shoreline. Clay and mud dominate the substrate at all stations.

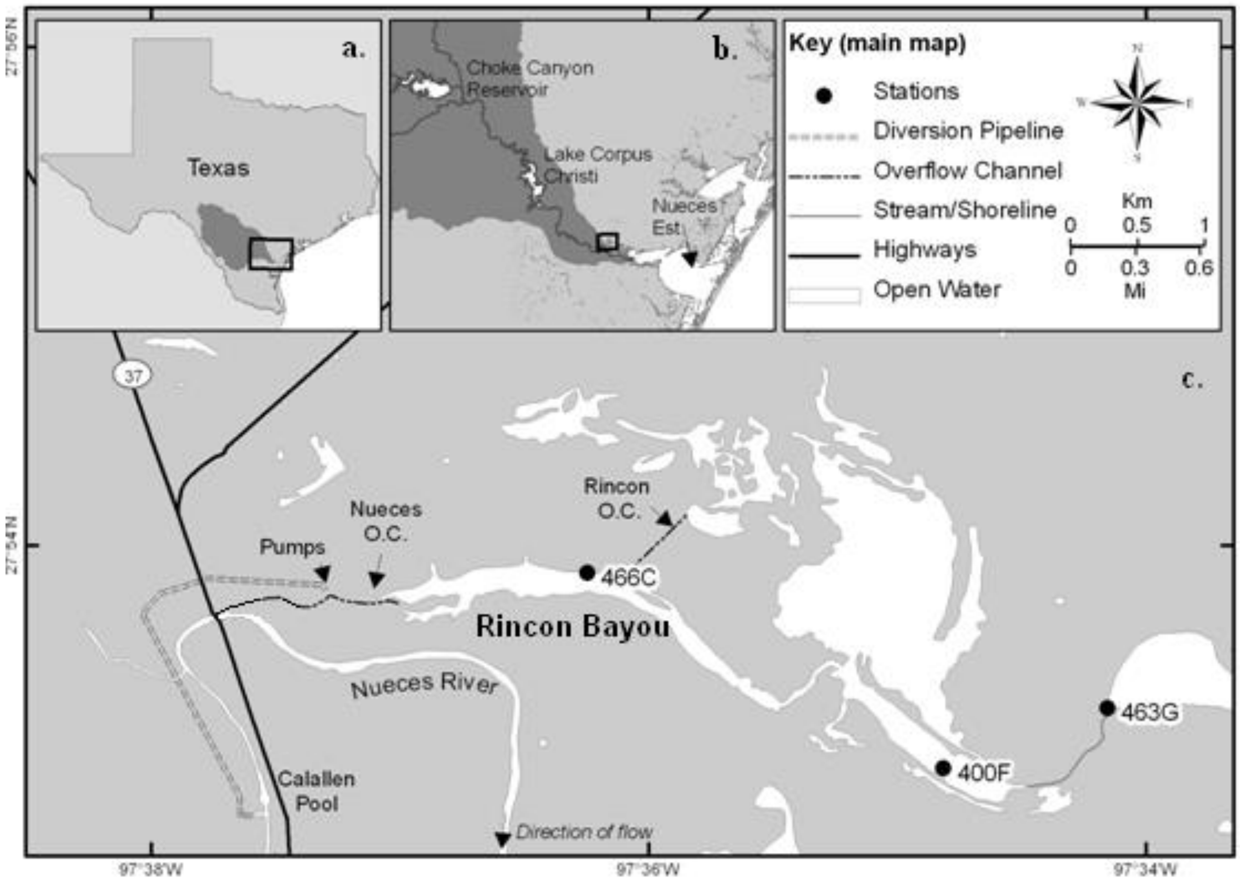

Figure 1. Map of study area. a) State of Texas with the Nueces Basin highlighted. b) Location of Choke Canyon Reservoir, Lake Corpus Christi and Nueces Estuary (Nueces Bay) within the Nueces Basin. c) Location of the Nueces Delta marsh containing Rincon Bayou.

Temporal Sampling

Together the two monitoring studies (pre-and post- channel opening, and pre- and post-pumping) provide a long-term 23-year period of data (1994 – 2017), which can be used to determine the ecological responses to inflow into the Rincon Bayou channel. However, various parts of the overall study were conducted at different time scales (Table 1).

Table 1. Temporal frequency of sampling stations.

Period	Frequency	Samples	Stations
Oct 1994 - Oct 1999	Quarterly	21	C, F
Nov 1999 - Aug 2001		0	
Oct 2001 - Apr 2002	Quarterly	3	C, F
Jul 2002 - Oct 2010	Monthly	99	C, F, G
Jan 2011 - Oct 2013	Quarterly	11	C, F, G
Oct 2013 - Apr 2016	Bi-weekly	63	C
Oct 2013 - Apr 2016	Quarterly	11	F, G
Jul 2016 - Feb 2017	Quarterly	3	C, F, G

Rincon Bayou was sampled a total of 211 times (Table 1). During the original Bureau of Reclamation project to divert the river via an overflow channel to enhance the opportunities for flow into the Nueces Marsh, six stations were sampled quarterly between October 1994 and October 1999 (Montagna et al. 2002). However, only two stations (C and F) were sampled in later studies, so those are the only stations listed here. No sampling occurred between November 1999 and August 2001 because the Nueces River overflow channel was filled in after the project ended in September 2000 (Montagna et al. 2009). The Nueces River overflow channel was reopened in October 2001 by the City of Corpus Christi and quarterly monitoring resumed. There was a concern that quarterly sampling would miss inflow events, so the NEAC recommended monthly sampling for benthos (Nicolau et al. 2002), and so monthly sampling was sponsored by the City of Corpus Christi for a period of 8 years. Once pumping began in 2009, a different strategy was attempted to create a paired-sample before and after pumping events, where each event would be a replicate. However, this did not work because it was impossible know in advance when pumping would occur, so a bi-weekly sampling scheme was devised assuming that this would capture all pumping events as discrete events. However, this bi-weekly sampling occurred at only Station C to reduce costs, and the sampling scheme was only marginally successful because the length of pumping events varied and pumping occurred only during periods when there was already an inflow event (Montagna et al. 2016, 2018). Quarterly sampling occurred at all stations (C, F, and G) between January 2011 and February 2017.

Measurement Methods

Macroinfauna samples were collected using a 6.7-cm diameter benthic core (area=35.23 cm^2) (Montagna and Kalke 1992, Montagna et al. 2002). 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 10% 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 then placed on pre-weighed aluminum pans and dried in an oven for a minimum of 24 hours at 55 °C. Organism weight was recorded to the nearest 0.01 mg. Specimens weighing less were assigned a weight of 0.01 mg. Mollusk shells were dissolved in 1 N HCL prior to biomass measurements.

Water quality measurements were taken at each station per sampling event with a YSI 6920 multiparameter sondes, initially a YSI 6920 was used and it was replaced with a YSI 600LS sonde. Measurements were made at 0.1 m below the surface and at the bottom depth. Temperature (ºC), dissolved oxygen (mg L^{-1}), salinity (psu), conductivity (mS cm^{-1}), depth (m), and pH were measured. Calibrations were made using known standards for pH, conductivity, salinity, depth, turbidity, and dissolved oxygen (DO) concentration and percent saturation.

Statistical Methods

Database programming, calculations, and statistical analyses were performed using SAS 9.4 software (SAS Institute Inc. 2013). 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 exponentiated form of the Shannon diversity index:

$$\text{Shannon diversity index: } H' = -\sum_{i=1}^{R} p_i \ln p_i$$

$$\text{Hill's N1 diversity: } N1 = e H'$$

As diversity decreases N1 will tend toward 1. The Shannon index, H', is the average uncertainty per species in an infinite community made up of species with known proportional abundances (Shannon and Weaver 1949). 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. This index is based on the Shannon diversity index:

$$\text{Pielou's evenness index: } J' = \frac{H'}{H'max} = \frac{H'}{\log S}$$

Abundance and biomass data were transformed using the natural logarithm. The log of zero is unknown, so 1 was added to all values prior to transformation:

$$\text{LogX} = \text{Log}(X + 1)$$

Several statistical procedures (i.e., PROCs) were used to perform different statistical analyses SAS 14.3 software (SAS Institute Inc. 2014, 2017a, 2017b). 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. The Pearson product-moment correlation determines the strength of linear relationships between variables:

Pearson product-moment correlation: $r = r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$

Community structure of macrofauna and epifauna species were 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 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.

Hydrography Response

Salinity at station C was consistently lower than stations F and G, with mean salinity at 16.0 (PSU), 23.0 (PSU), and 22.0 (PSU) respectively over the entire time series (Table 2 and Figure 2). Temperature was similar at all stations (Figure 3). However, water depth (m) was consistently higher at station G (0.40 m) while stations C and F were similar at 0.23 (m) and 0.18 (m) respectively (Table 2 and Figure 4). Dissolved Oxygen (mg/L) was consistently high (> 6 mg/L) at all stations (Table 2 and Figure 5). The pH averaged above 8 pH but there were several low periods of < 7 pH observed in 1996, 1998, 2005, 2006, and 2016 (Table 2 and Figure 6).

Table 2. Summary statistics of hydrological parameters collected biweekly at stations C, F, and G from October 1994 to February 2017. Observations at each collection were measured at surface (0.1 m water depth) and at bottom depth (within 0.1 m of sediment). Variable water depth (m) is the reported total depth at each station per observation period.

Variable (units)	Station	N	Mean	Std Dev	Minimum	Maximum
Depth (m)	All	591	0.26	0.19	0	1.6
Depth (m)	C	223	0.23	0.19	0	1.6
Depth (m)	F	204	0.18	0.14	0	0.75
Depth (m)	G	164	0.40	0.16	0.01	1.25
DO (mg/L)	All	581	8.34	2.30	1.01	17.57
DO (mg/L)	C	219	8.13	2.52	1.01	17.57
DO (mg/L)	F	199	8.56	2.21	3.61	16.61
DO (mg/L)	G	163	8.35	2.09	3.41	15.79
pH	All	575	8.33	0.35	6.39	10.85
pH	C	217	8.31	0.41	6.39	10.85
pH	F	195	8.34	0.35	6.77	9.94
pH	G	163	8.34	0.26	7.35	9.06
Salinity (psu)	All	598	20.17	19.61	0	159.2
Salinity (psu)	C	223	16.02	20.52	0	159.2
Salinity (psu)	F	204	22.99	19.21	0.5	93.57
Salinity (psu)	G	171	22.22	17.98	0.78	93.27
Temperature (°C)	All	582	24.24	6.09	7.98	40.54
Temperature (°C)	C	220	23.20	5.93	7.98	36.14
Temperature (°C)	F	199	25.01	6.10	8.58	40.54
Temperature (°C)	G	163	24.71	6.12	9.49	36.12

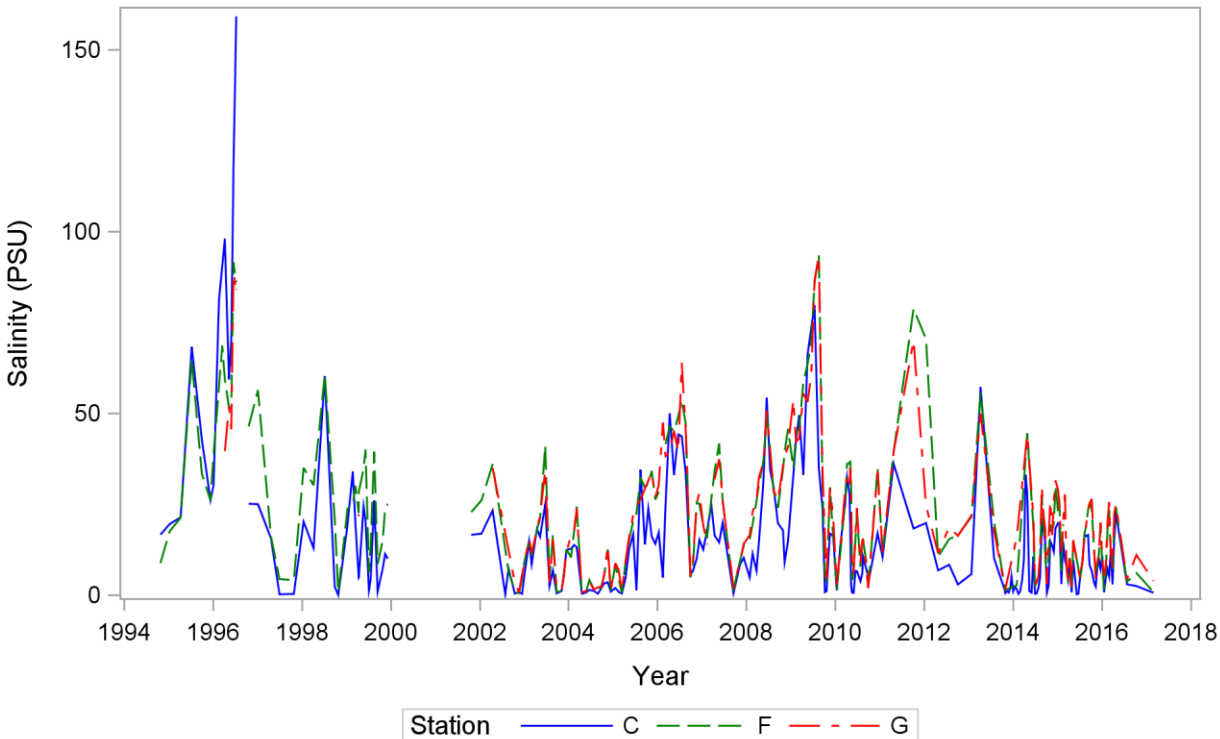

Figure 2. Rincon Bayou salinity (PSU) observations from October 28, 1994 to February 28, 2017 for stations C, F, and G.

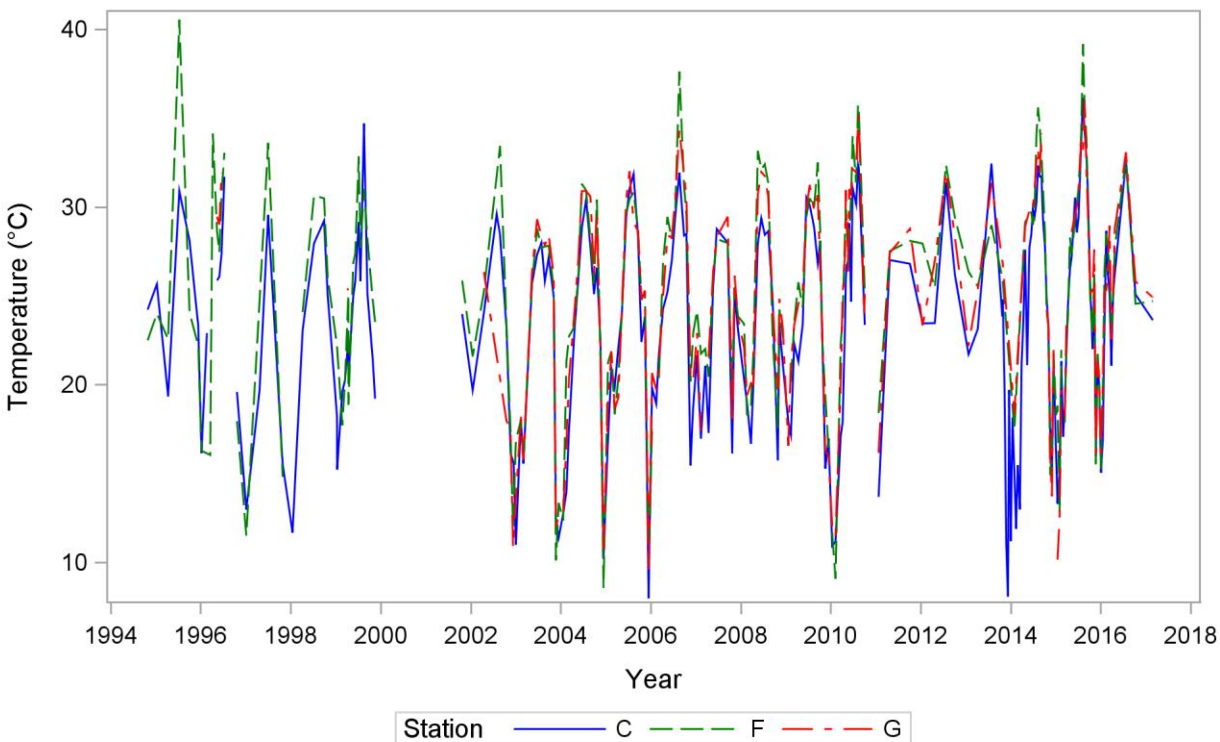

Figure 3. Rincon Bayou mean sonde temperature (°C) observations from October 28, 1994 to February 28, 2017 for stations C, F, and G.

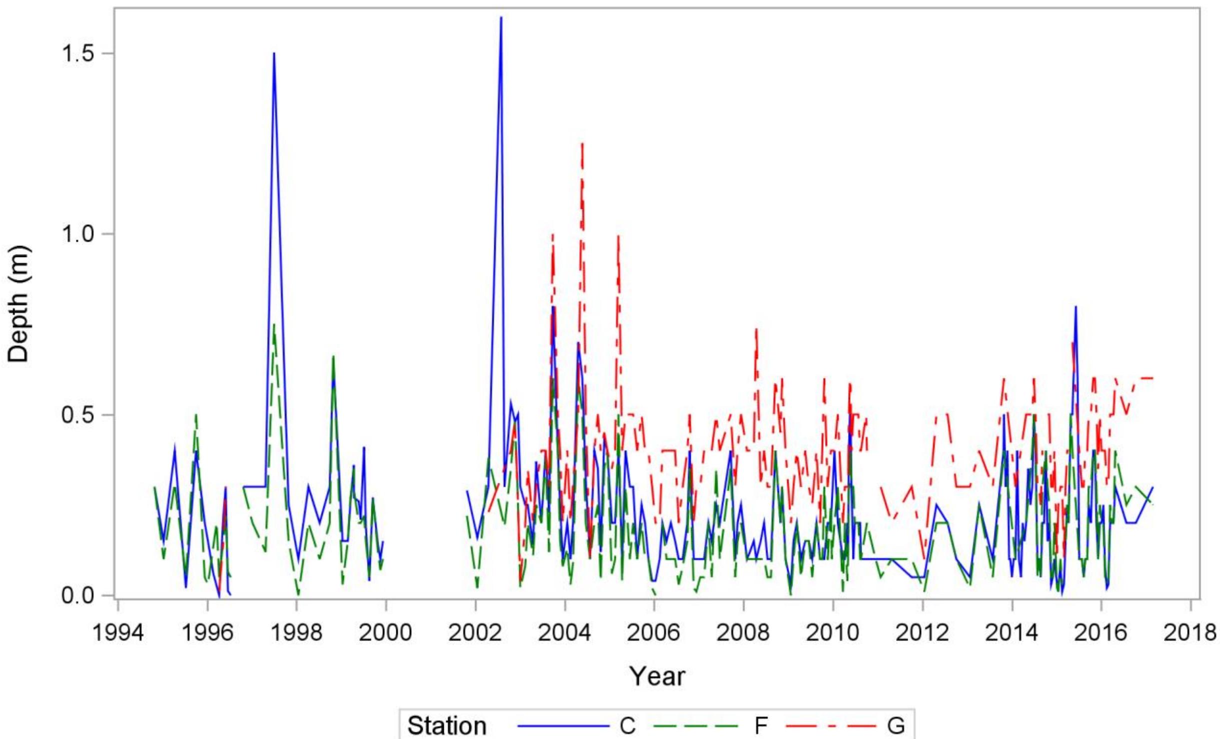

Figure 4. Rincon Bayou water depth (m) observations from October 28, 1994 to February 28, 2017 for stations C, F, and G.

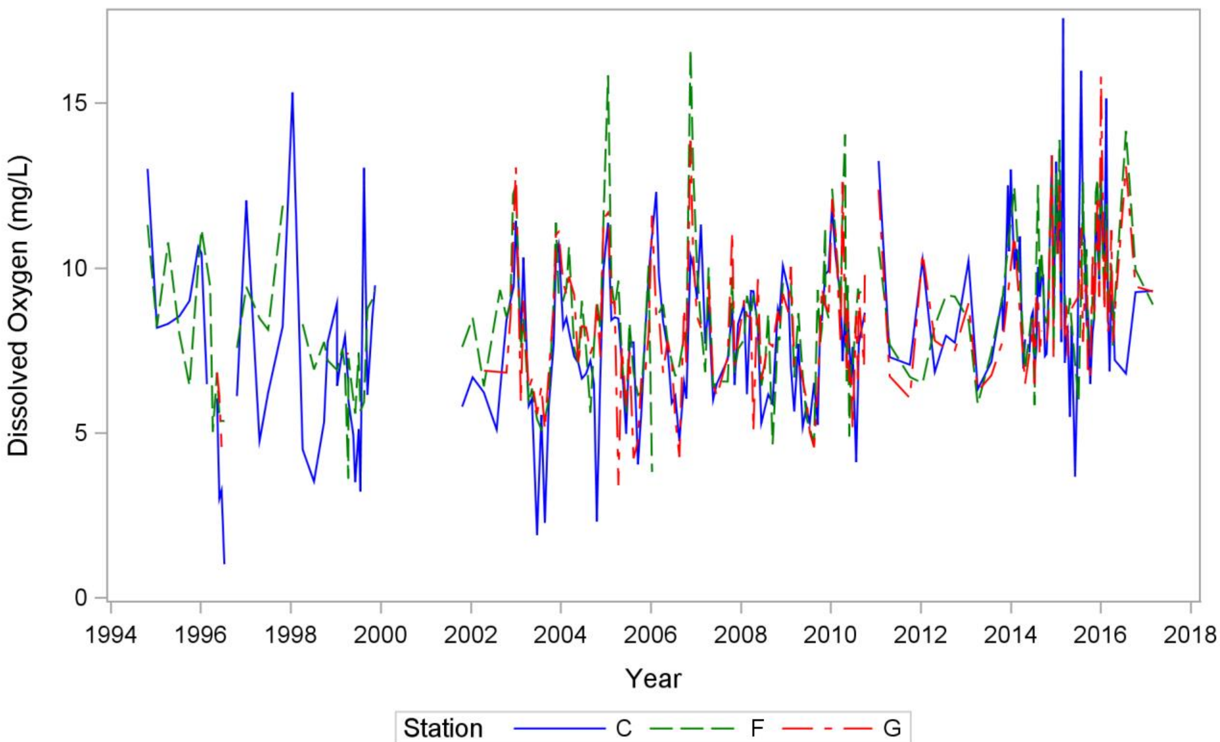

Figure 5. Rincon Bayou dissolved oxygen (DO) sonde observations from October 28, 1994 to February 28, 2017 for stations C, F, and G.

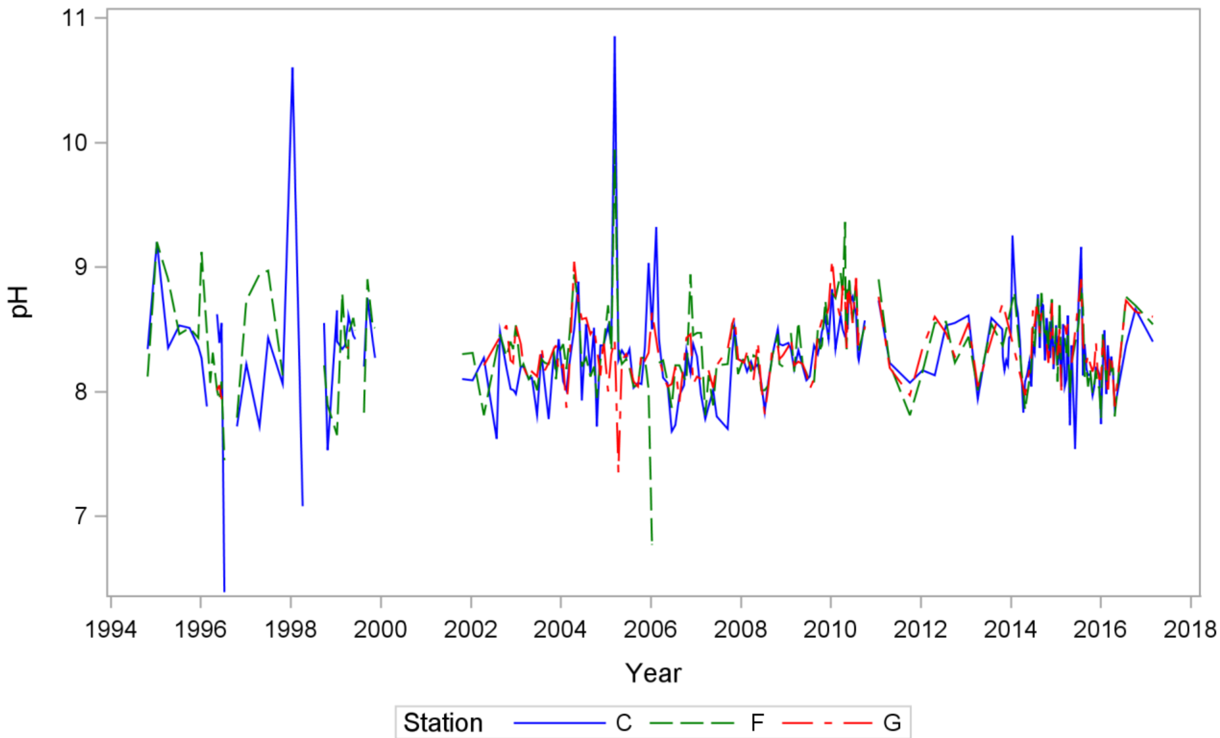

Figure 6. Rincon Bayou pH sonde observations from October 28, 1994 to February 28, 2017 for stations C, F, and G.

Macroinfauna Response

Station C exhibited the highest (193,253 n/m^2) mean benthic infaunal abundance over the entire time series (Figure 7 and Table 3). All stations had zero abundances in times of extreme drought when there was no water present. Stations F and G exhibit similar trends in abundance while station C's trend is typically higher than that of the other stations. Mean abundance peaked at station C in the early part of the time series while station F and G exhibited peak mean abundance towards the end of the time series.

Station C exhibited both the highest (33.1 g/m^2) and mean (1.3 g/m^2) benthic infaunal biomass (Figure 8 and Table 3). All stations had zero biomass in times of extreme drought when there was no water present. The other two stations had similar mean biomass of 1.2 g/m^2 at station F and 0.8 g/m^2 at station G. The largest biomass at station C occurred in 2008 and 2016.

The highest mean benthic infaunal diversity (2.2 N1) was found at station G, followed by station F at 2.0 N1, and station C at 1.8 N1 (Figure 9, Table 3). The maximum mean diversity was in reverse order, but never higher than 7. N1. The largest mean diversity was observed in 2002, 2007, and 2016.

The highest mean benthic infaunal Shannon diversity index (1.9 H′) was found at station F (Figure 10, Table 3). The overall means decreased from 0.7 H′ downstream at G, to 0.6 H′ at station F, and to 0.5 H′ at station C. Over the entire time series, H′ varied less than N1.

Station G had the highest mean benthic infaunal richness (10 species) and an average of 3.8 species (Figure 11, Table 3). The other two stations decreased to 3.5 at station F and 3.2 at station C.

Because the samples were collected at different sampling frequencies (Table 1), it is difficult to perform time series or correlation analyses with lags, so two data sets were prepared for analyses. The first dataset included the biweekly sampling at station C only, but this series is only 19 months long, from October 2014 to April 2017. The entire data set, which is 22.5 years long from October 1994 to February 2017, was aggregated by station and quarter, because quarters are the longest frequency between sampling events in the entire series. It is common for living resources to be affected after events rather than simultaneously with events, so the biweekly data set was lagged 6 times, which corresponds to a full quarter (Table 4).

There were no correlations between abundance and biomass and any of the lagged salinity variables in the biweekly data set (Table 4, Figures 7 and 8). There was only one weak correlation between species richness and a lag of 4 weeks (Figure 11). However, there are inverse correlations between richness and diversity for salinity during the first six weeks, and positive correlations for lags at weeks 8, 10 and 12. This trend suggests that floods initially knock out species, but after time they recover. In contrast, when the entire data set is used and aggregated by quarter, every benthic metric is significant with concurrent and quarterly lagged salinity (Table 5). Abundance and biomass are positively correlated with salinity and lagged salinity. In contrast, richness and diversity appears to have a mostly inverse relationship with salinity.

Table 3: Summary statistics of benthic infaunal variables collected October 28, 1994 to February 28, 2017.

Variable	Station	N	Mean	Std Dev	Minimum	Maximum
Abundance (n/m²)	All	465	12479	21256	0	193253
Abundance (n/m²)	C	199	13961	24807	0	193253
Abundance (n/m²)	F	145	12828	16626	0	86510
Abundance (n/m²)	G	121	9623	19693	0	187581
Biomass (g/m²)	All	465	1.2	2.6	0	33.1
Biomass (g/m²)	C	199	1.3	3.5	0	33.1
Biomass (g/m²)	F	145	1.2	1.7	0	10.3
Biomass (g/m²)	G	121	0.8	1.2	0	5.3
Diversity (N1/core)	All	465	2.0	1.1	0	7.0
Diversity (N1/core)	C	199	1.8	0.8	0	7.0
Diversity (N1/core)	F	145	2.0	1.1	0	6.0
Diversity (N1/core)	G	121	2.2	1.3	0	5.7
Diversity (H'/core)	All	465	0.6	0.5	0	1.9
Diversity (H'/core)	C	199	0.5	0.4	0	1.9
Diversity (H'/core)	F	145	0.6	0.5	0	1.8
Diversity (H'/core)	G	121	0.7	0.5	0	1.7
Richness (Taxa/Core)	All	465	3.5	2.0	0	10.0
Richness (Taxa/Core)	C	199	3.2	1.6	0	9.0
Richness (Taxa/Core)	F	145	3.5	2.1	0	9.0
Richness (Taxa/Core)	G	121	3.8	2.5	0	10.0
Evenness (J'/core)	All	465	0.4	0.3	0	1.0
Evenness (J'/core)	C	199	0.4	0.3	0	1.0
Evenness (J'/core)	F	145	0.4	0.3	0	1.0
Evenness (J'/core)	G	121	0.5	0.3	0	1.0

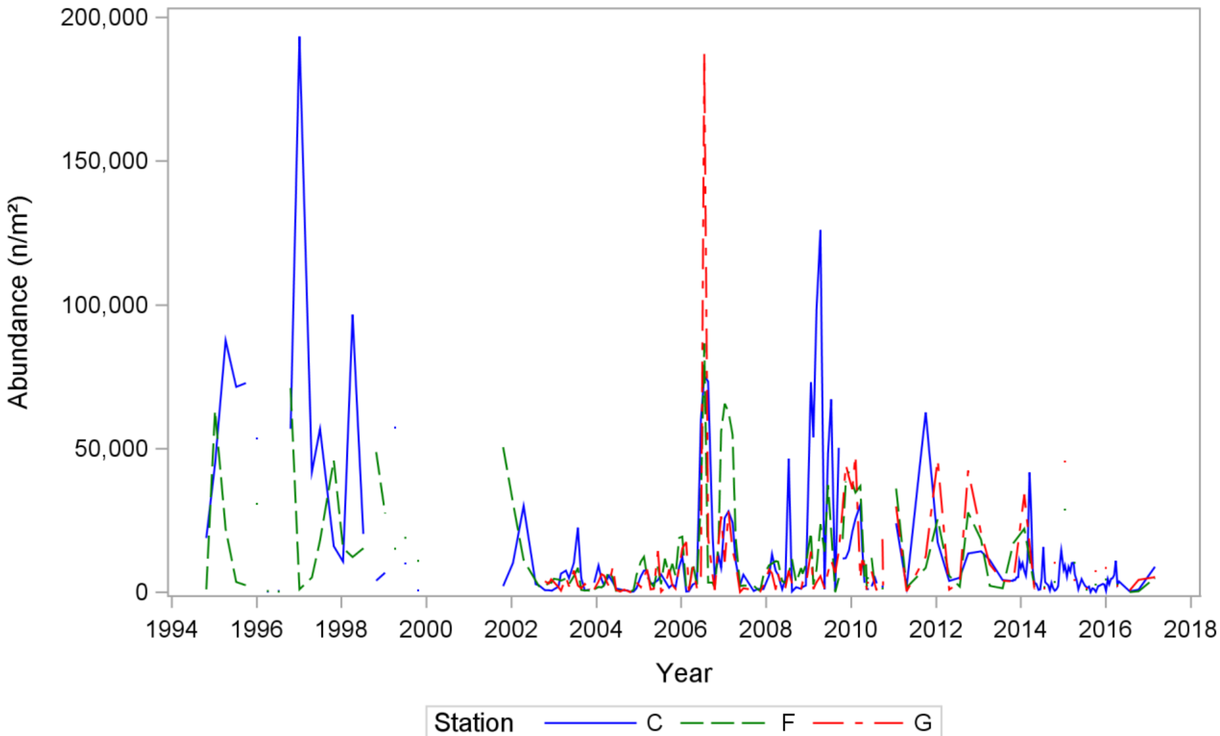

Figure 7: Mean benthic infaunal abundance over time for Rincon Bayou Stations C, F, and G from October 28, 1994 to February 28, 2017.

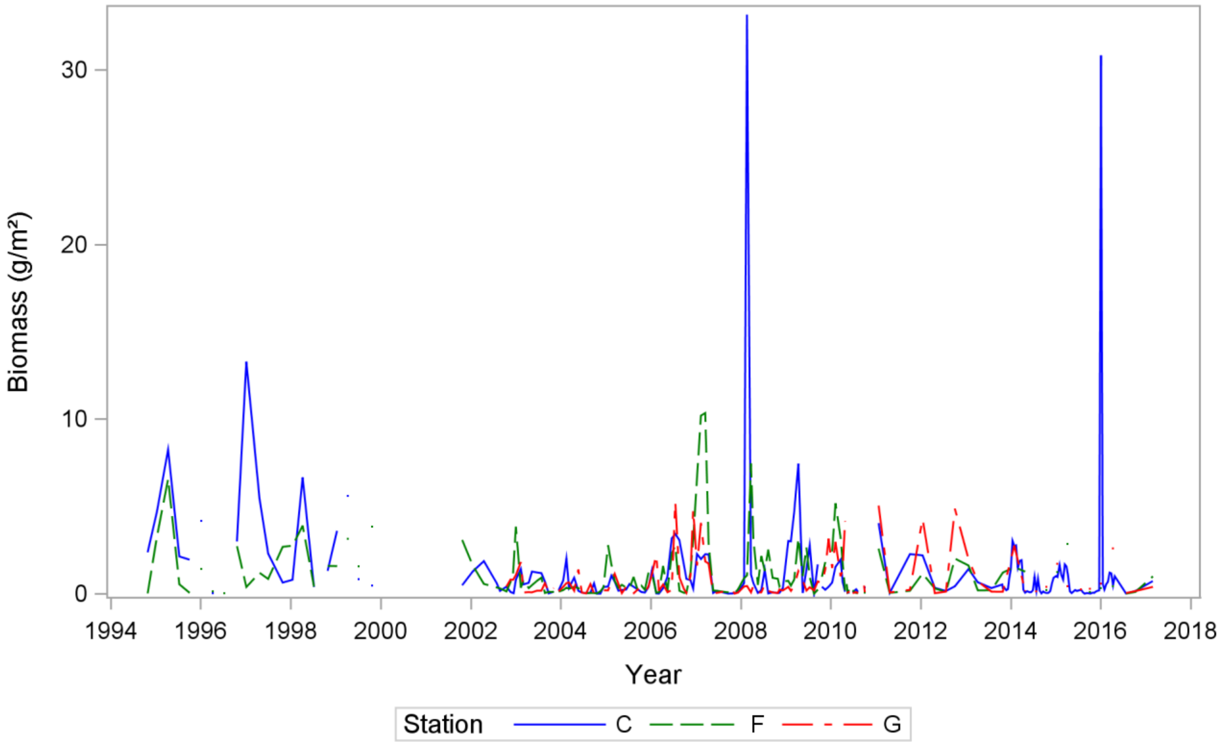

Figure 8: Mean benthic infaunal dry weight biomass over time for Rincon Bayou Stations C, F, and G from October 28, 1994 to February 28, 2017.

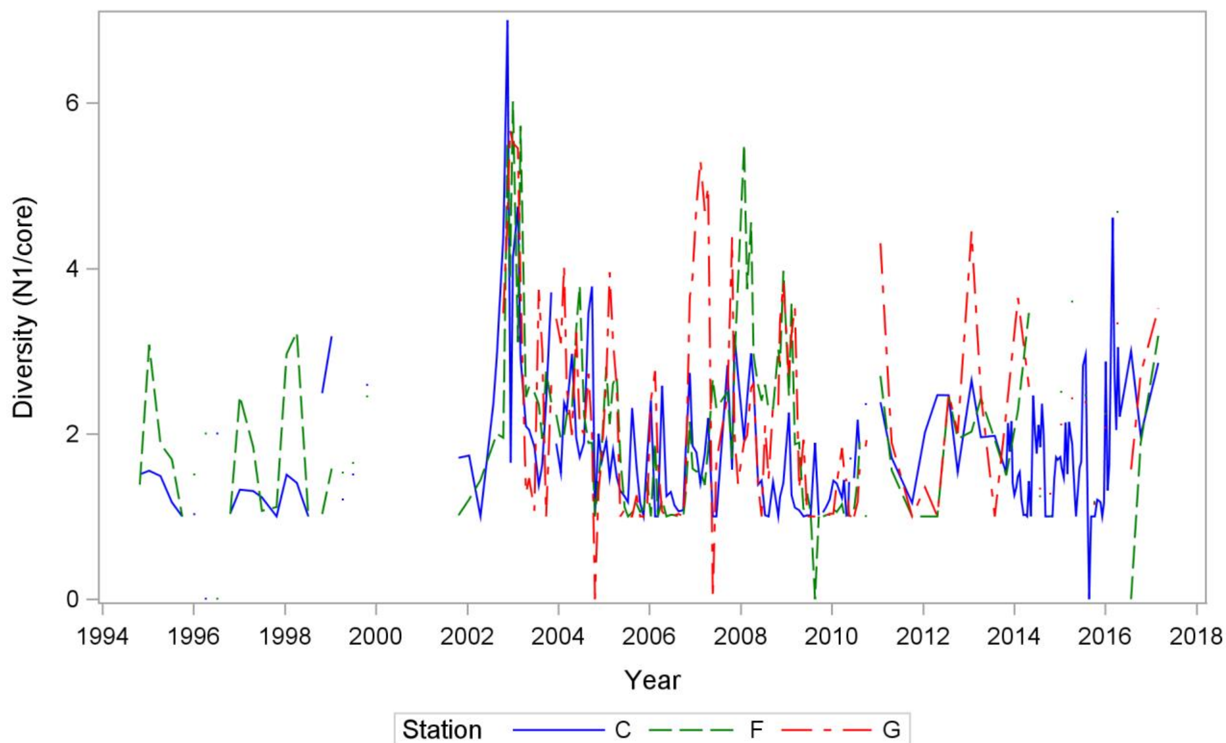

Figure 9: Mean benthic infaunal diversity over time for Rincon Bayou Stations C, F, and G from October 28, 1994 to February 28, 2017.

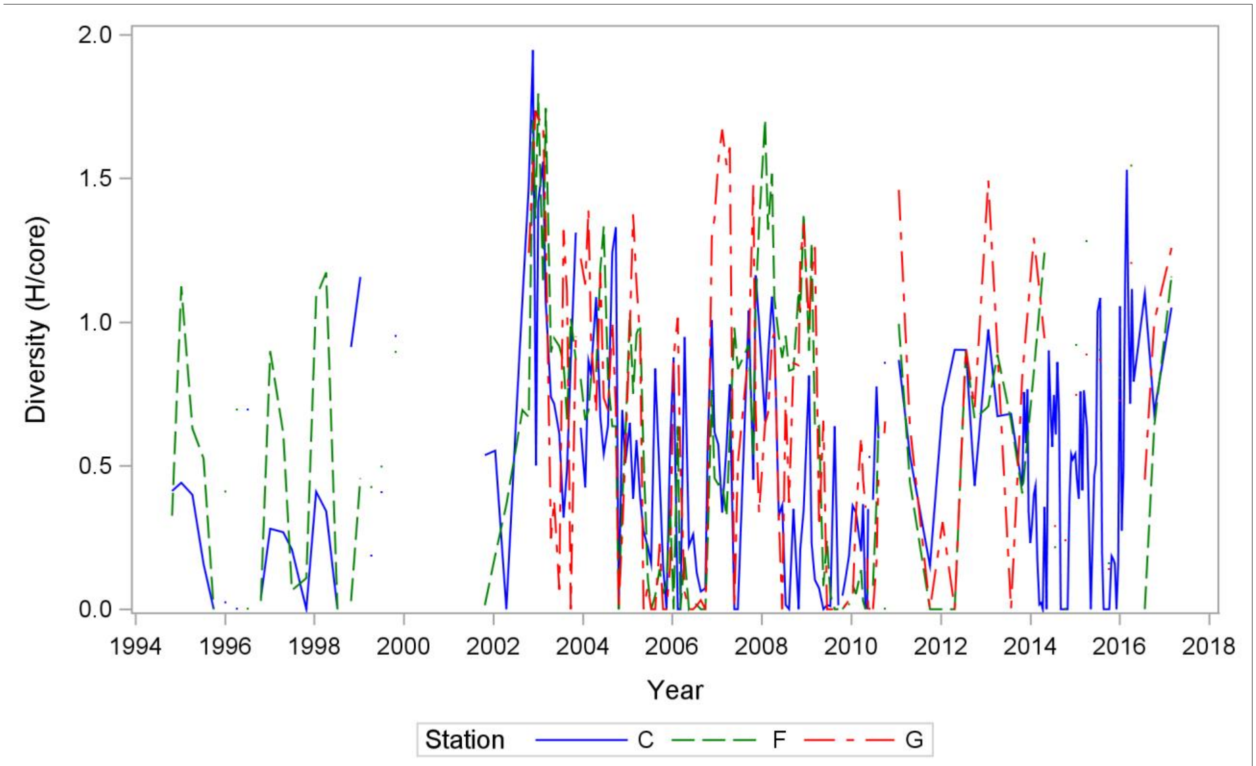

Figure 10: Mean benthic infaunal Shannon diversity index over time for Rincon Bayou Stations C, F, and G from October 28, 1994 to February 28, 2017.

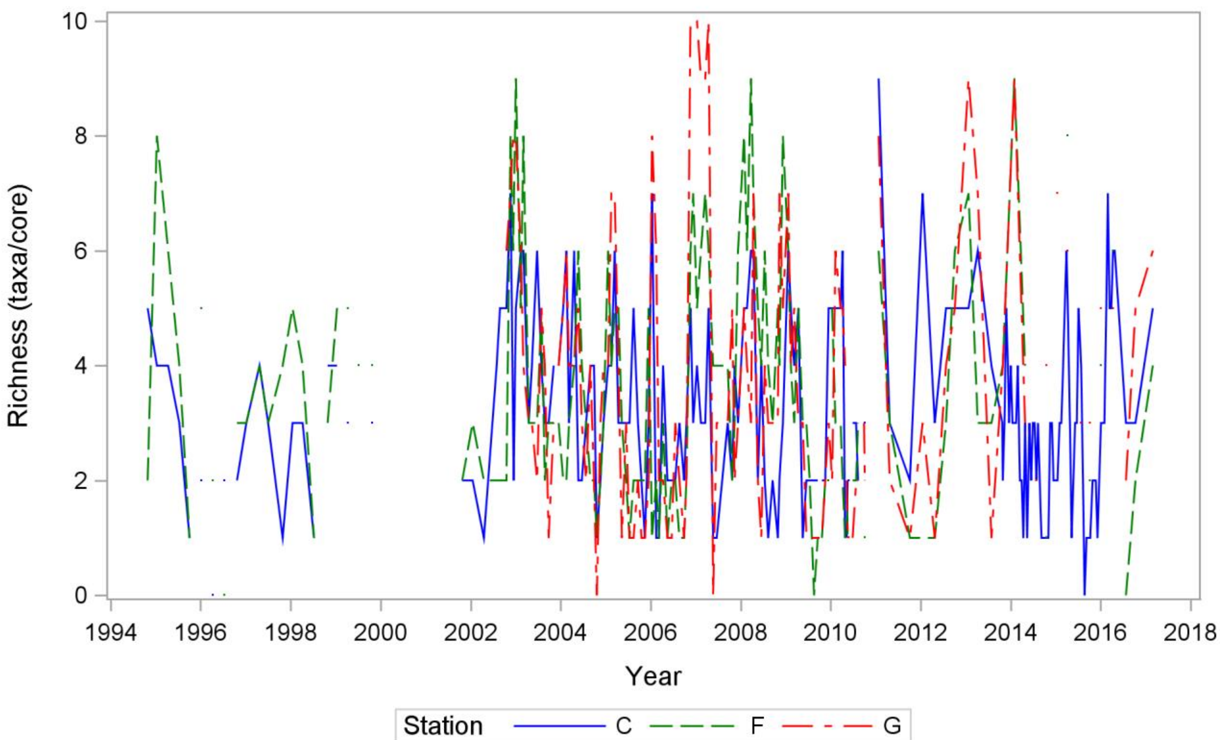

Figure 11: Mean benthic infaunal richness over time for Rincon Bayou Stations C, F, and G from October 28, 1994 to February 28, 2017.

Table 4: Spearman rank correlations for the key macrofauna metrics versus salinity for six lag periods at station C using the biweekly data (October 2014 – April 2016). Each lag period represents two week increments prior to sampling. Significant values highlighted in yellow.

		Salinity						
Metric (units)	**Statistic**	**lag0**	**lag2**	**lag4**	**lag6**	**lag8**	**lag10**	**lag12**
Abundance (n/m^2)	r	-0.15	-0.10	-0.20	-0.20	-0.18	0.00	0.18
	p	0.2222	0.4371	0.1093	0.1156	0.1642	0.9955	0.1631
	n	67	66	65	64	63	62	61
Abundance Log(n/m^2)	r	-0.15	-0.10	-0.20	-0.20	-0.18	0.00	0.18
	p	0.2222	0.4371	0.1093	0.1156	0.1642	0.9955	0.1631
	n	67	66	65	64	63	62	61
Biomass (n/m^2)	r	-0.11	-0.17	-0.20	-0.17	-0.14	-0.04	0.09
	p	0.3973	0.181	0.116	0.1673	0.2887	0.7771	0.4998
	n	67	66	65	64	63	62	61
Biomass Log(g/m^2)	r	-0.11	-0.18	-0.20	-0.18	-0.15	-0.04	0.08
	p	0.3632	0.1551	0.1055	0.1485	0.2264	0.7783	0.5456
	n	67	66	65	64	63	62	61
Total Species (R)	r	-0.23	-0.20	-0.25	-0.12	0.06	0.19	0.25
	p	0.0587	0.1031	0.0406	0.341	0.6254	0.1469	0.0503
	n	67	66	65	64	63	62	61
Diversity (N1)	r	-0.09	-0.24	-0.16	-0.03	0.14	0.20	0.23
	p	0.4658	0.0536	0.2024	0.7957	0.2852	0.1212	0.0766
	n	67	66	65	64	63	62	61

Table 5: Spearman rank correlations for the key macrofauna metrics versus salinity for one quarterly lag period at stations C, F and G over the entire times series, October 1994 to February 2017, and aggregated to quarterly data. Significant values highlighted in yellow.

Metric	Statistic	Salinity	Lag-Salinity
Abundance (n/m²)	r	0.27	0.25
	p	<0.0001	0.0002
	n	221	214
Abundance Log(n/m²)	r	0.21	0.20
	p	0.0017	0.0027
	n	221	214
Biomass (n/m²)	r	0.17	0.12
	p	0.0092	0.071
	n	221	214
Biomass Log(g/m²)	r	0.18	0.13
	p	0.0062	0.0505
	n	221	214
Total Species (R)	r	-0.18	-0.27
	p	0.0082	<0.0001
	n	221	214
Diversity (N1)	r	-0.29	-0.37
	p	<0.0001	<0.0001
	n	221	214

Another way to visualize the data set is to average benthic metrics and salinity over all stations for each sampling date (Figures 12 – 15). This also enables plotting the benthic metric and salinity values on the same graph. It is easier to see the trend of salinity and abundance (Figure 12) or biomass (Figure 13) increasing and decreasing at the same times. Diversity (Figure 14) and Richness (Figure 15) appear to have opposite trends with salinity; as salinity increases diversity declines, and as salinity decreases the diversity increases.

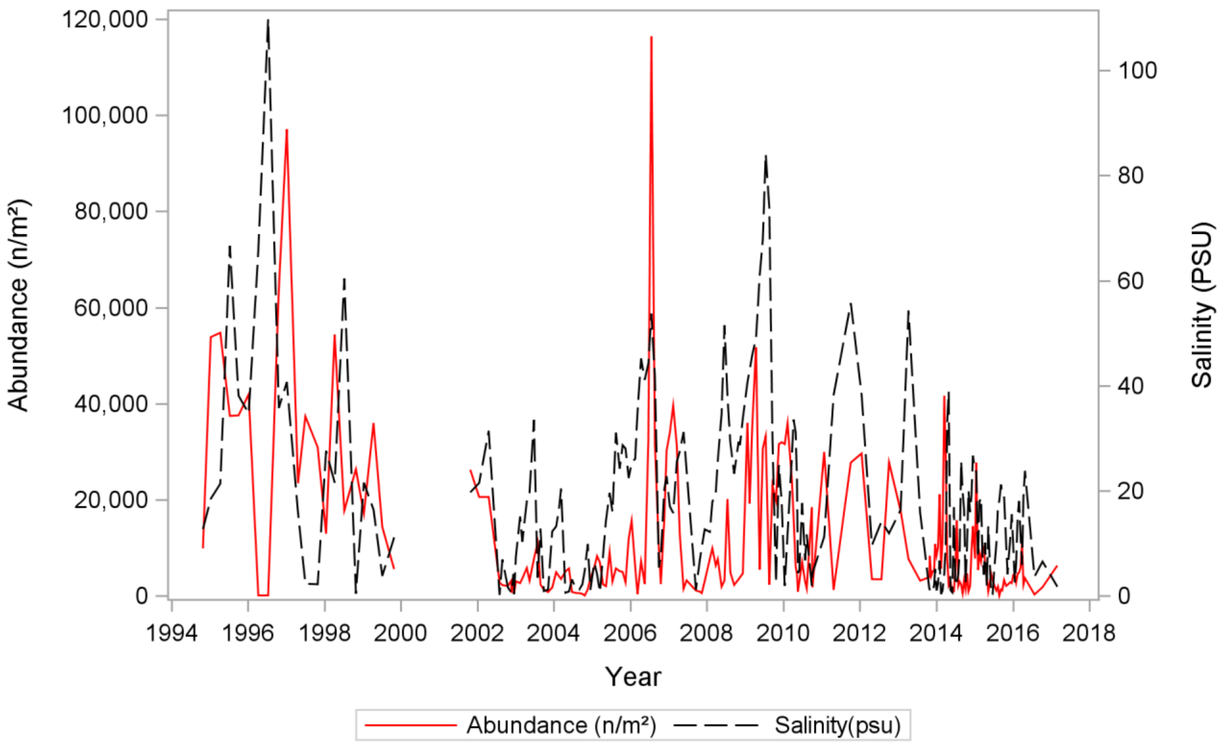

Figure 12: Mean benthic infaunal abundance and salinity at all stations from October 28, 1994 to February 28, 2017.

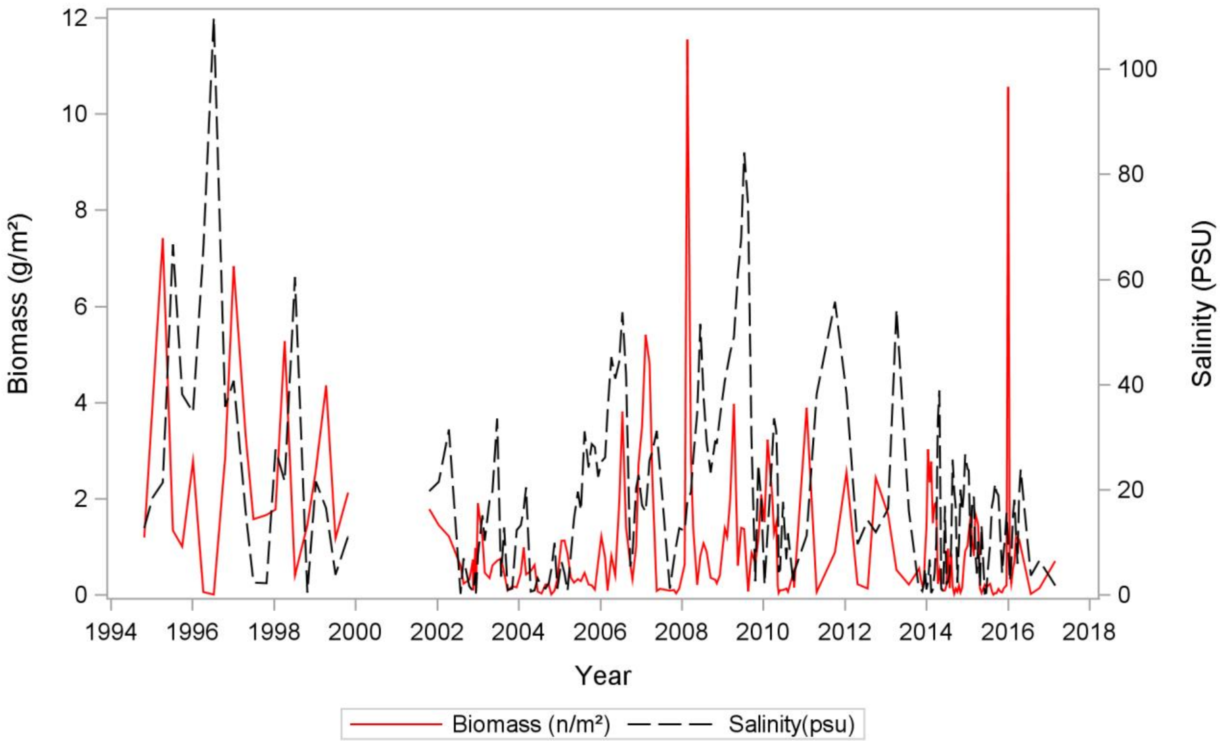

Figure 13: Mean benthic infaunal biomass and salinity at all stations from October 28, 1994 to February 28, 2017.

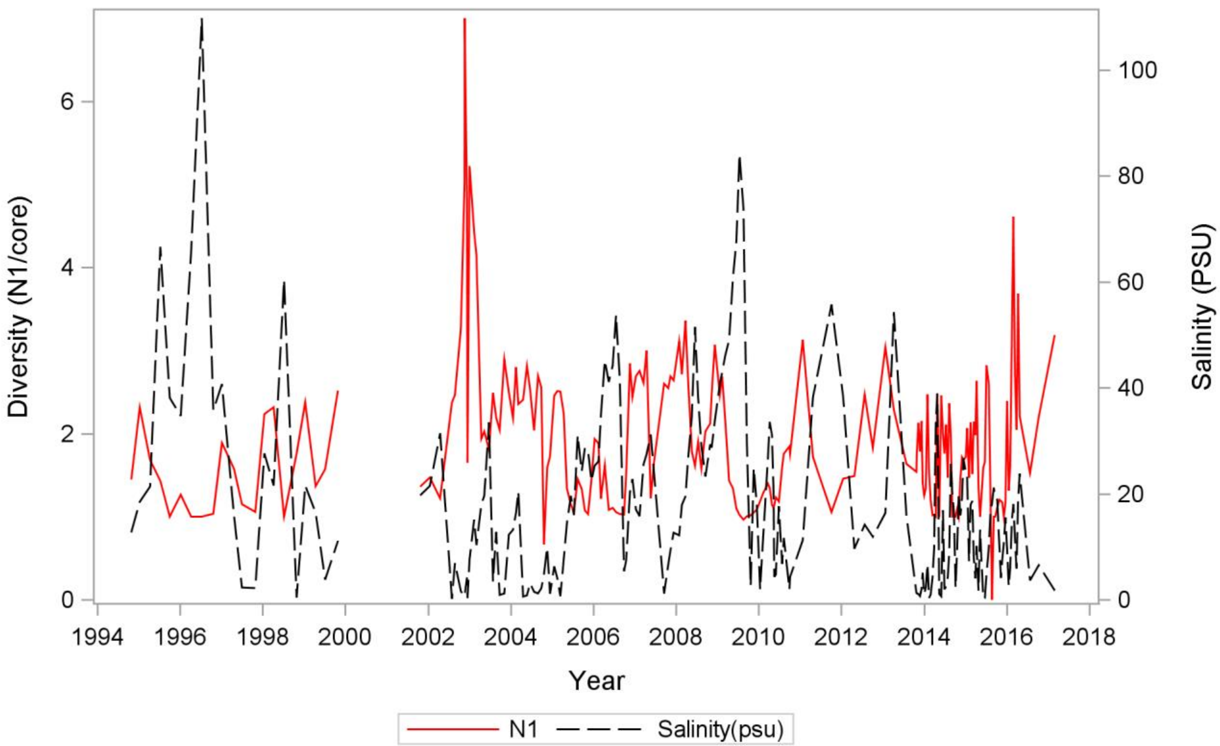

Figure 14: Mean benthic infaunal Shannon diversity index and salinity at Station C from October 28, 1994 to February 28, 2017.

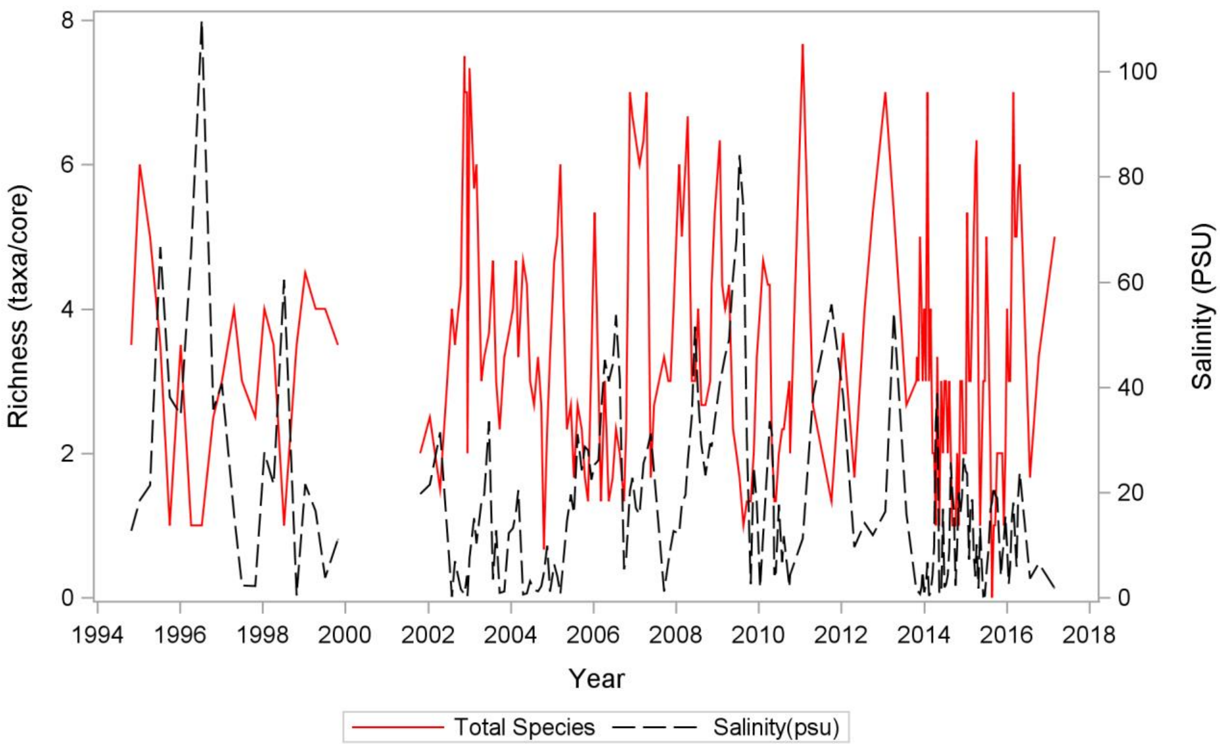

Figure 15: Mean benthic infaunal richness and salinity October 28, 1994 to February 28, 2017.

Science-Based Recommendation

The current study follows decades of research in Rincon Bayou, which started in 1994 (Irlbeck and Ward 2000). In the first decade, research was focused on the effects of the Nueces River Overflow channel to deliver fresh water into Rincon Bayou and its effects of biological communities (Montagna et al. 2009).

More recently, focus has switched to the operation and effects of pumping from the Rincon Bayou Pipeline, which delivers water directly into Rincon Bayou from the Calallen Pool (Montagna and Herdener 2015, Montagna et al. 2015). The current study is a direct continuation of these pipeline studies. In addition to the two reports listed above, the current studies have led directly to four Master of Science theses (Herdener 2015, Chaloupka 2016, DelRosario 2016, and Gordon 2016). So, the discussion will reference the previous reports, theses, and published journal articles, to frame the results of the current study in the context of factors not measured during the current study, and dynamics beyond just one year.

To discuss the relationship of measured salinity to pumped inflow, flow data was obtained from multiple sources (DelRosario 2016, Figure 16). Pumped inflow data from September 2009 to December 2016 was obtained from the Nueces River Authority (NRA) website: http://www.nuecesra/CP/CITY/rincon/. Flow through the Nueces River Overflow Channel into Rincon Bayou was measured at the United States Geological Survey (USGS) Rincon Bayou Channel Gage No. 08211503. Flow data from September 2009 to December 2016 was obtained from the USGS website: http://nwis.waterdata.usgs.gov. Salinity data from May 2009 to December 2016 was obtained from the CBI website: http://www.cbi.tamucc.edu/dnr/station for salinity stations Nueces Delta 2 (NUDE2) and SALT03.

Figure 16: Map of station locations for measuring flow, salinity, and weather in Rincon Bayou. From DelRosario (2016).

The absence of a distinct elevation gradient in Rincon Bayou at the pumping outfall area allows pumped inflow to flow both upstream and downstream resulting in both positive inflow and negative discharge readings at the USGS Rincon Bayou Channel Gage (DelRosario 2016). A weir was constructed at the pumping outfall in May 2010 to reduce the amount of pumped inflow going upstream. It was replaced in July 2014 with a back-flow preventer consisting of gates, which must be manually operated. The back-flow preventer washed out in the summer flooding of 2015, which reduced negative flows back to the Nueces River while it was in place (Figure 17). The back-flow preventer was repaired and completed in March 2016 (Del Rosario 2016, Montagna et al. 2018).

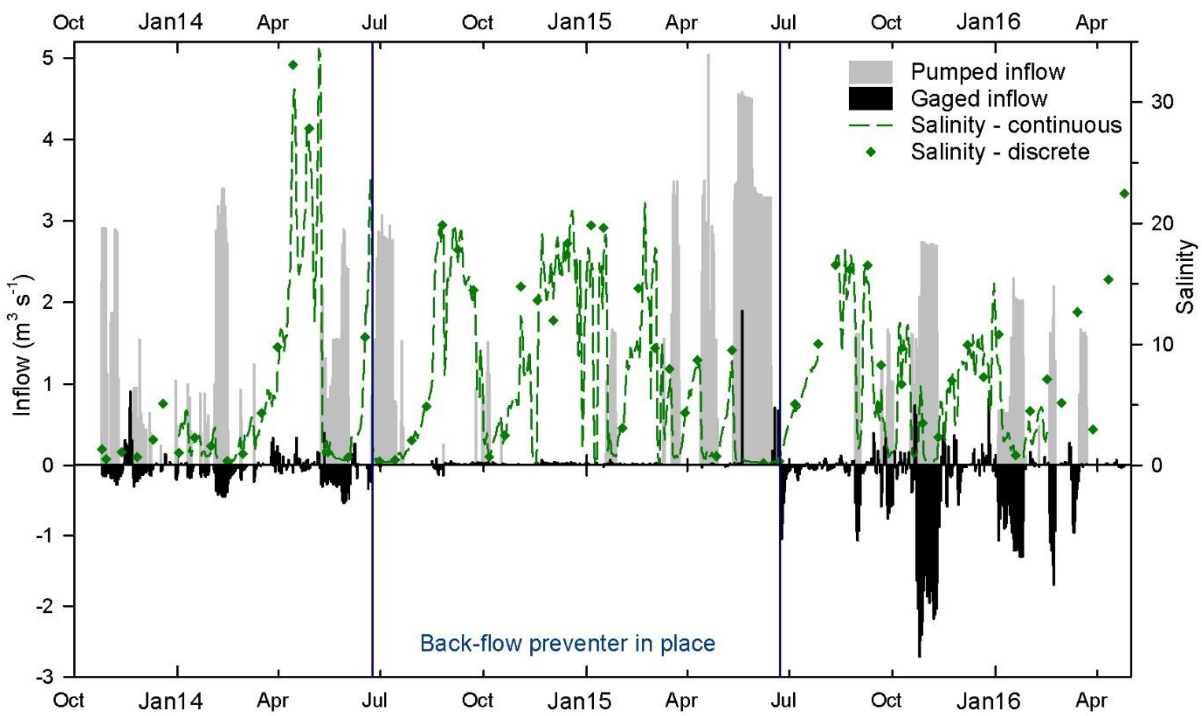

Figure 17: Pumped and Gaged inflow into Rincon Bayou and salinity at station C. Discrete salinity measurements were made simultaneously with fauna samples during the bi-weekly sampling period.

The Nueces Estuary can shift between positive and negative estuarine conditions depending on the volume of inflow and precipitation (DelRosario 2016). A positive estuary is defined as a system where salinities are lower than the adjacent sea due to freshwater inflow (Bianchi, 2006). In contrast, a negative estuary is a system where salinities are greater than the neighboring sea due to the process of evaporation. In the five-month period prior to the Rincon Bayou pipeline becoming operational in September of 2009, the Nueces Estuary was negative with a mean daily salinity upstream at NUDE2 being higher than the mean daily salinity downstream in the Nueces Bay at SALT03 (DelRosario 2016, Figure 17). The Nueces Estuary oscillates between positive and negative conditions with pumping events. Pumping events coincided with periods of positive estuary conditions and the greatest difference in salinity between the bay and the upper delta happened immediately after pumping ceased (Figure 17). In summary Rincon Bayou has transitioned from a negative hypersaline estuary to a positive estuary due to pumping of freshwater to the delta.

Streblospio is the dominant benthos species in Rincon Bayou and the most resilient to higher salinities and salinity changes. *Laeonereis culveri* and Chironomidae larvae are predominantly found in upper Rincon Bayou Station C and are typically associated with lower salinity levels. Chironomidae larvae are documented as freshwater and water quality indicators (Rosenberg, 1992; Saether, 1979). This indicates sustained freshwater inflow to upper Rincon Bayou during the period between from September 2009 to April 2016 likely altered the diversity and community structure to be favorable to freshwater indicator species such as Chironomidae.

The benthic community structure in Rincon Bayou during the pumping period from September 2009 to April 2016 was similar to that in previous studies, which found *S. benedicti* and chironomid larvae were the two dominant species (Montagna et al. 2002, Palmer et al. 2002, Ritter et al. 2005, Montagna et al. 2015, Chaloupka 2016). When salinities peak and plummet, the benthic infaunal community exhibits shifts in species dominance (Figure 18). Since 2013, there has been a clear division in salinity by macroinfauna; as expected, chironomid larvae were dominant when the salinity was low, and *S. benedicti* were dominant when the salinity was higher (Chaloupka 2016, Figure 18). Dominance by a pioneer species (*S. benedicti*) and insect larvae is typical during disturbance events (Montagna et al. 2002). Because one or both of these species were dominant on any given trip during sampling, it is possible to view the majority of the pumping period from September 2009 to April 2016 as disturbed.

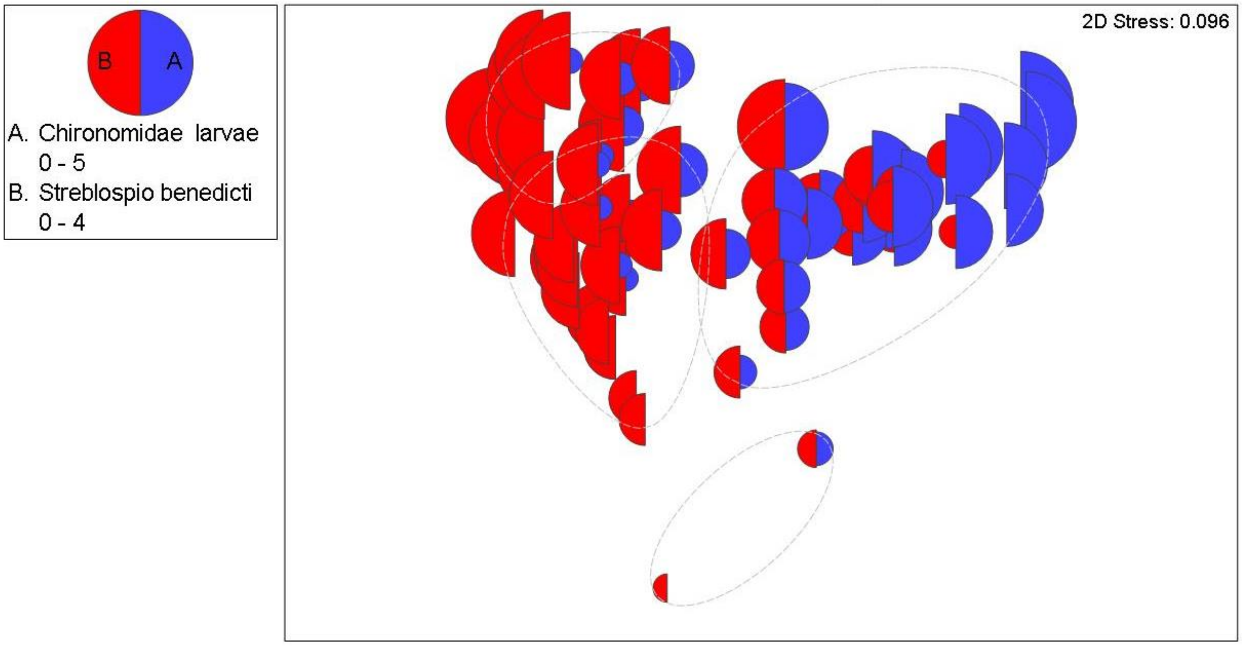

Figure 18: Multi-Dimensional Scaling plot of community structure over time overlaid with relative abundances of Chironomidae larvae and *Streblospio benedicti*.

Epifauna Response to Salinity

A study was also performed on benthic epifauna to complement the previously described macroinfauna data. Infauna are smaller, fixed in place, and live in the mud. Epifauna are larger, mobile, and live on the mud. Epifauna include shrimps, crabs, and fish, and are known to feed on the smaller infauna (Flasch 2003).

Grass shrimp, *Paleomonetes* sp., were the most abundant estuarine species identified in the epifauna community (Figure 19). Grass shrimp were dominant when salinities were higher. In contrast, two insects, the water boatman, *Tricho corixa*, and the mayfly, Ephermeroptera. dominated during the wetter periods. The alteration between estuarine and freshwater insects is the same pattern as found in the infauna.

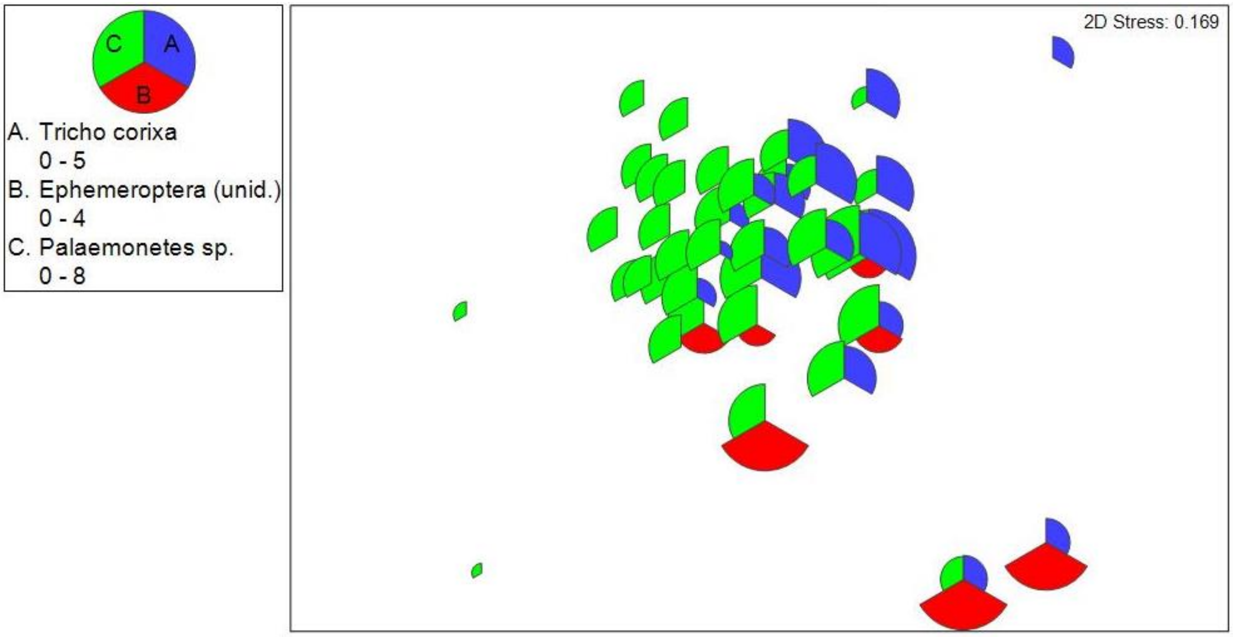

Figure 19: Multi-Dimensional Scaling plot of community structure over time overlaid with relative abundances of *Tricho corixa*, unidentified Ephermeroptera, and *Palaemonetes* sp.

Grass shrimp tend to enter the marsh region in higher abundance in the spring and fall and are a food source for penaeid shrimp, which migrate into the region (Lesutiene 2008, Riera et al 2000). Brown shrimp were found in lower abundance when grass shrimp abundance was high, with little overlap. This may imply that larger shrimp (typically found in fewer numbers) are present in these periods, but post-larval and early juvenile shrimp do not overlap in these periods, reducing competition. Grass shrimp accounted for greater than 25 percent of the crustacean community in Rincon Bayou. Grass shrimp are a species that spend the entirety of their life in the same marsh habitat (Kneib 1985). Of the most abundant fish species identified in Rincon Bayou, sheepshead minnow and silversides would be considered resident species that contribute to the trophic food web for larger predators (Gosselink 1984, Longley 1994). Gulf menhaden are a commercially valued, migratory spring fish that enter the region as juveniles, utilizing marsh habitat during early development as refuge (Lowther and Liddel 2014).

The mobility of epifaunal organisms makes them more adaptable to fluctuating environmental conditions because they can simply relocate. The 22 June 2015 flood event had been identified previously as an event that was dominated by freshwater organisms, especially *S. benedicti*, Ceratopogonidae larvae, *Ephemeroptera* sp., and Lymnaeidae sp., and with minimal marine species present (DeWalt et al 2010, Gordon 2016, Palmer et al 2002). This provided some indication that inundation of freshwater into the bayou makes the environment unsuitable for marine species, whereas freshwater species are better able to exploit the region (Tolan and Newstead 2005, Turner and Brody 1983). Changes in diversity of the epifaunal community occurred within a few weeks after pumping, whereas responses to salinity were not identified in abundance and biomass right away, but positive relationships between abundance and biomass were evident after 6 to 8 weeks (Figure 19).

Mechanistic Modeling of Benthic Response

A modeling study was performed to determine the effects of pumped inflows into Rincon Bayou on benthic macrofauna during normal and low flow events (Montagna et al. 2015). The low flow events are essentially zero flow rates when no water is pumped, and this is especially true when the back-flow preventer gate is in place. Rincon Bayou became a reverse estuary, where higher salinities are at the head of the estuary and lower salinities are away from the inflow source, after construction of the two reservoirs (Asquith et al. 1997, Irlbeck and Ward 2000). However, the two restoration projects (i.e., the overflow channel and the pump station) have helped to mitigate the reverse estuary conditions (Del Rosaria and Montagna 2018, Montagna et al. 2108). While Rincon can occasionally exhibit periodic hypersaline conditions (i.e., > 34 psu), this is becoming increasingly rare because of the hydrological restoration that has taken place. However, the salinity can fluctuate from fresh to hypersaline, and hypersaline to fresh in very short time periods. Pumping from the Calallen Pool into Rincon Bayou occurs only when there is also natural inflow because that is the only time when pass-throughs are required. When water is flowing in Rincon Bayou, nutrients are high and salinity is low.

The diversity of macro-infauna and macro-epifauna in Rincon Bayou is low compared to Nueces Bay. There are very high fluctuations of abundance and biomass related to fluctuations in inflow. The low diversity and population fluctuations are characteristic of a very disturbed ecosystem. A model of benthic dynamics, currently in its third major revision, does predict fluctuations of the populations of the three dominant taxa: *Streblospio benedicti*, *Laeonereis culveri*, and Chironomidae larvae with changes in pumping, and thus salinity.

Based on the modeling study, there are several recommendations that can be made to improve the ecosystem health and create a stable environment in the upper delta of Rincon Bayou based upon results presented here and a review of previous studies.

- Salinity should be maintained between 6 and 18 psu.
- Water depth should be maintained between 0.05 m to 0.2 m.
- To achieve the salinity and depth target, continuous inflows on the order of ≥ 0.41 m^3/s (28.72 ac-ft/day) to ≤ 0.689 m^3/s are required (48.26 ac-ft/day).
- To improve ecological stability, inflows should be a trickle, not a flood. Therefore inflows from pumping should be continuous and not haphazard, and not dependent on pass-through requirements.
- The current strategy of only pumping during rainfall and flood exacerbates the natural variability: floods become more severe, while droughts are dryer.

Empirical Modeling of Benthic Response

The large data set of benthos presents an opportunity to create empirical, or statistical models on how benthos respond to key environmental factors (Del Rosario 2016). The statistical modeling focused on three indicator species that were determined by the most numerically dominant species: *Streblospio benedicti*, Chironomidae larvae, and *Laeonereis culveri*. The biological responses of the indicator species to three physical variables (salinity, temperature, and depth) were examined. The optimal ranges for these environmental factors in Rincon Bayou were determined for the biweekly sampling program, which began 29 October 2013 and continued through 30 April 2015. The optimal salinity was between 1 and 15 psu for biomass and 1 and 14 psu for abundance, and the optimal depth range between 0.05 m and 0.2 m (2 – 7.9 inches).

The primary source of freshwater into Rincon Bayou is from pumped inflow, thus salinity and depth can be altered in direct response to management actions. Rincon Bayou has transitioned to a positive estuary with pumped inflow, but still occasionally exhibits reverse estuary conditions where salinity can fluctuate from fresh to hypersaline, and hypersaline to fresh in very short time periods when pumping is not occurring. Pumping has restored ecological function to Rincon Bayou by increasing inflow and decreasing salinity, but causes these extreme fluctuations. Salinities decrease immediately when pumping begins and remain low until the pumps are shut off, and then steadily increase until the pumps are turned back on. Other studies show that once the pumps are shut off it take salinities in Rincon Bayou about 20 days to reach within 5 psu of Nueces Bay salinities (Adams and Tunnell 2010; Tunnell and Lloyd 2011). Salinity fluctuations are a disturbance to benthic communities (Boesch et al. 1976, Harrel et al. 1976, Matthews and Fairweather 2004, Van Diggelen and Montagna 2016). Based on the low species diversity and frequent fluctuations in abundance and biomass of the indicator species the current method of pumping into Rincon Bayou is creating a disturbed estuary in which benthic succession dynamics are interrupted (Ritter et al. 2005).

The Rincon Bayou pumping station includes three 350 horsepower pumps, capable of delivering a minimum of 1.8 m^3/s (126 ac-ft/day) with one pump operating, 2.9 m^3/s (203 ac-ft/day) with two pumps in operation, and 3.8 m^3/s (266 ac-ft/day) with three pumps in operation (Tunnell and Lloyd 2011). With the current pumping capabilities this will result in a maximum salinity of around 0.5 psu and a depth of 1.05 m (41.34 inches) if one pump is operating continuously. The maximum salinity for Station C in Rincon Bayou was found to be 20 psu and the maximum depth was found to be 0.5 m (19.7 inches), with the optimum salinity range determined in the empirical modeling study being between 1 and 15 psu for biomass and 1 and 14 psu for abundance, and an optimum depth of 0.05 to 0.2 m (2 to 7.9 inches) for both. An inflow rate on the order of 0.41 m^3/s (28.72 ac-ft/day) would achieve a value in both the optimal salinity and depth range, with salinity at approximately 2.2 psu and a depth of approximately 0.2 m (7.9 inches) (Figure 20). However, to decrease the inflow from 1.8 m^3/s (126 ac-ft/day) to 0.41 $m^{3/}s$ (28.72 ac-ft/day) redesigning the pump station and reducing the pump size would be required.

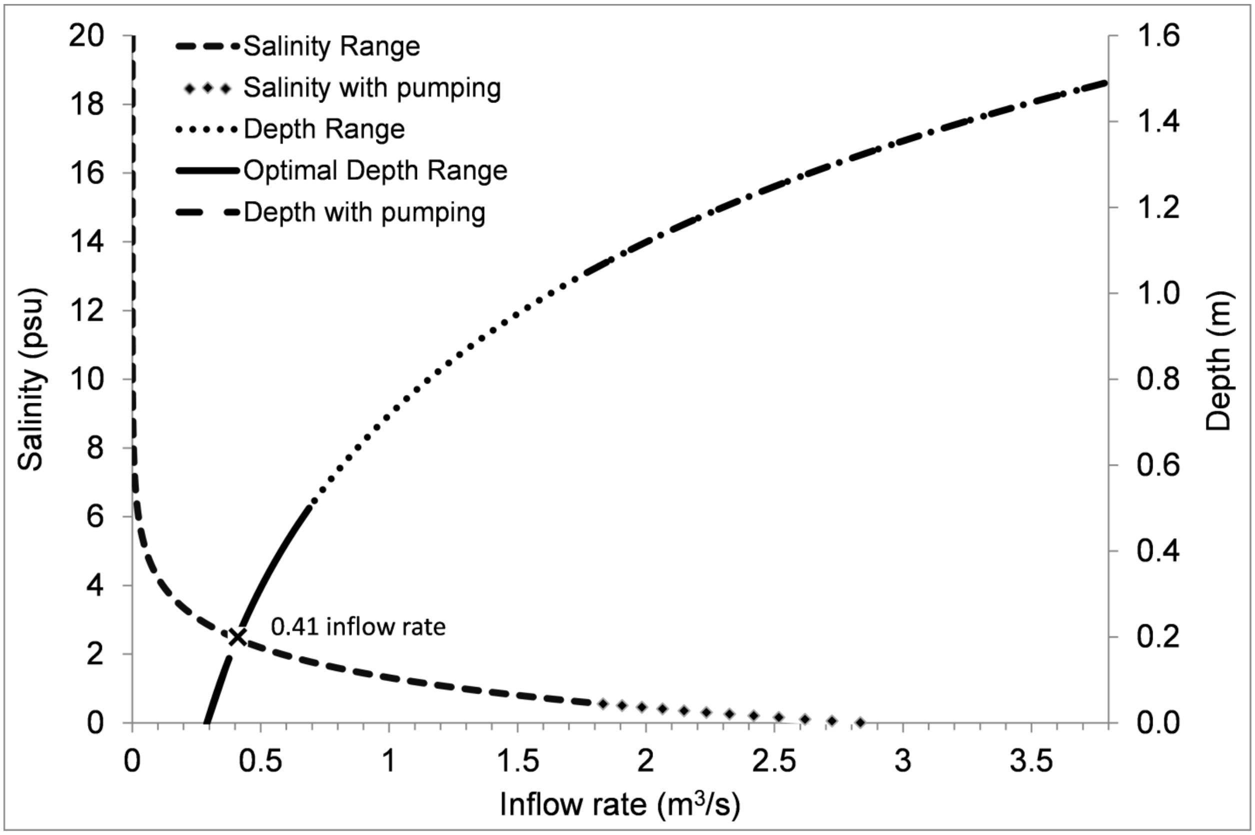

Figure 20: Relationship between Rincon Bayou pumping rates, salinity ranges, and depth ranges for the three indicator species at Station C.

Based on the empirical analyses, there are several management recommendations that can be made for Station C in Rincon Bayou: 1) to improve ecological stability: inflows should be a trickle, not a flood, releases should be continuous and not haphazard, only one pump should be used at a time, and releases should not be dependent on pass-through requirements; 2) to maximize ecological function: salinity should be maintained under 20 psu, and water depth should be maintained between 0.05 m and 0.2 m; 3) to maintain ranges: inflows rates on the order of ≥ 0.00102 m^3/s (0.084 ac-ft/day) are required to maintain salinities ≤ 20 psu, inflows on the order of ≤ 0.689 m^3/s (48.261 ac-ft/day) are required to maintain a depth ≤ 0.5 m, and inflow on the order of 0.41 m^3/s (28.72 ac-ft/day) will obtain an optimal value for both salinity at 2.2 psu and depth at 0.2 m (7.9 inches).

Consensus Recommendation

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 (TCEQ 1995). However, monthly inflows required are dependent on season, rainfall, stored levels of the reservoir system, and salinity levels in Nueces Bay (Montagna et al. 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 occurred naturally. It also means that there is no relief when salinities are high and the fresh water is needed the most. The initial response to floods is typically reduced abundance and diversity in the first 2 to 4 weeks, then often an increase after 6 to 8 weeks. However, the large swings in salinity from fresh to hypersaline conditions maintains this habitat in a constant state of disturbance with negative consequences on the community. The disturbed nature of the community is characterized by the presence of species that are known to be early colonizers or pioneer species, and this would explain the decreased diversity immediately after a flood. Therefore we have 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 paradigm should improve environmental conditions in Rincon Bayou.

Stakeholder Team

A stakeholder team was created to support the current project. The team consisted of people who have been engaged in studies or management of the Nueces Delta and Rincon Bayou and people who have been involved with managing water and environmental flows. Most of the people have more than 30 years' experience working on these issues. The team members are:

- Rae Mooney, Coastal Bend Bays & Estuaries Program (current Project Manager)
- Ray Allen, Coastal Bend Bays & Estuaries Program
- Rocky Freund, Nueces River Authority
- Jim Tolan, Texas Parks and Wildlife Department
- Jace Tunnell, University of Texas at Austin, Mission-Aransas National Estuarine Research Reserve
- Rick Kalke, Texas A&M University-Corpus Christi, Harte Research Institute
- Paul Montagna, Texas A&M University-Corpus Christi, Harte Research Institute (Convenor)
- Erin Hill, Texas A&M University-Corpus Christi, Center for Coastal Studies
- Brien Nicolau, Texas A&M University-Corpus Christi, Center for Coastal Studies

The team met 22 January 2019 to receive a briefing on project progress to date, and to discuss project findings and management options. Also invited but unable to attend was Ken Dunton (University of Texas at Austin, Marine Science Institute), and Steve Ramos (City of Corpus Christi, Water Department).

While the group agreed that we are not be ready to make requests for changes in the Agreed Order right now, some items of consensus evolved.

- The goal is to manage for a natural environment, so let Nature takes its course. The point being that calling for flows during droughts is problematic.
- Carry-over credits have affected inflows greatly. Carry-over credits mean that less water is pumped or passed through following wet months. Carry-over credits are accumulated when more water has flowed into the estuary system either from pumping or natural inflow than targeted. When this occurs, the City receives a 50% credit toward meeting the next month target. There is a salinity requirement for monthly targets measured at the station named Salt03. If salinity is below target for 10 consecutive days, then city gets carry-over credit.
- In order to seek any great change to the agreed order, it would be necessary to observe a large change in some key charismatic species.
- One goal could be to manage temporal changes to coincide with key times for larval recruitment of important species. However, recruitment is occurring throughout the year, so there would be a problem of picking winners and losers, and going contra to the goal of "letting Nature takes its course."
- Tides are a confounding influence because more water flows downstream when tides are higher, such as in the spring and fall.

Management or Regulatory Options

The main regulatory option is to use the NEAC to recommend changes to the Agreed Order. A request for a change has to be agreed to by three entities: The City of Corpus Christi, The City of Three Rivers, and the Nueces River Authority. This has happened twice before.

Based on NEAC recommendations, Texas Natural Resource Conservation Commission (but now the Texas Commission on Environmental Quality) issued a Final Agreed Order in April 1995 to amend many of the 1992 Agreed Order provisions. A key NEAC finding was based on inflow needs studies carried out jointly by the Texas Parks and Wildlife Department and the Texas Water Development Board indicating that maximum fishery harvest could be sustained with 138,000 ac-ft (170 10^6 m^3) per year delivered in monthly inflows to mimic natural hydrographic conditions in the Nueces Basin, Table 5. There were three other important revisions: 1) the minimum mandatory inflows were changed to targeted monthly inflows, 2) the releases were changed to pass-throughs, and 3) drought relief was granted in the form of different pass-through requirements based on the reservoir level.

Table 6: Pass-through targets for the Nueces Estuary set in the 1995.

Month	Pass-through Targets (Acre Feet = 1233 m^3)			
	Capacity ≥ 70%	40% ≤ Capacity < 70%	30% ≤ Capacity < 40%	Capacity < 30%
Jan	2,500	2,500	1,200	0
Feb	2,500	2,500	1,200	0
Mar	3,500	3,500	1,200	0
Apr	3,500	3,500	1,200	0
May	25,500	23,500	1,200	0
June	25,500	23,000	1,200	0
July	6,500	4,500	1,200	0
Aug	6,500	5,000	1,200	0
Sept	28,500	11,500	1,200	0
Oct	20,000	9,000	1,200	0
Nov	9,000	4,000	1,200	0
Dec	4,500	4,500	1,200	0
Total	*138,000*	*97,000*	*14,400*	*0*

There are important distinctions between the words release, pass-through, and spill. A release is stored water that is let out of a lake to meet downstream water rights and supply raw water to water treatment plants. A pass-through is water that has flowed into the reservoir system, up to the monthly target amount, and is let out of Lake Corpus Christi to meet the freshwater inflow requirements to the Nueces Estuary. Thus, if there are inflows to the reservoirs, the City is required to pass-through the target amount based on the level of the reservoir. A spill is water that is let of a lake because the lake is full.

The inflow targets to the estuary can be met by rain, river inflow, return flows, or diversions. Releases, when required to satisfy a targeted pass-through requirement, are made at the end of a month if it is projected that the target flow will not be met by these other sources. However, this is a pass-through plan and at no time is the City required to release water from system storage to satisfy the estuary target inflow amount if insufficient flows enter the reservoir.

Another amendment to the agreed order was obtained by the City of Corpus Christi in April 2001, and this was largely based on the research performed in the Rincon Bayou Demonstration Project (Bureau of Reclamation 2000). The main changes were related to revising the drought management measures in the 1995 order. In the 1995 order, the initiation of the drought relief was solely at the discretion of the City, which means that every time the City wanted to use the drought measures, it required action by the Mayor and City Council. This became a highly politicized issue. In the 2001 amendment, the City is now required to implement drought mitigation measures, such as lawn and outdoor water use restrictions, at the reservoir level amount that provide drought relief. Also, new bathymetric surveys were performed that increased the total water storage capacity by 16,019 ac-ft (19.75 10^6 m^3) because of sediment retention. In exchange for these benefits the City agreed to: 1) reconstruct the Nueces River Overflow Channel to Rincon Bayou, 2) construct a pipeline to convey up to 3,000 ac-ft (3.7 10^6 m^3) directly to the Nueces Delta, and 3) implement an on-going monitoring and assessment program to facilitate adaptive management for freshwater flows into the Nueces Estuary.

The results of the literature review, data analysis, and meetings have made it clear that some changes are in order. While changing the Agreed Order is a long and difficult task with uncertain outcomes, there are at least four options that don't require that drastic step.

- One is to request a one-time, 10-year, pilot project to try different pumping regimes.
- A second is to modify the operation of the back-flow gate to enhance connectivity in the system.
- A third is to try and coordinate and mechanize the operation of the pumps and the gate to try and have more of a continuous than pulse flow.
- A fourth option is to spread out a pumping for longer time periods. The pumps are on or off, and one pump puts out 105 ac-ft/day, so if the use of multiple pumps can be avoided, then the pumping could be more continuous. There is one important constraint, and that is that the pass-throughs must occur within 10 days of the end of the month. So it would take 28.6 days, nearly the whole month, to pump 3,000 ac-ft when that would be required, and this requirement may strain our ability to predict weather and flows a month in advance.

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