Determining Optimal Pumped Flows to Nueces Delta

Principal Investigator:
Dr. Paul A. Montagna

Co-Authors:
Leslie Adams, Crystal Chaloupka, Elizabeth DelRosario, Richard D. Kalke, and Evan L. Turner

Harte Research Institute for Gulf of Mexico Studies
Texas A&M University - Corpus Christi
6300 Ocean Drive, Unit 5869
Corpus Christi, Texas 78412
Phone: 361-825-2040
Email: paul.montagna@tamucc.edu

Final report submitted to:
Texas Water Development Board
P.O. Box 13231
17000 N. Congress Avenue
Austin, TX 78711-3231

Contract # 1548311787

July 2016

Cite as:
Montagna, P.A., L. Adams, C. Chaloupka, E. DelRosario, R.D. Kalke, and E.L. Turner. 2016. Determining Optimal Pumped Flows to Nueces Delta. Final Report to the Texas Water Development Board, Contract # 1548311787. Harte Research Institute, Texas A&M University-Corpus Christi, Corpus Christi, Texas, 75 p.

Table of Contents

List of Figures

List of Tables

Abstract

The purpose of the current project is to determine the effects of pumped inflows into Rincon Bayou on benthic macrofauna during normal and low flow events. The low flow events are essentially zero flow rates. This information is needed by managers to create an effective pumping strategy for the Rincon Bayou pipeline that maximizes the ecological benefit from freshwater placement in the Nueces Delta, near Corpus Christi, Texas.

Historically, Rincon Bayou was a reverse estuary, where higher salinities are at the head of the estuary and lower salinities are away from the inflow source, but that has been largely mitigated. 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.

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 $\geq 0.41\ m^3/s$ (28.72 ac-ft/day) to $\leq 0.689\ m^3/s$ 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.

Introduction

The Nueces River System has been subject to adaptive management since construction of the Choke Canyon Reservoir in 1982 (Montagna et al. 2009). Special condition required the City of Corpus Christi to provide not less than 185 million cubic meters (151,000 ac-ft) of water per year to the Nueces Estuary through a combination of spills, releases, and return flows to maintain ecological health and productivity of living marine resources. However, creation of Choke Canyon Reservoir resulted in a 99.6% decrease of river inflow into the Nueces Delta and a 54.9% decrease into the Nueces Estuary (Bureau of Reclamation 2000, Espey, Huston & Associates 1981). No required water releases were made, and after public complaints, the Texas Water Commission (TWC) issued an order in May 1990 requiring the City to meet the special conditions contained in their water right permit that required freshwater inflows to the estuary.

In April 1995, the Texas Natural Resource Conservation Commission (formerly TWC, but now the Texas Commission on Environmental Quality [TCEQ]) issued a Final Agreed Order in April 1995 to amend earlier provisions. The minimum annual inflow requirement was reduced to 138,000 ac-ft per year to be delivered in a monthly regimen to mimic natural hydrographic conditions in the Nueces Basin. There were three other 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. The permit revisions ensured environmental flows to the estuary.

In October 1995, the U.S. Bureau of Reclamation (BOR 2000) constructed a demonstration project to open an overflow channel at a depth of 1.0 ft-msl (~ 30 cm) from the Nueces River to Rincon Bayou, which is the main stem channel of the Nueces Delta marsh. The purpose of the overflow channel was to increase opportunities for freshwater inflow into the delta to improve ecological value of the marsh. The project was very successful improving hydrology (Ward et al. 2002) by restoring the number of overflow events from one in three years to three in each year; however, the historical volumes of the floods were not restored. At first, the initial flooding events actually increased salinity because of the large amount of salt that had evaporated in the delta over the years. By 1997, the restored flow began to reduce salinities in the delta during floods. The reduced salinities led to increased productivity of the marsh and living resources (Montagna et al. 2002, Palmer et al. 2002, Alexander and Dunton 2002). However, because this demonstration project did not have permanent easements and additional easements could not be obtained, the channel was closed in September 2000.

In April 2001, changes were made to revise drought management measures in the 1995 order. Water use restrictions, such as lawn and outdoor water usage, are now tied to the reservoir level to provide relief during drought. Also, new bathymetric surveys were performed that demonstrated the total water storage capacity was 6,019 ac-ft higher than thought, because of sediment retention. The Texas Water Development Board (TWDB) performed bathymetric surveys in 2012 and reported that the reservoir loses capacity every year due to sedimentation (TWDB 2013). 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 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.

In 2009, the pipeline and pumping station was constructed to pump freshwater from the Calallen Pool directly to Rincon Bayou so that flow would not rely on overflowing the Calallen Dam. The pumping station contains three pumps that can be used alone or in unison. The time needed to pump 3,000 ac-ft depends on the number of pumps running at one time. It takes roughly one week to pump the required amount if all three pumps are running, or three weeks if one pump is running. Thus the most beneficial pumping regime (i.e., the timing and quantity of pumped inflow) has yet to be resolved. The purpose of the current project is to determine the effects of pumped inflows into Rincon Bayou on benthic macrofauna during normal and drought precipitation events. This information is needed by managers to create an effective pumping strategy for the Rincon Bayou pipeline that maximizes the ecological benefit from freshwater placement in the Nueces Delta, near Corpus Christi, Texas.

Methods

The primary objective of the current study is to determine the effects of pumped inflows into Rincon Bayou on benthic macrofauna in order to inform water managers on how to create an effective pumping strategy to maintain or enhance the ecological soundness of the environment. 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 (i.e., they stay in one place), therefore they integrate pollutant or disturbance 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 (i.e., synthetic chemicals that are foreign to the ecosystem) materials. The approach used here is to relate samples of water quality and benthic macrofauna response to inflow and pumping events.

Sampling

The Nueces Estuary is one of seven major estuarine systems along the Texas Coast. The Nueces Estuary includes the marsh system in Nueces Delta, Nueces River tidal segment, one primary bay Corpus Christi Bay (connected to the Gulf of Mexico by Aransas Pass), one secondary bay Nueces Bay (that connects the river and delta to the primary bay), and two tertiary bays Oso and Redfish Bay (Figure 1). The Nueces River Saltwater Barrier Dam, located adjacent to Interstate Highway (IH) 37, was originally constructed in 1898 to restrict saltwater intrusion to the upstream nontidal segment of the river. The Nueces Estuary is unlike typical estuaries because the Nueces River empties directly into Nueces Bay without traversing the Nueces Delta. Rincon Bayou is a creek connecting to the tidal segment of the Nueces River to the delta during flood events, and the bayou runs down the main stem of the Nueces Delta.

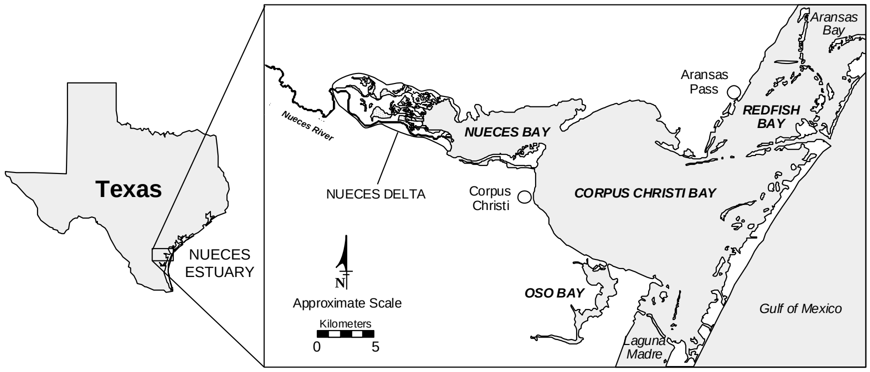

Figure 1. Location of the Nueces Delta within the Nueces Estuary.

Three stations were sampled for study here (Figure 2). Station C is located at 27.89878 °N latitude and 97.60417 °W longitude. Station F is located at 27.87760 °N latitude and 97.57873 °W longitude. Station G is located at 27.88992°N latitude and 97.56910 °W longitude. These are historical stations sampled since 2002 and previously named 466C, 400F, and 463G respectively (Montagna et al. 2009).

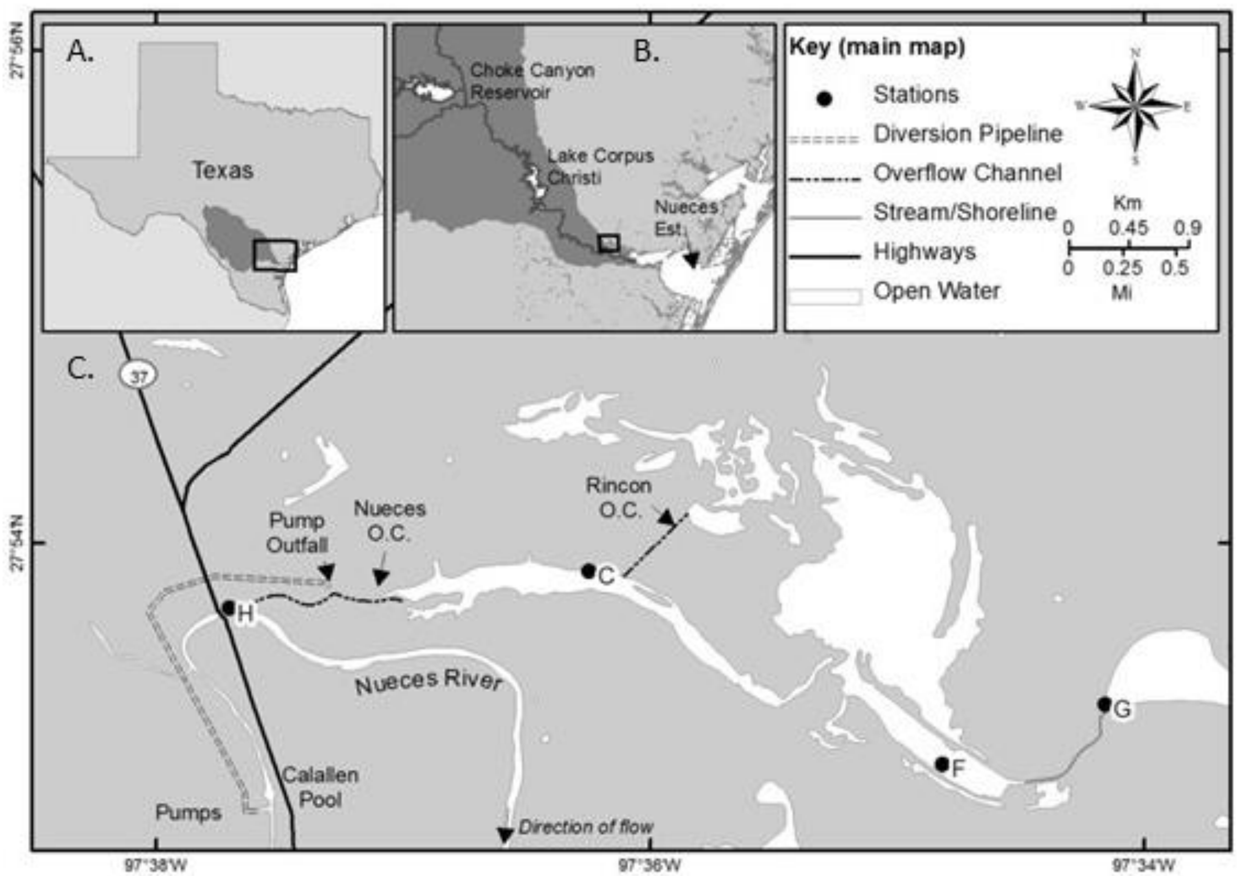

Figure 2. Study area with sample locations. A) State of Texas with the Nueces Basin highlighted. B) Location of Choke Canyon Reservoir and Lake Corpus Christi within the Nueces Basin. C) Location of the Nueces Delta marsh containing Rincon Bayou.

Station C was sampled biweekly from October 25, 2013 through April 30, 2016. Stations F and G were sampled quarterly from October 25, 2013 through April 30, 2016. Originally we proposed to sample before, during and after pumping events, but this proved to be impossible because we were not notified until after pumping began, which mean we could never obtain pre-pumping samples. To resolve the problem, we sampled one station (C) every two weeks to ensure that we captured all inflow events including natural flooding.

Water Quality

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

The depth of the water column was measured, and water samples for chlorophyll and nutrients were collected just beneath the surface and at the bottom of the water column at all stations on each sampling date. Chlorophyll and nutrients were sampled in duplicate.

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

Nutrient samples were filtered to remove biological activity (0.45 μm polycarbonate filters) and placed on ice (<0.4 °C). Water samples were analyzed at the Harte Research Institute using a OI Analytical Flow-4 autoanalyzer with computer controlled sample selection and peak processing. Typical lowest concentration minimum reportable levels (LCMRL) are: nitrate+nitrate (0.25-10.0 μM; OI Analytical method 15040908, OIA 2008), silicate (10.0-300.0 μM; O.I. Analytical method 15061001, OAI 2001a), and ammonium (0.25-10.0 μM; OI Analytical method 15031107, OIA 2007). The orthophosphate method has a LCMRL of 0.10-10.0 μM (Perstorp Analytical method 000589, OIA 2001b), but is a modification of the Alpkem chemistries method (Alpkem 1993).

Macrofauna-Infauna

Benthic infaunal biomass, abundance and community structure was measured using the standard techniques that we have been using since 1984 (Kalke and Montagna, 1991; Montagna and Kalke, 1992, Montagna et al. 2002). The sediment cores were taken by hand within a 2 m radius. The cores are 6.715 cm diameter, covering an area of 35.4 cm^2. The cores were sectioned (at 0-3 cm, and 3-10 cm) to examine the vertical distribution of macrofauna. Animals were extracted using a 0.5 mm mesh sieve, and identified to the lowest taxonomic unity possible. In the laboratory, animals were enumerated, identified, and dried at 50 °C for 24 hours and weighed. Mollusk shells are removed by an acidic vaporization technique (Hedges and Stern, 1984).

Diversity was calculated using Hill's diversity number one (N1) (Hill, 1973). Hill’s N1 is a measure of the effective number of species in a sample, and indicates the number of numerically dominant species. It is calculated as the exponentiated form of the Shannon diversity index:

$$N1 = e^{H'}$$

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. The obvious richness index is simply the total number of all species found in a sample regardless of their abundances. Hill (1973) named this index N0.

Analytics

Water Quality Response to Inflow

Mean water quality parameters (salinity, temperature, dissolved oxygen, nutrients, chlorophyll a, and pH) and water depth were calculated for each date-station combination. All variables, except pH, were transformed by adding 1 to the concentration (x) and computing the natural logarithm, ln(x+1). Log transformation removes the skewness of the data. After transformation, the data was standardized to a normal distribution with a mean of 0 and variance of 1 using PROC STANDARD in SAS (2013a). The standardized data has the same scale for all variables so that scaling will not affect multivariate analysis.

Multivariate analyses were used to analyze how the physical-chemical environment changes over time. Principal components analyses (PCA) was used to classify the samples. PCA is a variable reduction technique that can be used to reduce a large number of variables to a reduced set of new variables, which are uncorrelated and contain most of the variance in the original data set. The water quality variables are reduced to two new axes, PC1 and PC2, which are called variable loads. The new axes are then interpreted based on the variables that load highly in both the positive and negative direction. A PC1 and PC2 score is computed for each sample, i.e., sample scores, and the relationship among the samples is interpreted based on its position in the bivariate plot of the two PC axes. PCA was performed using the PROC FACTOR procedure in the SAS (2013) software suite. The FACTOR analysis was run using options for the PCA method on the correlation matrix.

Two PCA analyses were run: one to identify spatial trends at all stations (C, F, and G), and one to identify the high-frequency temporal trends at station C. All water quality variables were measured simultaneously at Stations C, F, and G every 1-3 months from August 2004 to June 2005 (8 dates) and every 3-12 months from April 2010 to 21 December 2015 (19 dates); and this data set was used primarily to identify spatial trends, and secondarily to identify long-term temporal trends. All water quality variables were sampled at Station C only on either monthly or biweekly basis since October 2013 (an additional 50 dates sampled); and this high-frequency data set was used to identify temporal trends as it relates to the pumping.

Community Structure

Benthic community structure was analyzed using Primer-e software (Clarke et al. 2014; Clarke and Gorley 2015). Community structure was classified using non-metric multidimensional scaling (MDS) and cluster analysis using a Bray-Curtis similarity matrix (Clarke 1993, Clarke et al. 2014). Prior to analysis, the abundance data (n) was transformed by adding 1 and computing the natural logarithm: ln(n+1). 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 be displayed on the MDS plot to elucidate grouping of station-date combinations. The group average cluster mode was used for the cluster analysis.

The most influential infaunal species on overall community structure were determined using the BEST procedure. The BEST procedure is used to find the best match between multivariate community patterns. The BVSTEP option of the BEST procedure is used to carry out a step-wise search for the best single variable (i.e., species) to match the pattern of the overall community. Then a second variable is added until the matching coefficient ρ is maximized. The step repeats and more variables are added until ρ is maximized based on the original ordination for the full community (i.e., all species). This is done by calculating weighted Spearman rank correlations (ρw) between sample ordinations from all of the species and an ordination of species' abundances so that a subset of species that best matches the multivariate response pattern of the whole community can be identified (Clarke and Warwick 1998, Clarke and Gorley 2015).

Biotic Response to Salinity, Temperature, and Depth

Salinity is often used as a proxy for freshwater inflow because inflow dilutes sea water and thus decreases salinity. The relationship between macrofauna abundance, diversity, and salinity has been examined using a non-linear model, which was used successfully in Texas (Montagna et al. 2002) and Florida estuaries (Montagna et al. 2008). The assumption behind the model is that there is an optimal range for salinity and values decline prior to and after reaching this optimum salinity value. That is, the relationship resembles a bell-shaped curve. The shape of this curve can be predicted with a three-parameter, log normal model:

$$Y = a \times \exp\left(-0.5 \times \left(\ln \frac{\left(\frac{X}{c}\right)}{b}\right)^2\right)$$

The model was used to characterize the nonlinear relationship between a biological characteristic (Y, *e.g.,* abundance, biomass, or diversity) and salinity (X). The three parameters characterizes different attributes of the curve, where *a* is the peak abundance value, *b* is the skewness or rate of change of the response as a function of salinity, and *c* the location of the peak response value on the salinity axis (Montagna et al. 2002).

One issue is that has limited the use of the relationship between salinity and macrofauna density in the past is that variability in inflow and in life cycles are not always in sync. For example, if a species has cyclical reproductive cycles, then the density will be low regardless of the salinity. This will result in an area under a curve rather than points lining up along a curve. What is wanted to run the model is the relationship between the maximum number of organisms and the salinity. Therefore, by taking 10 bins of maximum organism responses the maximum relationship to salinity, temperature, and depth is achieved (Turner and Montagna 2016). This is a significant improvement in the statistical method. The same maximum binning method was used to identify biotic responses to temperature and water depth, i.e., temperature or depth replaces salinity as X in the equation.

Hydrology

Salinity was measured continuously by HRI using a YSI 6600 sonde at Station C (Figure 3) from January 2014 to December 2016. Pumped inflow data from September 2009 to December 2016 was obtained from the Nueces River Authority (NRA) website: http://www.nueces-ra.org/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 (Figure 3). Flow data from September 2009 to December 2016 was obtained from the USGS website: http://nwis.waterdata.usgs.gov. Rainfall data from January 2014 to December 2016 was obtained from the Conrad Blucher Institute for Surveying and Science (CBI) website: http://www.cbi.tamucc.edu/dnr/station for the Nueces Delta Weather Station (NUDEWX). 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 3).

Figure 3. Map of station locations for measuring flow, salinity, and weather in Rincon Bayou.

Modeling

Benthic Ecology Model Design

Models of ordinary differential equations have been used previously in simulating the responses of benthic macrofauna to freshwater inflow in Texas estuaries (Montagna and Li, 2010; Kim and Montagna, 2012; Kim and Montagna, 2009). The governing equation for benthic growth is based on a template of the Lotka-Volterra growth model (Lotka, 1925) influenced by a density-dependent logistical population maximum (Brown and Rothery, 1993):

$$\frac{dB}{dt} = r * B * \left(1 - \frac{B}{C}\right) - g * F$$

From the Brown and Rothery (1993) formulation of the predator prey equation benthic populations *B* are inhibited by the environmental carrying capacity *C*. For this experiment, the carrying capacity is defined as the largest abundance or biomass of benthos observed during the study period.

The current Benthic Ecology Model (BEM) is the third generation from a direct lineage from previous benthic modeling experiments starting in the 1990s (Montagna and Li, 2010; Montagna and Li, 1997; Montagna and Li, 1996). While Montagna and Li (1996) was the first version, the differences between the current model and the previous version (Kim and Montagna, 2009) are a redesign of the forcing equations for growth and mortality along with the simplification of the overall design. Additionally, the model will be applied to species independently rather than entire functional groups. The current design uses salinity, and temperature as primary drivers of benthic infaunal growth, while salinity and depth are also drivers of mortality (Figure 4).

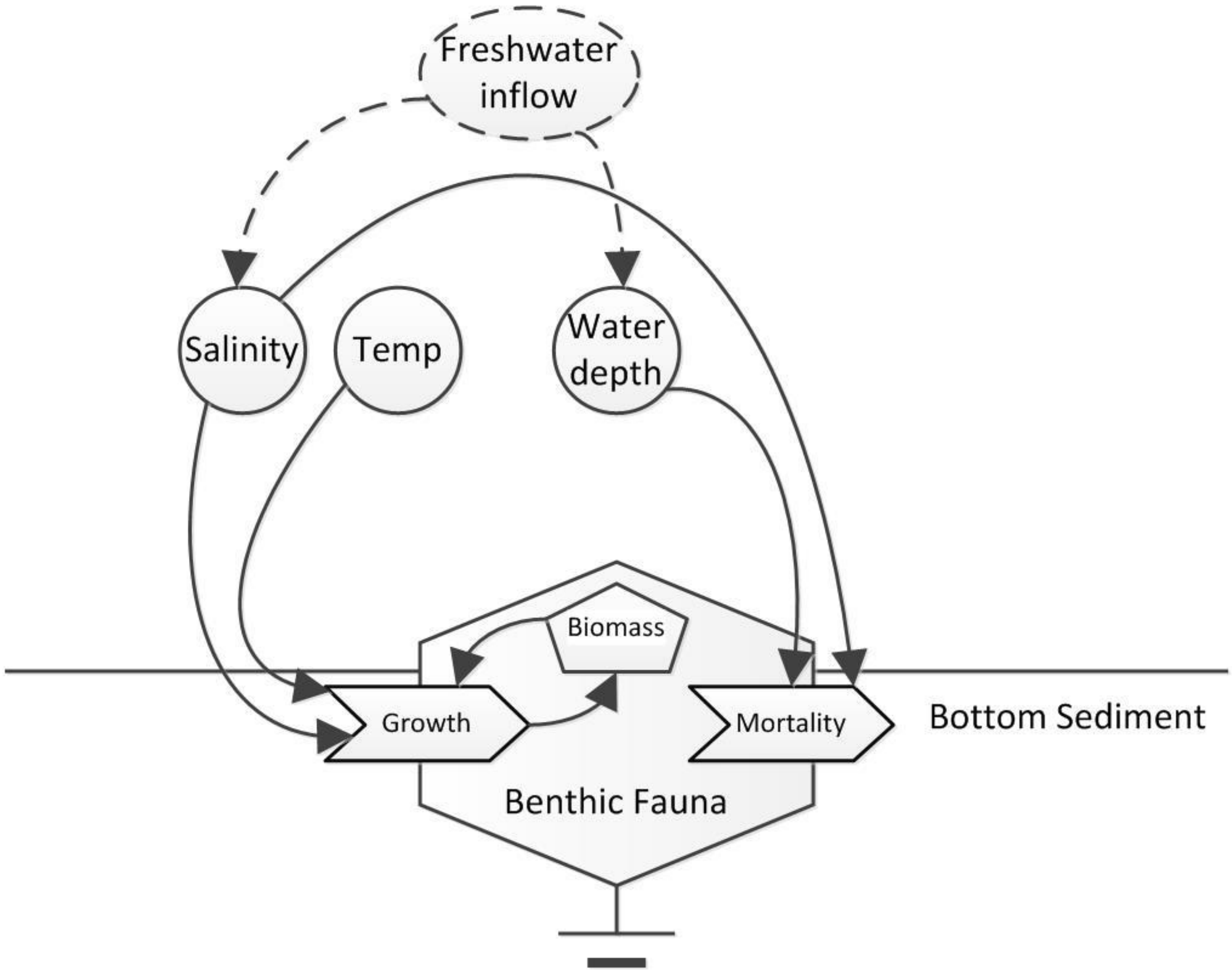

Figure 4. Flow diagram of the Benthic Ecology Model.

The premise of the updated model design is that freshwater inflow drives the majority of the benthic macrofauna population variability. Inflow lowers salinity, increases water depth, and brings imports nutrients. However, flooding conditions where depth > 0.5m was found to be negatively related to benthic biomass and abundance. The benthic ecology model is comprised of four main forcing equations and 11 coefficients per species (Table 1).

Table 1. Rincon Bayou Benthic Ecology Model. A) State equations. B) Functions. C) Variables.

State Equations	Description
(a) $\frac{dB}{dt} = (Gsal * Gtemp * Kg * B) * \left(1 - \frac{B}{Bcc}\right) - (Km * B) - (Kmds * Mdep * B^2) - (Kmss * Msal * B^2)$	State equation for benthos

Functions	Description
(b) $Gsal = e^{-\frac{(salinity-Sopt)^2}{(2*Kgs)^2}}$	Benthos growth by salinity
$Gtemp = e^{-\frac{(temp-Topt)^2}{(2*Kgt)^2}}$	Benthos growth by temperature
$Msal = 1 - e^{-\frac{(salinity-Sopt)^2}{(2*Kms)^2}}$	Benthos mortality due to Salinity
$Mdep = 1 - e^{-\frac{(depth-Dopt)^2}{(2*Kmd)^2}}$	Benthos mortality due to depth

Variable	Definition	Unit
(c)		
B	Benthic Biomass	mg dw (milligrams dry weight)
salinity	Salinity	psu (practical salinity units)
depth	Depth	m (meter)
temp	Temperature	C (centigrade)
Kgs	Salinity growth factor	d^{-1} (per day)
Kgt	Temperature growth factor	d^{-1} (per day)
Kg	Benthic growth	mg d^{-1} (milligrams per day)
Km	Benthic mortality	mg d^{-1} (milligrams per day)
Kms	Salinity mortality factor	mg d^{-1} (milligrams per day)
Kmds	Depth Mortality Scalar	mg d^{-1} (milligrams per day)
kmss	Salinity Mortality Scalar	d^{-1} (per day)
Bcc	Benthos carrying capacity	mg dw d^{-2} (milligrams dry weight per day)
Dopt	Optiml Depth	m (meter)
Topt	Optimal Temperature	C (centigrade)
Sopt	Optimal Salinity	psu (practical salinity units)

Rincon Bayou Macrofauna Modeling Study Species

The Benthic Ecology Model was calibrated for the three most abundant species in Rincon Bayou: *Streblospio benedicti*, *Laeonereis culveri*, and Chironomidae larvae. The log-normal max bin technique previously described in this report was used to determine the ideal salinity, depth, and temperature for growth of each species. This data was used as a guide to the calibration process to determine the best fit to the microfaunal biomass data collected at Station C from 29 October 2013 through 11 April 2016. YSI sondes deployed at Station C continuously through this time period were used for the hydrological forcing of salinity, temperature, and depth to the model. To model as a daily ΔT the YSI sonde collections means were taken to the daily level.

Model Implementation and Validation

For purposes of validation the sample sets for each species biomass dry weight were separated randomly with 2/3^{rds} of the observations used as a calibration set and the remaining 1/3rd as the validation set. The full data set was parsed using a random uniform selection method by using the SAS function UNIFORM(), which returns a random variable from a uniform distribution (SAS, 2013b). This ensured an even distribution of observation ranges for each computational data set. This method was chosen to separate the validation sets because each species has a different maximum growth period between 2013 and 2016 that did not overlap with each other.

The model is implemented in the Python programming language (Appendix I) using the EasyModeler 2.2.6 pypi toolbox (Turner, 2016). This method was used previously to test multiple models of nutrient dynamics in San Antonio Bay, Texas (Turner et al., 2014). The model was integrated using the VODE algorithm with order 12 and a maximum 3000 internal steps per ΔT. A Monte Carlo approach was used to determine the best fit to the calibration set for each species. Each set was executed for 20,000 iterations as a broad first pass to determine the local coefficient maximums, then a fine tune pass of 10,000 iterations against the best found fit with the 50% of the previous coefficient ranges. This process was repeated 10 times for a total of 300,000 iterations. A final smoothing pass of 20,000 iterations with 75% of the original coefficient ranges was then performed. In total 960,000 model iterations were performed to fit all three case study species.

The primary goodness of fit statistic to evaluate model performance is the percent root mean square (RMS) difference between observations and model outputs. The %RMSD is defined as:

$$\%RMSD = \sqrt{\frac{\sum \frac{(X_{MOD} - X_{OBS})^2}{N}}{\sum \frac{(X_{OBS})^2}{N}}} \times 100$$

where X_{MOD} and X_{OBS} are model simulations and observed data respectively and N is the size of the overall sample.

Results

Hydrology and Salinity

The salinity gradient from the upper delta extending to the Nueces Bay defines whether Rincon Bayou has either positive or negative estuarine conditions. An increasing salinity gradient results in a positive estuarine condition with lower salinities upstream; a decreasing salinity gradient results in a negative estuarine condition with higher salinities upstream. The Nueces Estuary can shift between a positive and negative estuarine conditions depending on the volumes of inflow and precipitation. In the five-month period prior to the Rincon Bayou pipeline becoming operational in September of 2009, the Nueces Estuary was negative (Figure 5) with a mean daily salinity upstream at NUDE2 being higher than the mean daily salinity downstream in the Nueces Bay at SALT03. The Nueces Estuary oscillates between positive and negative conditions with pumping events (Figure 5). 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 5).

A test run of the pipeline was performed in 2007 with pumping beginning into Rincon Bayou in September 2009 (Table 2). The mean pumped inflow per pumping event was 12 m^3/s with a maximum pumping rate of 126.86 m3/s and a minimum pumping rate of 0.11 m^3/s. With pumping, Rincon Bayou has transitioned from a negative hypersaline estuary to a positive estuary with a mean daily salinity at NUDE2 of 23.22 psu (Figure 6). Rincon Bayou had a maximum daily mean salinity of 86.29 psu and a minimum daily mean salinity of 0 psu (Table 4). Salinity declined after each pumping event and gradually increased until the next pumped inflow (Figure 7). The mean of continuous daily salinities at Station C during the sampling period (January 1, 2014 to December 31, 2015) was 6.74 psu, with a maximum daily mean salinity of 46.38 psu, and a minimum daily mean salinity of 0.00 psu (Table 5). The mean of continuous daily depth was 0.49 m with a maximum of 1.82 m and a minimum of 0.00 (Table 5).

The mean rainfall at NUDEWX was 1.92 cm/day with a maximum of 142 cm/day (Table 4). This may have accounted for decreases in salinity when pumping was not occurring (Figure 8). Because pumping occurs only to satisfy pass-through requirements, the pumping events correlate with rainfall, and typically occur after or during rainfall periods (Figure 9). The mean pumped inflow was 1.71 m^3/s with a maximum of 5.04 m3/s and a minimum pumped amount of 0.03 m^3/s (Table 4).

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 and negative discharge readings at the USGS Rincon Bayou Channel Gage (Figure 10). A weir was constructed at the pumping outfall in May 2010 to reduce the amount of pumped inflow going back upstream (R.D. Kalke personal communication). 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 (R.D. Kalke personal communication). It reduced negative flows back to the Nueces River while it was in place (Figures 7 and 10).

Table 2. Rincon Bayou Pipeline pumping events from the Nueces River Authority. A test run was conducted in 2007 with the pipeline becoming operational in September 2009.

Pumping Event Number	Duration	Number of Days of Inflow	Total Pumped Inflow		
			Ac-ft / day	ft^3/s (cfs)	m^3/s (cms)
0	April 17, 2007	1	36	18.15	0.51
1	Sept. 28 - Oct 21, 2009	24	2,987	1,506.05	42.65
2	Jan. 6 - Jan. 14, 2010	9	742	374.12	10.60
3	May 10 - May 31, 2010	22	2,288	1,153.61	32.67
4	March 21-March 30, 2010	10	1,006	507.23	14.37
5	May 3 - May 12, 2011	10	1,002	505.21	14.31
6	June 13 - June 22, 2011	10	994	501.17	14.19
7	Sept. 13 - Sept. 14, 2011	2	98	49.41	1.40
8	Nov. 2 - Nov. 22, 2011	21	2,027	1,022.01	28.95
9	March 7 - March 19, 2012	13	1,309	660.00	18.69
10	June 21 - July 13, 2012	23	2,354	1,186.89	33.62
11	Aug. 7 - Aug. 24, 2012	18	2,004	1,010.42	28.62
12	Aug. 27 - Aug. 28, 2012	2	109	54.96	1.56
13	Sept. 14 - Sept. 16, 2012	3	212	106.89	3.03
14	Sept. 30- Oct. 1, 2012	2	135	68.07	1.93
15	Oct. 5, 2012	1	36	18.15	0.51
16	Oct. 8 - Oct. 18, 2012	11	1,981	998.82	28.29
17	Oct. 27, 2012	1	27	13.61	0.39
18	Nov. 26, 2012	1	31	15.63	0.44
19	Dec. 8 - Dec. 9, 2012	2	95	47.90	1.36
20	Dec. 16 - Dec. 20, 2012	4	159	80.17	2.27
21	Jan. 15 - Jan. 16, 2013	2	62	31.26	0.89
22	Jan. 26 - Jan. 28, 2013	3	152	76.64	2.17
23	April 29, 2013	1	40	20.17	0.57
24	May 14 - May 15, 2013	2	15	7.56	0.21
25	June 1 - June 10, 2013	9	847	427.06	12.10
26	June 24 - July 2, 2013	8	731	368.57	10.44
27	July 17 - July 24, 2013	8	665	335.29	9.50
28	Aug. 12 - Aug. 13, 2013	2	161	81.18	2.30
29	Aug. 20 - Aug. 22, 2013	2	124	62.52	1.77
30	Aug. 27- Aug. 29, 2014	3	273	137.65	3.90
31	Sept. 12 - Sept. 13, 2013	2	161	81.18	2.30
32	Oct. 11, 2013	1	45	22.69	0.64
33	Oct. 21, 2013	1	27	13.61	0.39
34	Oct. 24 - Oct. 30, 2013	7	1,131	570.25	16.15
35	Nov. 2 - Nov. 9, 2013	8	1,190	600.00	16.99

36	Nov. 22 - Dec 1, 2013	9	509	256.64	7.27
37	Dec. 4, 2013	1	31	15.63	0.44
38	Dec. 7 - Dec 8, 2013	2	73	36.81	1.04
39	Dec. 17, 2013	1	17	8.57	0.24
40	Dec. 30 - Dec 31, 2013	2	107	53.95	1.53
41	Jan. 10 - Jan. 13, 2014	4	177	89.24	2.53
42	Jan. 21 - Jan. 22, 2014	2	89	44.87	1.27
43	Jan. 25 - Jan. 28, 2014	3	141	71.09	2.01
44	Feb. 3 - Feb. 15, 2014	13	2,466	1,243.36	35.21
45	Feb. 26 - Feb. 27, 2014	2	105	52.94	1.50
46	March 10, 2014	1	87	43.87	1.24
47	April 15, 2014	1	8	4.03	0.11
48	May 9 - June 3, 2014	24	2,736	1,379.49	39.07
49	June 23 - July 15, 2014	23	3,531	1,780.33	50.42
50	July 19 - July 21, 2014	3	177	89.24	2.53
51	Aug. 26, 2014	1	18	9.08	0.26
52	Sept. 24, 2014	1	66	33.28	0.94
53	Sept. 30 - Oct. 1, 2014	2	116	58.49	1.66
54	Oct. 4 - Oct. 6, 2014	3	264	133.11	3.77
55	Oct. 17, 2014	1	35	17.65	0.50
56	Jan. 18 - Jan. 27, 2015	9	695	350.42	9.92
57	March 10 - March 12, 2015	3	210	105.88	3.00
58	March 18 - March 25, 2015	8	1,535	773.95	21.92
59	April 13 - April 28, 2015	16	2,455	1,237.81	35.06
60	May 12 - June 15, 2015	35	8,884	4,479.31	126.86
61	Aug. 29 - Sept. 2. 2015	5	448	225.88	6.40
62	Sept. 21 - Sept. 22, 2015	2	167	84.20	2.38
63	Sept. 26 - Oct. 1, 2015	6	475	239.50	6.78
64	Oct. 17 - Nov. 10, 2015	25	3,734	1,882.68	53.32

Table 3. Sampling trip number with corresponding sample date for Station C, number of days between sampling trips, and total inflow into Rincon Bayou prior to the sampling trip.

Sampling Trip Number	Sampling Date	Number of Days Between Sampling	Total Inflow (Gage + RBP) (m^3/s)
0	11-May-10	-	-
1	28-Jun-10	48	26.27
2	25-Jan-11	211	5.66
3	25-Apr-11	90	12.82
4	25-Jul-12	457	100.97
5	5-Oct-12	72	32.34
6	24-Jan-13	111	32.59
7	9-Apr-13	75	4.20
8	29-Jul-13	111	29.70
9	25-Oct-13	88	16.96
10	29-Oct-13	4	11.03
11	12-Nov-13	14	15.73
12	26-Nov-13	14	5.68
13	10-Dec-13	14	3.18
14	19-Dec-13	9	0.07
15	2-Jan-14	14	1.22
16	16-Jan-14	14	1.75
17	31-Jan-14	15	2.21
18	14-Feb-14	14	30.08
19	28-Feb-14	14	0.14
20	17-Mar-14	17	0.61
21	31-Mar-14	14	1.09
22	14-Apr-14	14	-0.20
23	28-Apr-14	14	0.62
24	15-May-14	17	6.73
25	2-Jun-14	18	24.73
26	17-Jun-14	15	0.29
27	30-Jun-14	13	14.21
28	14-Jul-14	14	34.37
29	29-Jul-14	15	3.35
30	11-Aug-14	13	0.05
31	25-Aug-14	14	-0.43
32	8-Sep-14	14	0.42
33	22-Sep-14	14	0.22
34	6-Oct-14	14	6.77
35	20-Oct-14	14	0.72

36	3-Nov-14	14	0.04
37	18-Nov-14	15	0.02
38	2-Dec-14	14	0.37
39	15-Dec-14	13	0.34
40	5-Jan-15	21	0.36
41	16-Jan-15	11	0.07
42	2-Feb-15	17	10.31
43	16-Feb-15	14	0.16
44	3-Mar-15	15	0.17
45	16-Mar-15	13	3.06
46	30-Mar-15	14	21.92
47	10-Apr-15	11	-0.06
48	27-Apr-15	17	34.52
49	11-May-15	14	0.45
50	8-Jun-15	28	107.99
51	22-Jun-15	14	23.32
52	6-Jul-15	14	-4.49
53	27-Jul-15	21	-1.07
54	11-Aug-15	15	-0.27
55	24-Aug-15	13	-0.11
56	9-Sep-15	16	2.18
57	21-Sep-15	12	1.32
58	9-Oct-15	18	4.53
59	28-Oct-15	19	6.14
60	11-Nov-15	14	9.86
61	23-Nov-15	12	-1.55
62	7-Dec-15	14	-0.84
63	21-Dec-15	14	0.53

Table 4. Daily means for USGS Rincon Gage, CBI salinity stations (SALT03, NUDE2) and weather station (NUDEWX), Station C, and the Rincon Bayou Pipeline (September 2009 to December 2015).

Sampling Location	Number of Observations	Mean	Std Dev	Min. Mean	Max. Mean
USGS Rincon Gage (m^3/s)	2311	-0.02	0.32	-2.72	4.93
Rincon Bayou Pipeline - RBP (m^3/s)	457	1.71	0.97	0.03	5.04
Total inflow - Gage + RBP (m^3/s)	2311	0.31	0.79	-1.70	6.48
NUDEWX - Rainfall (cm)	2182	1.92	7.78	0.00	142.00
SALT03 - Salinity (psu)	2413	31.65	9.96	0.36	47.28
NUDE2 - Salinity (psu)	2301	23.22	18.17	0.00	86.29
Station C - Salinity (psu)	734	6.77	6.65	0.01	34.41
Station C - Depth (m)	734	0.48	0.24	0.00	1.82
Station C - Temperature (°C)	734	22.60	6.61	3.39	34.85

Table 5. Continuous sonde data at Station C in Rincon Bayou from January 2014 to December 2015.

Variable	Number of observations	Mean	Std Dev	Minimum	Maximum
Depth (m)	17810	0.49	0.24	0.00	1.86
Temperature (°C)	17810	22.50	7.08	1.44	41.96
Salinity (psu)	17810	6.74	6.81	0.00	46.38

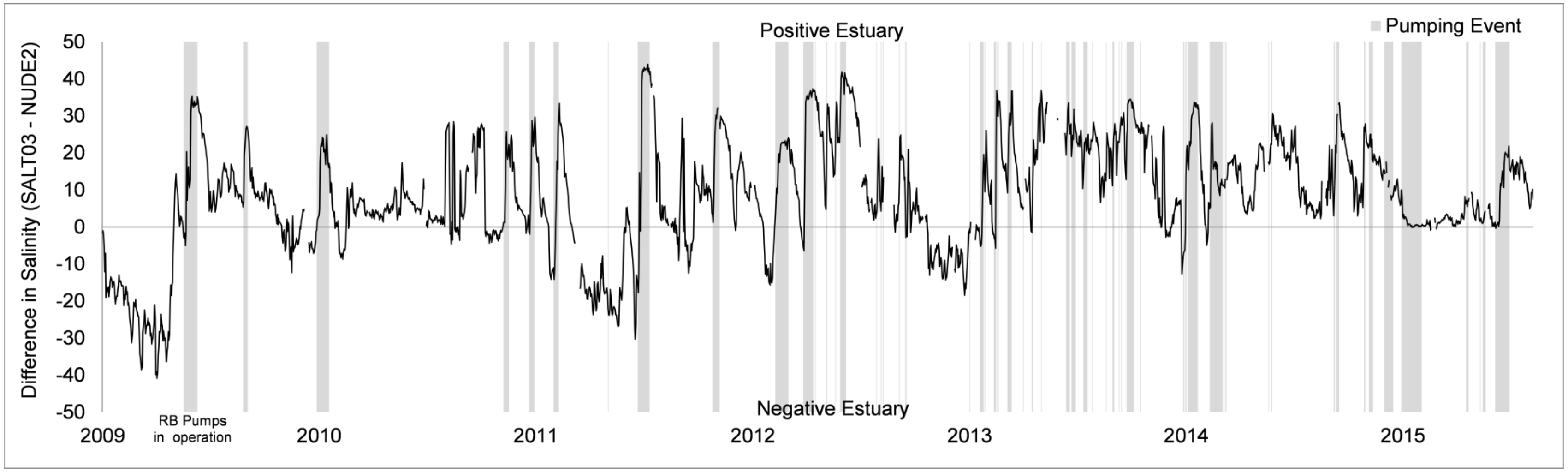

Figure 5. Salinity gradient (i.e., black line is the difference between downstream SALT03 and upstream NUDE2) and gray bars are periods of pumping operations May 2009 to December 2015.

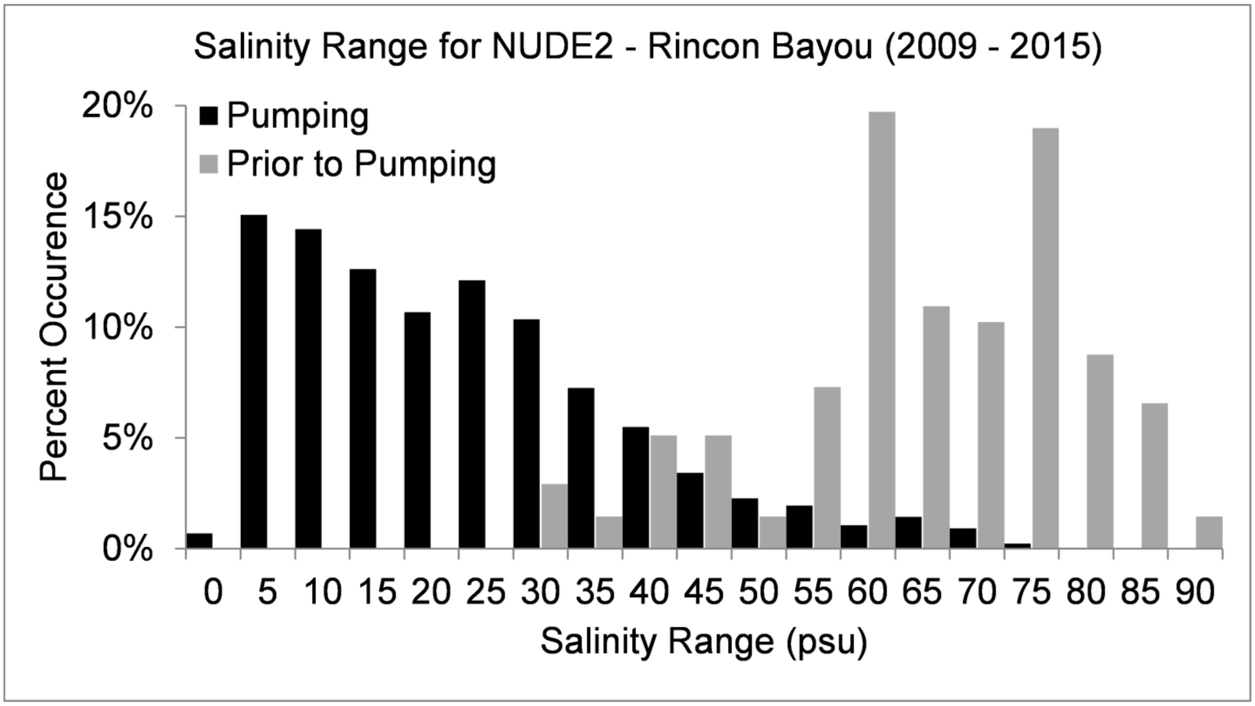

Figure 6. Percent occurrence of salinity ranges in Rincon Bayou (NUDE2) from May 2009 to December 2015. Prior to pumping is 1994 to 2008, and pumping is 2009 to 2015.

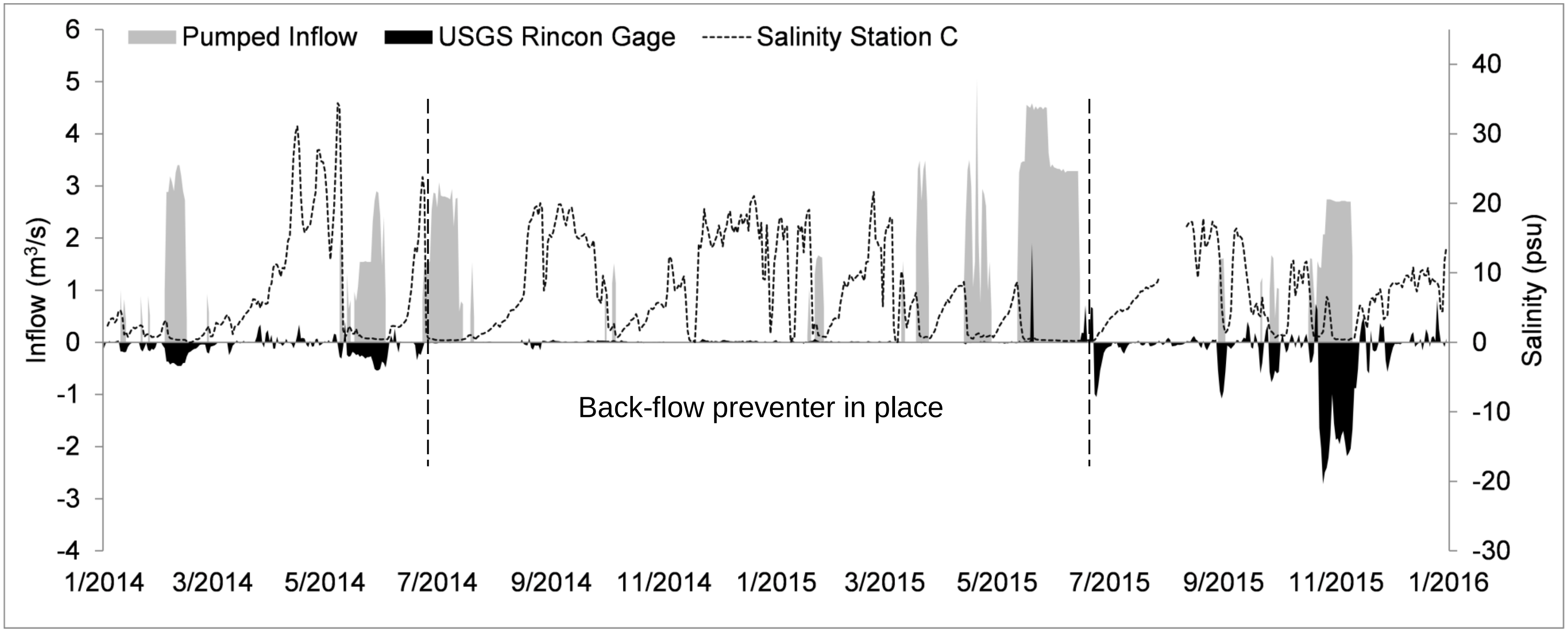

Figure 7. Salinity at Station C in Rincon Bayou TX, with inflow and discharge from the Rincon Bayou channel gage and pumped inflow, January 2014 to December 2015.

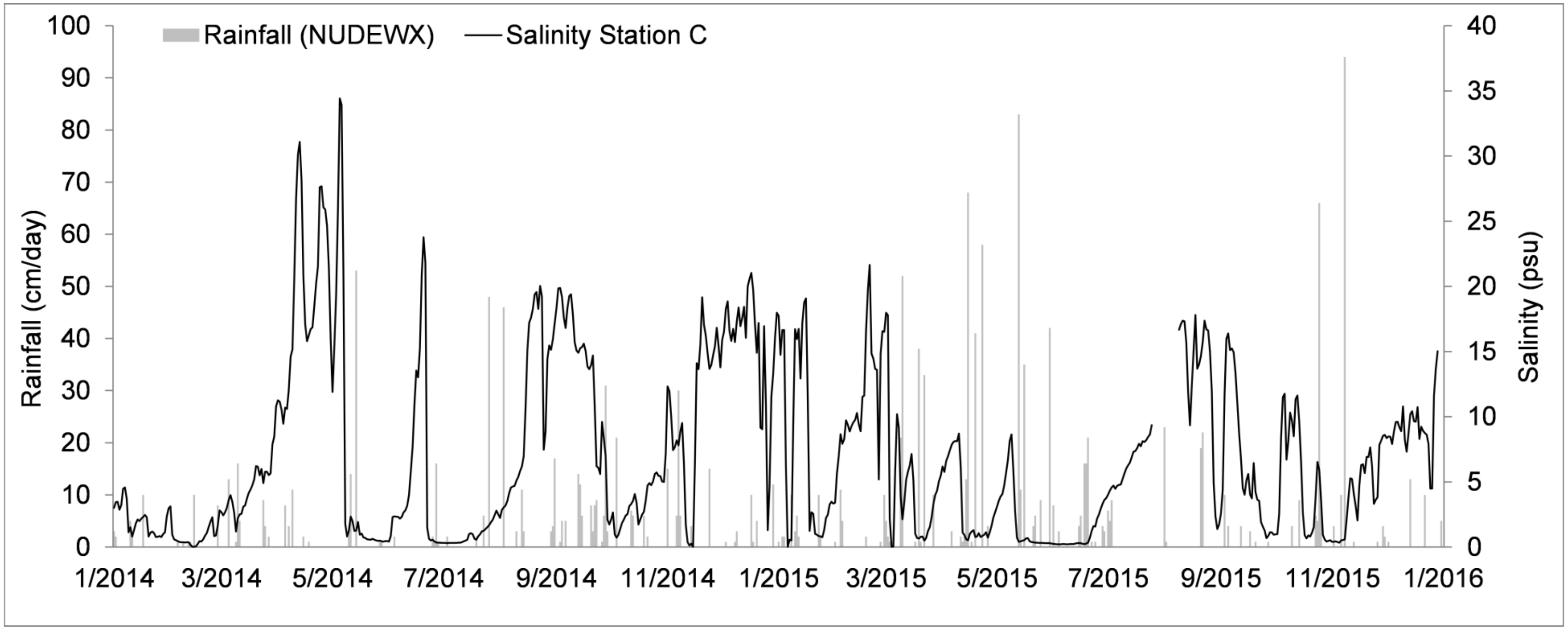

Figure 8. Salinity at Station C in Rincon Bayou TX, with daily total rainfall from CBI NUDEWX Station, January 2014 to December 2015.

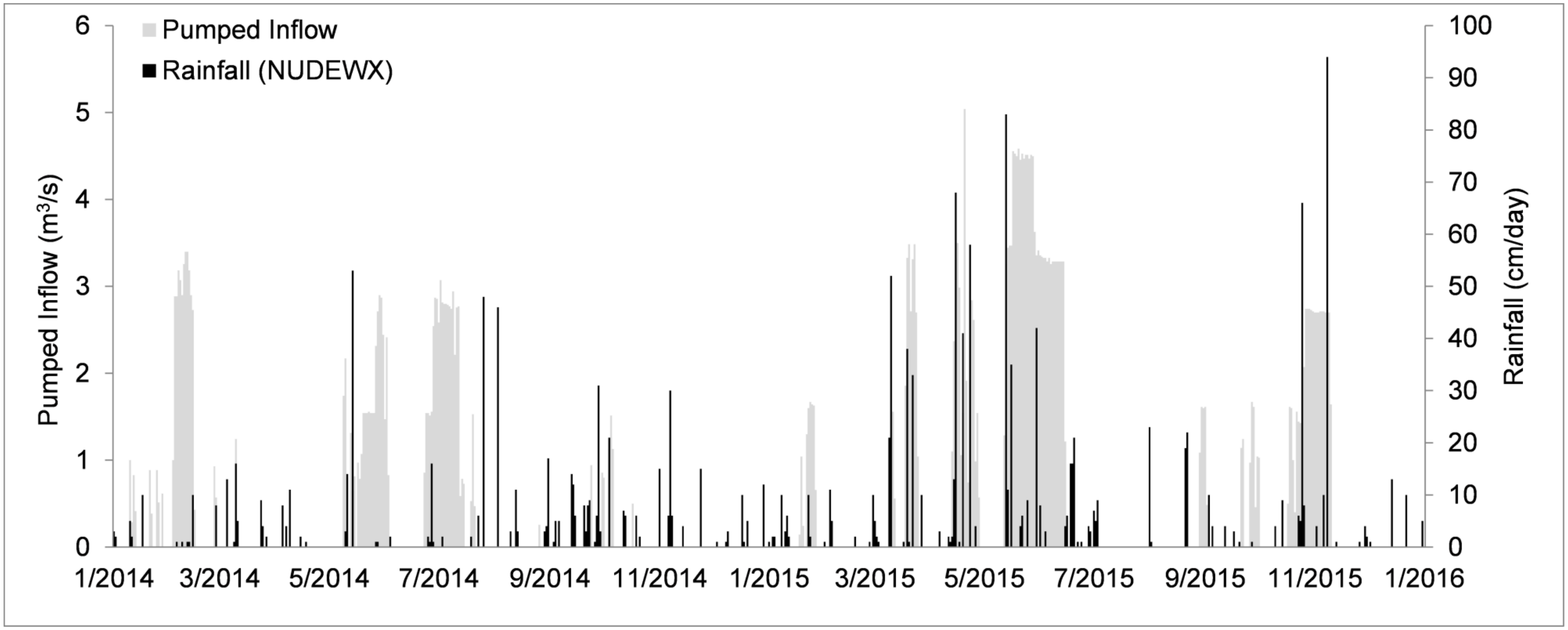

Figure 9. Pumped inflow into Rincon Bayou, TX with daily total rainfall from CBI NUDEWX Station, January 2014 to December 2015.

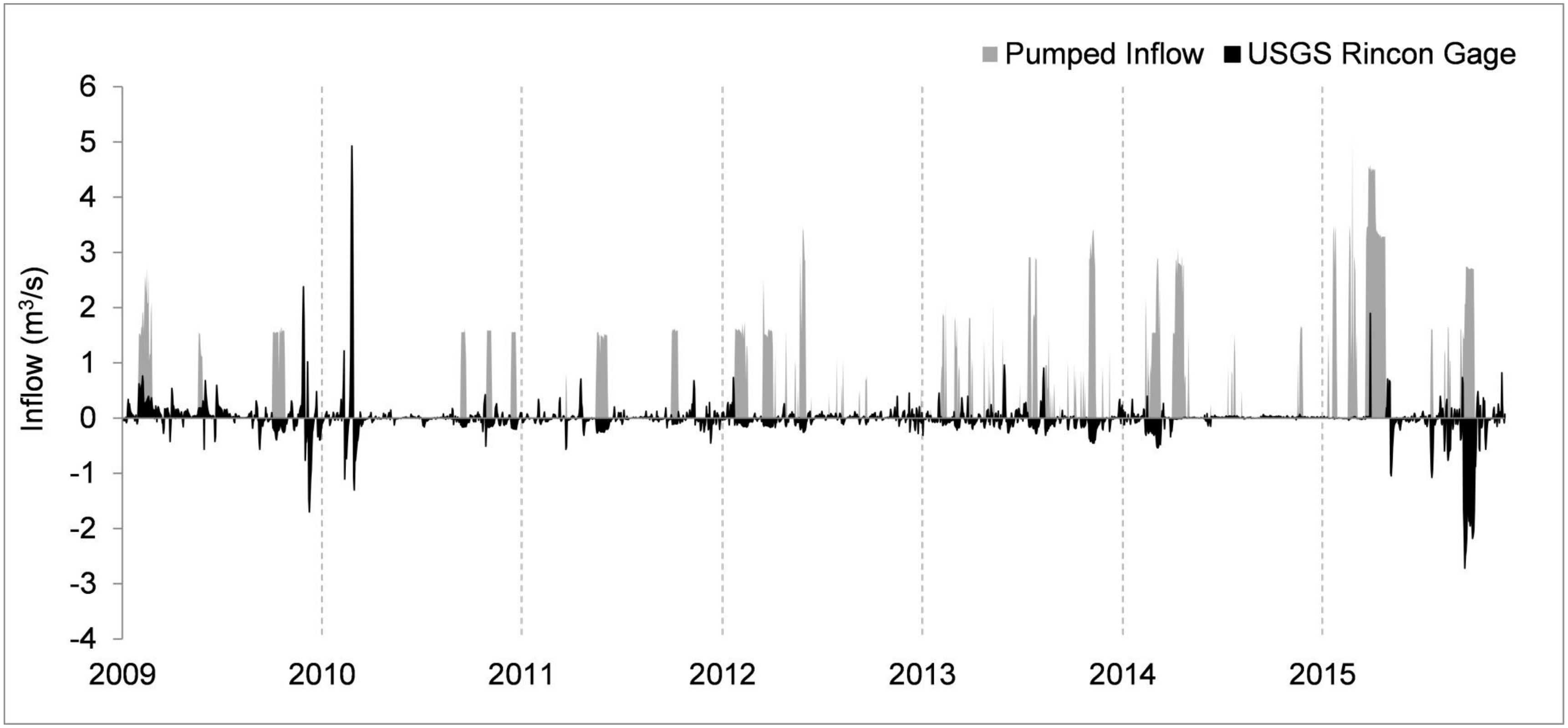

Figure 10. Inflow (+) and discharge (-) at the USGS Rincon Bayou Channel Gage, and pumped inflow, September 2009 to December 2015.

A flow duration curve illustrates the percentage of time a given flow was equaled or exceeded during a specified period of time. From January 2009 through December 2015 positive inflow into Rincon Bayou occurred or exceeded 40% of the time, with pumped inflow accounting for most of the inflow into Rincon Bayou (Figure 11). Natural inflows into Rincon Bayou have been reduced by river impoundment to low flow or drought flow, with events over 5 m^3/s being equaled or exceeded < 1% of the time. Freshwater was pumped into Rincon Bayou at least 20% of the time, and accounted for most of the high or medium flow events. The mean inflow volume from pumping was 1.71 m^3/s with a maximum total inflow rate (pumping and Rincon gauged discharge) of 6.48 m^3/s (Table 4). The percent of time that inflow from the Rincon Bayou diversion channel was greater than 0.2 m^3/s was less than 10% of the time with an inflow rate between 0 and 0.1 m^3/s occurring most often (Figure 12). The mean of daily inflow rate at the USGS Rincon Bayou Channel Gage was -0.02 m^3/s with a maximum daily mean discharge rate of 4.93 m^3/s and a minimum daily mean rate of -2.72 m^3/s.

Percent occurrence is defined as how often the event has occurred in a time period. Salinity, depth, and temperature ranges for the discrete sonde data for Station C in Rincon Bayou before pumping began, October 1994 – August 2009, and after pumping began, September 2009 to December 2015 is summarized in Figure 13. In the 15 year before pumping began into Rincon Bayou salinity ranges of less than 5 psu had an occurrence of 26%, salinity ranges over 40 psu occurred approximately 15% of the time, and water depth of 0.2 m occurred most often 36% of the time. In the 6 years since pumping began into Rincon Bayou salinity ranges of less than 5 psu occurred 43% of the time, salinity ranges over 40 psu occurred approximately 2% of the time, and water depth of 0.1 m occurred most often 48% of the time. The percent occurrences for the temperature ranges at Station C were slightly higher before September 2009. Since September 2009, temperatures greater than 30 ºC have occurred 20% of the time vs. 8% of the time prior, and temperatures less than 10 ºC occurred slightly more prior to September 2009. Prior to pumping the mean depth was 0.21 m , mean salinity was 21.37 psu, and the mean temperature was 22.87 ºC; after pumping began the mean depth was 0.15 m , mean salinity was 9.66 psu, and the mean temperature was 23.54 ºC (Table 6).

Table 6. Discrete sonde data at Station C in Rincon Bayou from October 1994 to December 2015.

Pumping	Variable	Number of observations	Mean	Std Dev	Minimum	Maximum
Before (1994 - 2008)	Depth (m)	123	0.21	0.17	0.00	1.50
	Temperature (°C)	121	22.87	5.51	7.98	31.93
	Salinity (psu)	123	21.37	25.00	0.00	159.20
After (2009 - 2015	Depth (m)	87	0.15	0.08	0.01	0.45
	Temperature (°C)	86	23.54	6.61	8.08	36.14
	Salinity (psu)	86	9.66	10.09	0.22	57.27

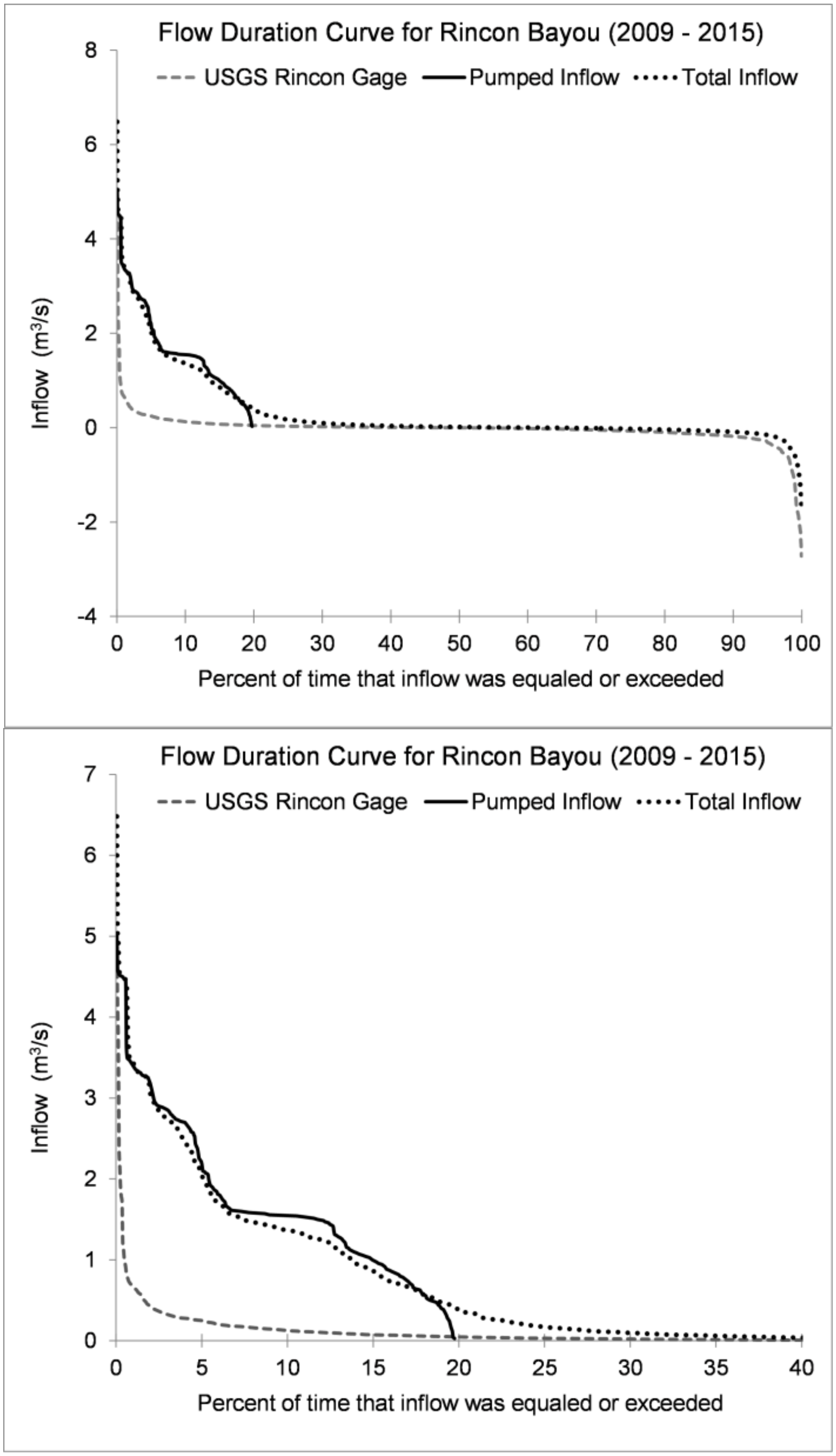

Figure 11. Flow duration curve for Nueces River inflow (+) and discharge (-) at the Rincon Bayou Channel Gage, September 2009 to December 2015. Top: full inflow scale. Bottom: zoom to positive inflow values only.

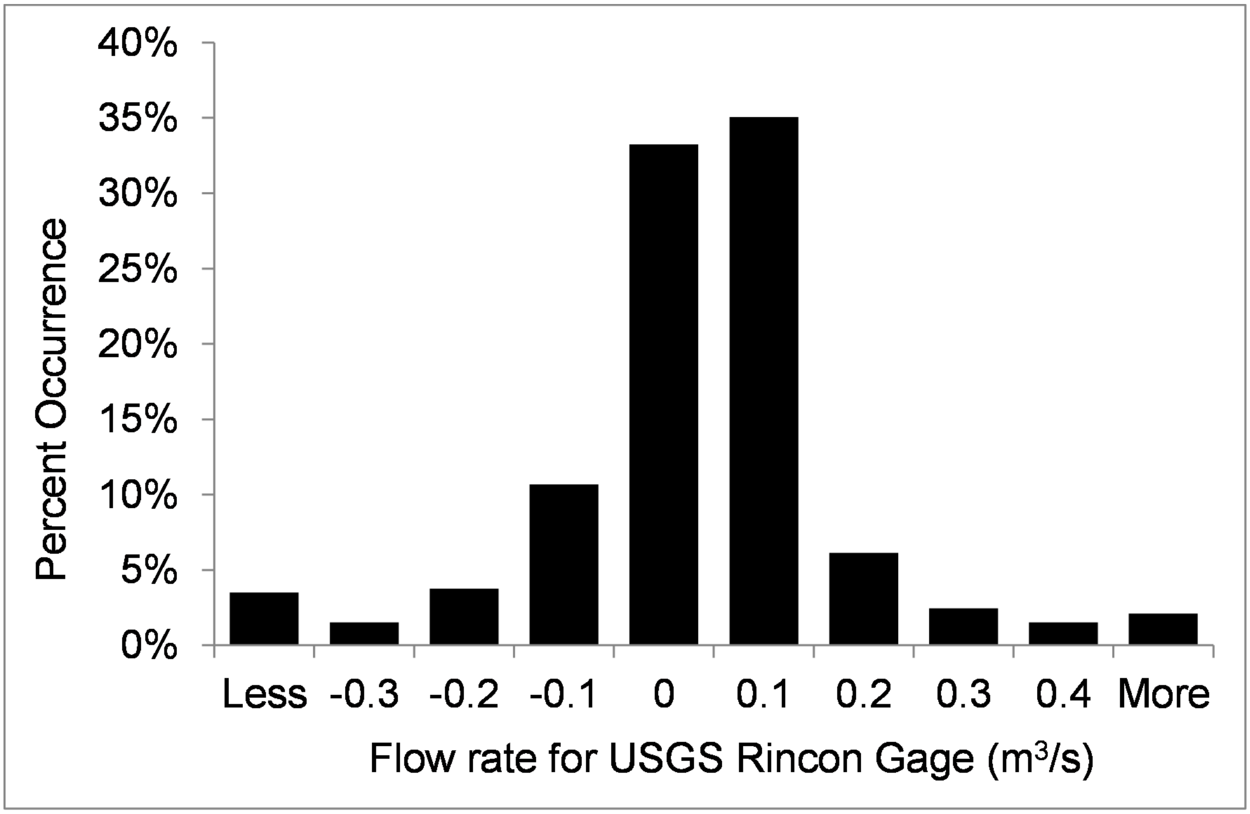

Figure 12. Percent occurrence for Nueces River flow rate at the Rincon Bayou Channel Gage September 2009 to December 2015.

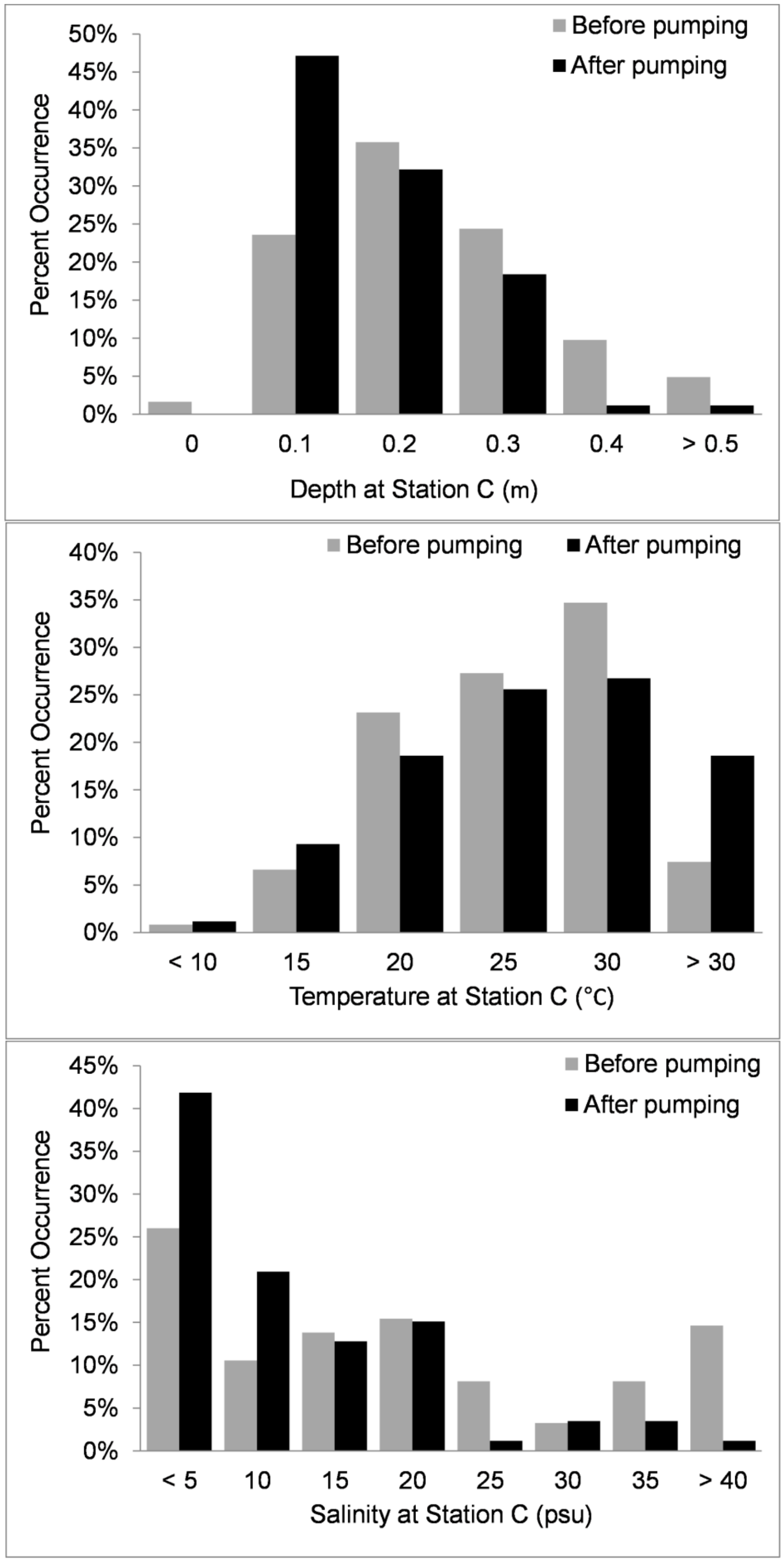

Figure 13. Percent occurrence of physical variables at Station C in Rincon Bayou, before pumping began (October 1994 to August 2009) and after pumping began (September 2009 to December 2015). A) depth, B) temperature, and C) salinity ranges

There is an inverse exponential relationship between salinity and inflow, and a logistic relationship between depth and inflow (Figure 14). There is a large scatter in the relationships, especially at the low end of salinity and inflow and the mid-range of depth and inflow, but a non-linear regression yields a small bound of error. The negative exponential regression equation produced the parameters *a* = 2.834752, *b* = 0.792677 for salinity using the equation:

$$\text{inflow} = a * \exp(-b * \text{salinity})$$

Very little inflow (3.69 x 10^{-7} to 1.02 x 10^{-3} m^3/s) is needed to maintain salinity values between 10 and 20 psu. An inflow rate of 2.83 m^3/s or greater will result in zero salinity values.

There is a logistic relationship between depth and inflow (Figure 14). The nonlinear regression produced the parameters and *a* = 0.6637, *k* = 12.2166, and *max* = 0.67898 for depth, using the equation:

$$\text{inflow} = \frac{max}{1 + \exp(-k \times (\text{depth} - a)}$$

An inflow rate of 0.317 to 0.689 m^3/s is needed to maintain a depth between 0.05 m and 0.5 m. An inflow rate of 2.83 m^3/s or greater will result in a depth of 1.3 m.

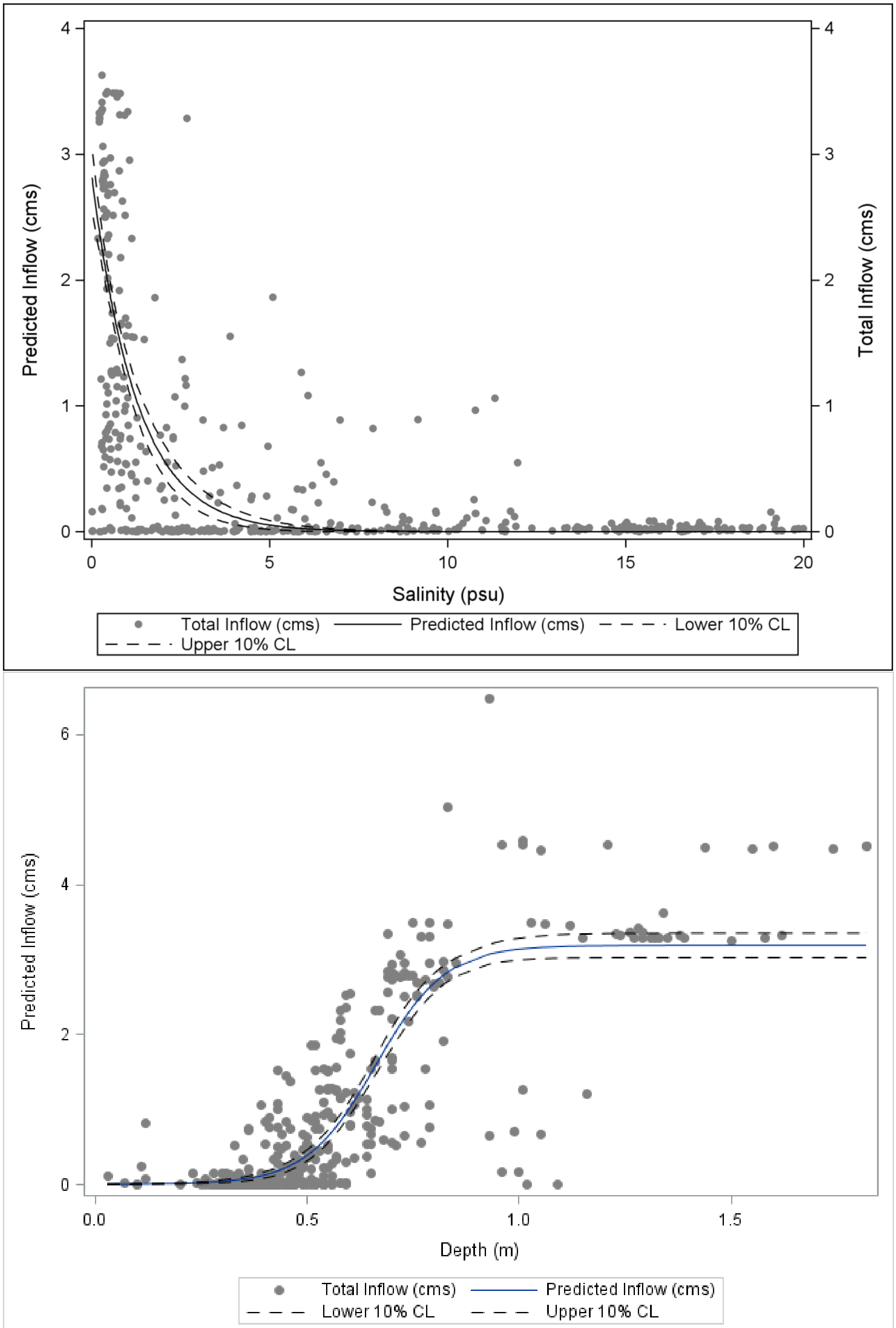

Figure 14. Prediction of inflow needed to produce salinities in the range of 0 to 20 psu (top) and water depths less than 1.50 m (bottom) in Rincon Bayou using the regression equations: inflow = a*exp(-b*Sal) and inflow = max / (1 + exp(-k*(depth - a))).

Water Quality

The relationships among water quality variable loads for the principal components (PC) at all three stations (C, F, and G) is easily interpretable (Figure 15A). There is an inverse relationship between salinity and nutrients along the PC1 axis, which means that PC1 is the freshwater inflow axis. High inflows lead to low salinities and high nutrients, so negative PC1 values mean high inflow. Surprising, depth does not load highly on PC1, meaning the inverse relationship between depth and salinity is somewhat diminished for all stations. This is surprising because one would assume the when inflow is high and salinity is low, water elevation level would be high, and depth would group with the nutrients.

The PC2 axis represents the seasonal gradient because temperature is a strong positive value and dissolved oxygen (DO) is inversely related to temperature (Figure 15A). Depth is loading on the PC2 axis with temperature and opposite DO. Depth is likely on PC2 because of tidal inundation. Tides in south Texas have a strong seasonal component where they are higher in fall and spring, and lower in winter and summer.

The samples scores are for the three stations collected quarterly (Figure 15B). The sample PC scores for station C have a tendency to group to the right (i.e., have mostly positive values) of PC1, which indicates that it is more influenced by inflow (i.e., it has higher nutrients and low salinities) than stations F and G (Figure 15B). Stations F and G mostly have negative PC1 values and are mostly mixed together indicating these two stations are not very different in their response to inflow. The sample scores for stations are relatively well sorted along the PC2 axis, indicating there are no seasonal differences among the stations.

A second PCA was run for just the high-frequency (biweekly) data collected at station C. The relationships among water quality variable loads at all three stations (Figure 15) are similar to the variable loads for Station C only, so this PCA is not presented.

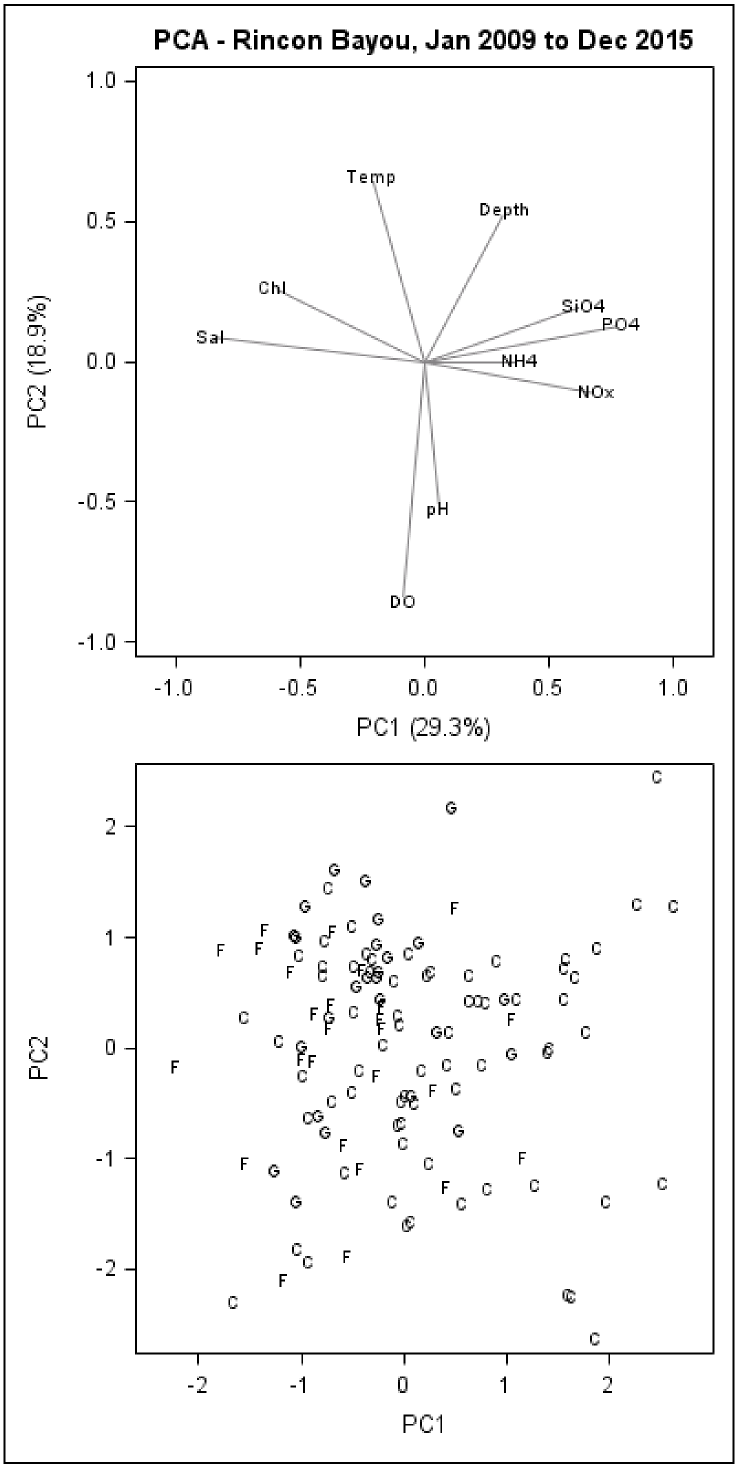

Figure 15. Principal Components Analysis (PCA) of water quality variables from Station C in Rincon Bayou. Top: Variable loads. Abbreviations: Sal=salinity, Chl=Chlorophyll a, Temp=temperature, SiO4=silicate, PO4=phosphate, NH4=ammonium, NOx=nitrite+nitrate, and DO=dissolved oxygen. Bottom: Sample scores using the station name as the symbol.

Macroinfauna

Long-term Trends

The time series at station C is best for analyzing response to pumping because of the biweekly sampling between 2013 and 2016. The temporal trends of infaunal abundance (Figure 16), biomass (Figure 17), and diversity (Figure 18) show that there is a great variability over time for all benthic response metrics.

The benthic infaunal abundances in Rincon Bayou averaged 12,900 individuals m^{-2} (standard deviation 21,560) with a coefficient of variation of 168. Abundance ranged as high as 125,000 n m^{-2} to as low as zero (Figure 16). The highest abundances occurred early in the study during 2009 when salinities were in the high 30's, but the abundances dropped to zero when hypersaline (80 psu) conditions occurred in July 2009. In general, there are three trends: 1) abundance decline during and following hypersaline (i.e., > 36 psu conditions), 2) where fluctuations of salinity range between about 5 and 40, abundance follows a similar trend as the fluctuations in salinity, and 3) when salinities are persistently (i.e., for several months) low (i.e., < 10 psu) abundances stay low as they did throughout the middle of 2014 to the end of 2015.

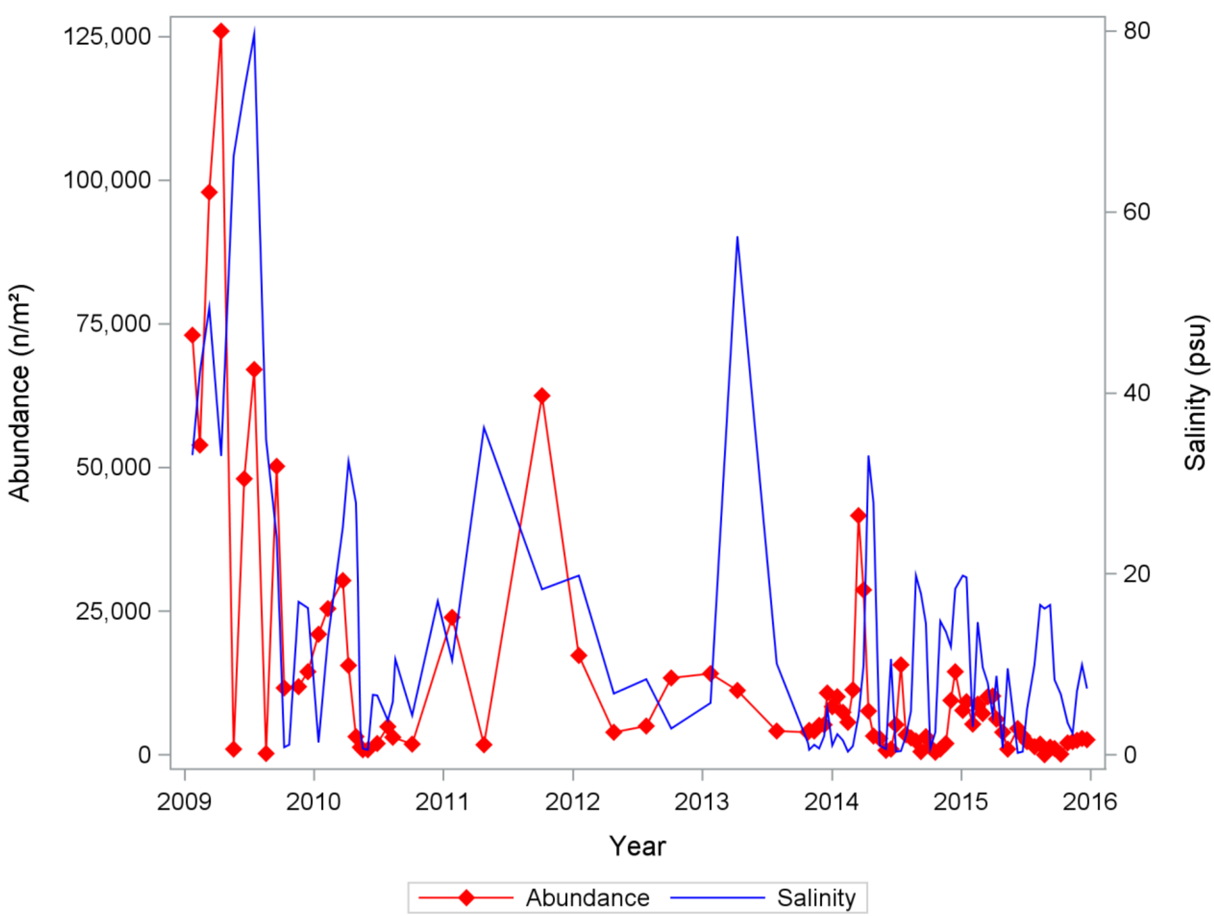

Figure 16. Macroinfauna abundance and salinity at Station C over time since pumping began.

The trend of biomass over time (Figure 17) generally follows the trend in abundance over time. The average biomass in Rincon Bayou is low, 0.862 g m^{-2} (standard deviation of 1.222 g m^{-2}) with a coefficient of variation of 142. Biomass range is from 0 to 7.446 g m^{-2}, but the peaks typically between 3 and 4 g m^{-2}.

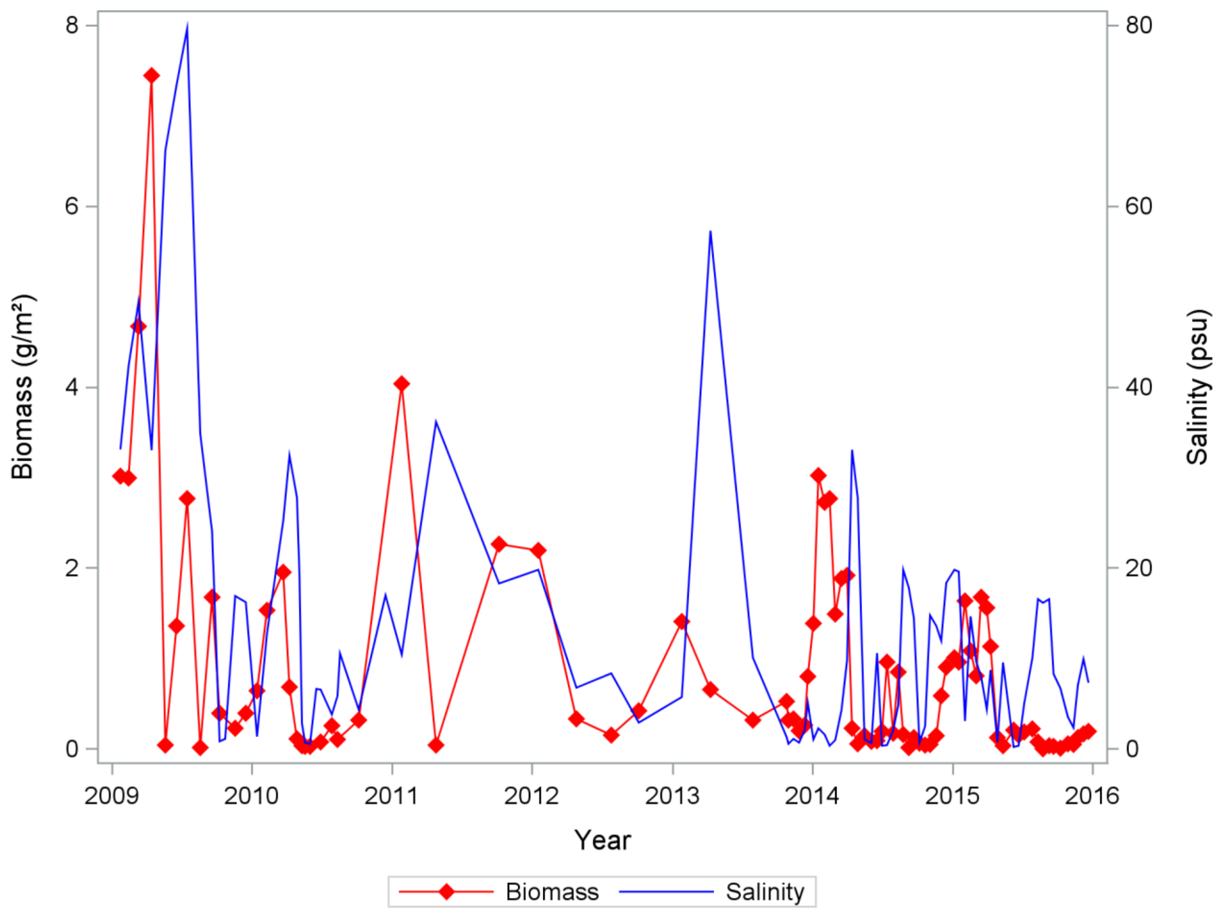

Figure 17. Macroinfauna biomass and salinity at Station C over time since pumping began.

Diversity in Rincon Bayou, is very low, ranging from only 1 to 3 dominant species (N1/3 pooled cores) (Figure 18). The average N1 diversity was 1.5 species per 3 cores (standard deviation 0.5) and the coefficient of variation was 34. The much lower coefficient of variation for diversity compared to abundance and biomass, indicates that the variability of diversity is less than for abundance and biomass. Diversity fluctuation typically follows salinity fluctuation, i.e., when salinity decreases or stays low, the diversity declines. A notable exception is the period between 2013 and 2015 because salinities were low, abundance and biomass were low, but diversity was generally above average. In fact, the highest diversity (N1 = 2.9) occurred in July 2015 when salinity was 16 psu, but had increased from 0.2 – 0.3 psu in June 2015.

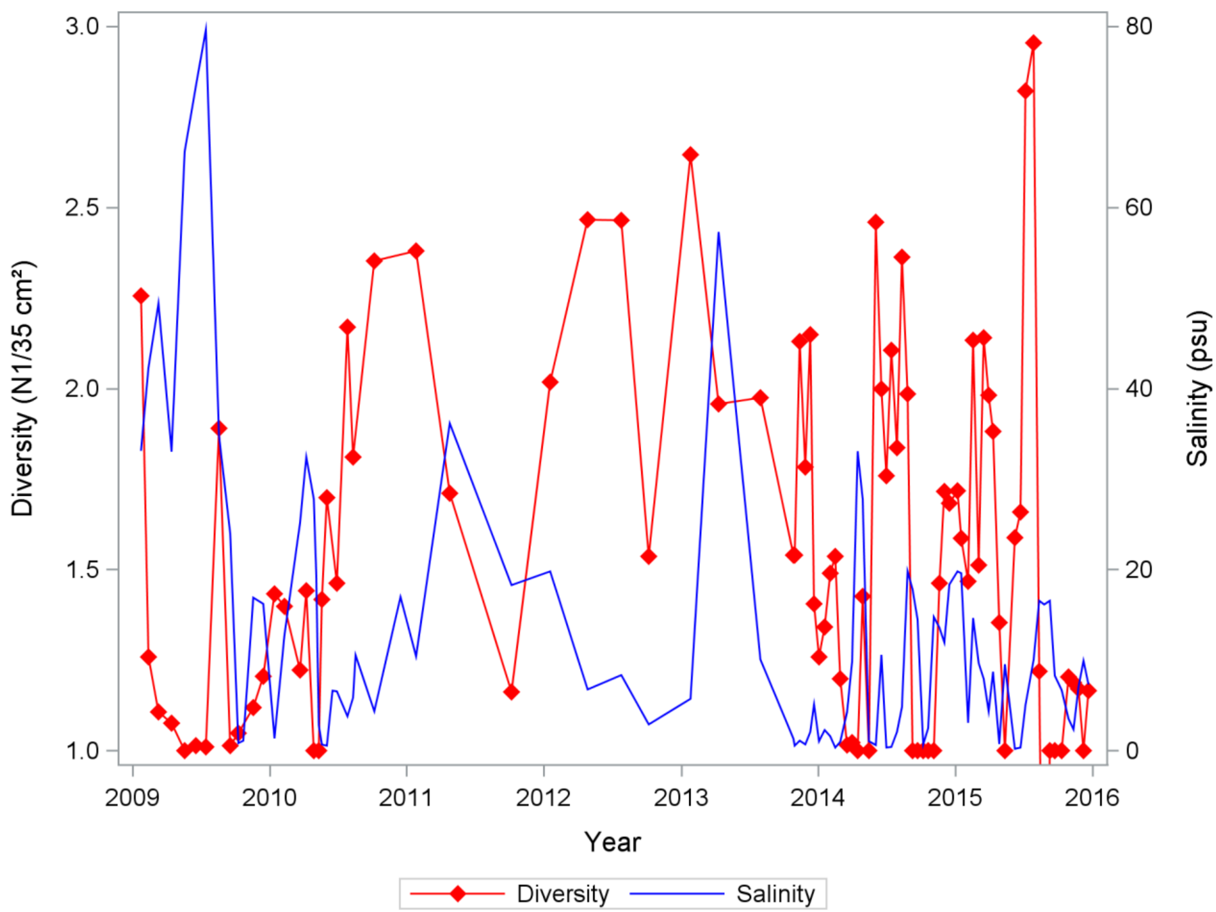

Figure 18. Macroinfauna diversity and salinity at Station C over time since pumping began.

Response to Physical Variables

Community Level Responses

There were no significant Pearson correlations ($p > 0.05$) correlations among the biotic factors of abundance, evenness, diversity and biomass against salinity, the Rincon Pump, the Rincon Gage, and depth (Table 7). However, while richness did not have a significant correlation with the Rincon pump, gage or depth; richness did have a significant correlation ($p = 0.01$) with salinity. Their relationship exhibits a negative correlation; as salinity increases, richness decreases; and this is similar to the relationship with N1 diversity (Figure 18) even though the correlation between N1 and salinity is not significant.

Table 7 Pearson correlations for the key biotic factors versus the key hydrographic factors from October 2013 to December 2015. Significant correlations are in bold.

		Pearson Correlation Coefficients (r) Probability (P) > |r| under H0: Rho=0 in Parentheses				
		Abundance (n/m^2)	**Richness (S/core)**	**Evenness (Pielou's J')**	**Diversity (Hill's N1)**	**Biomass (g/m^2)**
Salinity (psu)	r	-0.048	**-0.339**	-0.052	-0.189	-0.211
	P	(0.73)	**(0.01)**	(0.71)	(0.17)	(0.13)
Rincon Pump (cms)	r	0.005	0.168	0.069	0.091	0.059
	P	(0.97)	(0.22)	(0.62)	(0.51)	(0.67)
Rincon Gage (cms)	r	0.145	0.045	0.029	0.018	0.090
	P	(0.30)	(0.75)	(0.84)	(0.90)	(0.52)
Depth (m)	r	-0.194	-0.030	-0.061	-0.045	-0.250
	P	(0.16)	(0.83)	(0.66)	(0.75)	(0.07)

One important trend in the time series (Figures 16-18), is that there appears to be biological responses after inflow and low salinity events, so Pearson correlations were run against lagged salinity (Table 8). There were no significant correlations ($p > 0.05$) between the biotic factors of abundance and evenness against the pump lags exhibited. Conversely, richness showed significant positive correlations with the pump lag variable after 2 weeks and 4 weeks ($p = 0.05$) and N1 diversity showed significant correlation after 4 weeks ($p = 0.01$).

Table 8. Pearson correlations for the key biotic factors versus the pump lag calculations for four lag periods. Each lag period represents 2 weeks since sampling took place.

		Pearson Correlation Coefficients (r) Probability (P) > |r| under H0: Rho=0			
		Abundance (n/m^2)	**Richness (S/core)**	**Evenness (Pielou's J')**	**Diversity (Hill's N1)**
Pump Lag 1	r	-0.009	**0.272**	0.166	0.248
(2 weeks)	P	0.95	**0.05**	0.24	0.07
Pump Lag 2	r	0.104	**0.273**	0.192	**0.365**
(4 weeks)	P	0.46	**0.05**	0.17	**0.01**
Pump Lag 3	r	0.051	0.093	0.128	0.201
(6 weeks)	P	0.72	0.51	0.37	0.16
Pump Lag 4	r	-0.05	-0.117	-0.128	-0.172
(8 weeks)	P	0.73	0.42	0.37	0.23

There were no significant correlations between abundance and salinity lags ($p > 0.05$) (Table 9). Although barely non-significant ($p = 0.06$), evenness did have an inverse correlation with salinity after a 2 week lag. However, richness showed significant inverse correlations with the salinity lag variable after 2 weeks ($p = 0.03$) and 4 weeks ($p = 0.05$), and diversity showed significant correlation after 2 weeks ($p = 0.01$). Both richness and diversity showed a negative correlation with the salinity lags, indicating when salinity decreased, it caused diversity to decrease.

Table 9. Pearson correlations for the key biotic factors versus the salinity lag calculations for four lag periods. Each lag period represents two weeks since sampling took place.

		Pearson Correlation Coefficients (r) Probability (P) > |r| under H0: Rho=0			
		Abundance (n/m^2)	Richness (S/core)	Evenness (Pielou's J')	Diversity (Hill's N1)
Salinity Lag 1 (2 weeks)	r	-0.171	**-0.291**	**-0.258**	**-0.343**
	P	0.22	**0.03**	**0.06**	**0.01**
Salinity Lag 2 (4 weeks)	r	-0.167	**-0.274**	-0.115	-0.124
	P	0.24	**0.05**	0.42	0.38
Salinity Lag 3 (6 weeks)	r	-0.24	-0.101	0.157	0.088
	P	0.08	0.48	0.27	0.54
Salinity Lag 4 (8 weeks)	r	-0.238	0.047	0.207	0.185
	P	0.10	0.74	0.14	0.20

There was no significant correlations ($p > 0.05$) for the change over time for abundance and diversity against salinity and the Rincon pump flow volume (Table 10). Nevertheless, biomass did have a significant inverse correlation with the change in salinity ($p = 0.03$). This negative correlation shows that as the change in salinity decreases so does relate to change in biomass.

Table 10. Pearson correlations for the change over time at station C for abundance, biomass and diversity versus the change over time of salinity and the Rincon pump from October 2013 to December 2015.

		Pearson Correlation Coefficients (r) Probability (P) > |r| under H0: Rho=0		
		Abundance (n/m^2)	**Biomass (g/m^2)**	**Diversity (Hill's N1)**
Salinity (psu)	r	-0.14915	**-0.29711**	0.01022
	P	0.2865	**0.0307**	0.9421
Rincon Pump (cms)	r	0.15338	0.18095	0.02053
	P	0.2729	0.1947	0.8840

Diversity was plotted against salinity (Figure 19), the volume of water released from Rincon pump (Figure 20), and water depth (Figure 21); and fitted to a log normal curve using the maximum bin method. For salinity, diversity appears to peak between 4 psu and 10 psu (parameter c = 6.1 psu), beginning to decline thereafter. The optimal range for diversity with regards to the Rincon pump appears to be between 0.6 and 1.4 m^3/s (parameter c = 1 m^3/s). Diversity seems to peak at around a depth between 0 and 0.1 m (parameter c = 0.05 m) and begins to decrease around 0.1 m.

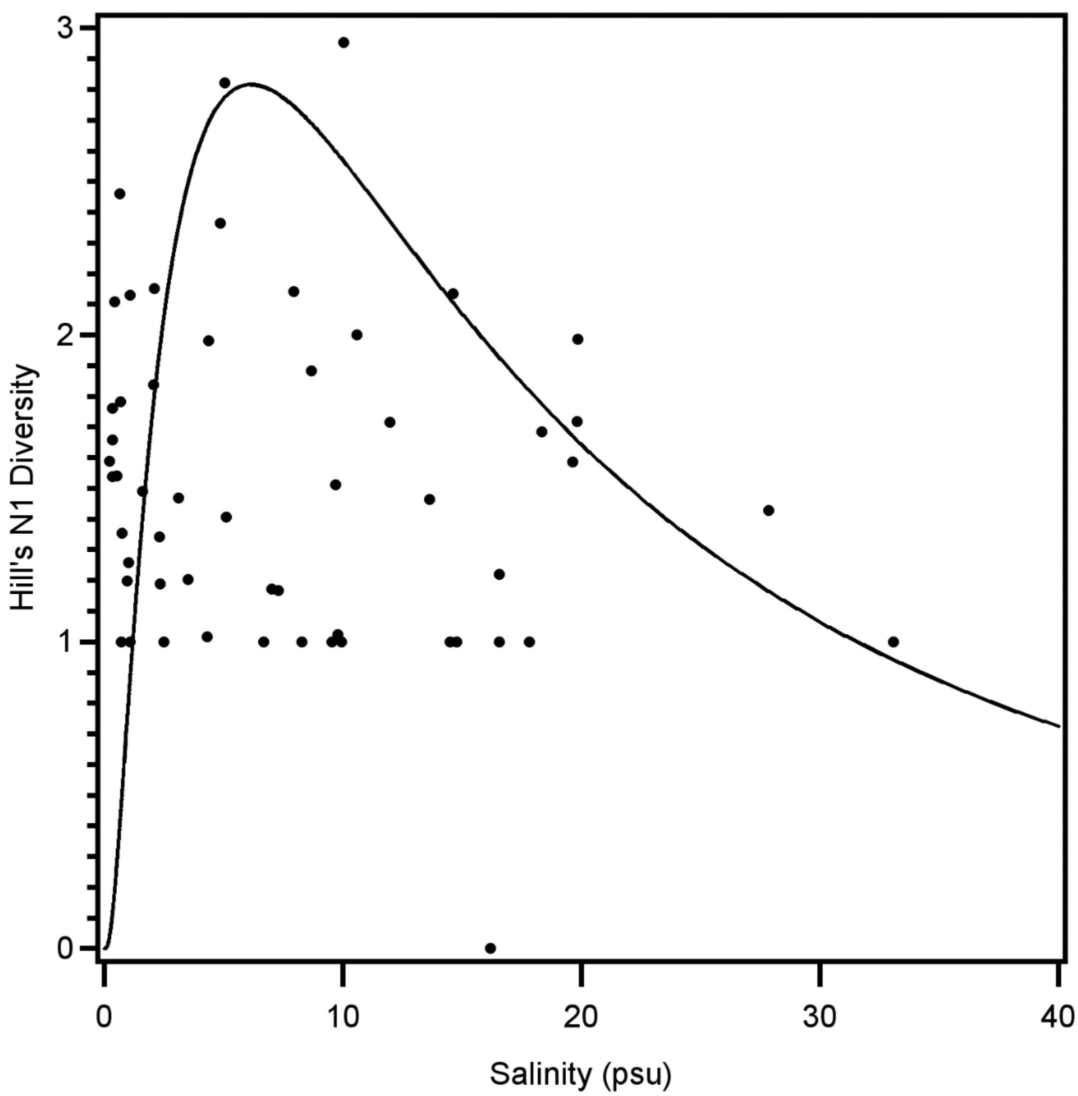

Figure 19. Max Bin, log normal, regression of Hill's N1 diversity versus salinity in Rincon Bayou.

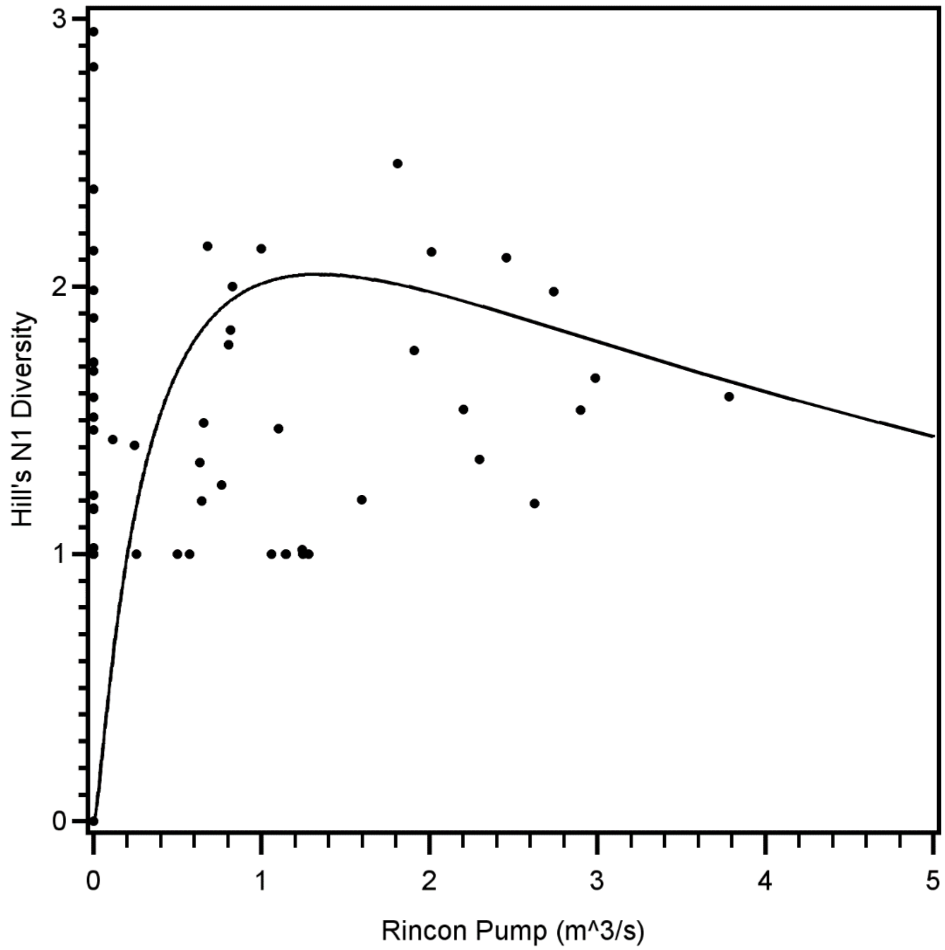

Figure 20. Max Bin, log normal, regression of Hill's N1 diversity versus flow rates from the Rincon Bayou pump.

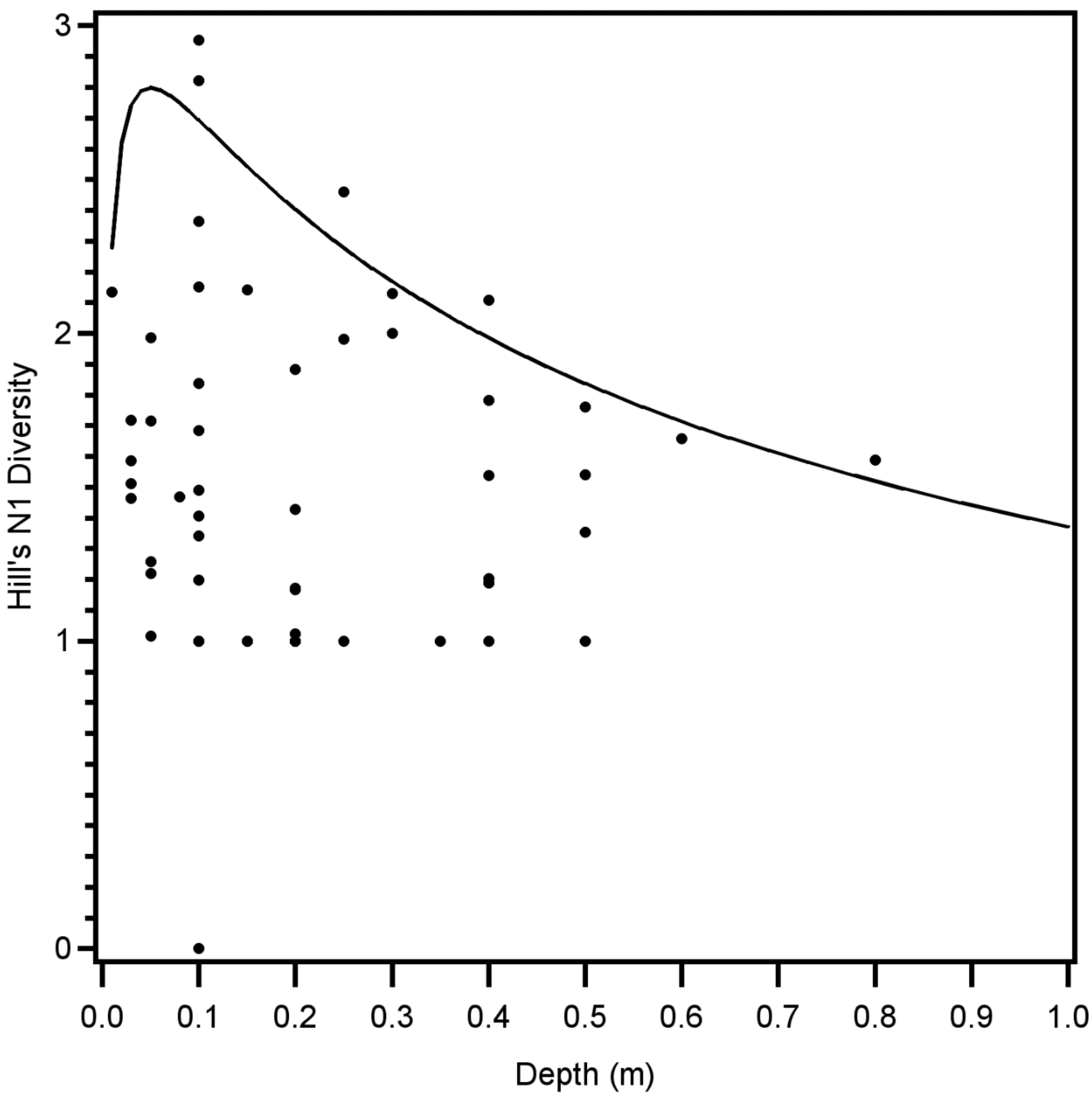

Figure 21. Max bin, log normal, regression of Hill's N1 diversity to depth in Rincon Bayou.

Macrofauna Species Level Response to Salinity, Depth, and Temperature

The indicator species were chosen because they were three most numerically dominant species at Station C in Rincon Bayou from May 2010 to December 2015 (Table 11). These were: *Streblospio benedicti*, *Laeonereis culveri*, and Chironomidae larvae. Out of the total number of individuals found 44.3 % were *Streblospio benedicti*, 43.6% were Chironomidae larvae, and 4% were *Laeonereis culveri*.

A shift in dominant species occurred since the bi-week sampling began in October 2013 indicating a transition to a more predominantly freshwater environment at Station C during that period, when of the total number of individuals found 50.6 % were Chironomidae larvae, 39.0% were *Streblospio benedicti*, and 4.82% were *Laeonereis culveri*.

Table 11. Macrofauna data at Station C in Rincon Bayou (May 2010 to December 2015).

Species name	**Total number (n)**	**Abundance (n/m^2)**	**Species % composition**	**Dry Wt (mg)**	**Dry Wt (g/m^2)**
Streblospio benedicti	669	189755	44.3%	33.37	9.47
Chironomidae (larvae)	658	186682	43.6%	73.34	20.80
Laeonereis culveri	61	17207	4.0%	44.60	12.65
Mediomastus ambiseta	32	9076	2.1%	2.91	0.82
Nemertea (unidentified)	24	6807	1.6%	7.36	2.09
Oligochaeta (unidentified)	24	6665	1.6%	0.62	0.18
Mulinia lateralis	10	2695	0.7%	3.05	0.87
Ceratopogonidae (larvae)	10	2836	0.7%	1.49	0.42
Ostracoda (unidentified)	9	2553	0.6%	1.52	0.43
Hobsonia florida	9	2553	0.6%	1.32	0.37
Farfantepenaeus setiferus	1	284	0.1%	27.49	7.80
Americamysis almyra	1	284	0.1%	0.07	0.02
Palaemonetes sp.	1	284	0.1%	0.15	0.04

Species composition with inflow rates from the bi-weekly sampling (November 2013 to December 2015) is shown in Figure 22. A total of 12 species were found. The highest species biomass (g/m^2) was produced with inflow rates greater than 9 m^3/s, while the highest species abundances are with inflow rates of 0 to 1 m^3/s. Chironomidae larvae compose of the highest species biomass and abundance with inflow of 0 to 1 m^3/s and 1 to 3 m^3/s. *Laeonereis culveri* compose of the species highest biomass with negative inflow rates (upstream flow) and inflow rates of 3 to 5 m^3/s and > 9 m^3/s. *Streblospio benedicti* compose the highest species abundance at inflow > 9 m^3/s but do not compose the highest biomass at any inflow level. The mean number of species was fairly consistent with inflows greater than 9 m^3/s and 3 to 5 m^3/s having the most species.

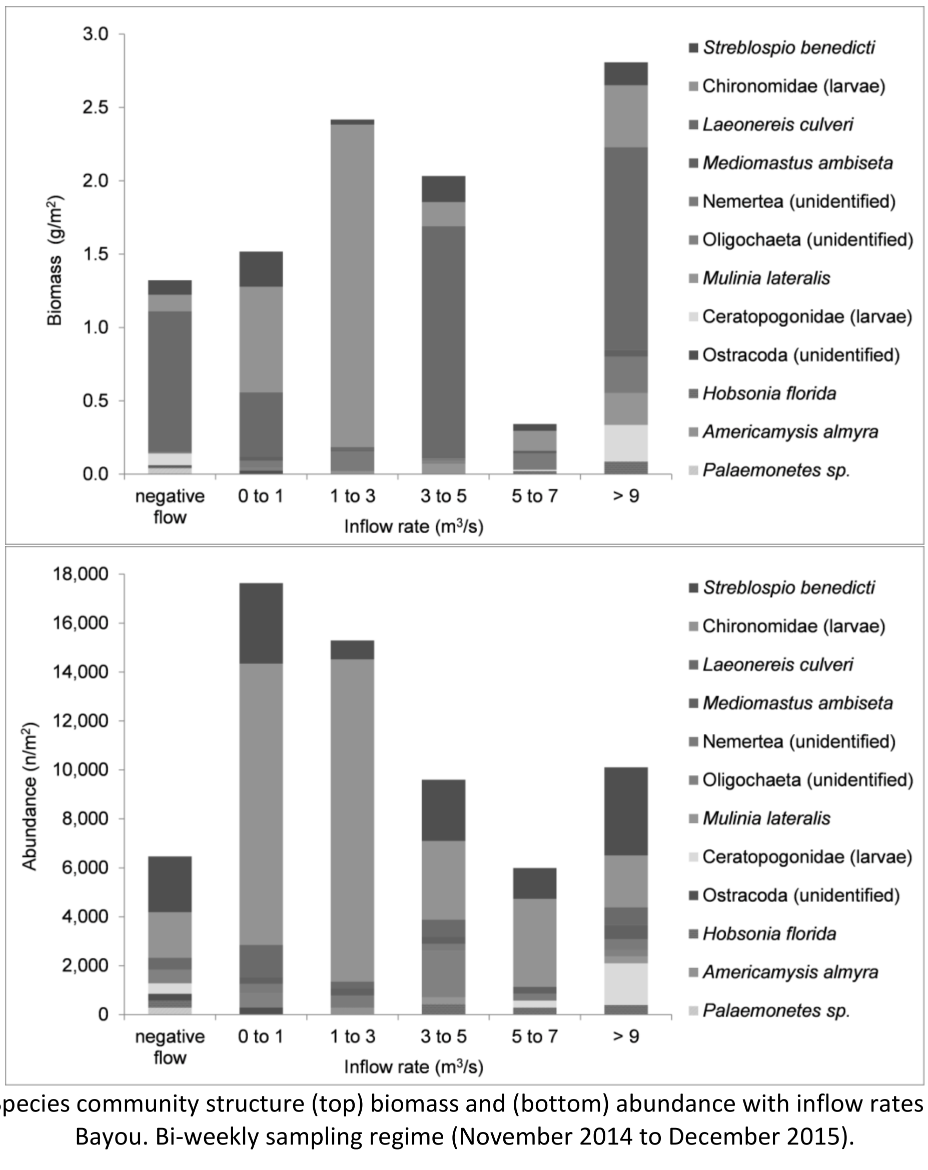

Figure 22. Species community structure (top) biomass and (bottom) abundance with inflow rates into Rincon Bayou. Bi-weekly sampling regime (November 2014 to December 2015).

The max bin, log normal, regression method (Turner and Montagna 2016) was used to determine the relationhip between the hydrographical variables of salinity (psu), temperature (ºC), water depth (m), and the biological response variables of biomass (g/m^2) and abundance (n/m^2) of *Streblospio benedicti*, Chironomidae larvae, and *Laeonereis culveri* sampled from October 2013 to December 2015 from Stations C, F, and G in Rincon Bayou. The optimal conditions for biomass and abundance along with the regression parameters are listed in Table 12.

For *Streblospio benedicti* the optimal conditions to produce the highest biomass were found to be at a salinity of 14.1 psu, a temperature of 14.8 ºC, and a depth of 0.12 m, with the optimal conditions to produce the highest abundance being at a salinity of 13.5 psu, a temperature of 18.2 ºC, and a water depth of 0.12 m (Figure 23).

For Chironomidae larvae the optimal conditions to produce the highest biomass were found to be at a salinity of 1.8 psu, a temperature of 18.2 ºC, and a depth of 0.08 m, with the optimal conditions to produce the highest abundance being at a salinity of 1.4 psu, a temperature of 15.6 ºC, and a water depth of 0.09 m (Figure 24).

For *Laeonereis culveri* the optimal conditions to produce the highest biomass were found to be at a salinity of 5.4 psu, a temperature of 18 ºC, and a depth of 0.09 m, with the optimal conditions to produce the highest abundance being at a salinity of 11.6 psu, a temperature of 17.7 ºC, and a depth of 0.08 m (Figure 25).

Table 12. Parameter estimates for the log-normal model where *a* is the peak value, *b* is the rate of change of the response, and *c* is the location of the peak response for variable (*X*) and the biological variable (*Y*).

Indicator Species	Biomass							Abundance						
	Units		# of Bins	Approx. Pr > F	Parameters			Units		# of Bins	Approx. Pr > F	Parameters		
	X	*Y*			*a* *peak*	*b* *skewness*	*c* *optimal x*	*X*	*Y*			*a* *peak*	*b* *skewness*	*c* *optimal x*
Streblospio benedicti	psu	g/m^2	5	0.1113	0.67	0.53	14.14	psu	n/m^2	5	0.1836	10.36	0.77	13.49
	°C	g/m^2	5	0.0035	0.59	0.49	14.83	°C	n/m^2	10	<.0001	9.41	1.02	18.15
	m	g/m^2	5	0.0193	0.56	0.62	0.12	m	n/m^2	5	0.0015	9.48	2.18	0.12
Chironomidae Larvae	psu	g/m^2	12	0.0026	1.44	0.97	1.81	psu	n/m^2	10	0.0157	9.96	1.99	1.84
	°C	g/m^2	6	0.0008	1.48	0.42	15.32	°C	n/m^2	6	0.0002	10.73	0.80	15.55
	m	g/m^2	6	0.0408	1.52	0.66	0.10	m	n/m^2	8	0.0047	11.34	1.00	0.09
Laeonereis culveri	psu	g/m^2	13	<.0001	0.82	0.84	5.38	psu	n/m^2	8	0.0142	9.02	0.71	11.55
	°C	g/m^2	8	0.0035	0.80	0.32	18.03	°C	n/m^2	5	0.0044	8.42	0.59	17.65
	m	g/m^2	10	0.0003	0.82	0.62	0.09	m	n/m^2	9	0.0007	8.21	1.10	0.08

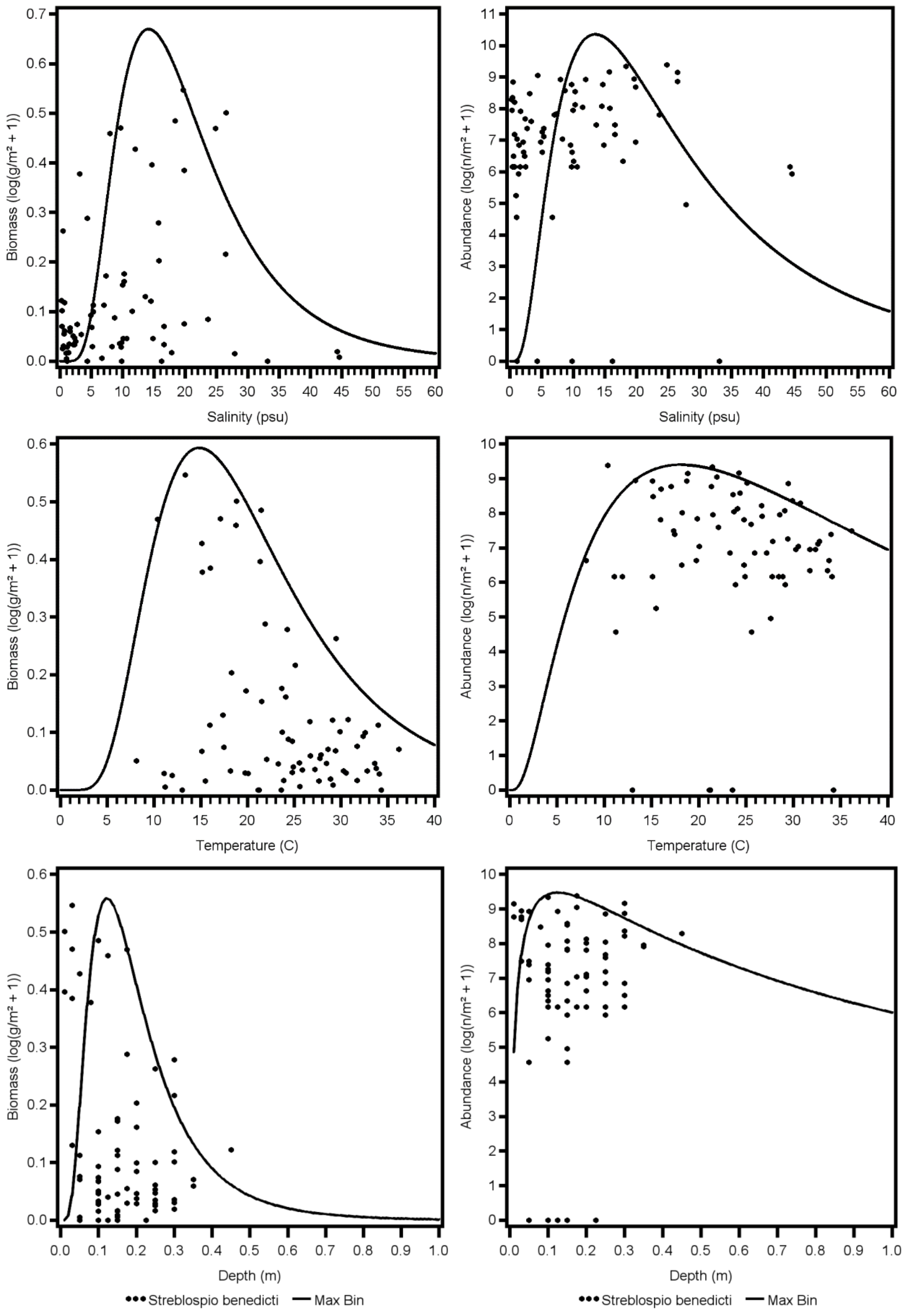

Figure 23. Relationship between hydrographical variables (salinity, temperature, depth) with (left) biomass and (right) abundance for *Strebiospio benedicti*, October 2013 to December 2015.

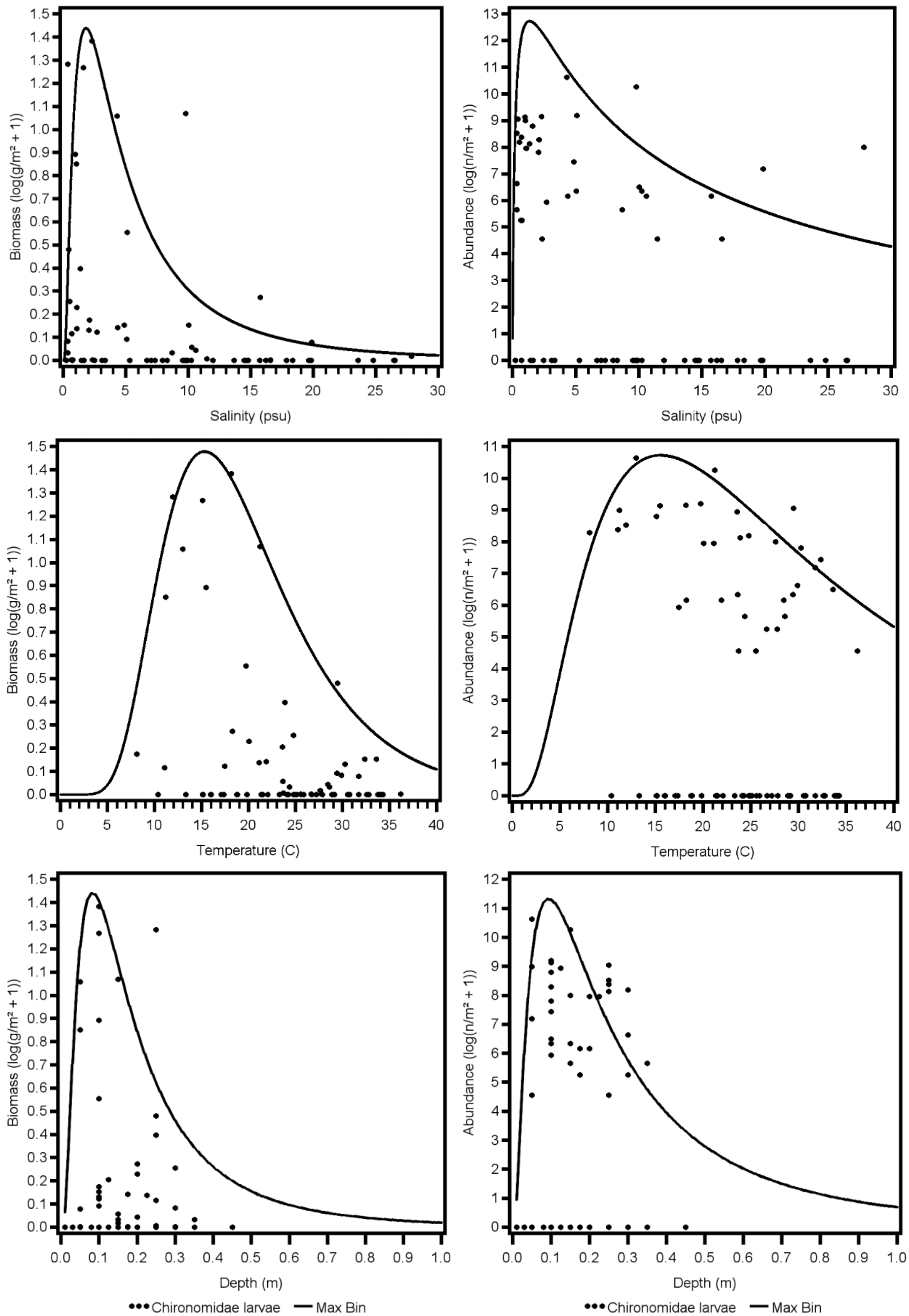

Figure 24. Relationship between hydrographical variables (salinity, temperature, depth) with (left) biomass and (right) abundance for Chironomidae larvae, October 2013 to December 2015.

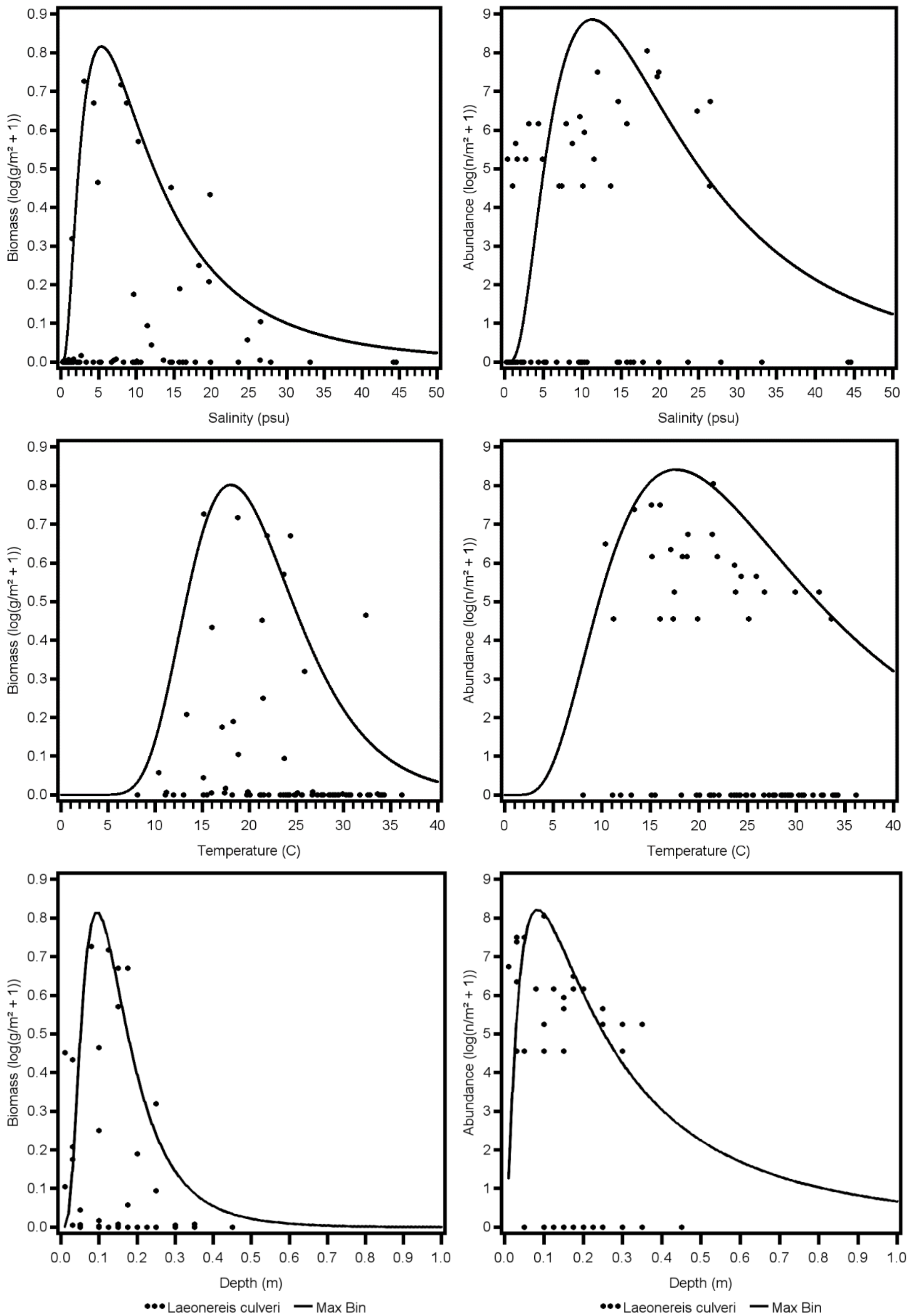

Figure 25. Relationship between hydrographical variables (salinity, temperature, depth) with (left) biomass and (right) abundance for *Laeonereis culveri*, October 2013 to December 2015.

Benthic Ecology Model

The full goodness of fit statistics for the Benthic Ecology Model (BEM) runs are listed in Table 13, and the tests are defined in Turner et al. (2014). The BEM fit within 81% of the RMSD for Chrionomidae larvae in site C between February 2014 and December 2015. *Streblospio benedicti*, the most abundant species in the data set, fit within 65% of the RMSD. *Laeonereis culveri* was the least abundant of the indicator species and only fit within 23% of the RMSD. The optimal coefficient parameter set for each species derived through the Monte Carlo approach is listed in Table 14.

Table 13. Benthic Ecology Model Validation to Individual Species.

Species	%Observation Set	Goodness of Fit Test				
		RMSD	RMSE	% RANGE	MSER	WMSE
Streblospio benedicti	33%	47.6%	0.4	17.9%	1.7	1.9
	67%	50.7%	0.4	27.5%	2.2	2.6
	100%	65.1%	0.3	50.0%	1.1	1.8
Laeonereis culveri	33%	30.2%	2.8	0.0%	7.8	7.8
	67%	28.0%	2.9	18.8%	11.2	11.5
	100%	23.5%	3.1	23.5%	12	12.2
Chironomidae larvae	33%	67.5%	1.5	13.3%	5.8	5.8
	67%	75.6%	1.1	12.5%	4.6	5.3
	100%	81.8%	0.8	28.0%	2.6	3.9

Abbreviations: RMSD: Root Mean Square Deviation
RMSE: Root Mean Square Error
MSER: Mean square Error outside Weighted Range
WMSE: Weighted Mean Square Error.

Table 14. Benthic Ecology Model Calibration Coefficients. Coefficients defined in Table 1.

Coefficient	Species		
	Streblospio benedicti	***Laeonereis culveri***	**Chironomidae Larvae**
Kgs	2.94	11.04	11.90
Kgt	5.48	5.49	2.50
Kg	8.78	15.77	47.00
Km	0.23	6.13	7.30
Kms	2.79	10.47	11.90
Kmds	7.60	6.47	4.80
kmss	3.00	4.54	5.16
Bcc	12.00	12.00	12.00
Dopt	0.10	0.10	0.10
Topt	16.47	16.59	12.80
Sopt	13.47	6.78	4.60

The Benthic Ecology Model run for Chrionomidae larvae indicates an increase of biomass in early 2014 and declining to near zero biomass by May 2014 (Figure 26). Chrionomidae larvae do not recover biomass further in the time series despite low salinity periods in spring of 2015. *Streblospio benedicti* biomass was constantly measured between 0.1 and 0.5 mg/m^2 throughout the time series with a pronounced increase during the spring of 2015 (Figure 27). Although *Laeonereis culveri* was the third most abundant species in Rincon Bayou their presence was inconstant with the majority of observations during the spring of 2015 (Figure 28). The model indicates that spring is the ideal period for growth of *Laeonereis culveri.*

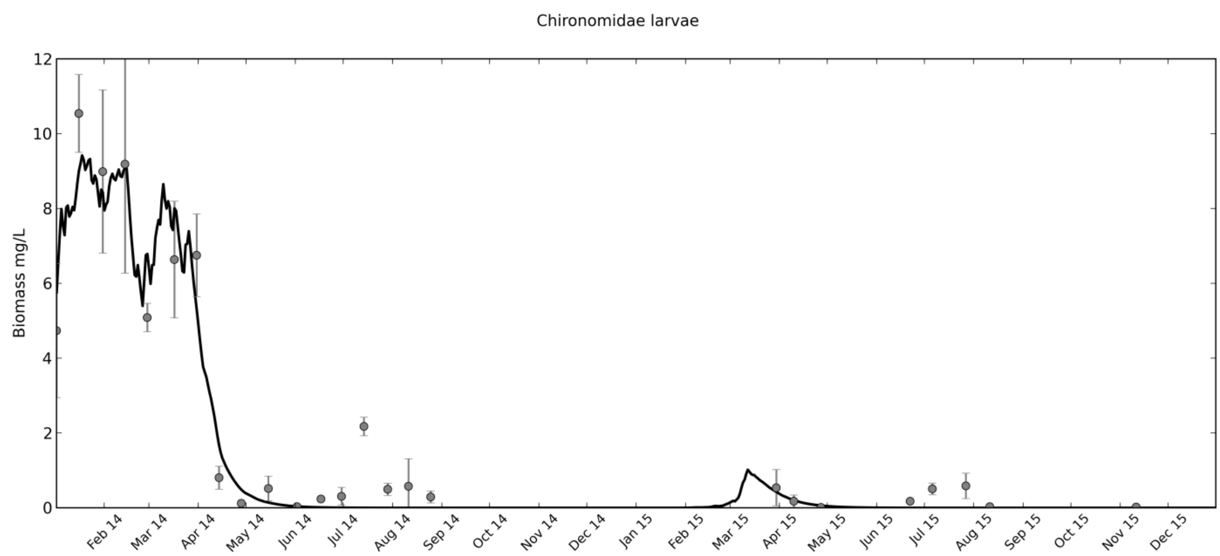

Figure 26. The Benthic Ecology Model simulation of Chironomidae larvae biomass (black line) and observed biomass (closed symbols and standard deviation). Fit is within 81% of the RMSD.

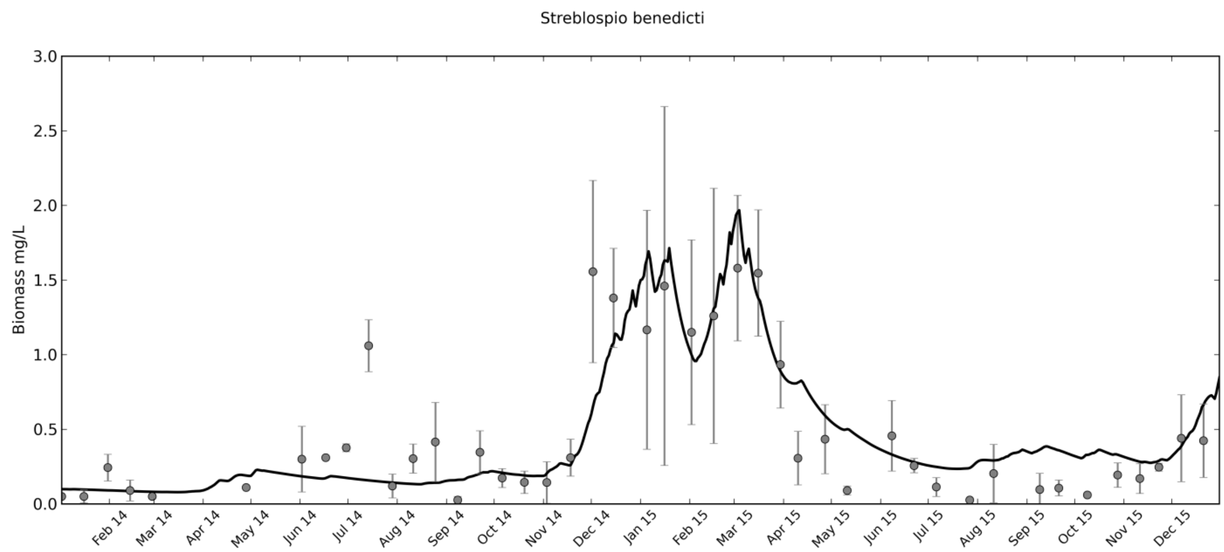

Figure 27. The Benthic Ecology Model simulation *of Streblospio benedicti* biomass (black line) and observed biomass (closed symbols and standard deviation). Fit is within 65% of the RMSD.

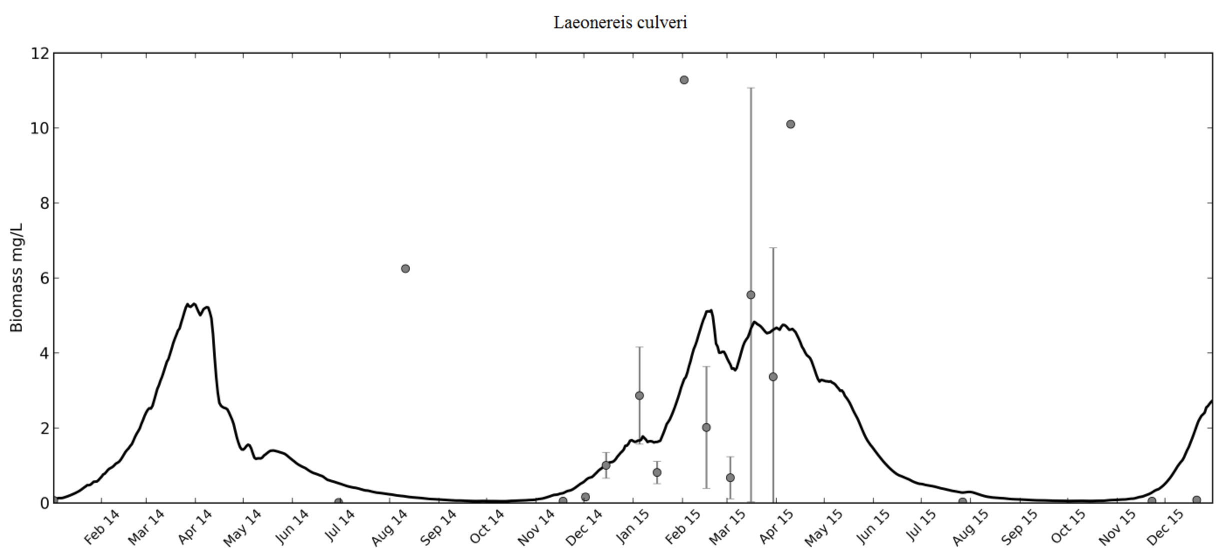

Figure 28. The Benthic Ecology Model simulation of *Laeonereis culveri* biomass (black line) and observed biomass (closed symbols and standard deviation). Fit is within 23% of the RMSD.

Discussion

Biotic Response to Salinity

Detailed analyses of changes in biomass over time for three dominant species (*Streblospio benedicti*, *Laeonereis culveri*, and Chironomidae larvae) were made to determine relationships with physical parameters of salinity, depth, and temperature in Rincon Bayou. Biomass is an indicator of secondary productivity (Banse and Mosher 1980, Montagna and Li 2010, Kim and Montagna 2012). *Streblospio* is the dominant species in Rincon Bayou benthos and the most resilient to higher salinities and salinity changes. *Laeonereis culveri* and Chironomidae larvae were predominantly found in upper Rincon Bayou Station C and are typically associated with lower salinity levels. Chironomidae larvae in particular are well documented as freshwater and water quality indicators (Rosenberg, 1992; Saether, 1979). This indicates sustained freshwater inflow to upper Rincon Bayou during the current wet period has likely altered the diversity and community structure to be favorable to freshwater indicator species such as Chironomidae.

There is a strong relationship between higher depth values to low biomass. No benthic communities are observed when water is absent (i.e., < 0.01 m) from the sample location. However, a strong link between lowered biomass and higher depth (> 0.4 m) is observed for all species. Because higher water depth is associated with freshwater, higher biomass' of *Laeonereis culveri* and Chironomidae larvae are expected. Additionally, great care is taken to collect sediment core samples at the same locations regardless of depth. From examining the raw time series core data from before and after flooding events a logical explanation is that higher floodwaters physically dislocate benthos species from the upper marsh. This is corroborated by historical physical examinations of the topology of the marsh after flooding events where floods often relocate channels, roadways, and structures. The optimal biomass for all species was found at depths between 0.05 m to 0.2 m (Table 15).

Table 15. Summary optimal physical parameters for indicator species.

Indicator	Optimal Salinity (psu)	Optimal depth (m)	Optimal depth (inches)
Biomass	1 - 15	0.05 - 0.2	2 - 7.9
Abundance	1 - 14	0.05 - 0.2	2 - 7.9
Maximum	20	0.5	19.7

Simulated Species Responses

The Benthic Ecology Model (BEM) was very successful at predicting Chironomidae larvae biomass within the sample period. Overall BEM simulated above 80% of the RMSD (Figure 26). Chironomidae larvae populations experienced a strong growth period early in the time series (January through March 2014) when salinities were low and varied little (mean 2.9 psu ± 3.3 psu) and depth was 0.14 m ± 0.12 m. Chironomidae not only is a freshwater species, but is extremely sensitive to depth disturbances. During the 2015 spring flooding Chironomidae Larvae biomass and abundance was consistently low due to higher and inconsistent water depth levels.

An interpretation of model results is Chironomidae larvae require both freshwater and consistently lower water depth to maintain a larger population as high water depth indicates flooding conditions where Chironomidae are displaced lower into the Bayou.

Streblospio benedicti was simulated above 65% of the RMSD of the observations (Fig 27). *Streblospio benedicti* was consistently found at almost every observation period in the study, which aids in the confidence of the results. *Streblospio benedicti*, as the most abundant species in Rincon Bayou, has the most resilience to disturbances of salinity and depth changes. The populations of *Streblospio benedicti* peak during the floods of spring 2015 despite flooding conditions. Additionally, the species regularly maintained biomass of 0.1 to 0.5 mg/L regardless of time of year or inflow.

Laeonereis culveri was a special case because it was the most difficult species for BEM to predict having matches less than 30% of the RMSD (Figure 28). Although this species is the third most abundant observed at the study site, it did not occur throughout the entire time series. It occurred primarily between November 2014 and April 2015 during a spring flood, which makes it difficult to have an accurate calibration over the entire study period. There were also three outlier observations that were above the overall mean and were outside the range of the model simulation.

BEM also predicts *Laeonereis culveri* should have had a population bloom during the spring of 2014, yet *Laeonereis culveri* was not observed at this time. This is a good example of the model giving an incorrect prediction because observations were not found. It may be that the model was predicting that conditions were good for *Laeonereis culveri* and that its abundance would have increased, but because the species was actually absent it could not increase, and the model was wrong about this period. Because Rincon Bayou is relatively isolated from the Nueces River and Nueces Bay populations that may be seeding the population in Rincon Bayou, it is possible that *Laeonereis* was blooming in other parts of the ecosystem during favorable conditions, or that a lack of seed population was responsible for the lack of a bloom.

The existing observations of *Laeonereis culveri* during spring 2015 give evidence to the suggestion above that *Laeonereis culveri* may indeed have also peaked during spring 2014 given a seed population. During the floods of spring 2015 a large quantity of freshwater inflow overran the banks of the saltwater dam disconnecting the Rincon Bayou from the Nueces River. This period was categorized as volatile with low salinities and higher water depth. *Streblospio benedicti* also peaked during this period when depth was high and salinity low. Given these conditions, *Laeonereis culveri* appears to be reasonably adapted to harsh variable flooding hydrological conditions, and thus should have been able to cope with the conditions during the spring of 2014.

Laeonereis culveri is a predominantly brackish water species and is only rarely measured at stations below C. The major difference between the springs of 2014 and 2015 is a major flood occurred in 2015 where the Nueces River overflowed the salt water dam complex and the flow control device into Rincon Bayou. In spring 2014, however, freshwater inflow to Rincon Bayou was supplied via pumping activities and local runoff from rainfall to the adjacent countryside. It follows that logically inflow from pumping activities would contain different constituents than natural riverine flooding. Freshwater inflow from pumping and local runoff differs from riverine runoff in that population migration does not occur, and sediment is from upstream the river is not transferred, and large organic matter is not deposited. Thus, the flood of 2015 provided not only freshwater to Rincon Bayou, but also indirectly seeded the populations of *Laeonereis culveri* by allowing population migration to occur through the upper Rincon Bayou through the water control overflow structure (Figure 2).

Species Relationships to Pumping Activities

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). The optimum salinity range for species in the current study is between 1 and 15 psu for biomass, 1 and 14 psu for abundance, and an optimum depth of 0.05 to 0.2 m (2 to 7.9 inches) for both (Table 12). 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 29). 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 (Allen and Mooney personal communication).

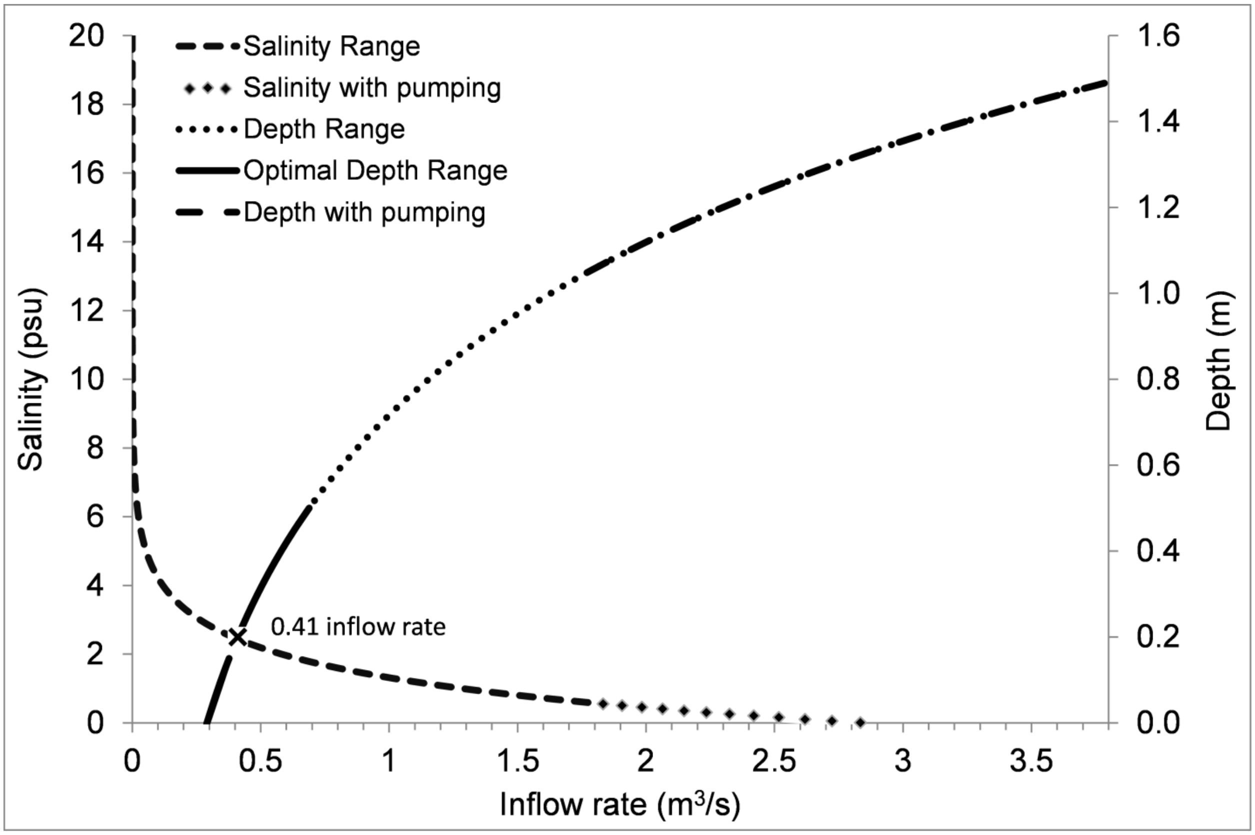

Figure 29. Relationship between RBP pumping capacity, salinity ranges, and depth ranges for the indicator species at Station C.

With the current pumping capacity, at most one pump should be used and ran continuously to create a stable environment in the upper delta. Running one pump continuously would result in an inflow rate of 1.8 m^3/s (126 ac-ft/day) which would deliver the required 3.7 x 10^6 m^3 (3,000 ac-ft) per month in approximately 24 days, and pump an excess of 0.99 to 1.11 x 10^6 m^3/s (800 to 900 ac-ft) per month. Adams and Tunnel (2010) found that it takes approximately 27 days to pump the required 3.7 x 10^6 m^3 (3,000 ac-ft) with one pump in operation which is slightly more than the estimated 24 day from this study. Reducing the pumping capacity to pump the 0.41 m^3/s (28.72 ac-ft/day) continuously would result in approximately 1.06 x 10^6 m^3/s (862 ac-ft) per month of water being delivered to the upper delta. However, this does not meet the 2001 Agree Order's pass-through requirement of 3.7 x 10^6 m^3 (3,000 ac-ft) per month.

Management Recommendations

Although lower salinities have been maintained in Rincon Bayou due to pumping activities, lower diversity and high fluctuations of abundance and biomass are indicative of a very disturbed ecosystem. 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 1 and 15 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 viability: floods become more severe, while droughts are dryer.

References

Adams, J.S. and J. Tunnell. 2010. Rincon Bayou Salinity Monitoring Project. Coastal Bend Bays & Estuaries Program. Corpus Christi, Texas. Project 0921, CBBEP-66. 18 pp. http://cbbep.org/publications/virtuallibrary/0921report.pdf

Alexander, H.D. and K.H. Dunton. 2002. Freshwater inundation effects on Emergent vegetation in a hypersaline salt marsh. Estuaries 25: 1426-1435.

Allen, Ray and Rae Mooney. Personal interview. 10 November 2015.

Alpkem Corporation. 1993. Orthophosphate. Alpkem Corporation, Wilsonville, Oregon.

Banse, K. and S. Mosher. 1980. Adult body mass and annual production/biomass relationships of field populations. Ecological Monographs 50: 355-379.

Bureau of Reclamation (BOR). 2000. Concluding Report: Rincon Bayou Demonstration Project. United States Department of Interior, Bureau of Reclamation, Oklahoma-Texas Area Office, Austin, Texas, 2000.

Brown, D., Rothery, P. 1993. Models in biology: mathematics, statistics and computing. Oceanography of the Ross Sea, Antarctica. John Wiley & Sons. p. 688.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18: 117–143.

Clarke, K.R. and R.N. Gorley. 2015. PRIMER v7: User Manual/Tutorial. PRIMER-E, Plymouth, UK.

Clarke, K.R. and R.M. Warwick. 1998. Quantifying structural redundancy in ecological communities. Oecologia 113: 278-289

Clarke, K.R., R.N. Gorley, P.J. Somerfield and R.M. Warwick. 2014. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 3rd ed. Primer-E, Plymouth, UK.

Conrad Blucher Institute for Surveying and Science (CBI), Texas A&M University - Corpus Christi. 2015. http://www.cbi.tamucc.edu/dnr/station

Espey, Huston & Associates. 1981. Nueces marsh development: A feasibility study of the introduction of river flows. Document # 81328. EH&A, Austin, Texas.

Hedges, J.I. and J.H. Stern. 1984. Carbon and nitrogen determinations of carbonate-containing solids. Limnology and Oceanography 29:657-663.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology 54:427-432.

Kalke, R. and P.A. Montagna. 1991. The effect on freshwater inflow on macrobenthos in the Lavaca River delta and upper Lavaca Bay, Texas. Contributions in Marine Science 32:49-77.

Kim, H. C., & Montagna, P. A. 2009. Implications of Colorado River (Texas, USA) freshwater inflow to benthic ecosystem dynamics: A modeling study.Estuarine, Coastal and Shelf Science 83(4): 491-504.

Kim, H.-C. and P.A. Montagna. 2012. Effects of climate-driven freshwater inflow variability on macrobenthic secondary production in Texas lagoonal estuaries: A modeling study. Ecological Modelling 235– 236: 67– 80.

Lotka, A.J., 1925. Elements of Physical Biology. Williams & Wilkins, Baltimore, Maryland, p. 460.

Montagna, P.A., E.D. Estevez, T.A. Palmer, and M.S. Flannery. 2008. Meta-analysis of the relationship between salinity and molluscs in tidal river estuaries of southwest Florida, U.S.A. American Malacological Bulletin 24: 101-115.

Montagna, P.A, E.M. Hill, and B. Moulton. 2009. Role of science-based and adaptive management in allocating environmental flows to the Nueces Estuary, Texas, USA. In: Brebbia, C.A. and E. Tiezzi (eds.), Ecosystems and Sustainable Development VII, WIT Press, Southampton, UK, pp. 559-570.

Montagna, P.A. and R.D. Kalke. 1992. The Effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces Estuaries, Texas. Estuaries 15:266-285.

Montagna, P.A., R.D. Kalke, C. Ritter. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. Estuaries 25: 1243-1245.

Montagna, P. A., and Li, J. 1996. Modeling and monitoring long-term change in macrobenthos in Texas estuaries. University of Texas at Austin, Marine Science Institute.

Montagna, P. A., and Li, J. 1997. Modelling contaminant effects on deposit feeding nematodes near Gulf of Mexico production platforms. Ecological Modelling 98(2): 151-162.

Montagna, P.A. and J. Li. 2010. Effect of Freshwater Inflow on Nutrient Loading and Macrobenthos Secondary Production in Texas Lagoons. In: Coastal Lagoons: Critical Habitats of Environmental Change, M. J. Kennish and H. W. Paerl (eds.), CRC Press, Taylor & Francis Group, Boca Raton, FL, pp. 513-539.

Montagna, P.A., T. Palmer, M. Gil, E. Hill, B. Nicolau, and K. Dunton. 2009. Response of the Nueces Estuarine Marsh System to Freshwater Inflow: An Integrative Data Synthesis of Baseline Conditions for Faunal Communities. Coastal Bend Bays & Estuaries Program Publication CBBEP-62 for project # 0821, 27 pp. http://cbbep.org/publications/virtuallibrary/0821.pdf

NBBEST (Nueces River and Corpus Christi and Baffin Bays Basin and Bay Area Stakeholder Committee and Expert Science Team). 2011. Environmental Flows Recommendation Report. Final Submission to the Environmental Flows Advisory Group, Nueces River and Corpus Christi and Baffin Bays Basin and Bay Area Stakeholders Committee, and Texas Commission on Environmental Quality. http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/20111028nuecesbbest_recommendations.pdf

Nueces River Authority. 2015. Rincon Pipeline Events. http://www.nueces-ra.org/CP/CITY/rincon/

OIA. 2008. Nitrate plus Nitrite and Nitrite in Seawater by Segmented Flow Analysis (SFA). Alpkem Corporation, College Station, Texas, http://www.oico.com.

OIA. 2007. Ammonia in Seawater by Segmented Flow analysis (SFA). O.I. Analytical, College Station, Texas, http://www.oico.com.

OIA. 2001a. Silica in Seawater by Segmented Flow analysis (SFA). O.I. Analytical, College Station, Texas, http://www.oico.com

OIA. 2001b. Orthophosphate in Seawater by Segmented Flow Analysis (SFA). O.I. Analytical, College Station, Texas, http://www.oico.com.

Palmer, T.E., P.A. Montagna, and R.D. Kalke. 2002. Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. Estuaries 25: 1448-1456.

Rosenberg, D.M. 1992. Freshwater biomonitoring and Chironomidae. Netherland Journal of Aquatic Ecology 26: 101-122.

Saether, O.A. 1979. Chironomid communities as water quality indicators. Ecography 2:65-74.

SAS Institute Inc. 2013a. SAS/STAT® 13.1 User's Guide. Cary, NC: SAS Institute Inc.

SAS Institute Inc. 2013b. SAS® 9.4 Functions and CALL Routines: Reference, Second Edition. Cary, NC: SAS Institute Inc.

Shannon, C. E. and W. Weaver. 1949. The Mathematical Theory of Communication. University of Illinois Press. Urbana, IL.

Texas Water Development Board (TWDB). 2013. Volumetric and Sedimentation Survey of Choke Canyon Reservoir June 2012 Survey. Austin, Texas, USA. http://www.twdb.texas.gov/hydro_survey/chokecanyon/2012-06/chokecanyon2012_finalreport.pdf accessed 20 July 2016.

Tunnell, J.W. and L. Lloyd. 2011. Effects of Rincon Bayou Pipeline Inflows on Salinity Structure within the Nueces Delta, Texas. Coastal Bend Bays & Estuaries Program project 1106. Corpus Christi, Texas. Publication No. CBBEP-76. 23 pp.

Turner, E.L. 2016. EasyModeler 2.2.6, https://pypi.python.org/pypi/EasyModeler

Turner, E. L., Bruesewitz, D. A., Mooney, R. F., Montagna, P. A., McClelland, J. W., Sadovski, A., Buskey, E. J. 2014. Comparing performance of five nutrient phytoplankton zooplankton (NPZ) models in coastal lagoons. Ecological Modelling, 277: 13-26.

Turner, E.L, Montagna, P.A. 2016. Quantifying responses of ecological indicators to environmental variables using a maximum bin method. Ecoinformatics. In review.

USGS. National Water Information System: Web Interface. 2015. http://waterdata.usgs.gov/nwis/uv?site_no=08211500

Ward, G.H., M.J. Irlbeck, and P.A. Montagna. 2002. Experimental river diversion for marsh enhancement. Estuaries 25: 1416-1425.

Appendix I. Python script for the Benthic Ecology Model

```
#Benthic Ecology Model May 2016
#Evan Lee Turner evanlee.turner@gmail.com
#Compiled using EasyModeler 2.2.6
#https://pypi.python.org/pypi/EasyModeler


import matplotlib.pyplot as plt
import os
import sys
import csv
from bemmodel import ODE_RBBEM
import numpy as np
import datetime
import math
from matplotlib.dates import MONDAY, SATURDAY
from matplotlib.dates import MonthLocator , WeekdayLocator ,DateFormatter, YearLocator,
num2date, date2num
import logging
import emlib
import gc



emlib.emlog.setLevel(logging.INFO)  #set our emlib printing level.

RUNS=0#number of times to run the calibrator.  0 runs prints base validation
SP=487 # species number

BCFILE = "BEMSP"+str(SP)+"BEST-" +str(RUNS)+".csv"    #the file to place your best
coefficients
CFILE = "BEMSP"+str(SP)+".csv"  #base calibration file we will generate
MYOBS = "RBMGSP"+str(SP)+".sas7bdat"  #observation file
myObs = emlib.Observation("mg",dirname="C:/Users/eturner/Box Sync/Evans CMSS
Research\Montagna N/Evan/computed data and model input/",filename=MYOBS,
fformat="sas")
myInput = emlib.TimeSeries(dirname="C:/Users/eturner/Box Sync/Evans CMSS
Research\Montagna N/Evan/computed data and model input/",
filename="RBSONDE_PREDICTION.sas7bdat",fformat="sas")
VObs = emlib.Observation("Vmg",dirname="C:/Users/eturner/Box Sync/Evans CMSS
Research\Montagna N/Evan/computed data and model input/",filename="V" + MYOBS,
fformat="sas")
```

```
CObs = emlib.Observation("Cmg",dirname="C:/Users/eturner/Box Sync/Evans CMSS
Research\Montagna N/Evan/computed data and model input/",filename="C" + MYOBS,
fformat="sas")


#myInput.Draw(block=False)

startdate = datetime.date(2014,01,02)
enddate = datetime.date(2016,01,01)

myC = []
if SP == 81  or SP == 7 or SP == 562 or SP == 999:
    myC.append(emlib.Coefficient("Kg",val=8.78,min=8.0,max=10.0))
    myC.append(emlib.Coefficient("Km",val=0.23,min=0.2,max=0.4))
    myC.append(emlib.Coefficient("Bcc",val=12.0,isconst=True))
    myC.append(emlib.Coefficient("Kgt",val=5.48,min=4.8,max=5.5))
    myC.append(emlib.Coefficient("Sopt",val=13.47, min=11.0,max=14.0))
    myC.append(emlib.Coefficient("Topt",val=16.47, min=16.0,max=18.0))
    myC.append(emlib.Coefficient("Dopt",val=0.1, isconst=True))
    myC.append(emlib.Coefficient("Kgs",val=2.94,min=2.8,max=4.0))
    myC.append(emlib.Coefficient("Kmd",val=2.75,min=2.0,max=3.0))
    myC.append(emlib.Coefficient("Kms",val=2.79,min=2.0,max=3.0))
    myC.append(emlib.Coefficient("Kmds",val=7.6,min=7.0,max=8.0))
    myC.append(emlib.Coefficient("Kmss",val=3.0,min=3.0,max=4.0))


if SP == 655:
    myC.append(emlib.Coefficient("Kg",val=4.45,min=4.0,max=5.0))
    myC.append(emlib.Coefficient("Km",val=1.2,min=1.0,max=1.8))
    myC.append(emlib.Coefficient("Bcc",val=2.5,isconst=True))
    myC.append(emlib.Coefficient("Kgt",val=20.6,min=18.0,max=25.0))
    myC.append(emlib.Coefficient("Sopt",val=20.1, min=16.0, max=22.0))
    myC.append(emlib.Coefficient("Topt",val=25.0, isconst=True))
    myC.append(emlib.Coefficient("Kgs",val=6.7,min=5.0,max=9.0))
    myC.append(emlib.Coefficient("Kmd",val=5.8,min=0.5,max=8.0))

if SP == 81655:
    myC.append(emlib.Coefficient("Kg",val=3.5,min=2.5,max=6.0))
    myC.append(emlib.Coefficient("Km",val=1.52,min=1.0,max=2.0))
    myC.append(emlib.Coefficient("Bcc",val=2.5,isconst=True))
    myC.append(emlib.Coefficient("Kgt",val=22.91,min=18.0,max=25.0))
    myC.append(emlib.Coefficient("Sopt",val=21.1, min=16.0, max=22.0))
    myC.append(emlib.Coefficient("Topt",val=25.0, isconst=True))
    myC.append(emlib.Coefficient("Kgs",val=6.08,min=5.0,max=9.0))
    myC.append(emlib.Coefficient("Kmd",val=5.8,min=0.5,max=8.0))
```

```
if SP == 491:

    myC.append(emlib.Coefficient("Kg",val=12.51,min=9.0,max=13.0))
    myC.append(emlib.Coefficient("Km",val=0.78,min=0.5,max=2.0))
    myC.append(emlib.Coefficient("Bcc",val=12.0,isconst=True))
    myC.append(emlib.Coefficient("Kgt",val=5.0,min=4.5,max=6.0))
    myC.append(emlib.Coefficient("Sopt",val=15.71, min=6.0,max=16.0))
    myC.append(emlib.Coefficient("Topt",val=21.62, min=12.0,max=23.0))
    myC.append(emlib.Coefficient("Dopt",val=0.1, isconst=True))
    myC.append(emlib.Coefficient("Kgs",val=8.48,min=7.5,max=10.0))
    myC.append(emlib.Coefficient("Kmd",val=0.86,min=0.8,max=3.0))
    myC.append(emlib.Coefficient("Kms",val=8.29,min=7.5,max=11.0))
    myC.append(emlib.Coefficient("Kmds",val=6.92,min=5.0,max=8.0))
    myC.append(emlib.Coefficient("Kmss",val=5.55,min=4.0,max=6.0))


if SP == 487:
    myC.append(emlib.Coefficient("Kg",val=47.0,min=20.0,max=70.0))
    myC.append(emlib.Coefficient("Km",val=7.3,min=2.5,max=10.0))
    myC.append(emlib.Coefficient("Bcc",val=12.0,isconst=True))
    myC.append(emlib.Coefficient("Kgt",val=2.5,min=2.0,max=6.0))
    myC.append(emlib.Coefficient("Sopt",val=4.6, min=0.1,max=5.0))
    myC.append(emlib.Coefficient("Topt",val=12.8, min=12.0,max=18.0))
    myC.append(emlib.Coefficient("Dopt",val=0.1, isconst=True))
    myC.append(emlib.Coefficient("Kgs",val=7.6,min=7.5,max=10.0))
    myC.append(emlib.Coefficient("Kmd",val=2.39,min=1.1,max=3.0))
    myC.append(emlib.Coefficient("Kms",val=11.9,min=10.5,max=15.0))
    myC.append(emlib.Coefficient("Kmds",val=4.8,min=4.0,max=7.0))
    myC.append(emlib.Coefficient("Kmss",val=5.16,min=3.0,max=6.0))

RBBEM = emlib.Calibration(coeffs=myC)
RBBEM.Write(filename=CFILE)



RBBEM.initial = [.1]

if SP == 487:
   RBBEM.initial = [4.8]

myModel = emlib.Model(ODE_RBBEM)

if RUNS == 0:
    myModel.Integrate(RBBEM.initial,Calibration=RBBEM, TimeSeries=myInput, dt=.01,
start=startdate,end=enddate)
```

```
    GF  = myModel.Validate(VObs,graph=False)
    GF.Print()
    GF  = myModel.Validate(CObs,graph=False)
    GF.Print()
    if SP == 491:
        GF  = myModel.Validate(myObs,graph=True, ylabel= "Number of
Individuals",title="Laeonereis culveri",ylim=[0,12],savefig="491Nfig.png")
    if SP == 81:
        GF  = myModel.Validate(myObs,graph=True, ylabel= "Biomass mg/L",title="Streblospio
benedicti",ylim=[0,3],savefig="81fig.png")
    if SP == 487:
        GF  = myModel.Validate(myObs,graph=True, ylabel= "Biomass
mg/L",title="Chironomidae larvae",ylim=[0,12],savefig="487fig.png")
    GF.Print()
else:

    BestCalibration =
myModel.Calibrate(RBBEM,CObs,runs=RUNS,TimeSeries=myInput,dt=.01,Algorithm=emlib.
GF_BruteForceRMSD, start=startdate,end=enddate)
    BestCalibration.Print()
    BestCalibration.Write(filename=BCFILE)

    myModel.Integrate(RBBEM.initial,Calibration=BestCalibration, TimeSeries=myInput,
dt=.01, start=startdate,end=enddate)
    GF = myModel.Validate(VObs,graph=True)
    GF.Print()
#Benthic Ecology Model May 2016
#Evan Lee Turner evanlee.turner@gmail.com
#Compiled using EasyModeler 2.2.6
#https://pypi.python.org/pypi/EasyModeler

import math

def ODE_RBBEM(t,initial,dtinput,coeffs):

    #initial conditions
    B = initial[0]

    #coefficients
    Kg = coeffs.Val("Kg")
    Bcc = coeffs.Val("Bcc")
    Kgs = coeffs.Val("Kgs")
    Kgt = coeffs.Val("Kgt")
    Km = coeffs.Val("Km")
    Kms = coeffs.Val("Kms")
    Kmd = coeffs.Val("Kmd")
```

```
    Kmds = coeffs.Val("Kmds")
    Kmss = coeffs.Val("Kmss")
    Topt = coeffs.Val("Topt")
    Sopt = coeffs.Val("Sopt")
    Dopt = coeffs.Val("Dopt")
    temp = dtinput.Val("temp")
    sal = dtinput.Val("sal")
    depth = dtinput.Val("depth")

    gsal = ( math.exp(- pow((sal - Sopt),2)/ pow((2 * Kgs),2)))
    gtemp =  ( math.exp(- pow((temp - Topt),2)/ pow((2 * Kgt),2)))
    mdep = (1 - ( math.exp(- pow((depth - Dopt),2)/ pow((2 * Kmd),2))))
    msal = (1 - ( math.exp(- pow((sal - Sopt),2)/ pow((2 * Kms),2))))

    B_dot =    ( Kg  * gsal * gtemp * B * ( 1 - (B/Bcc)))  - (Km * B) -  (Kmss * msal * B *B) -
(Kmds * mdep * B *B)

    return [B_dot]
```

Apendix II. Review and comments letter from the Texas Water Development Board

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

June 30, 2016

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

RE: Research Contract between the Texas Water Development Board (TWDB) and Texas A&M University-Corpus Christi (TAMU-CC), TWDB Contract No. 1548311787, Draft Report Comments for a report Entitled "***Determining Optimal Pumped Inflows to Nueces Delta, FY15-16***"

Dear Dr. Hough:

Staff members of the TWDB have completed a review of the draft report prepared under the above-referenced contract. Attachment 1 provides the comments resulting from this review. As stated in the TWDB contract, TAMU-CC will consider revising the final report in response to comments from the Executive Administrator and other reviewers. In addition, TAMU-CC will include a copy of the Executive Administrator's draft report comments in the Final Report.

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

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

If you have any questions concerning the contract, please contact Ms. Caimee Schoenbaechler, the TWDB's designated Contract Manager for this project, at (512) 463-3128 or caimee.schoenbaechler@twdb.texas.gov.

Sincerely,

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

Attachment

c: Caimee Schoenbaechler, TWDB

Attachment 1

Determining Optimal Pumped Inflows to Nueces Delta, FY15-16
P.I. Paul Montagna
Contract #1548311787
TWDB Comments to Final Report

REQUIRED CHANGES

General Draft Final Report Comments:

The purpose of the study was to identify a beneficial pumping strategy for delivering 3,000 acre-feet of freshwater to the Nueces Delta via the Rincon Bayou Pipeline to restore and enhance ecosystem function in the delta. The study determined the effects of pumped inflows into the Rincon Bayou on benthic macrofauna during low and normal precipitation conditions. A model of benthic dynamics was calibrated and used to simulate the impacts of pumping on macrofauna productivity (biomass and abundance) and to predict the optimal quantity and frequency of pumped inflows. Using several benthic species as indicators of ecosystem health, recommendations for freshwater inflows were offered for achieving optimal ranges of salinity and water depth. A continuous pumping strategy that is not dependent on pass-through requirements was recommended for improving the ecological stability of the Nueces Delta. This report meets all of the objectives laid out in the scope of work.

Please check the document for grammar, spelling, typographical errors, and randomly dispersed symbols. Please spell out all acronyms, with the acronym in parentheses, the first time they are used. Please correct the page numbering scheme throughout the document and update the Table of Contents, where the page number after page 12 reverses to 1. Please include a list of acronyms used in the report after the Table of Contents.

Specific Draft Final Report Comments:

1) Abstract, page v, 1st paragraph, 2nd sentence: Please change "drought precipitation" to "low flow events" and make this change in other occurrences in the report. Also, please define "low flow events."

2) Abstract, page v, 2nd paragraph: Please offer a definition of "reverse estuary."

3) Abstract, page v, 2nd paragraph: Please provide a definition with a quantitative range for the term "hypersaline."

4) Abstract, bullet points, page v: Please provide the acre-feet per day conversion for the flow recommendations.

5) Abstract, page v, last bullet: Change "viability" to "variability."

6) Introduction, page 1, 3rd paragraph: Please clarify the following statement: "The reduced salinities led to reduced increased productivity of the marsh and living resources."

7) Introduction, page 1, last paragraph: Please revise the following statement which implies that bathymetric surveys increase storage capacity and add a citation: "Also, new bathymetric surveys were performed that increased the total water storage capacity by 16,019 ac-ft because of sediment retention." TWDB surveyed Choke Canyon in 2012 and reported that the reservoir loses capacity every year due to sedimentation. http://www.twdb.texas.gov/hydro_survey/ChokeCanyon/2012-06/ChokeCanyon2012_FinalReport.pdf

8) Methods page 2, 1st paragraph: Please define the term "sessile."

9) Methods, page 2, 1st paragraph: Please offer a definition of the term "xenobiotic."

10) Methods, Sampling, page 2, 1st paragraph: Please clarify the use of "odd" or consider different wording in the following statement: "The Nueces Estuary is odd in that the Nueces River runs parallel to and on the south side of the Nueces Delta and the river empties in to Nueces Bay below the delta." The Nueces Estuary is unlike typical estuaries because the river empties into the bay without traversing through the delta.

11) Methods, Sampling, page 2: Please provide the full term of IH before using it in acronym form.

12) Methods, Sampling, page 3, 1st paragraph: Please make a reference to Figure 2 in the text.

13) Methods, Sampling, page 3, 1st paragraph: Please move the statement about the sampling scheme to the paragraph below where sampling scheme is discussed. "Two other stations (F and G) were sampled quarterly (beginning October 1, 2015 and ending April 30, 2016) to capture changes over larger spatial scales."

14) Methods, Sampling, page 3: Please clarify the following statement: "…we were always notified of pumping until after pumping began."

15) Methods, Water Quality, page 4, 1st paragraph: Please mention the depth of the water column.

16) Methods, Water Quality, page 4, 2nd paragraph: Please define the upside down A symbol or remove.

17) Methods, Water Quality, page 4: Please define EC, AU, EPA, and all other acronyms the first time they are used in the text.

18) Methods, Water Quality, page 4, 4th paragraph: Please provide more explanation of the analysis methods used. Ideally, the methods section should be comprehensible to the non-specialist.

19) Methods, Water Quality, page 4, 5th paragraph: Please provide additional description of the multivariate analysis methods and more detailed explanation on how the water column structure was analyzed using Principal Component Analysis. Some explanation is provided on page 5 under 'Analytics,' but please consider combining these sections to improve the flow of the report.

20) Methods, Analytics, Water Quality Response to Inflow, page 5, 1st paragraph: Usage of the phrase ".....were loge(x+1) transformed" is awkward. Please revise the phrase to describe the data transformation process used. Same section, remove "\" before "of."

21) Methods, Analytics, Water Quality Response to Inflow, page 5, 1st paragraph: Please spell out the acronym SAS the first time it is used and explain what packages were used and why.

22) Methods, Analytics, Water Quality Response to Inflow, page 5, 2nd and 3rd paragraphs: Please provide more explanation on exactly how the Principal Component Analysis was conducted. Typically, both the temporal scores of a Principal Component would elucidate any temporal trends in the data set. Please explain why it was necessary to undertake two separate analyses.

23) Methods, Analytics, Water Quality Response to Inflow, page 5, 3rd paragraph: Only two years of data, sampled either monthly or biweekly, is used in the trend analysis. Please provide some discussion on how such a short data sample can provide insights into trends.

24) Methods, Analytics, Community Structure, page 5, last paragraph: Please correct the typo in "multidimensional."

25) Methods, Analytics, Community Structure, page 5, last paragraph: Usage of the following phrase is awkward: "....the data was natural logarithm transformed." Please revise to include a more readable description.

26) Methods, Analytics, Community Structure, page 6, 2nd paragraph: Please explain the BIO-BIO and BIO-ENV procedures.

27) Methods, Modeling, Benthic Ecology Model Design, Rincon Bayou Macrofauna Modeling Study Species, page 10, 1st paragraph, last sentence: Please clarify the following statement: "To model as a daily ΔT the YSI sonde collections means were taken to the daily level" and what "sonde collections means" refers to. Consider revising the statement to something similar to the following: "To model the daily change in temperature, YSI sonde measurements taken in thirty-minute intervals were averaged to a daily time-step."

28) Methods, Modeling, Benthic Ecology Model Design, Model Implementation and Validation, page 10, 2nd paragraph: Please explain what "SAS statement UNIF( )" means. It is recommended that the authors explain the analysis procedure undertaken so that it can be understood by a non-specialist. If necessary, model code and terminology can be provided, with adequate annotation, in an appendix.

29) Results, Hydrology and Salinity, page 11, 2nd paragraph: Please provide a quantitative range for the term "mesohaline."

30) Results, Hydrology and Salinity, page 11, 3rd paragraph: Please provide clarification to the statement as to why there are no instances when pumping takes place without rainfall: "Pumping events correlate with rainfall and typically occur after or during rainfall periods."

31) Results, Hydrology and Salinity, page 11, 4th paragraph: The first statement claims that, "The absence of a distinct elevation gradient in Rincon Bayou at the pumping outfall area (Figure 3) 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 (Figure 10)." However, Figure 3 does not appear to show elevation data. Please make the appropriate correction.

32) Results, Hydrology and Salinity, page 12, 1st paragraph: Please revise the following statement to improve clarity: "Freshwater pumped into Rincon Bayou was equaled or exceeded 20% of the time and accounted for most of the high/medium flow events."

33) Results, Hydrology and Salinity, page 12, last paragraph: Please double check the values reported (3.69×10^{-7} to 1.02×10^{-3} m^3/s) in the first statement, which differ by several orders of magnitude from other flow values reported throughout the document.

34) Results, Water Quality, page 17 (to be revised), 1st paragraph: Please provide a detailed description of exactly what the Principal Component Analysis results reveal. Please explain how the following statements can be inferred from Figure 15:

   a. "The inverse relationship between depth and salinity is somewhat diminished for all stations."
   b. "PC1 still represents the inflow gradient and PC2 still represents the seasonal gradient."

35) Results, Macrofauna, Long-term Trends, page 19 (to be revised), 1st paragraph: Please describe in more detail the trends observed over the entire period of record.

36) Results, Response to Physical Variables, Community Level Responses, page 21 (to be revised), 1st paragraph, last sentence: The last sentence references an incorrect Figure number, Figure 5. Please revise.

37) Results, Response to Physical Variables, Community Level Responses, page 22 (to be revised), 3rd paragraph: The reference to Figure 6 showing diversity and salinity is incorrect. Please revise.

38) Results, Response to Physical Variables, Macrofauna Species Level Response to Salinity, Depth, and Temperature, page 28 (to be revised), 1st paragraph, last sentence: The last sentence reports species composition as 50.6 % Chironomidae larvae, 39.0% *Streblospio benedicti*, and 4.82% *Laeonereis culveri*, but these values are different from what is reported in Table 11. Please explain where those data are reported or connect the values in the text.

39) Results, Response to Physical Variables, Community Level Response, page 29 (to be revised): Please change the term "hydrographical" to "hydrological" in this instance and elsewhere in the report.

40) Discussion, Biotic Response to Salinity, page 38 (to be revised), 1st paragraph: Please use language that reflects probability rather than absolute certainty for the last sentence: "This indicates sustained freshwater input to upper Rincon Bayou has altered the diversity and community structure to be favorable to freshwater indicator species such as Chironomidae."

41) Discussion, Simulated Species Response, page 38, last paragraph: It is unclear what salinities and depth were consistent with in the following statement: "Chironomidae larvae populations experienced a strong growth period early in the time series when salinities and depth we consistent." Please clarify the meaning of this statement and make the correction from "we" to "were."

42) Discussion, Simulated Species Response, page 39 (to be revised), 2nd paragraph: Please consider changing "species" to "population" in the following sentence: "An interpretation of model results is that Chironomidae larvae require both freshwater and consistently lower water depth to maintain a larger species…."

43) Discussion, Simulated Species Response, page 39 (to be revised), 3rd paragraph: Please clarify the meaning of this statement: "….the distribution of observations along the time series makes calibration difficult for modeling."

44) Discussion, Simulated Species Response, page 39 (to be revised), 4th paragraph: Please clarify the following statements and provide more explanation to back the inferences made:

a. "However, there is a distinction between when models give an incorrect prediction where observations exist versus when the species was not found."
b. "It may be that the model was correct in interpreting that *Laeonereis culveri* would have increased population if the species was actually present in the environment to do so."
c. "Since the Rincon Bayou is physically disconnected from the Nueces River population, seeding by species may not be guaranteed during favorable conditions."

45) Discussion, Simulated Species Response, page 39 (to be revised), 5th paragraph: It is unclear what theory is being referred to in the following statement. Please consider changing theory to hypothesis. "The existing observations of *Laeonereis culveri* during spring 2015 give evidence to the <u>theory</u> that *Laeonereis culveri* may indeed have also peaked during spring 2014 given a seed population." Please explain what theory is being referred to.

46) Discussion, Species Relationships to Pumping Activities, page 40 (to be revised), 1st paragraph: Please reference the correct Table in the following sentence: "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 for the current 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 (Table 10)." Table 10 shows Pearson correlations, not actual salinity values. Table 15 should be the correct table to reference.

47) Discussion, Species Relationships to Pumping Activities, page 41(to be revised), 1st paragraph, 2nd sentence: Please replace "access" with "excess."

48) Discussion, Management Recommendations, page 41 (to be revised): Please describe how the recommended range of salinity (6–18 psu) was determined from the optimal salinity range for indicator species (1–15 psu). Please also report the flow recommendations in acre-feet/day.

49) References, page 41 (to be revised): There are missing references for Montagna *et al.*, 2015, Turner *et al.*, 2012. Please include these citations in the reference list. Several references are listed in the references section but are not cited in the report. Please make the appropriate corrections for the following: DeWalt *et al.* 2010, Haney 1999, Kneib 1985, Larson *et al.* 1989, Lesutiene *et al.* 2008, Raimondo *et al.* 2013, Rosenberg 1992, Turner *et al.* 2014, and Weisberg *et al.* 1997. There are references for Montagna *et al.* 2002a and Montagna *et al.* 2002b, but only Montagna *et al.* 2002 is cited in the report. Please make the appropriate corrections.

Figures and Tables Comments:

1) Table 1, Methods, Modeling, page 9: Please spell out all of the units listed in Table 1. Please move the (a), (b), and (c) demarcations to the title line.

2) Table 6, page 16 (to be revised): Please add the dates associated with "Before pumping" and "After pumping."

3) Table 7, page 24 (to be revised): All correlation values, including those that are not significant, appear as bold text. Please correct this to only show significant correlations in bold text. Also, please explain which values in the table are Pearson correlations and which values are p-values.

4) Table 8, page 25 (to be revised): All correlation values, including those that are not significant, appear as bold text. Please correct this to only show significant correlations in bold text. Also, please explain which values in the table are Pearson correlations and which values are p-values.

5) Table 9, page 26 (to be revised): Please explain which values in the table are Pearson correlations and which values are p-values.

6) Table 10, page 26 (to be revised): All correlation values, including those that are not significant, appear as bold text. Please correct this to only show significant correlations in bold text. Also, please explain which values in the table are Pearson correlations and which values are p-values.

7) Table 13, page 35 (to be revised): Please define the Goodness of Fit Test performance measures (RMSD, RMSE, MSER,WMSE).

8) Figure 2, page 3: Please add the a), b), and c) demarcations on the map.

9) Figure 5, Results, page 1(to be revised): Pumping event daily totals are not shown in this plot. Consider revising the title to convey that "grey bars represent periods of time when Rincon Bayou pumps are in operation," or use similar wording.

10) Figure 6, page 2 (to be revised): Please include the date ranges for both periods of pumping and prior to pumping, and revise the legend and figure title.

11) Figure 25, page 36 (to be revised): Please revise the figure caption to read: "The Benthic Ecology Model simulation of Chironomidae larvae biomass (black line) and observed Chironomidae larvae biomass (closed symbols)."

12) Figure 26, page 37 (to be revised): Please revise the figure caption to read: "The Benthic Ecology Model simulation *of Streblospio benedicti* biomass (black line) and observed *Streblospio benedicti* biomass (closed symbols)."

13) Figure 27, page 37 (to be revised): Please revise the figure caption to read: "The Benthic Ecology Model simulation of *Laeonereis culveri* biomass (black line) and observed *Laeonereis culveri* biomass (closed symbols)."

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1) Introduction, page 1, 2nd paragraph: Please consider describing what the permit revisions meant for freshwater delivery to the estuary at that time.

2) Results, Response to Physical Variables, Community Level Response, page 28 (to be revised): Please consider revising the first statement to remove awkward wording, "The indicator species were determined as the three most numerically dominant species at Station C in Rincon Bayou from May 2010 to December 2015, *Streblospio benedicti, Laeonereis culveri*, and *Chironomidae larvae*."

Figures and Tables Comments:

1) Figure 10, page 6 (to be revised): Please consider providing a zoom of the period when the backflow prevention weir was in place. Having an inset graph showing just the period from 2014 – 2015 within Figure 10 would be sufficient.

2) Figure 15, page 18 (to be revised): This figure is difficult to interpret. Please consider highlighting on the figure particular points that are referred to in the discussion.