SB3 Work Plan (2013-2015 biennium)

Defining Bioindicators for Freshwater Inflow Needs Studies

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Final Report

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List of Abbreviations

BBEST – Bays and Basin Expert Science Team
FWBI - Freshwater bioindicator(s)
GBEP – Galveston Bay Estuary Program
HARC – Houston Advanced Research Center
LGB – Lower Galveston Bay
SJR – San Jacinto River
SWQM – Surface Water Quality and Monitoring Database
TB - Trinity Bay
TCEQ – Texas Commission on Environmental Quality
TPWD - Texas Parks and Wildlife Department
TR – Trinity River
TSJ-BBEST - Trinity-San Jacinto Bays and Basins Expert Science Team
TWDB – Texas Water Development Board
UGB - Upper Galveston Bay

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EXECUTIVE SUMMARY

Freshwater inflow (river discharge) is necessary for the maintenance of ecosystem health in coastal bays and estuaries. Inflow drives the water (salinity, nutrients, and chlorophyll) and sediment quality, in turn driving the health of biological systems. This study focused on two of the three activities identified for Trinity-San Jacinto River Basin and Galveston Bay (hereafter referred to as Galveston Bay only) as a result of the Senate Bill 3 process to determine freshwater inflows needs for this ecosystem using data collected from various agencies from 1980 to 2010. These were (i) to test the conclusion that the bioindicators identified were appropriate for representing the health of Galveston Bay, and (ii) to consider the addition of new species which were previously not recognized during the process. Further, we continued our monthly water quality sampling during the study period, albeit at a reduced rate.

The Trinity-San Jacinto Bays and Basins Expert Science Team (TSJ-BBEST) developed a list of potential bioindicators of freshwater inflow to Galveston Bay placing an emphasis on sessile species. Blue catfish (*Ictalurus furcatus*) exhibited a statistically significant (p<0.05) positive correlation in response to increased freshwater inflow and reduced salinities in the Trinity River Basin and Upper Galveston Bay. We found Blue catfish could act as a beneficial freshwater bioindicator for the bay. The abundance of Gulf menhaden collected with the bay trawl in winter across Galveston Bay was significantly positively correlated to surface water inflow (TWDB), Trinity River and San Jacinto River discharge therefore we support the use of Gulf menhaden as a beneficial indicator of freshwater inflow. The increased abundance of Pinfish in UGB was significantly correlated to a decrease surface water inflow. The results of the analysis of Pinfish to salinity and freshwater inflow did definitively support the use of this species as a high salinity or low freshwater inflow as mentioned by the TSJ-BBEST. Atlantic rangia (*Rangia cuneata*) are found in the Trinity River Basin but these were not specifically collected historically; the available data and findings must be considered with caution. Several of the species proposed in the TSJ-BBEST report were found not be useful going forward; these include wild celery (*Vallisneria americana*) and Mantis shrimp (*Squilla empusa*).

The eastern oyster (*Crassostrea virginica*) was not included by the TSJ-BBEST as it is a well-known euryhaline species. The Oyster drill (*Stramonita haemastoma floridana*), a known predator, however was recommended. It was absent in the Trinity River Bay, but present in both upper and lower Galveston Bay. There was a significant correlation between increased Oyster drill abundance and decreased San Jacinto River discharge in lower Galveston Bay. Based on these results the increased abundance of Oyster drills in Upper and Lower Galveston Bay may is strongly correlated with increased salinity and decreased freshwater inflow. Dermo is a disease in oysters caused by the parasite *Perkinsus marinus* (formerly *Dermocystidium marinum*) that can result in the mortality of eastern oysters In Galveston Bay we found the frequency of juveniles infected with Dermo was significantly correlated to increasing salinity and decreasing surface water inflow and Trinity River discharge. In Upper Galveston Bay, increasing temperature and decreasing dissolved oxygen were significantly related to the increase in the number of juvenile and commercial sized oysters infected with Dermo. While in the lower Galveston Bay, there was a significant increase in the number of commercial sized oysters infected with decreasing San Jacinto River discharge. Overall the highest number of oysters infected (both juvenile and commercial sized) were collected in lower Galveston Bay where we saw higher salinities. While the oysters themselves may not prove to be a useful bioindicator, their predators and occurrence of disease appears to be.

Phytoplankton pigments as a proxy for taxonomic groups have been used as indicators of physical, chemical and biotic disturbances in various estuaries. Seasonal patterns (2008-2013) were observed with diatoms and dinoflagellates dominating in the cooler months and cyanobacteria being more prevalent during the warmer months. Further complicating our analysis was a significant period of drought (October 2010 through December 2011) in the middle of the time series. More data and analyses would be required before dismissing the potential of this approach.

In addition to evaluating the species listed in the TSJ-BBEST report and phytoplankton pigments, we analyzed additional fish and invertebrate species as potential bioindicators. We are able to show that Atlantic croaker (*Micropogonias undulatus*), Southern flounder (*Paralichthys lethostigma*) and Blue crabs (*Callinectes sapidus*) were correlated with lower salinity waters and increased freshwater inflow in Trinity Bay and hence could be useful. Further evaluation of these bioindicators will be required going forward.

INTRODUCTION

Freshwater inflows are necessary for the maintenance of ecosystem health in coastal bays and estuaries. These inflows contribute to the water (salinity, nutrients, and chlorophyll) and sediment quality in turn affecting the health of biological systems. Texas bays are under increased stress from development, greater demands on their fisheries resources and human activities which may lead to water quality degradation (e.g. returned flows, water use upstream for agriculture, pollutants moving downstream) (Lester and Gonzalez, 2011). To accommodate for the increasing human coastal populations and their activities, there is a need to balance demands on coastal resources against demands for ecosystem services to develop strategies for resilient communities and economies. Estuarine water quality and ecosystem health are fundamentally dependent on freshwater inflows, and with them, appropriate nutrient and sediment loads (Boesch et al. 1984; Longley, 1994; Nixon 1995; Quigg et al. 2007).

Indicators of ecological health, herein indicators of freshwater inflow, have physiological requirements to inhabit acceptable ranges of environmental water quality parameters. Salinity in the coastal environments is primarily influenced by river inflow and land runoff and is inversely related to freshwater inflows. As freshwater inflows are altered, the estuarine environment faces ecological consequences, some of which include changes in the abundance and distribution of species requiring varying salinity regimes. Decreasing the freshwater pulses to an estuary may result in a concurrent decrease in food and habitat for the resident biota. As freshwater decreases and salinities increase, species with a higher salt tolerance have the opportunity to encroach on the native habitat compromising function, integrity and sustainability of the natural habitat (Montagna et al., 2013; Flemer and Champ, 2006). Sustainability, a proxy of ecological health, is the capacity of a biological system to maintain diversity and productivity. In this study we are reporting the results a small subset of the biological community within Galveston Bay, which will offer a glimpse into the biotic diversity and response to freshwater inflows.

When greater volumes of freshwater are required for human needs, the impacts on downstream ecosystems translates to changes in spatio-temporal patterns of salinity and water quality parameters that can negatively affect productivity and species diversity within the emergent plant, planktonic, and benthic algal communities. These changes can lead to a decline in overall ecosystem health and stability and may have deleterious bottom-up effects on higher trophic levels. Identifying correlations between phytoplankton and freshwater inflows is important for predicting ecological impacts resulting from urbanization and industrialization upstream as well as climate change and sea level rise associated with coastal processes downstream. Phytoplankton populations are especially sensitive to changes in water chemistry and nutrient regimes. Nutrient (C, N, P, Si) loading driven by inflow events temper primary production and alter phytoplankton community composition. The nutrient input (primarily nitrogen) to a coastal system is directly proportional to the increasing human population within a watershed (Rabalais and Turner, 2001; Paerl et al., 2007). When supplied in the appropriate concentrations and ratios, nutrients contribute positively to estuarine water quality and resident primary producers. Variable phytoplankton responses (biomass, community composition, turnover rates, timing and magnitude of blooms) in turn influences higher trophic levels that depend on them for the assimilation of organic matter (Roelke et al. 2013; Dorado et al. 2015).

Defining "beneficial" flows for Galveston Bay in terms of nutrient loads from freshwater inflows is a critical step to understanding healthy ecosystems. Freshwater inflows are associated with various parameters including but not limited to salinity, turbidity and dissolved nutrients (Palmer and Montagna, 2013). Water resource managers must be able to meet current and future societal demands of freshwater while still meeting inflow criteria necessary to maintain beneficial inflows. The development of the Espey et al., (2009) report by the TSJ-BBEST (hereafter referred to as the TSJ-BBEST report) was part of the Senate Bill 3 process for establishing and facilitating the adaptive management of the environmental flow standards for Texas. The present study was designed to statistically analyze the efficacy of the freshwater bioindicator species (FWBI) identified in the TSJ-BBEST report. In addition, we have evaluated a suite of fish, invertebrates and phytoplankton taxonomic groups in relation to measured environmental parameters associated with freshwater inflows to determine if they may be appropriate bioindicators of freshwater inflow in Galveston Bay.

PROJECT GOALS AND OBJECTIVES

The goals of this project were identified on the "List of Priority Work Plan Elements for the Trinity-San Jacinto River Basins and Galveston Bay" presented by John R. Bartos (Chair) of the Trinity and San Jacinto and Galveston Bay Basin and Bay Area Stakeholder Committee to the SAC Chairman, Robert J. Huston, on August 20, 2013.

The study focused on two of the three activities identified for Trinity-San Jacinto River Basin and Galveston Bay (hereafter referred to only as Galveston Bay):

(i) Test the conclusion that the bioindicators (either the three immobile species or an expanded list) reported in TSJ-BBEST report (Table 1) are appropriate for representing the **health of Galveston Bay**, and

(ii) Consider the addition of new species which were previously not recognized during the TSJ-BBEST process.

In addition, we conducted surveys of water quality in Galveston Bay during 2014 (Jul, Aug, Sept) and 2015 (Jan, Feb, May). This data has contributed to the continued evaluation of the magnitude and mode (e.g., continuous vs. pulsed flows, and frequency of pulsed flows) and type (quantity, quality, ratios) of inflows into Galveston Bay on downstream ecological effects. We have assessed patterns in phytoplankton biomass and community composition over an annual cycle. The monthly surveys included data collection to create high spatial (> 2000 points) and temporal (monthly) resolution maps of water quality (temperature, pH, salinity, water clarity, chlorophyll *a*, dissolved organic matter, phycocyanin and phycoerythrin) data. Lower resolution (6 stations; monthly) measurements of dissolved (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-} and SiO_3) and total (nitrogen, phosphorus) nutrients and phytoplankton community composition were also collected. These findings will be made publically available (by request), and the data will be shared with those interested. Detailed protocols can be found in publications (e.g., Roelke et al. 2013; Dorado et al. 2015) and reports (e.g., Quigg et al. 2013; Quigg 2011; Quigg 2010a,b).

Table 1 Current bioindicator species proposed for Galveston Bay, Texas (Table 33 from the TSJ-BBEST report).

	Common Name	Scientific Name	Criterion	Period of Concern
Habitat Indicator	Wild Celery	*Vallisneria americana*	<5 psu for germination and establishment	Spring
	"	"	<10 psu for survival	Summer and Fall
Low Salinity Indicators	Atlantic *Rangia*	*Rangia cuneata*	2 – 10 psu for spawning and larval survival	Spring and Fall
	Gulf menhaden	*Brevoortia patronus*	5 – 15 psu for occurrence as forage fish	Winter and Spring
	Blue catfish	*Ictalurus furcatus*	<10 psu for occurrence as predator	Single pulse in winter or spring
High Salinity Indicators	Mantis shrimp	*Squilla empusa*	>25 psu for abundance	Summer - Fall
	Pinfish	*Lagodon rhomboides*	>25 psu for abundance	Summer - Fall
Oyster Health Indicators	Dermo and oyster drill impacts on oyster	Dermo= *Perkinsus marinus* Oyster drill= *Stramonita haemastoma* Oyster= *Crassostrea virginica*	10 – 20 psu to prevent excessive parasitism and predation	July - September
	"	"	<5 psu to remove parasite load from central reefs	2 weeks at 10 year intervals

METHODS

Re-evaluating current FWBI

We have re-evaluated the bioindicators established during the state-wide SB3 process summarized in Table 1 in light of new information collected by the PI and others. We applied a variety of approaches to disentangle the effect of inflows over other factors in impacting potential bioindicators. To do so, we employed multi-variate multi-dimensional statistical approaches as well as GIS and more traditional approaches. The FWBI *Vallisneria* sp. was included in the TSJ-BBEST report but was not included in this analysis. It's potential as a bioindicator requires further investigation as it was not found in the bay from 2011-2014 (Parnell et al. 2011; Quigg et al. 2013) but has mostly recently been documented in the Trinity River Delta in August 2015 (personal communication with Scott Alford (USDA – Natural Resources Conservation Service). The Mantis shrimp (*Squilla empusa*) was not collected by the Texas Parks and Wildlife Department (TPWD) during the study period and therefore will not be included in this analysis.

Study site

Galveston Bay was subdivided into three bay segments using divisions similar to the segments designated by the Texas Commission of Environmental Quality (TCEQ) https://gisweb.tceq.texas.gov/segments/default.htm (Fig. 1). Galveston Bay species and abundance data that was collected by TPWD –Coastal fisheries division (Rockport, Texas) and then QA/QC'ed at Houston Advanced Research Center (HARC) was also divided into 3 segment sections: Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) as shown in Fig. 1. The dividing line between UGB and LGB is 29.49°N latitude eastward to 94.79°W longitude up to Smith Point (29.55°N; 94.79°W) (see dashed line on Fig. 1). TB, UGB and LGB were analyzed independently for the statistical analyses.

East Bay and West Bay were not included in this analysis as the water quality parameters were significantly different (higher salinities and lower nutrients) than those observed in TB, UGB and LGB during similar time frames in the study period. Further, these lower bays had less data (number of collections, locations, and timing) than that available for the three bay segments examined. The final three bay segment division chosen as shown in Fig. 1 allowed for spatial and temporal resolution which we could clearly use to provide evidence to support or refute the use of current FWBI species.

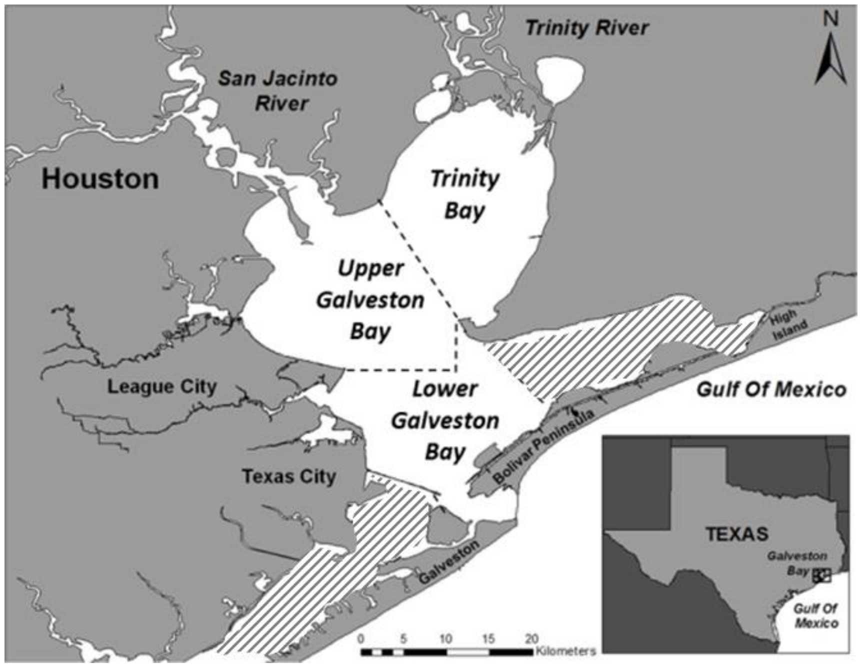

Figure 1 Map of Galveston Bay divided into segments including Trinity Bay, Upper Galveston Bay and Lower Galveston Bay. East Bay and West Bay are shown with hash marks as they were not included in the analysis. East and West Bays will not be included in any of the analyses presented herein.

Water quality and species abundance data 1980-2010

Species abundance and water quality data were gathered from multiple sources to ensure high spatial and temporal resolution (Table 2 and 3). There was an average of 125 sample sites where species abundance and water quality data were concurrently collected in each bay segment (Table 2). Each of the stations was sampled approximately 4-5 (±3-5) times over the sample period 1980-2010 (Table 2).

TPWD has a random sampling method where the bay is divided into sample grids (one minute latitude by one minute longitude in size) (TPWD, 2012). Each sample grid is further subdivided into sample gridlets (five seconds latitude by five seconds longitude). The number of samples collected across Galveston Bay annually for each of the gear types presented in this study include: Bag seine (240), Bay trawl (240) and Oyster dredge (360) (TPWD, 2012). For a complete description of gear types and sampling methods please refer to the TPWD Resource Monitoring Operations Manual (2012).

The surface area of TB and UGB is ~300 km^2 each and LGB encompasses a smaller surface area at ~250km^2. The total surface area of LGB is ~80% that of each of TB and UGB. The number of total stations sampled over the course of the study in TB and UGB were 137 and 134 respectively and in LGB 104 stations were sampled (Table 2). The number of stations sampled in LGB was ~76% of the number of stations sampled in TB or UGB. We plotted the locations of these stations across each of the bay segments to ensure even sampling coverage for each of the bay segments (data not shown).

Preliminary CPUE data showed similar trends when compared to the abundance data across each of the bay segments. This data is not presented herein will be available upon request when completed.

Table 2 Number of sampling locations in each bay segment during each season where indicator species included in this study were collected. The number of sampling events represents the total number of sampling events for each segment across the total number of sites for the respective season.

	Total #	No. sampling events				Average Station Sample Frequency			
Subbay	stations	W	SP	SU	F	W	SP	SU	F
TB	137	588	783	757	820	4(±3)	5(±4)	5(±3)	5(±4)
UGB	134	592	733	705	829	4(±3)	5(±3)	5(±3)	6(±4)
LGB	104	406	566	495	529	4(±3)	5(±4)	4(±3)	5(±3)

Table 3 Number of samples collected by each TPWD gear type by season over the sampling period 1980-2010 when indicator species inlcuded in this study were collected. Gear types include: GN: Gill net; BT: Bay trawl; BS: Bag seine; Oyster dredge: DG.

	Winter				**Spring**				**Summer**				**Fall**			
	GN	BT	BS	DG	GN	BT	BS	DG	GN	BT	BS	DG	GN	BT	BS	DG
TB	2	408	137	42	125	440	149	70	49	465	175	69	174	421	166	61
UGB	5	434	75	79	98	459	101	80	52	445	104	101	154	479	119	81
LGB	1	287	75	47	47	356	114	60	12	341	124	40	79	311	105	48

FWBI species in GB

Data presented in this study can be separated into three main categories. Note that the time frame for each varies (Tables 4 and 5) depending upon the data available.

1) **TPWD species abundance (for current TSJ-BBEST and proposed FWBI species) and environmental parameters (TPWD, TCEQ) and corresponding freshwater inflows (TWDB, USGS) for the time frame of 1980-2010:** The quality assurance and quality controlled TPWD species abundance data collected by the Coastal Fisheries Division out of Rockport, Texas was requested from HARC. The species from the TSJ-BBEST report include: Gulf menhaden (*Brevoortia patronus*), Blue catfish (*Ictalurus furcatus*), Pinfish (*Lagodon rhomboides*), Atlantic rangia (*Rangia cuneata*) and Oyster drill (*Stramonita haemastoma floridana*) (Table 4). The mantis shrimp (*Squilla empusa*) was not present during the study period (data not shown) and wild celery (*Vallisneria americana*) data were not available; therefore neither of these species will be presented in this report. The additional species which we will consider as FWBI species in Galveston Bay include: blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), spotted seatrout (*Cynoscion nebulosus*), Atlantic croaker (*Micropogonias undulates*) and southern flounder (*Paralichthys lethostigma*). All species will be referred to by their common names from this point forward. The species abundance data utilized for this study does not take into account time points where species were not present. Zeros in species abundance were not included in the TSJ-BBEST analysis and therefore will not be addressed in this report.

   This species abundance data was analyzed against water quality parameters that correspond the TPWD catch data including (temperature (°C), salinity (psu), dissolved oxygen (mg L^{-1}), and turbidity (NTU). Nutrient data (NO_3^- + NO_2^-, µM, NH_3 µM, PO_4^{3-} µM) was obtained from the TCEQ Surface Water Quality Monitoring program (SWQM) from 1980-2010 (Table 4). Total surface inflow volumes were collected from the TWDB website for this the study period (Jan. 1980 – Dec. 2010). Discharge rates were collected for the Trinity River at Romayor (USGS 08066500) and San Jacinto River at the East Fork

(USGS 08070000) and West Fork (USGS 08067650) using United States Geological Survey (USGS) gages at these stations.

2) **Oyster Sentinel (http://www.oystersentinel.org/) data for the time frame of 1998-2010 of the infection rate of Dermo (*Perkinsus marinus, formerly Dermocystidium marinum*)*:*** Data for the occurrence of the oyster *(Crassostrea virginica*) infected with the Dermo disease was retrieved from the Oyster Sentinel website from 1998-2010 (Tables 4 and 5). The data is presented in this report is provided as the percentage of oysters infected with Dermo out of the total number of oysters tested during each sampling event (Table 15). At each of the reef sites a total of 5-30 oysters from each size group (juvenile/commercial) were collected per sampling event (Fig. 32; Table 15). The same water quality data (1998-2010) used for the FWBI analysis was also used in the statistical analysis with the Dermo data. TWDB total surface inflow volumes and USGS river inflow rates for the Trinity and San Jacinto Rivers were also included in the statistical analysis (see above).

3) **Phytoplankton pigments and environmental variables collected by the Phytoplankton Dynamics Laboratory (TAMUG) *for the time frame of 2008-2013*:** The phytoplankton pigment concentration data from 2008-2013 were collected by the PI on this project. Pigment groups included: Chlorophytes (chlorophyll b), cryptophytes (alloxanthin), cyanobacteria (zeaxanthin) diatoms (fucoxanthin) and dinoflagellates (peridinin) (Tables 4 and 5) (Paerl et al., 2003; Quigg et al., 2010b, 2013). Corresponding water quality parameters were collected at the time of phytoplankton pigment sampling including temperature (°C), salinity (psu), dissolved oxygen (% and mg L^{-1}), transmittance (rfu), pH, nutrients (NO_3^- + NO_2^-; µM, NH_4 ; µM, PO_4^{3-}; µM), chromophoric dissolved organic matter (CDOM; µg L^{-1}).

For the phytoplankton pigment analysis we did not statistically analyze against the TCEQ water quality data as this data was not collected at the same time or locations as the sampling by the PI. TWDB total surface inflow volumes and USGS river inflow rates for the Trinity and San Jacinto Rivers were also included in the statistical analysis.

Table 4 Data sources for biotic (common names) and abiotic parameters used in this report.

Agency	Data provided by (if not collecting agency):	Time frame:	Type of data:	Comments:
TCEQ[1]	GBEP[2]	1980-2010	Nutrients (NO_3^- + NO_2^-, NH_4, PO_4-)	GBEP Status and Trends
TPWD	HARC	1980-2010	Temperature, salinity, dissolved oxygen, turbidity	
TPWD	HARC	1980-2010	Atlantic croaker, Atlantic rangia, Blue catfish, Blue crab, Brown shrimp, Oyster drill, Gulf menhaden, Pinfish, Southern flounder, Spotted seatrout	
Oyster Sentinel[3]		1998-2010	Dermo (*Perkinsus marinus*)	
TAMUG	Quigg lab	2008-2013	Phytoplankton pigments (chlorophytes, cryptophytes, alloxanthin, cyanobacteria, diatoms, dinoflagellates	
TAMUG	Quigg lab	2008-2013	Water quality corresponding to pigment data (temperature (°C), salinity (psu), dissolved oxygen (% and mg L-1), transmittance (rfu), pH, nutrients (NO_3^- + NO_2^-, NH4, PO_4-), chromophoric dissolved organic matter (CDOM; µg L-1)	
TWDB		1980-2010	Total Surface Inflow (ac-ft mon^{-1})	
USGS		1980-2010	Trinity River and San Jacinto River discharge rates (cfs)	USGS Gages: Romayor (08066500), East Fork SJR (08070000), West Fork SJR (08067650)

[1]TCEQ Surface water quality monitoring data: http://www.tceq.texas.gov/waterquality/monitoring/index.html
[2]GBEP Galveston Bay Status and Trends: http://www.galvbaydata.org/WaterSediment/WaterandSedimentQuality/DataPortal/tabid/214/Default.aspx)
[3]Oyster Sentinel: http://www.oystersentinel.org/

Table 5 List of all species (common names, scientific names and TPWD species codes) included in this study. Bold font identifies freshwater indicator species that were presented in the TSJ-BBEST report.

	Common Name	Scientific Name
Crustaceans	Blue crab	*Callinectes sapidus*
	Brown shrimp	*Farfantepenaeus aztecus*
Finfish	Atlantic croaker	*Micropogonias undulatus*
	Blue catfish	***Ictalurus furcatus***
	Gulf menhaden	***Brevoortia patronus***
	Pinfish	***Lagodon rhomboides***
	Spotted seatrout	*Cynoscion nebulosus*
	Southern flounder	*Paralichthys lethostigma*
Molluscs	**Atlantic rangia**	***Rangia cuneata***
	Oyster drill	***Stramonita haemastoma floridana***
Parasite	**Dermo**	***Perkinsus marinus***
Phytoplankton Pigments	Chlorophytes	Chlorophyll *b*
	Cryptophytes	Alloxanthin
	Cyanobacteria	Zeaxanthin
	Diatoms	Fucoxanthin
	Dinoflagellates	Peridinin
Plant	**Wild Celery**	***Vallisneria americana***

Data consolidation

For all water quality parameters the individual observations were averaged into the four seasons according to the TSJ-BBEST report. These were defined as winter (Dec (of previous year), Jan, Feb), spring (March, April, May), summer (June, July, August) and fall (September, October, November).

The abundance data was reported from TPWD as the number of individuals of each species that were collected per sampling event by gear type (Tables 2 and 3). These totals per sampling event were summed over each of the bay segments for each of the seasons for each gear type (Tables 2 and 3). The species abundance was calculated for each of the seasons in each of the respective bay segments.

Abundance data is presented separately for each of the TPWD gear types. For this study we are presenting abundance data from the bay trawl, bag seine and oyster dredge. The bay trawl targets open water and catch juvenile and subadult fish and invertebrates (TPWD, 2012). Gill net gear type was not included as this is a method to collect adult and subadult life stage individuals near the coastal region (TPWD, 2012). The nearshore region bag seine collection was included to target the subadult and juvenile life history stages (TPWD, 2012). Figures and data presented will indicate the specific gear type.

The abundance data we are utilizing were collected with a bay trawl and bag seine (TPWD gear types 5 and 7 respectively) for Blue catfish, Gulf menhaden, Atlantic rangia and Pinfish. The abundance for the Oyster drill was determined with samples taken from an oyster dredge (TPWD gear type 16).

Galveston Bay Freshwater Inflow

Surface water inflow data was acquired from the Texas Water Development Board (TWDB; http://midgewater.twdb.texas.gov/bays_estuaries/hydrology/summary/galvestonsum.txt). Total flow from drainage basin runoff was calculated by summing flows originating in from both gaged and ungaged watersheds. Gaged flows were obtained from USGS stream flow records. Ungaged runoff is the sum of i) computed runoff, using a rainfall-runoff simulation model, based on precipitation over the watershed, ii) flow diverted from streams by municipal, industrial, agricultural, and other users, and iii) unconsumed flow returned to streams (http://www.twdb.texas.gov/surfacewater/bays/coastal_hydrology/index. asp).

The total surface inflow reaching the estuary included the sum over all gaged watersheds (USGS Gaged Flow) added to the sum of both the modeled and returned flows (ungaged watersheds) less the diverted flow (ungaged watersheds) (Fig. 2). The data from TWDB is a summed monthly value. The TWDB monthly total surface inflow (ac ft s^{-1}) volumes were converted to ac ft mon^{-1} and then averaged for each season (winter: Dec (previous year), Jan, Feb; spring: Mar-May; summer: Jun-Aug; fall: Sep-Nov) for each year. The gaged USGS data is an average rate of discharge (ft^3 s^{-1}). These monthly discharge rates were averaged over seasons for each year.

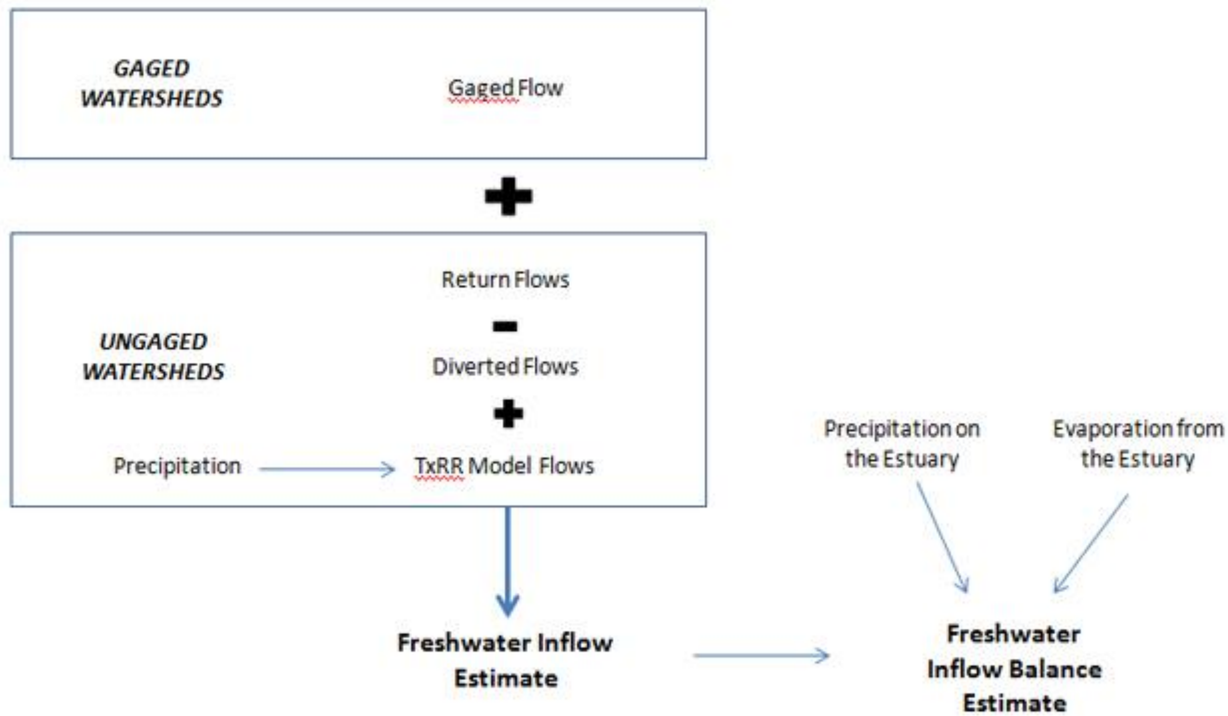

Figure 2 Conceptual model displaying the TWDB parameters used to calculate surface inflow volumes (i.e. Freshwater inflow estimate (from TWDB website: http://www.twdb.texas.gov/surfacewater/bays/coastal_hydrology/index.asp)

Statistical analyses

Statistical analyses were performed using the PRIMER-E v6.1.15 with the PERMANOVA V1.0.5 add-on package (Plymouth Routines in Multivariate Ecological Research; Clarke and Warwick 2001; Anderson et al. 2008). PRIMER is a statistical software tool which can be used to analyze biotic assemblages along with many other ecological factors in both terrestrial and aquatic ecosystems. This statistical tool is widely used in environmental impact assessments and community ecology and biomarker studies. More information on the procedures and statistical details of PERMANOVA+ routines can be found in McArdle and Anderson (2001) and Anderson et al. (2008).

Pre-treatment of data for statistical analysis

Transformation and normalization of environmental data

Prior to the all statistical analyses the environmental data were evaluated by draftsman plots to determine collinearity. All mutual correlations were below 0.95 which is the upper threshold for collinearity according to Clarke and Ainsworth (1993). No collinearity was observed among the environmental parameters and therefore all were included in the statistical analysis. All environmental water quality data (TPWD, TCEQ, USGS, TWDB, TAMUG-PDL, Oyster Sentinel) were log [x+1] transformed in order to decrease skewness and increase linearity (Clarke and Warwick, 2001). Transformed environmental data were then normalized to account for differences in units of measurement and a Euclidean distance resemblance matrix computed.

Transformation of abundance data

The species abundance data (fish and invertebrates) and Dermo data (Oyster Sentinel) were subjected to a square root transformation to down-weigh the effects of a single group on the ordination and increase the contribution of rare groups (Clarke and Warwick, 2001). The square root transformed abundance data was used to compute a Bray-Curtis dissimilarities resemblance matrix.

Standardization of Phytoplankton Pigment Concentrations

To calculate the relative pigment abundance, a community data matrix was developed using Equations 1 and 2 in which each accessory pigment concentration was divided by the respective chlorophyll *a* (Chl *a*) concentration (standardization to maximum) for that station:

$$xAP_{1,2,\ldots n}/xChl_{1,2,\ldots n} = x'_{1,2,\ldots n} \qquad \text{(Eqn. 1)}$$

and then divided by the sum of all the accessory pigments (standardize to total):

$$x'_{1,2,\ldots n}/\Sigma x'_{1,2,\ldots n} \qquad \text{(Eqn. 2)}$$

where xAP is the concentration of an accessory pigment (µg/L) and xChl is the concentration of Chl *a* (µg/L) in Equations 1 and 2 respectively. The result is equivalent to a Wisconsin double standardization commonly used in ecological phytoplankton community analysis methods (see

Dorado et al. 2012, 2015). This pigment matrix was used to determine the relative importance of algal groups using environmental vector fitting. After the pigment concentrations were standardized to the chlorophyll *a* concentrations they were subjected to a square root transformation. The square root transformed data was used to compute a Bray-Curtis dissimilarity resemblance matrix.

Permutational Multivariate Analysis of Variance (PERMANOVA)

The significance of differences in water quality parameters between bay segments within Galveston Bay was investigated using PERMANOVA (Anderson, 2001). The statistical design was analogous to one-way multivariate analysis of variance (MANOVA) but PERMANOVA is permutation based. We applied unrestricted permutation of raw data and Type III sums of squares (Anderson et al. 2008). PERMANOVA was also run to test for significant seasonal variability within each bay segment based on all environmental parameters as well as salinity independently (Table 6). Permutations were set to 9999 (in all analyses) to determine significance to level of up to p <0.001.

Distance-Based General Linear Model (DISTLM)

DISTLM is a routine that can be used to analyze the correlation between a multivariate data set (i.e. resemblance matrix of species abundance data) and one or more predictor variables (i.e. water quality parameters). For this analysis, the resemblance matrix (Bray-Curtis dissimilarity matrix) of each species, disease and phytoplankton pigment group, describes the dissimilarities among the set of samples on the basis of the multivariate species abundance and concentration data (respectively). We were interested in determining the correlation between each of the species/phytoplankton groups with each of the environmental parameters included in the study. The DISTLM (Anderson et al., 2008) routine was utilized to perform a permutational test of the null hypothesis that there is no correlation that exists between each of the environmental factors and each of the indicator species (fish, invertebrates, phytoplankton pigments) (Anderson et al., 2008). *P*-values for testing the null hypothesis of no correlation are formulated using permutation methods. We used the Akaike information criterion (AIC) as a measure of the relative goodness of fit of a statistical model. The alpha significance for PERMANOVA designs and for DISTLM marginal tests was set to $p < 0.05$.

In the results tables for the DISTLM results $SS_{(trace)}$ is the portion of the sum of squares that is related to the analyzed predictor variable. The pseudo-*F* statistic (PF) is a direct multivariate analogue of the Fisher's *F* ratio utilized in traditional regression (Anderson et al., 2008). As the pseudo-F values depart further from zero the likelihood of the null hypothesis being true decreases. *P*-values presented were calculated after 9999 permutations for all analyses. P-values lower than 0.05 indicates that the abundance of the species and respective environmental parameter are significantly correlated.

The proportion of variance explained has an inverse correlation to the *p*-value If the number calculated for the proportion of variance explained is multiplied by 100 this represents the percentage of variance by the respective environmental parameter. Proportion of variance explained is also included in the results table for each DISTLM. This proportion corresponds to the portion of variability of species abundance that is explained by each respective environmental parameter. If the species abundance displays a strong correlation with an environmental parameter there is also an increase in the amount of variance explained (i.e. proportion of variance explained) by that respective environmental parameter.

Species that were recommended as sufficient indicators of FWI were deemed so based on the significant correlation and amount of species abundance variation with respect to the parameters associated with freshwater inflows such as salinity, nutrient concentrations, and turbidity.

Principal Coordinates Ordination (PCO)

Correlations between environmental predictor variables and each of the species were visualized using principal coordinates analysis and Spearman derived correlated vectors. PCO provides a direct projection of the points in space by the actual dissimilarities themselves rather than displaying the variation in the ranks. PCO was utilized to visualize similarities and dissimilarities in environmental conditions among stations (Anderson et al. 2008). Vector length indicates the strength and the direction indicates the sign of the correlation between that particular environmental parameter and the corresponding species abundance or phytoplankton pigment concentration indicated (Anderson et al., 2008). For each PCO shown in this report, the vectors correspond to the environmental factors that have a significant correlation ($p < 0.05$; based on the DISTLM results) with the abundance of the species or concentration of phytoplankton pigment indicated in the figure.

ArcGIS Mapping

ArcGIS (ESRI, 2011) was used to map the distribution of abundance data across Galveston Bay for each of the indicator species included in the TSJ-BBEST report shown in Table 1. Abundance data for each sampling event from 1980-2010 is shown for each respective species across Galveston Bay. These maps were produced to provide a visual representation of the distribution of each of these indicator species across the Bay. The legend shows the corresponding abundance for each sample event at the respective sample site (Figs. 14-15, 18, 20-21, 24-25, 28-29). The Dermo data is shown as percent of individuals infected with Dermo by size class including juveniles (<3” in length) and commercial size (>3” in length) (Fig. 34 and 36). The phytoplankton pigments are represented as a relative abundance shown in a pie symbol at each of the 6 sample sites (Fig. 38).

Monthly water quality mapping

To facilitate the continued evaluation of the magnitude and mode (e.g., continuous vs. pulsed flows, and frequency of pulsed flows) and type (quantity, quality, ratios) of inflows into Galveston Bay on downstream ecological effects, we performed a high spatial and temporal resolution mapping of water quality in Galveston Bay. We will assess patterns in phytoplankton biomass and community composition from January 2014 – July 2015.

This data collection was performed monthly (weather permitting) with a Dataflow, a high-speed, flow-through measurement apparatus developed for mapping physico-chemical parameters in shallow aquatic systems (Madden and Day 1992; Davis et al. 2007) from a boat, running tight transects across the estuary (see black lines in Fig. 3). Water quality measurements were taken at 4-sec intervals (every 2–8 m depending on boat speed) from about 10 cm below the surface. An integrated GPS was used to simultaneously collect sample positions, allowing geo-referencing of all measurements for each variable. This integrated instrument system (Fig. 4) was used to concurrently measure water temperature, salinity, water clarity (beam transmittance), chl a (in situ fluorescence), and chromophoric dissolved organic matter (CDOM; in situ fluorescence), phycocyanin and phycoerythrin (in situ fluorescence). On average, it took two 8 hour days to physically map Galveston Bay. After each field trip, the data was checked and then used to generate high resolution maps using the software Surfer v. 8 (Golden software). Data from the continuous sampling Dataflow system was also cross checked with water samples taken from fixed stations throughout the bay.

At 6 stations, monthly measurements of dissolved (NO_3^- + NO_2^-, NH_4^+, PO_4^{3-} and SiO_3) nutrients and phytoplankton community composition (Fig. 3 and 4). Detailed protocols can be found in publications (e.g., Roelke et al. 2013; Dorado et al. 2012, 2015) and reports (e.g., Quigg et al. 2013; Quigg 2011; Quigg 2010a,b).

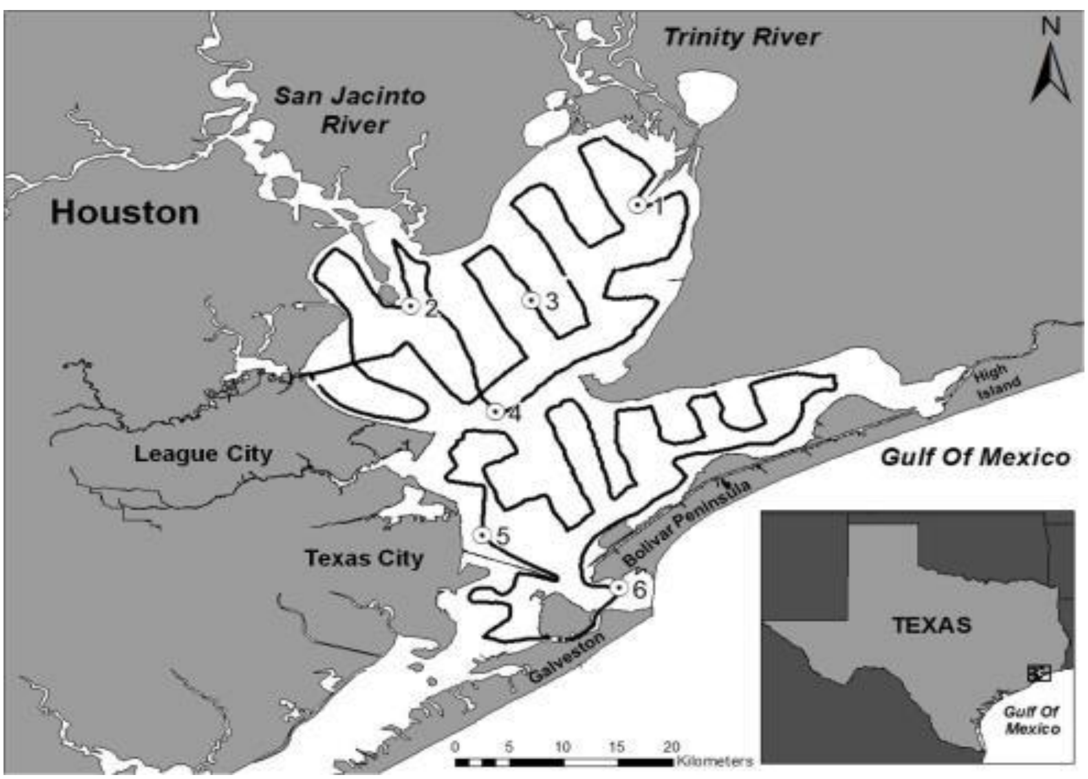

Figure 3 Map of Galveston Bay showing transect paths of data collection. Numbers 1-6 denote the location of fixed stations across the bay where discrete samples were collected to ground truth the continuous data collected with the dataflow.

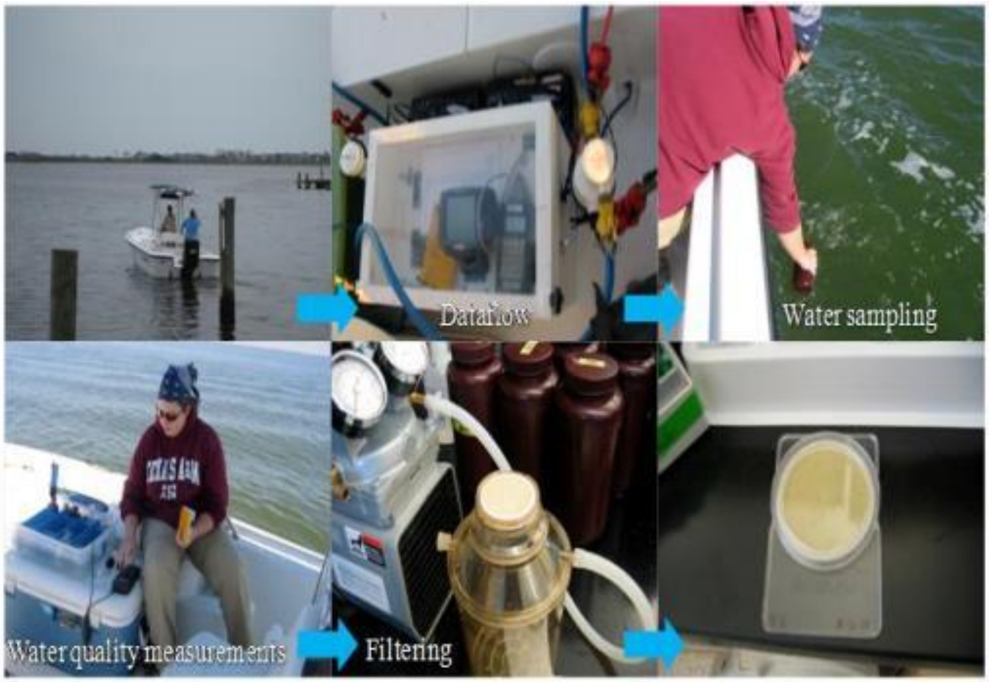

Figure 4 R/V Phyto I used for sampling with dataflow instrumentation collecting high temporal and spatial measurements of surface water quality parameters. Surface water samples were collected then filtered and processed in the Phytoplankton Dynamics Laboratory at Texas A&M University – Galveston Campus.

Biological and Chemical Protocols

For nutrient (dissolved and total) analysis, water samples (no less than 100 ml) from each station were filtered (4.7 cm GF/F; Whatman) onto a filter under low vacuum (< 130 kPa) pressure. The filtrate was stored in an acid cleaned HDPE rectangular bottle (125 mL; Nalgene) which was triple rinsed with extra filtrate before keeping the final sample for analysis. The filtrate was frozen immediately and then analyzed for dissolved inorganic nitrogen (NO_3^- + NO_2^- and NH_4^+), and dissolved inorganic phosphorus (PO_4^{3-}). Total nutrients were measured on unfiltered samples. Samples for nutrient analysis were frozen immediately until analysis was performed using analytical auto-analyzer according to Hansen et al. (1999). The ratio of inorganic nitrogen (DIN) to phosphate (P = PO_4-P) nutrients was calculated after summing the nitrogen inputs (DIN = NO_3^-N + NO_2^-N + NH_4-N). Total nutrients were determined on unfiltered water. All nutrient analyses will be performed at the Geochemical and Environmental Research Group (GERG) at TAMU. Accepted standard procedures were utilized in the storage, calibration, and analysis of each sample.

For measurement of total suspended solids, filters were precombusted (500ºC for 5 hrs) and preweighed. After filtration of a known volume of water, filters were dried in an oven at 60 ºC for no less than 48 hrs and then reweighed (Method 2540D; APHA 1998). Water (no less than 100 ml) from each station was filtered (GF/F; Whatman) onto a filter under low vacuum (< 130 kPa) pressure for chlorophyll (chl *a*) analysis. Filters were folded and frozen at -20°C and then analyzed according to Arar and Collins (1997) using a Turner 10-AU fluorometer with some modifications described in Quigg et al. (2007, 2009). The concentration of microalgae in the water column was assessed using high performance liquid chromatography (HPLC), which provides rapid and accurate quantification of chlorophylls and carotenoids according to (Millie et al. 1993, Jeffrey et al. 1997) with modifications as described in Dorado et al. (2015).

RESULTS

Based on all water quality parameters measured (see Table 4 as well as salinity alone), there was a significant difference between all 3 bay segments across all seasons (Table 6). The most significant differences ($p < 0.01$) were between TB and LGB during the winter, spring and summer and TB and UGB in the summer (Table 6). Given these differences, the statistical analyses within each of the bay segments were conducted independently of each other.

Table 6 PERMANOVA results of a test between bay segments showing the significant differences of environmental parameters and salinity alone.

Bay Segment	All Environmental Parameters				Salinity			
	W	SP	SU	F	W	SP	SU	F
TB x UGB	**0.0045**	**0.0058**	**0.0001**	**0.1167**	**0.0050**	**0.0030**	**0.0011**	**0.0120**
TB x LGB	**0.0001**	**0.0001**	**0.0001**	**0.0254**	**0.0001**	**0.0001**	**0.0001**	**0.0002**
UGB x LGB	**0.0006**	**0.0054**	**0.0018**	**0.1511**	**0.0158**	**0.0002**	**0.0007**	**0.0221**

There was increased variability between each of the bay segments across seasons compared to seasonal variability within each of the bay segments (Table 6 and 7). There were more seasonal differences observed within TB and UGB, which were both more influenced by river inflow compared to decreased seasonal differences in LGB (Table 7).

Table 7 Results of the PERMANOVA conducted to determine significant differences within the environmental parameters between seasons (Winter (W), Spring (SP), Summer (SU), Fall (F)), segments and seasons within bay segments. Bold indicates significant difference.

	TB			**UGB**			**LGB**		
Seasons	**t**	***p* (perm)**	**U. Perms**	**t**	***p* (perm)**	**U. Perms**	**t**	***p* (perm)**	**U. Perms**
W x SP	2.53	**0.0140**	9811	2.49	**0.0174**	9854	0.79	0.4263	9818
W x SU	1.51	0.1403	9837	0.89	0.3752	9832	1.02	0.3090	9833
W x F	1.90	0.0580	9839	1.76	0.0842	9799	1.88	0.0613	9821
SP x SU	0.82	0.4121	9822	1.56	0.1207	9830	1.85	0.0699	9844
SP x F	4.34	**0.0001**	9839	4.12	**0.0007**	9839	2.80	**0.0064**	9842
SU x F	3.18	**0.0017**	9805	2.57	**0.0138**	9827	0.80	0.4240	9837

Temperature was similar across Galveston Bay and there was little to no variation among the bay segments (Table 8). Dissolved oxygen was slightly higher (but not significantly) in TB compared to UGB and then LGB (Table 8). The dissolved nutrient concentrations (NO_3^- + NO_2^-, NH_3 and PO_4^+), nutrient ratio's (DIN:DIP) and turbidity were present in higher concentration in TB and UGB compared to LGB (Table 8). The nitrogen to phosphorus ratio is the quotient of dissolved inorganic nitrogen (NO_3^- + NO_2^-+ NH_3 mgL^{-1}) to dissolved inorganic phosphorus (PO_4^{3-} mgL^{-1}).

Table 8 Water Quality parameter ranges for Trinity Bay, Upper Galveston Bay and Lower Galveston Bay. Data Table is separated by season for each segment from 1980-2010. Trinity and San Jacinto River discharge was calculated for all of Galveston Bay and therefore is shown replicated for each segment.

Water Quality Parameter		TB				UGB				LGB			
		W	SP	SU	F	W	SP	SU	F	W	SP	SU	F
Temp (°C)	Min	9.79	19.91	28.32	10.00	10.29	18.79	24.08	16.77	10.86	20.72	24.97	19.16
	Max	17.24	25.17	31.72	26.39	18.62	25.22	32.00	26.69	17.98	29.00	31.01	33.00
	Median	13.48	22.87	29.52	23.54	13.34	22.09	29.70	22.81	13.34	22.48	29.47	23.63
DO (mg L^{-1})	Min	8.00	6.63	4.99	6.31	8.05	4.68	5.66	6.15	6.38	5.75	5.20	6.52
	Max	14.92	10.42	15.14	10.92	14.12	11.94	11.67	11.24	12.97	12.00	19.18	10.01
	Median	9.62	7.96	6.43	7.83	9.25	7.84	6.55	7.69	9.08	7.47	6.31	7.67
Salinity (PPT)	Min	2.52	0.61	0.00	1.48	5.33	3.11	3.77	4.54	7.71	7.51	6.44	8.55
	Max	21.68	20.31	17.38	22.91	25.41	22.88	21.43	24.60	30.43	27.58	26.29	28.51
	Median	8.10	4.76	6.59	11.92	11.67	9.42	11.00	15.92	17.29	15.19	18.93	19.39
Turbidity (NTU)	Min	11.17	19.74	9.96	4.59	11.79	18.04	10.59	10.16	9.13	12.71	7.00	6.75
	Max	128.00	171.12	134.00	109.99	92.62	148.25	125.36	130.46	183.33	197.23	97.49	167.52
	Median	37.14	43.85	35.88	26.92	35.92	38.98	27.90	26.04	29.94	34.20	29.00	27.42
NO_3+NO_2 (µM)	Min	1.64	2.86	0.29	0.74	1.97	1.91	0.59	1.31	1.01	1.15	0.27	0.34
	Max	5.49	5.98	5.22	8.05	3.54	4.47	2.58	4.57	3.83	11.57	1.76	3.51
	Median	1.64	2.86	0.29	0.74	1.97	1.91	0.59	1.31	1.01	1.15	0.27	0.34
NH_3 (µM)	Min	1.37	1.00	0.29	0.29	1.94	2.52	1.91	1.27	0.73	1.80	1.83	1.47
	Max	31.09	15.88	13.27	22.93	27.86	9.02	44.05	6.47	4.61	8.14	14.94	8.35
	Median	4.13	4.09	2.23	3.21	3.68	4.34	4.40	3.67	2.58	3.01	3.07	2.98
PO_4 (µM)	Min	0.39	0.78	1.06	0.72	0.71	0.80	1.43	1.39	0.41	0.63	0.66	0.83
	Max	4.07	4.25	5.66	4.71	5.20	4.44	5.37	5.23	2.21	5.90	5.16	5.37
	Median	1.43	1.94	2.04	1.84	2.51	2.45	3.33	2.36	1.21	1.22	1.56	1.60
DIN:DIP	Min	1.13	0.97	0.29	0.32	0.92	0.89	0.77	0.54	0.02	0.08	0.01	0.02
	Max	28.01	14.03	5.39	12.92	11.54	7.82	12.88	3.34	4.40	13.74	1.18	3.42
	Median	3.62	3.39	2.67	3.10	3.21	3.13	2.73	2.69	2.15	2.25	2.25	2.26

Over the 30 year study period there was a slight increase in salinity within all 3 bay segments. Higher salinities were observed in LGB (6.44 – 30.43 psu), with lower values in UGB (3.77-25.41 psu) and the lowest salinities in TB (0-22.91 psu) (Fig. 5; Table 8).

Turbidity was lowest within LGB which is furthest from the source of freshwater inflow (i.e. sediment input) into Galveston Bay (Fig. 6). The spike observed within all 3 bay segments in 1983 corresponds to Hurricane Alicia which made landfall (as a category 3 hurricane) in Galveston, Texas in August of 1983 (Fig. 6).

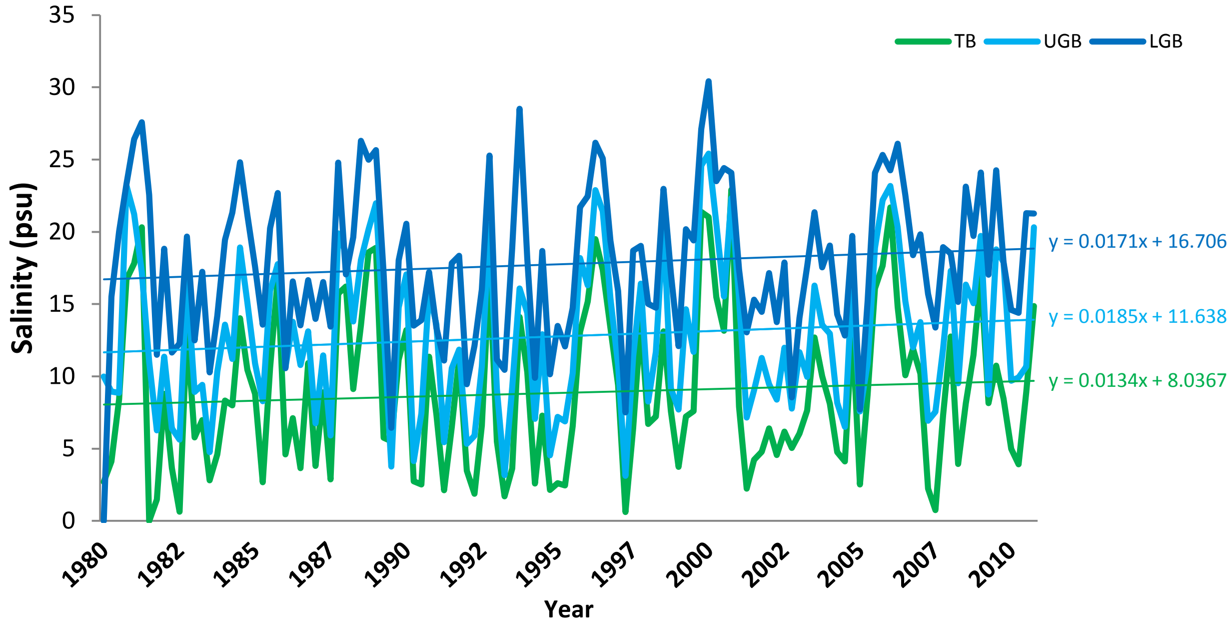

Figure 5 Line graph showing the salinity (psu) measurements from 1980 – 2010 (TPWD). Lines correspond to salinity (psu) for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

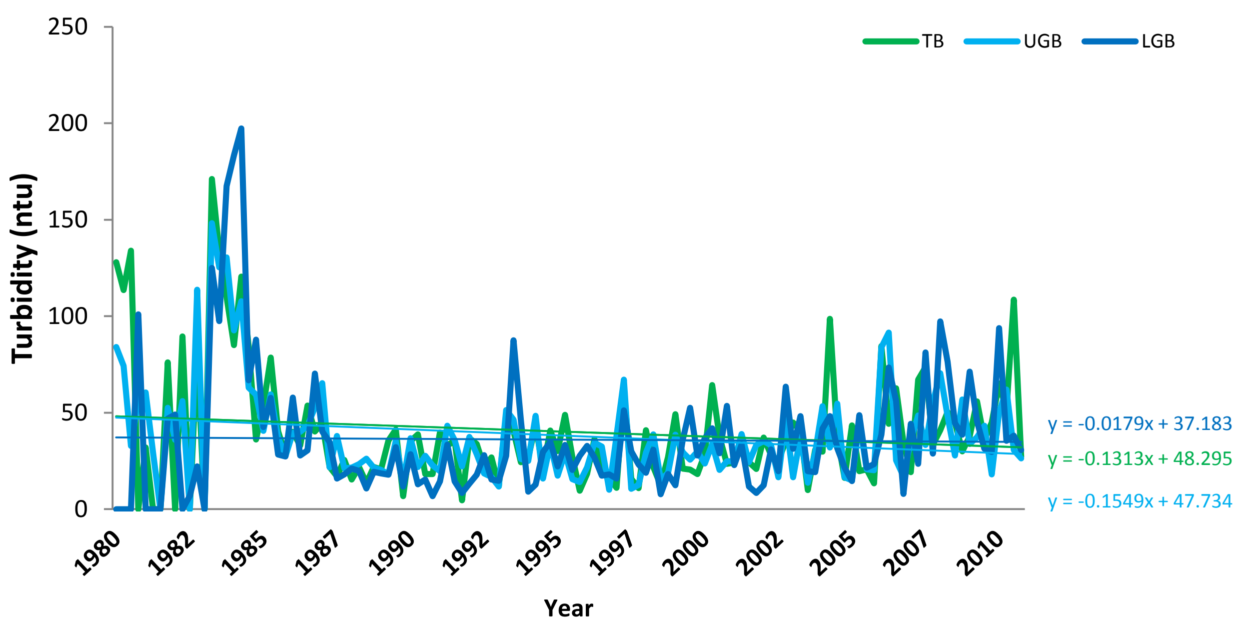

Figure 6 Line graph showing the turbidity (NTU) measurements from 1980 – 2010 (TPWD). Lines correspond to turbidity (NTU) for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

Phosphates display a decreasing trend over the study period (Fig. 7). TCEQ initiated corrective measures to improve the water quality of Galveston Bay before the passage of the Clean Water Act in 1972 (Lester and Gonzalez, 2011). This increasing improvement of water quality (i.e. decrease in nitrogen and phosphorus) can be attributed to the implementation of point source water quality permitting regulations while difficulty remains in controlling nonpoint sources of nutrients (Lester and Gonzalez, 2011). In the early 1990's Proctor and Gamble voluntarily removed phosphates from there detergents. With Proctor and Gamble leading the market at 25% of the global sales, this decrease in phosphates may also contribute to the decline of phosphorus observed over time (Fig. 7).

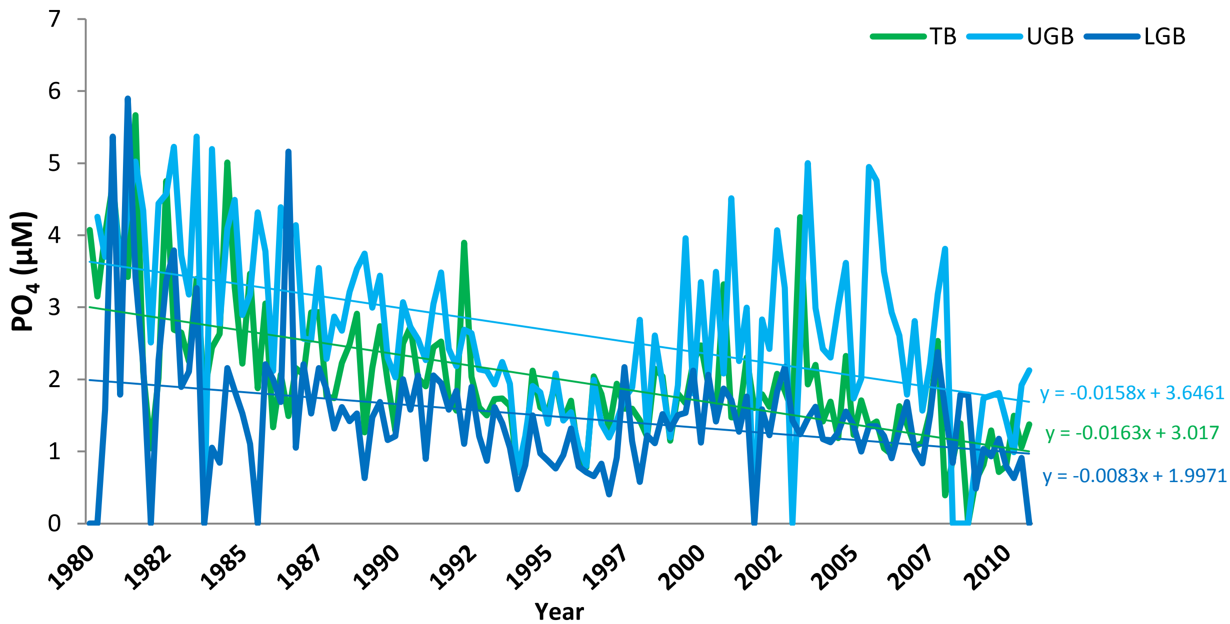

Figure 7 Line graph showing the concentration of PO_4 (µM) measurements from 1980 – 2010 (TCEQ- SWQM). Lines correspond to PO_4 concentrations for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

NO_3^- + NO_2^- and NH_3^+ appear to have decreased slightly over the study period with seasonal spikes during high freshwater inflow periods (Fig. 8 and 9). Average concentrations of NO_3^- + NO_2^- are the highest in TB (0.29-2.86 µM) compared to UGB (0.59-1.97 µM) and then LGB (0.27-1.15 µM) (Fig. 8; Table 8).

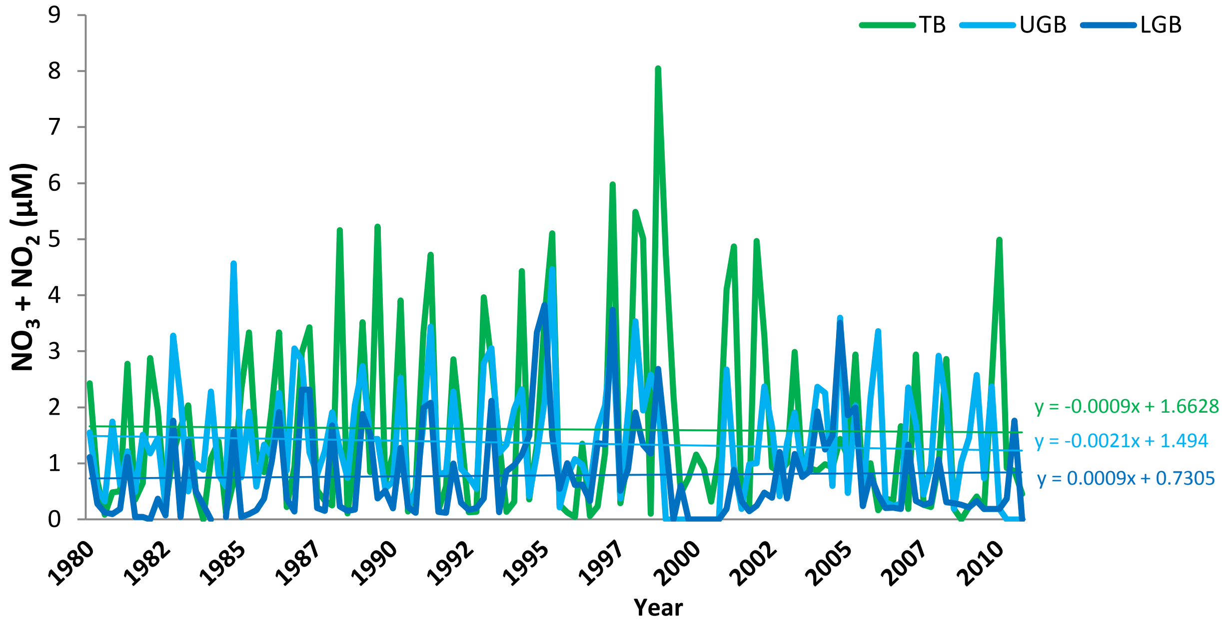

Figure 8 Line graph showing the concentration of NO_3^- + NO_2^- (µM) from 1980 – 2010 (TCEQ-SWQM). Lines correspond to NO_3^- + NO_2^- (µM) concentrations for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

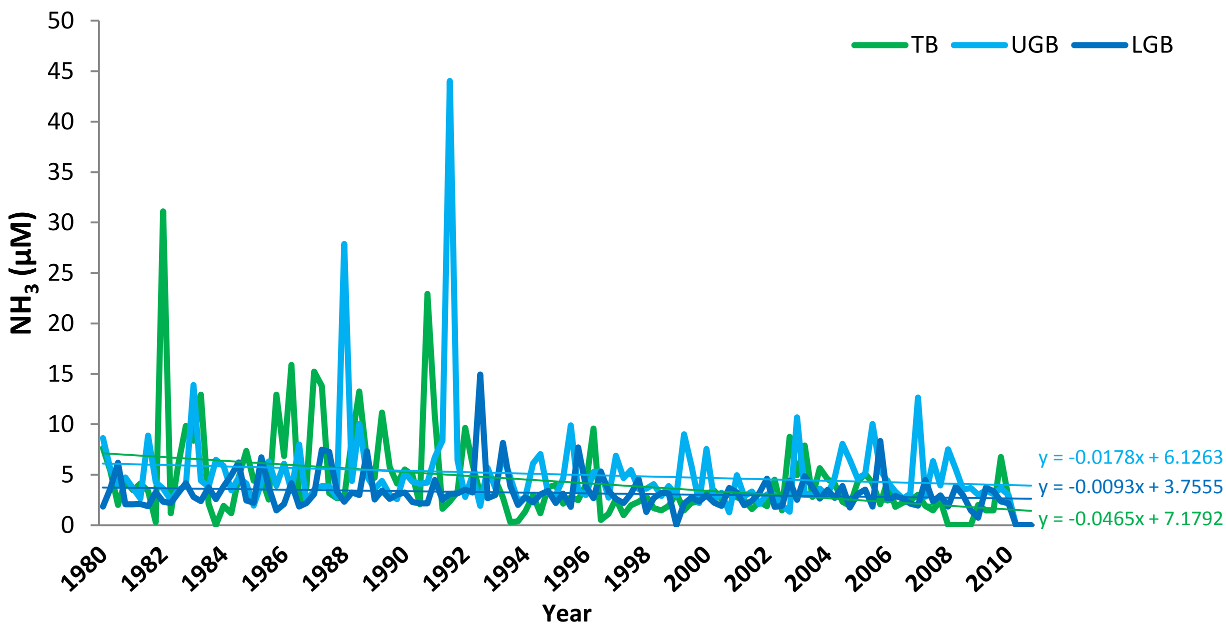

Figure 9 Line graph showing the concentration of NH_3 (µM) from 1980 – 2010 (TCEQ- SWQM). Lines correspond to NH_3 (µM) concentrations for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

The DIN:DIP ratios were highest in TB (avg. 2.67-3.67) nearest the largest source (in terms of volume) of freshwater inflow from the Trinity River. UGB has increased DIN:DIP (avg. 2.69-3.21) compared to LGB (avg. 2.15-2.61) (Fig. 10; Table 8). Ratios below 10 are associated with nitrogen limitation of phytoplankton growth (Wetzel and Likens, 2000) consistent with studies that have shown the bay to be predominantly N-limited.

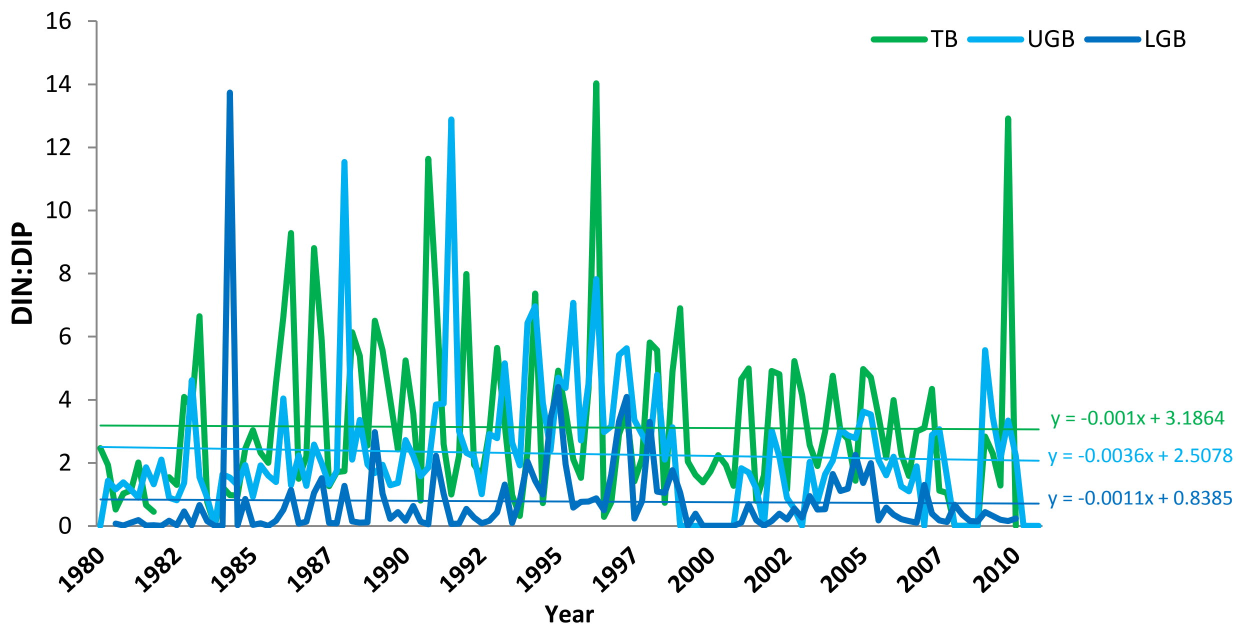

Figure 10 Line graph showing the concentration of DIN:DIP from 1980 – 2010 (TCEQ-SWQM). Lines correspond to the DIN:DIP for each of the bay segments: TB (Green), UGB (light blue) and LGB (dark blue). Equation of the trend line for the respective bay segment is shown to the right of the graph.

Total surface inflow volumes as calculated by the TWDB (Table 9) were highest in the spring (median 1.20 x 10^6 ac-ft mon^{-1}) in conjunction with the highest rates of river discharge from both the Trinity (median 3.48 x 10^4 cfs) and San Jacinto (median 3.40 x 10^2 cfs) Rivers (Table 9). The lowest surface inflow volume occurred in the fall (7.65 x 10^5 ac-ft mon^{-1}) with the lowest river discharge rates in the summer for the Trinity (2.23 x 10^4 cfs) and San Jacinto (6.30 x 10 cfs) River (Table 9).

Table 9 TWDB Surface Inflow volume across seasons. The minimum (min), maximum (max) and median (med) were calculated by taking the average over total monthly inflow volumes. Trinity River and San Jacinto river discharge flow rates were averaged over monthly data points

Freshwater Inflow Source		Galveston Bay			
		W	SP	SU	F
TWDB Surface Inflow	Min	151343	128761	222824	128514
(acre ft mon^{-1})	Max	3663956	2842980	2616325	2370078
	Median	1111498	1205023	782837	765306
Trinity River discharge	Min	2189	1867	1068	783
(cfs)	Max	37510	34848	22340	24540
	Median	10618	11235	2911	3063
San Jacinto discharge	Min	62	41	22	22
(cfs)	Max	1559	1103	339	2758
	Median	492	340	63	199

Statistical results

PCO was performed on the abiotic data for each bay segment to visualize the correlation between the data points in ordination space (Fig. 11). The ordination techniques of the PCO order the samples along axes expressing the main trends in the environmental data. Each of the data points are placed in ordination space based on the similarities and differences to the other data points. Data points located closer to each other indicate increased similarity across the measured parameters. Inversely data points with more distance between them have increased differences across the environmental parameters.

PCO results presented for the BBEST FWBI species were based on the environmental data collected from 1980 to 2010 (Table 4) with the abundance of different fauna shown for all species of interest (Table 5; Fig. 16-17, 19, 22-23, 26-27, 30-31, 46-50). The PCO results presented for the Dermo (juvenile and commercial percent infected) were based on percent of oysters infected and environmental data (Table 4) from 1998-2010. The phytoplankton pigment data presented in the PCO's with the corresponding environmental data were collected from 2008-2013 (Fig. 40-45). Throughout the results section, "bubbles" have been used to represent the abundance of various species at each of the corresponding data points shown in Fig. 11 and 12.

The vectors displayed for each of the species represent the same vectors displayed in the PCO created with the environmental variables (Fig. 16-17, 19, 22-23, 26-27, 30-31, 46-50).

The bubbles representing total abundance for each of the seasonal data points are overlayed for each respective species (Fig. 16-17, 19, 22-23, 26-27, 30-31, 46-50). A DISTLM test was run for each of the species presented to determine which of the environmental parameters had a significant correlation to the abundance. Only the vectors that correspond to the environmental parameters with a significant correlation (p<0.05) are shown for each species in each of the bay segments (Fig. 16-17, 19, 22-23, 26-27, 30-31, 46-50). The table of DISTLM results are following each PCO for each species.

In Fig. 11a, 56.8% of the abiotic data is separated along the PCO axis 1 (PCO1) which explains 36.6% of the total variation and the PCO axis 2 (PCO2) explains 20.2% of the total variation. The vectors in the PCOs represent magnitude (length) and direction (orientation) for each of the environmental parameters (Fig. 11). In TB the first axis separates the data primarily on freshwater inflow and river discharge and PCO2 by temperature and nutrient concentration (Fig. 11a). The vector points in the direction of increasing highest salinity falls in the opposite direction to both the highest Trinity and San Jacinto River inflows. In the opposite direction of the vector pointing towards increasing salinity the salinities decrease. This direction of decreasing salinities in the opposite direction of the vector is consistent with lower salinities present during increased river discharge rates/volumes. Given river flows tend to be lower in the summer and higher in the winter/spring, the finding of highest temperatures falling opposite highest nutrients is consistent with lower nutrients present during the summer months and vice versa.

In UGB, PCO1 explains 31.3% of the total variation and PCO2 18%. In Fig. 11b, PCO1 is predominantly separates the data points based on freshwater inflow (including river discharge) and PCO2 by temperature and nutrient concentration similar to TB. We see a negative association between temperature and PO_4^{3-} in relation to NO_3^- +NO_2^-, NH_3, DIN:DIP and dissolved oxygen (Fig. 11b). There is also a negative association between increasing salinity in relation to increasing freshwater discharge and turbidity (Fig. 11b).

In LGB, PCO1 explains 32% of the total variation and is defined by freshwater inflow and temperature while PCO2 explains 18.9% and is defined by nutrient concentration (Fig. 11c). Higher temperatures and higher salinities are observed during the seasons that are grouped within the high salinity range (Fig. 11). PCO1 is explained by the negative correlation between increasing salinity and increasing total surface freshwater inflow and freshwater discharge (Fig. 11c). PCO2 is explained by the negative correlation between PO4 and DIN:DIP (Fig. 11c).

In Fig. 12 the data points on the PCO are presented as salinity range: low (L; salinity 0<10), mid-range (M; 10-24) and high (H; >24). Please note that the data points and vectors are in the same location for Figs. 12 as in Fig. 11; the only change was that the data points were displayed as a different factor (i.e., salinity range). In Fig. 12a, 56.8% of the abiotic data is separated along the PCO axis 1 (PCO1) which explains 36.6% of the total variation and the PCO axis 2 (PCO2) explains 20.2% of the total variation. The data points are coded by the salinity range for each data point: low salinity (blue: low salinity (<10) and green: mid salinity (10-24)). In TB, the salinity separates along the PCO1 where increasing freshwater inflow and river discharge increase in the positive direction and increasing salinities in the negative direction which corresponds to split between lower and mid-range salinities respectively (Fig 12a.)

Similar to TB in UGB, PCO1 explains 31.3% of the total variation and PCO2 18%. In Fig. 12b, PCO1 is predominantly separates the data points based on freshwater inflow (including river discharge) similar to TB. In UGB, PCO1 separates the data primarily on increasing freshwater inflow and river discharge in the positive direction and increasing salinities in the negative direction which corresponds to split between lower and mid-range salinities respectively (Fig 12b.) Overall, there is an increase in data points that are grouped with the mid-range salinity within UGB compared to TB (Fig. 12a and b).

In LGB, PCO1 explains 32% of the total variation and is defined by freshwater inflow and temperature while PCO2 explains 18.9% and is defined by nutrient concentration (Fig. 12c). PCO1 is explained by the negative correlation between increasing salinity and increasing total surface freshwater inflow and freshwater discharge (Fig. 12c). The data points are coded by the salinity range for each data point: blue: low salinity (<10) and green: mid salinity (10-24); red: high salinity (>24)). In LGB the mid and high salinity data points are increased compared to both TB and UGB.

In Fig. 13 the data points on the PCO are presented as seasons: winter (blue), spring (green), summer (red) and fall (orange). Please note that the data points and vectors are in the same location for Figs. 13 as in Figs. 11 and 12; the only change was that the data points were displayed as a different factor (i.e., season). In Fig. 13a, 56.8% of the abiotic data is separated along the PCO axis 1 (PCO1) which explains 36.6% of the total variation and the PCO axis 2 (PCO2) explains 20.2% of the total variation. The data points that are grouped with increasing temperatures (summer) are opposite those with highest nutrients (winter/spring) (Fig. 13a and b).This is consistent with lower freshwater inflow in the summer and increased flows in the winter/spring in all 3 bay segments (Fig. 13).

During the spring season in both TB and UGB, there is an increase in total surface inflow and river discharge (Fig. 13a and b). TB and UGB have increasing NO_3^-+NO_2^-, NH_3, dissolved oxygen and higher DIN:DIP during the winter months. In TB and UGB increasing salinity and decreased freshwater inflow were observed during the fall season (Fig. 13a).

Seasonal variability within each of TB and UGB was more distinct between seasons than what is observed in LGB (Fig. 13). In LGB, the primary distinction between seasons is the increased temperature and salinity during the summer and fall seasons with increased total surface inflow and river discharge in the spring and winter (Fig. 13c).

The vectors displayed in Figs 11, 12 and 13 have been explained here and will be consistent for all PCO's (Fig. 16-17, 19, 22-23, 26-27, 30-31, 46-50).

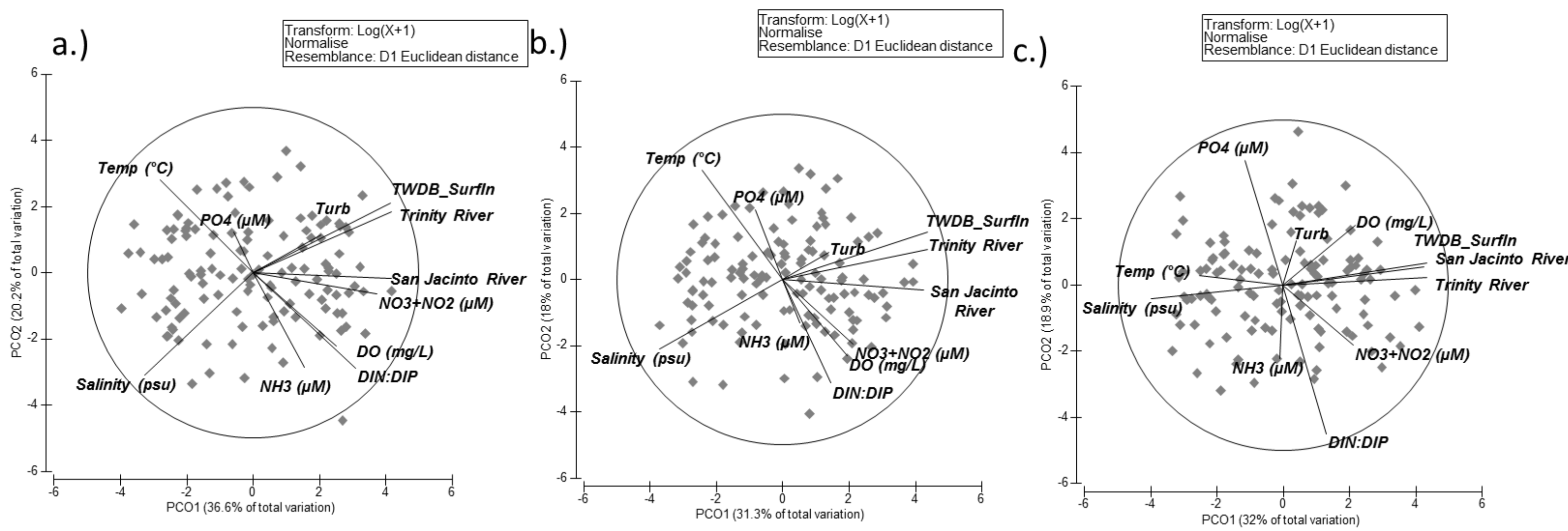

Figure 11 Principal coordinate ordination of environmental data for each bay segment a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Each point represents the averages of all water quality parameters for that season and respective year

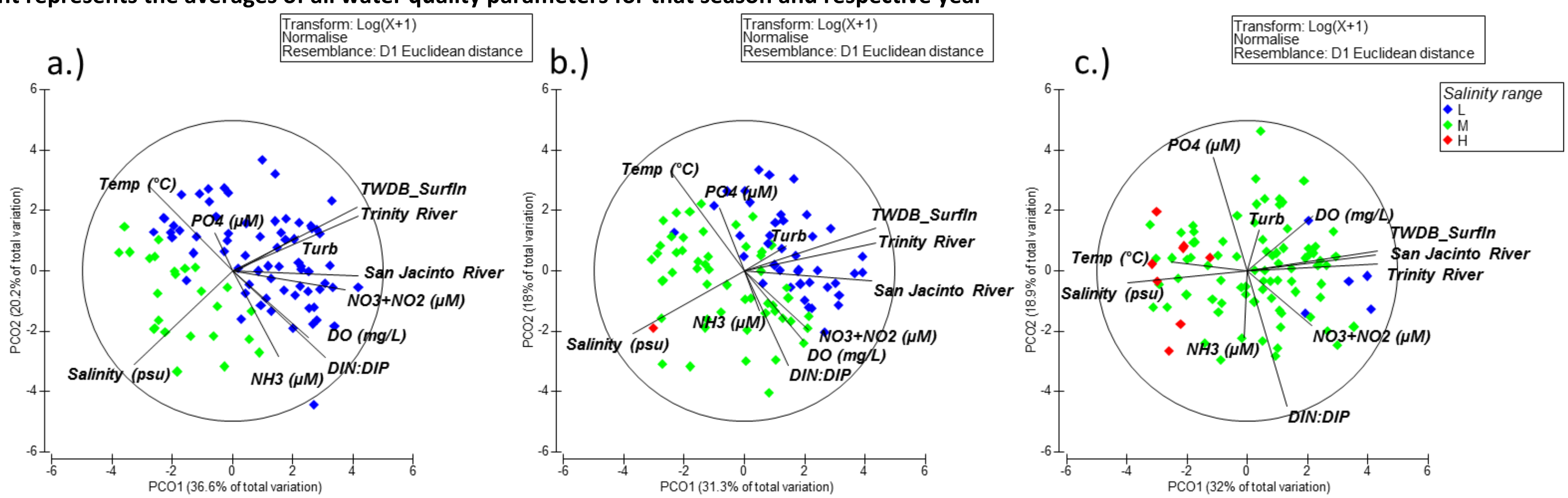

Figure 12 Principal coordinate ordination (PCO) of environmental data for each bay segment a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Each point represents the averages of all water quality parameters for that season and respective year. Data points are colored according to the salinity range at for that seasonal data point: low salinity (0-9 psu; blue), mid salinity (10-24 psu; green) and high salinity (>24 psu; red).

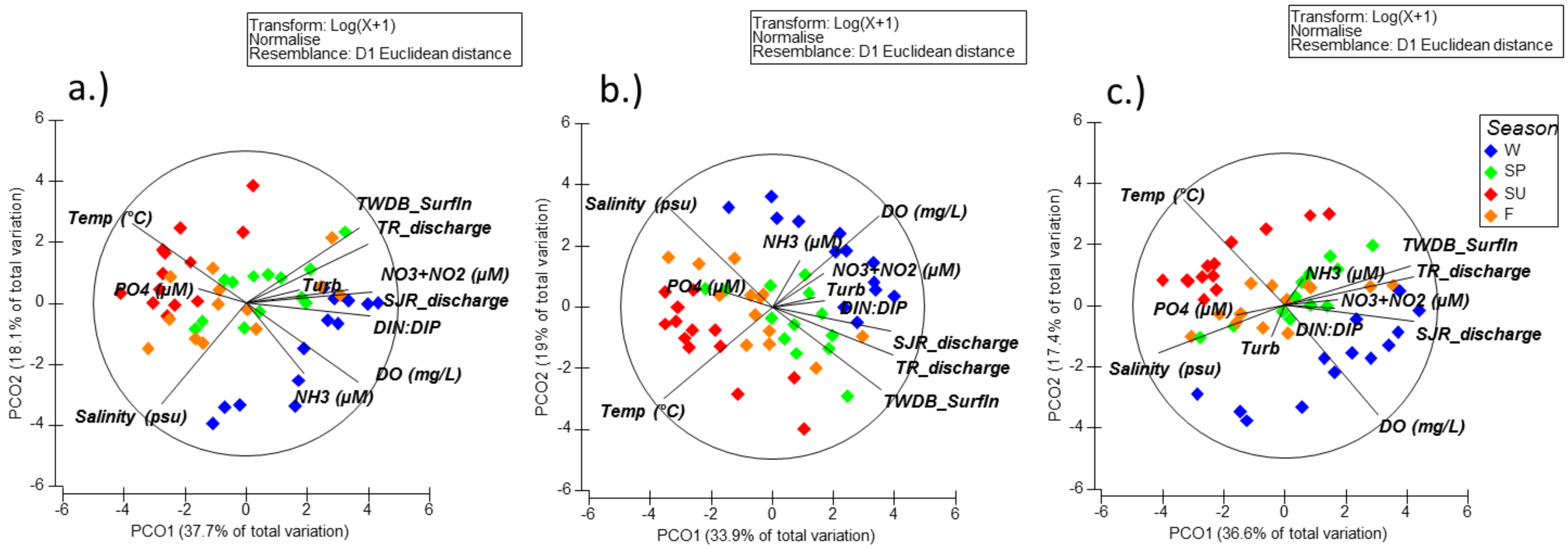

Figure 13 Principal coordinate ordination (PCO) of environmental data for each bay segment a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Each point represents the averages of all water quality parameters for that season and respective year. Data points are colored according to the season for each data point: winter (blue), spring (green), summer (red) and fall (orange). PCO is the same as shown in Figure 11 but with season shown rather than salinity range.

Galveston Bay FWBI Species (1980-2010)

For each of the FWBI species presented in the TSJ-BBEST report (Blue catfish, Gulf menhaden, Pinfish, Atlantic rangia, Oyster drill, Dermo), a subsection below has been created. Following will be the results of the phytoplankton pigment analysis and the results for the additional FWBI we are proposing for Galveston Bay. All size classes collected by each gear type were included for the analyses. Future work would focus on the separation of size classes by gear type to determine the sensitivity of the environmental variables at different life history stages. For each of the current and proposed FWBI species, we have included:

1) ArcGIS map(s) to show the distribution of each FWBI species collected with the appropriate TPWD gear type(s) across the 3 bay segments: TB, UGB and LGB. If multiple gear types are included there will be multiple maps for that species.
2) PCO(s) that display the species abundance data (bubble plots) in relation to the environmental parameters (shown in Fig. 11-13) collected with the appropriate gear type within each of the 3 bay segments: a.) TB, b.) UGB and c.) LGB. If multiple gear types are included there will be multiple sets of PCOs for that species.
3) Table of DISTLM results to depict the environmental variables that have a significant correlation with each of the FWBI species analyzed.

Blue catfish

The distribution of Blue catfish collected in the bay trawl samples is primarily seen in TB with few individuals collected in UGB and even fewer still in LGB (Fig. 14). This distribution corresponds to the increasing salinity gradient in Galveston Bay from the river basin to the Gulf as this species is typically found in fresh waters(Fig. 14 and 16). The number of Blue catfish collected during a sampling event using the bay trawl gear type ranged from 0-277 individuals over the study period (1980-2010) (Fig. 14). Blue catfish counts were higher from samples collected with the bay trawl (0-277 individuals) compared to the bag seine (0-277) (Fig. 15). Blue catfish were primarily collected in bag seines conducted in TB with one isolated occurrence in UGB and none in LGB (Fig. 16).

Both the visual display shown in the PCO (Fig. 16 and 17) and the test of significance run in the DISTLM (Table 10) show an increase in Blue catfish abundance (bay trawl) with increasing TWDB surface inflow (p<0.001), river discharge from both the TR (p<0.001) and SJR (p<0.001), decreasing salinity (p<0.001), increasing DIN:DIP (p<0.05), increasing $NO_3^- + NO_2^-$, (μM) (p<0.05) and increasing turbidity (p<0.05) in TB (Fig. 16a; Table 10).

In UGB, the Blue catfish increased in abundance (bay trawl) with decreasing salinity (p<0.001), increasing TWDB surface inflow (p<0.001), increasing river discharge from both the TR (p<0.001) and SJR (p<0.05) and decreasing PO_4 (p<0.05) (Fig. 16b; Table 10). In LGB, Blue catfish were collected in 3 bay trawls with relatively low counts per event. The increased abundance was correlated to increased TWDB surface inflow (p<0.05) and TR discharge (p<0.05), decreased salinity (p<0.01), increased $NO_3^- + NO_2^-$ (μM) (p<0.05) (Fig. 16c; Table 10).

Seasonal variation was also observed in the Blue catfish and this varied by bay segment. The highest abundances were observed during the spring and fall compared to the winter and summer. Overall higher abundances of Blue catfish were observed in TB, fewer in UGB and the least in LGB (Fig. 16). From the Blue catfish collected in the bay trawl gear type in TB, there was a significant positive correlation between abundance and PO_4, DIN:DIP, TWDB surface inflow and San Jacinto River discharge in the winter months (Table 10). In the spring there was a significant correlation between decreasing temperatures and salinity with increasing Blue catfish abundance (Table 10). There was also a positive correlation between abundance and TWDB surface inflow and Trinity River discharge (Table 10). During the summer months there was a significant correlation between decreasing temperature and salinity with increased abundances. In the fall within UGB, there was a significant correlation between increasing NO_3^- + NO_2^-, decreasing NH_3 and DIN:DIP, and increasing San Jacinto River discharge (Table 10).

Seasonal changed in Blue catfish were also observed in UGB. The abundance of Blue catfish was significantly correlated to decreasing salinity and increasing sources of freshwater (TWDB Surface inflow, Trinity and San Jacinto Rivers). In the Spring within UGB, there was a correlation between increased Blue catfish with decreasing salinity and an increase in NO3+NO2, NH3, DIN:DIP, TWDB surface inflow and Trinity River discharge (Table 10).

Bag seines collected along the shoreline typically target the smaller juvenile stage fish (TPWD, 2012). The correlations observed between the Blue catfish in TB that were collected with the bag seine were not as strongly correlated as those recorded when using the bay trawl. In TB, Blue catfish (bag seine) showed an increase in abundance with decreasing salinity (p<0.05), temperature ((p<0.05), increasing TWDB surface inflow (p<0.05), decreasing NH_3 (µM) (p<0.05), DIN:DIP (p<0.05) and dissolved oxygen (mg L^{-1}) (p<0.05) (Fig. 17a; Table 10). In UGB Blue catfish counts from the bag seines only correlated significantly with the TR discharge (p<0.05) (Fig. 17b; Table 10). No Blue catfish were collected by bag seine in LGB (Fig. 17c; Table 10).

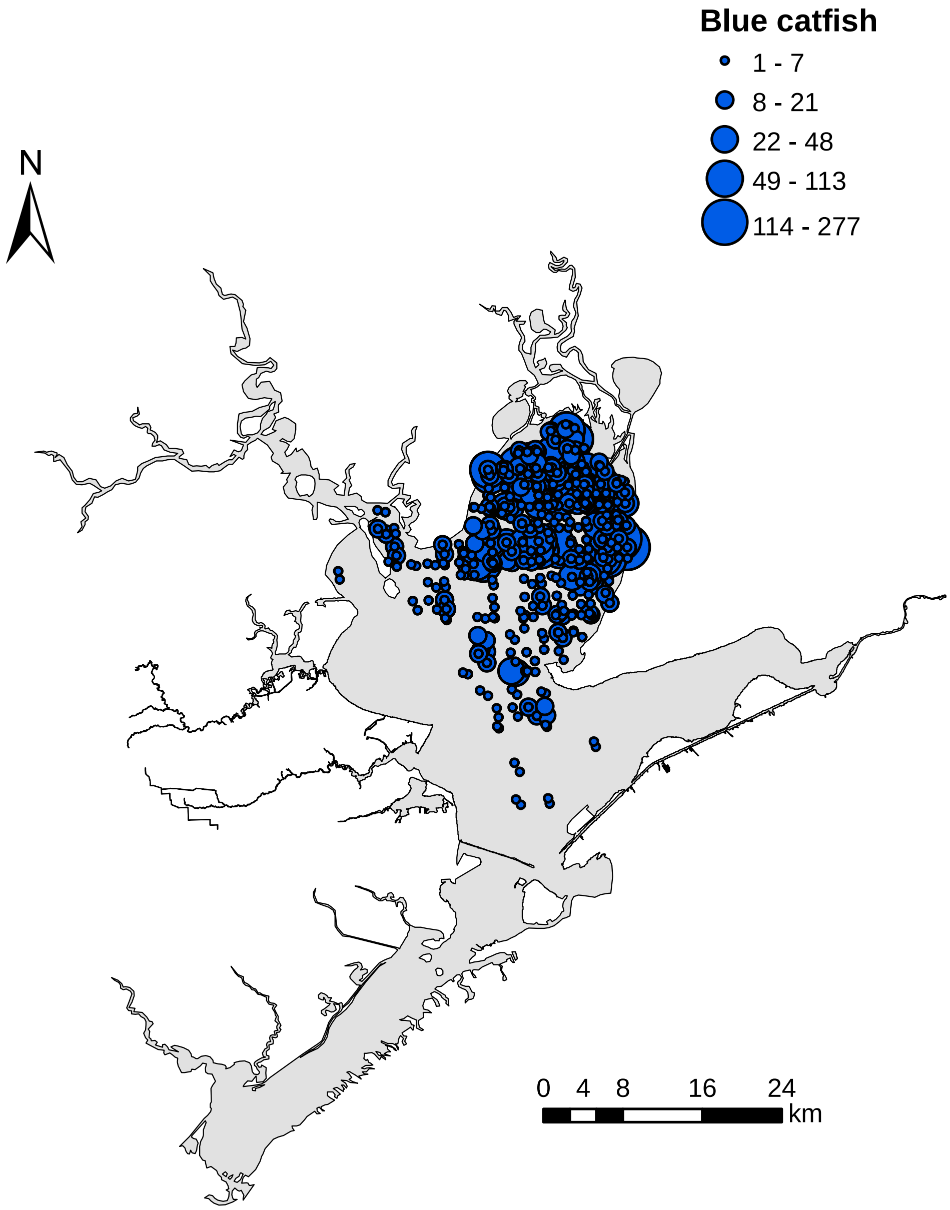

Figure 14 Distribution of Blue catfish collected in the bay trawl 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

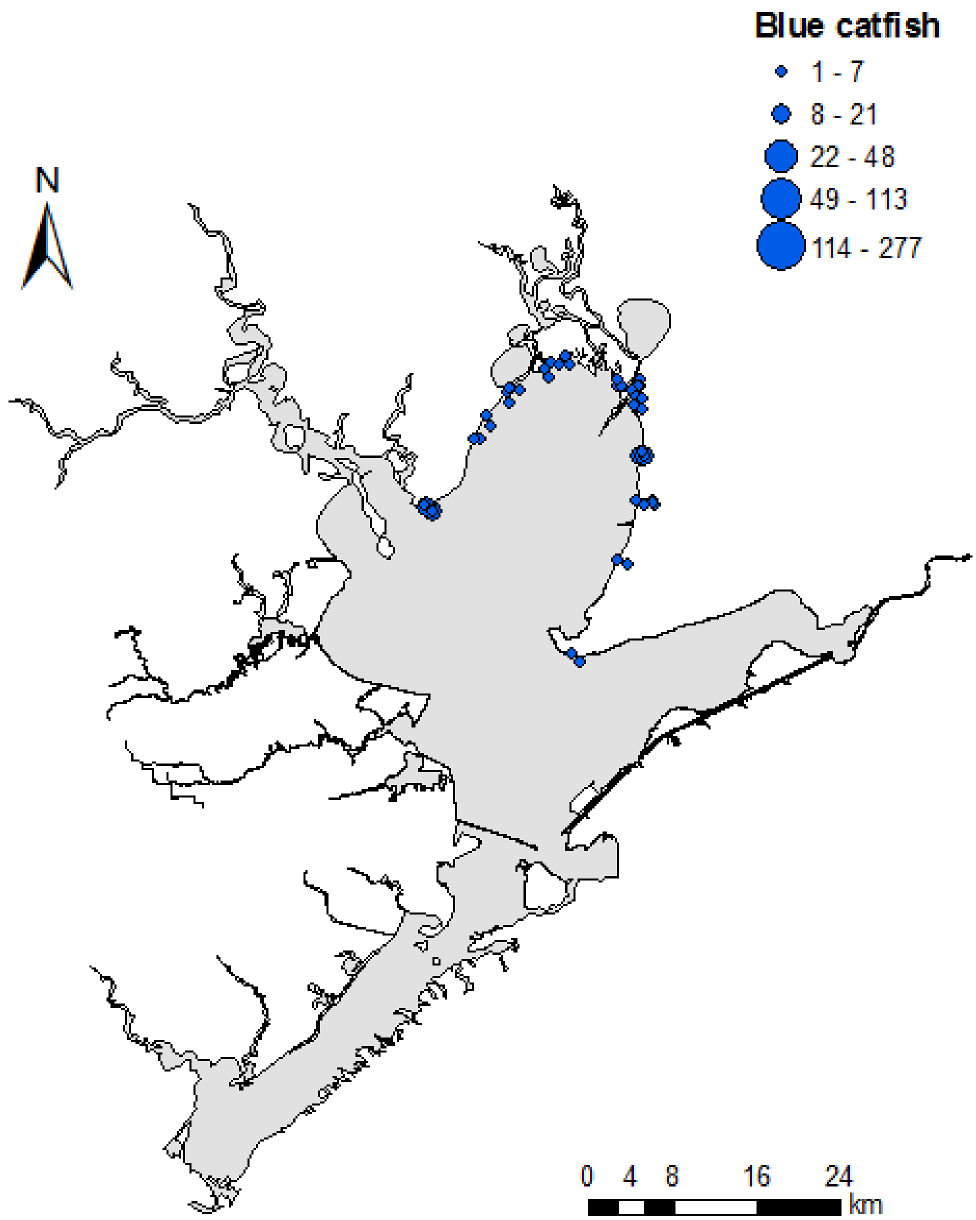

Figure 15 Distribution of Blue catfish collected in the bag seine 1980-2010 Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

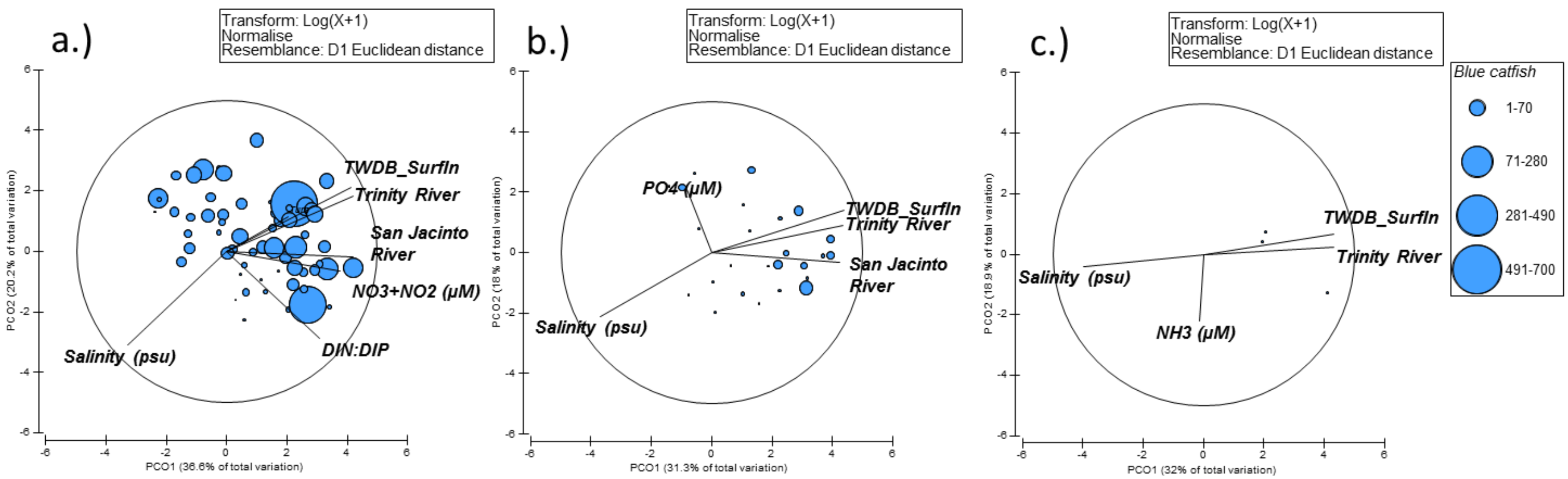

Figure 16 PCO of environmental data with the bubble underlay showing abundance of blue catfish catch data from TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Blue catfish abundance in each respective segment.

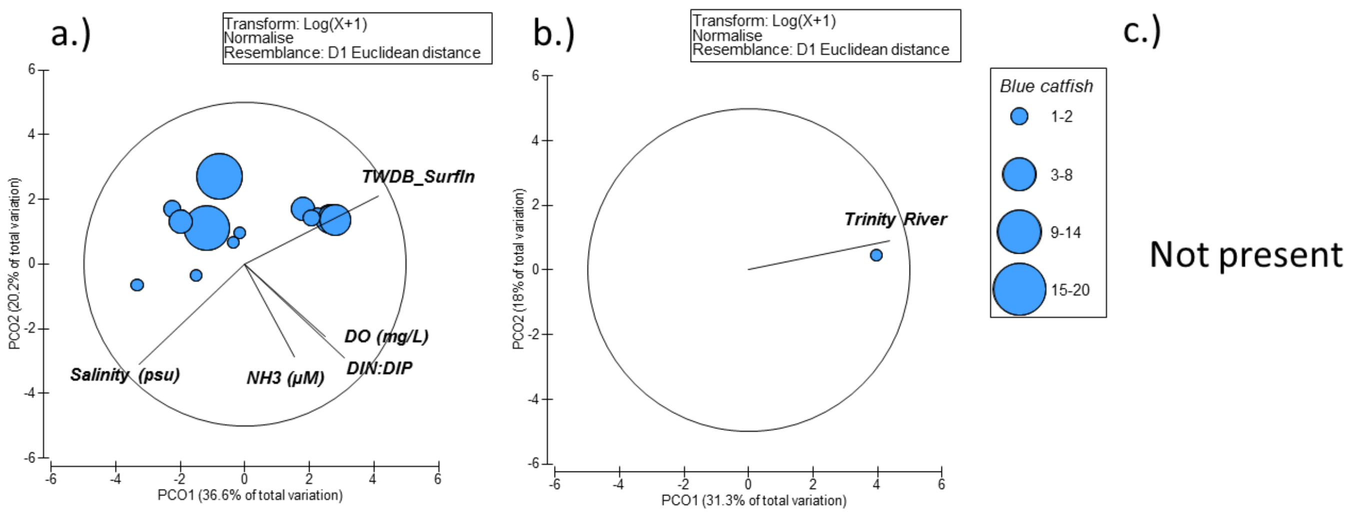

Figure 17 PCO of environmental data with the bubble underlay showing abundance of blue catfish catch data from TPWD bag seine for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Blue catfish abundance in each respective segment.

Table 10 Correlation between the abundance of Blue catfish to the each of the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl (Gear Type 5) and bag seine (Gear Type 7).

Subbay and Gear Type	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	Temp (°C)	171.30	0.12	0.8452	0.00	672.94	0.74	0.4677	0.02	5952.20	6.02	**0.0095**	0.17	9078.00	7.58	**0.0065**	0.21	28.92	0.03	0.8718	0.00
Bay trawl	DO (mg/L)	2109.40	1.49	0.2145	0.01	2366.60	2.78	0.0724	0.09	770.97	0.66	0.4784	0.02	1338.00	0.91	0.3820	0.03	2986.40	3.72	0.0565	0.11
	Salinity (psu)	55555.00	56.91	**0.0001**	0.32	927.63	1.03	0.3463	0.03	11927.00	15.23	**0.0003**	0.34	8513.20	7.00	**0.0090**	0.19	5281.00	7.29	**0.0122**	0.20
	Turb (NTU)	10914.00	8.13	**0.0034**	0.06	548.32	0.60	0.5418	0.02	1157.40	1.00	0.3463	0.03	929.89	0.63	0.4433	0.02	896.86	1.02	0.3127	0.03
	NO_3+NO_2 (μM)	29266.00	24.56	**0.0001**	0.17	1691.60	1.93	0.1491	0.06	3830.40	3.61	**0.0452**	0.11	1766.40	1.22	0.3076	0.04	4765.30	6.42	**0.0194**	0.18
	NH_3 (μM)	811.06	0.57	0.4896	0.00	150.26	0.16	0.8509	0.01	3217.00	2.97	0.0671	0.09	515.02	0.35	0.6076	0.01	111.09	0.12	0.7731	0.00
	PO_4 (μM)	2778.60	1.97	0.1561	0.02	3885.40	4.86	**0.0185**	0.14	160.72	0.14	0.8938	0.00	76.17	0.05	0.9136	0.00	5532.50	7.73	**0.0086**	0.21
	N:P	6068.00	4.39	**0.0254**	0.03	4020.40	5.06	**0.0160**	0.15	697.49	0.60	0.5190	0.02	341.12	0.23	0.7040	0.01	3219.90	4.05	**0.0485**	0.12
	Surf. In. (ac-ft/mon^{-1})	64184.00	70.89	**0.0001**	0.37	3872.40	4.84	**0.0153**	0.14	10526.00	12.66	**0.0001**	0.30	15329.00	15.61	**0.0002**	0.35	8724.20	14.41	**0.0006**	0.33
	TR (cfs)	50286.00	49.33	**0.0001**	0.29	2617.20	3.10	0.0559	0.10	7533.70	8.06	**0.0030**	0.22	14853.00	14.88	**0.0003**	0.34	7341.10	11.24	**0.0021**	0.28
	SJR (cfs)	26674.00	21.99	**0.0001**	0.15	3278.80	4.00	**0.0274**	0.12	2763.00	2.51	0.0973	0.08	5367.90	4.05	**0.0494**	0.12	10200.00	18.39	**0.0001**	0.39
TB	Temp (°C)	1420.40	6.02	**0.0131**	0.05	-	-	-	-	280.38	0.78	0.3895	0.03	301.73	0.75	0.4035	0.03	146.93	0.78	0.2090	0.03
Bag Seine	DO (mg/L)	1815.90	7.80	**0.0055**	0.06	-	-	-	-	13.84	0.04	0.8997	0.00	201.02	0.49	0.4769	0.02	831.33	5.01	**0.0314**	0.15
	Salinity (psu)	1462.10	6.20	**0.0112**	0.05	-	-	-	-	1729.50	5.55	**0.0229**	0.16	9.53	0.02	0.9611	0.00	407.90	2.26	0.1267	0.07
	Turb (NTU)	59.52	0.24	0.6747	0.00	-	-	-	-	59.70	0.16	0.7111	0.01	128.22	0.31	0.6386	0.01	18.00	0.09	0.7731	0.00
	NO_3+NO_2 (μM)	23.89	0.10	0.8265	0.00	-	-	-	-	366.81	1.02	0.3192	0.03	54.79	0.13	0.7740	0.00	73.10	0.38	0.4900	0.01
	NH_3 (μM)	1431.10	6.06	**0.0134**	0.05	-	-	-	-	458.36	1.29	0.2719	0.04	945.45	2.47	0.1187	0.08	142.50	0.75	0.3884	0.03
	PO_4 (μM)	44.24	0.18	0.7224	0.00	-	-	-	-	113.39	0.31	0.5822	0.01	413.59	1.03	0.3158	0.03	1.00	0.01	0.9797	0.00
	N:P	900.78	3.75	**0.0490**	0.03	-	-	-	-	350.55	0.98	0.3235	0.03	14.96	0.04	0.9484	0.00	197.52	1.05	0.2974	0.04
	Surf. In. (ac-ft/mon^{-1})	967.34	4.03	**0.0414**	0.03	-	-	-	-	2657.70	9.51	**0.0063**	0.25	121.14	0.29	0.6667	0.01	79.09	0.41	0.5353	0.01
	TR (cfs)	148.04	0.60	0.4557	0.00	-	-	-	-	1654.40	5.27	**0.0280**	0.15	9.54	0.02	0.9583	0.00	132.82	0.70	0.4267	0.02
	SJR (cfs)	2.31	0.01	0.9793	0.00	-	-	-	-	1397.60	4.33	**0.0395**	0.13	7.80	0.02	0.9715	0.00	27.88	0.14	0.7293	0.00
UGB	Temp (°C)	784.30	1.78	0.1697	0.01	1431.90	2.25	0.1334	0.07	1264.90	2.10	0.1494	0.07	181.46	0.72	0.3155	0.02	45.51	0.26	0.5555	0.01
Bay Trawl	DO (mg/L)	18.77	0.04	0.9362	0.00	1570.50	2.49	0.1068	0.08	139.03	0.22	0.6748	**0.01**	315.66	1.27	0.2330	0.04	98.32	0.56	0.3951	0.02
	Salinity (psu)	11640.00	33.10	**0.0001**	0.21	5355.30	10.68	**0.0017**	0.27	6451.50	15.24	**0.0003**	0.34	470.90	1.94	0.1646	0.06	504.56	3.14	0.0771	0.10
	Turb (NTU)	20.96	0.05	0.9274	0.00	1045.60	1.61	0.2091	0.05	173.88	0.27	0.6429	**0.01**	0.97	0.00	0.9957	0.00	33.43	0.19	0.7557	0.01
	NO_3+NO_2 (μM)	1104.90	2.52	0.1078	0.02	309.98	0.46	0.5480	0.02	4507.10	9.19	**0.0046**	0.24	416.35	1.70	0.1935	0.06	755.56	4.97	**0.0354**	0.15
	NH_3 (μM)	177.13	0.40	0.5613	0.00	1866.70	3.00	0.0786	0.09	3717.70	7.18	**0.0096**	0.20	149.02	0.59	0.4101	0.02	783.10	5.18	**0.0317**	0.15
	PO_4 (μM)	2163.60	5.04	**0.0234**	0.04	1535.00	2.42	0.1182	0.08	647.32	1.04	0.3105	**0.03**	35.10	0.14	0.8274	0.00	13.05	0.07	0.9104	0.00
	N:P	1405.20	3.23	0.0647	0.03	129.93	0.19	0.7379	0.01	2816.00	5.13	**0.0262**	0.15	87.10	0.34	0.5740	0.01	1185.40	8.64	**0.0119**	0.23
	Surf. In. (ac-ft/mon^{-1})	9250.20	24.91	**0.0001**	0.17	4286.10	7.96	**0.0060**	0.22	4642.20	9.56	**0.0031**	0.25	353.83	1.44	0.2410	0.05	426.56	2.61	0.1059	0.08
	TR (cfs)	8614.90	22.88	**0.0001**	0.16	5223.10	10.32	**0.0018**	0.26	3973.00	7.81	**0.0090**	0.21	420.42	1.72	0.1765	0.06	241.00	1.42	0.2835	0.05
	SJR (cfs)	4326.70	10.51	**0.0015**	0.08	3923.20	7.12	**0.0109**	0.20	1374.70	2.30	0.1295	0.07	202.61	0.80	0.3971	0.03	779.60	5.16	**0.0132**	0.15
UGB	Temp (°C)	16.48	1.85	0.1856	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bag Seine	DO (mg/L)	0.92	0.10	0.7425	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Salinity (psu)	25.61	2.90	0.0625	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Turb (NTU)	0.32	0.04	0.8459	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NO_3+NO_2 (μM)	7.92	0.88	0.4082	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3 (μM)	6.35	0.71	0.3040	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PO_4 (μM)	1.73	0.19	0.6672	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N:P	0.07	0.01	0.9738	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Surf. In. (ac-ft/mon^{-1})	36.47	4.18	0.0518	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR (cfs)	34.98	4.00	**0.0245**	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SJR (cfs)	25.82	2.93	0.0975	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LGB	Temp (°C)	0.14	0.00	0.9803	0.00	-	-	-	-	167.77	1.43	0.2300	0.05	-	-	-	-	-	-	-	-
Bay Trawl	DO (mg/L)	6.16	0.20	0.6403	0.00	-	-	-	-	97.46	0.82	0.3310	0.03	-	-	-	-	-	-	-	-
	Salinity (psu)	304.26	10.49	**0.0023**	0.08	-	-	-	-	892.41	9.69	**0.0039**	0.25	-	-	-	-	-	-	-	-
	Turb (NTU)	0.75	0.02	0.8908	0.00	-	-	-	-	19.86	0.16	0.6713	0.01	-	-	-	-	-	-	-	-
	NO_3+NO_2 (μM)	106.87	3.49	**0.0460**	0.03	-	-	-	-	130.07	1.10	0.2592	0.04	-	-	-	-	-	-	-	-
	NH_3 (μM)	14.50	0.46	0.4745	0.00	-	-	-	-	119.40	1.01	0.3330	0.03	-	-	-	-	-	-	-	-
	PO_4 (μM)	14.29	0.46	0.5056	0.00	-	-	-	-	8.81	0.07	0.7951	0.00	-	-	-	-	-	-	-	-
	N:P	12.69	0.40	0.5393	0.00	-	-	-	-	2.44	0.02	0.9064	0.00	-	-	-	-	-	-	-	-
	Surf. In. (ac-ft/mon^{-1})	170.42	5.66	**0.0169**	0.04	-	-	-	-	513.30	4.88	**0.0445**	0.14	-	-	-	-	-	-	-	-
	TR (cfs)	141.44	4.66	**0.0304**	0.04	-	-	-	-	269.14	2.37	0.1342	0.08	-	-	-	-	-	-	-	-
	SJR (cfs)	86.08	2.79	0.0993	0.02	-	-	-	-	257.47	2.26	0.1422	0.07	-	-	-	-	-	-	-	-

Atlantic rangia (*Rangia cuneata*)

Atlantic rangia collected in the bay trawl samples were primarily found in TB with few collected in UGB and even fewer still in LGB (Fig. 18). This distribution corresponds to the increasing salinity gradient in TB, that is, a greater number of individuals were present closer to the Trinity River mouth. The number of Atlantic rangia collected during a sampling event using the bay trawl gear type ranged from 0-1492 individuals (per bay trawl) over the study period 1980-2010 (Fig. 18). The bay trawl is not meant to specifically target Atlantic rangia. The data from the bay trawl collections nonetheless was the most comprehensive distribution of this species and was therefore chosen for this analysis.

Both the visual display shown in the PCO (Fig. 19) and the test of significance run in the DISTLM (Table 11) showed an increase in Atlantic rangia abundance with decreasing turbidity ($p<0.001$), increasing salinity ($p<0.05$) and increasing dissolved oxygen ($p<0.05$) in TB (Fig. 19a; Table 11). In UGB, the Atlantic rangia increased in abundance (bay trawl) with increasing salinity ($p<0.05$), decreasing turbidity ($p<0.05$), decreasing TWDB surface inflow ($p<0.001$) and TR discharge ($p<0.05$) (Fig. 19b; Table 11). In LGB, Atlantic rangia were not collected the bay trawls (Fig. 19c, Table 11).

Fewer seasonal trends were observed between the Atlantic rangia and environmental parameters compared to other species that were analyzed as freshwater bioindicators in this study. In TB during the spring there was a positive correlation between Atlantic rangia abundance and DIN:DIP. In the summer there was a significant correlation between the Atlantic rangia abundance and decreasing dissolved oxygen and decreasing turbidity (Table 11). During the fall season in UGB, Atlantic rangia are positively correlated with turbidity (Table 11). The trends observed in the Atlantic rangia could be inaccurate due to the sampling method of the bay trawl as this gear type is not designed to collect this species and therefore the clams that were collected could be considered by catch.

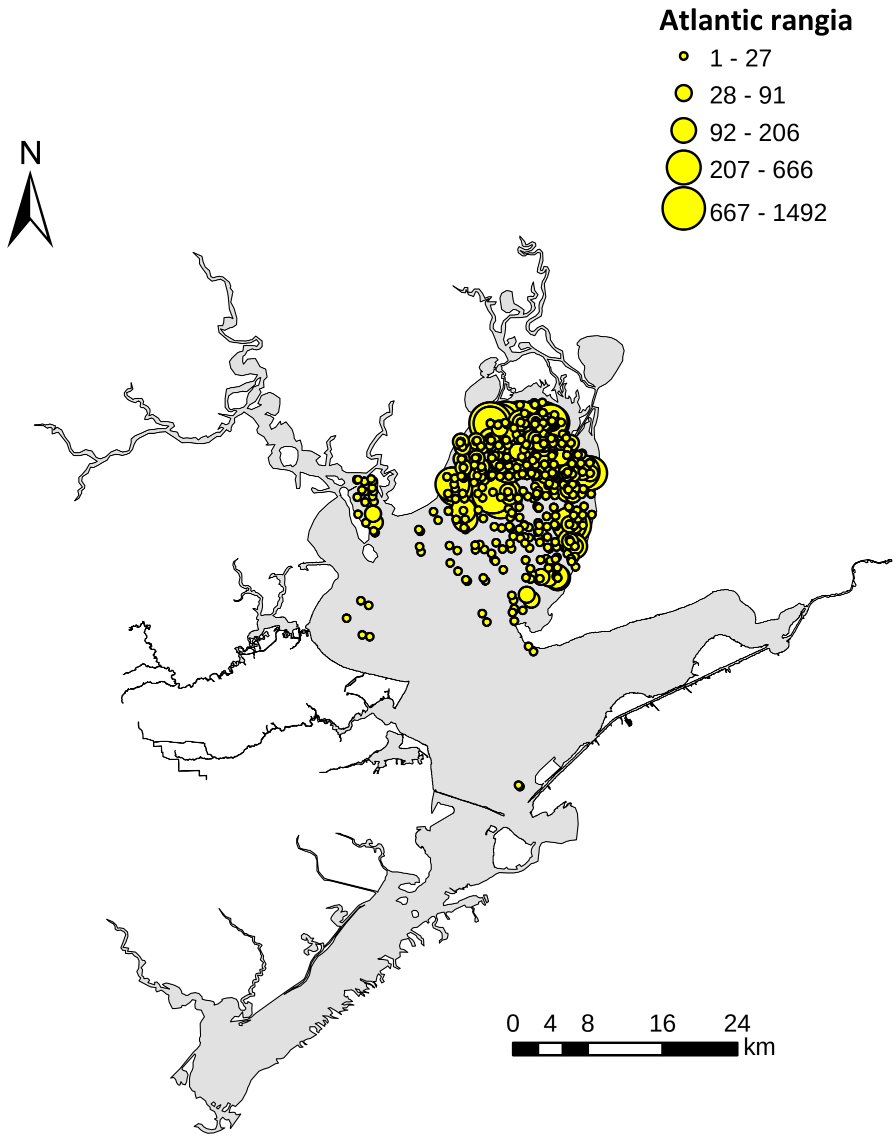

Figure 18 Distribution of Atlantic rangia collected with the bay trawl 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

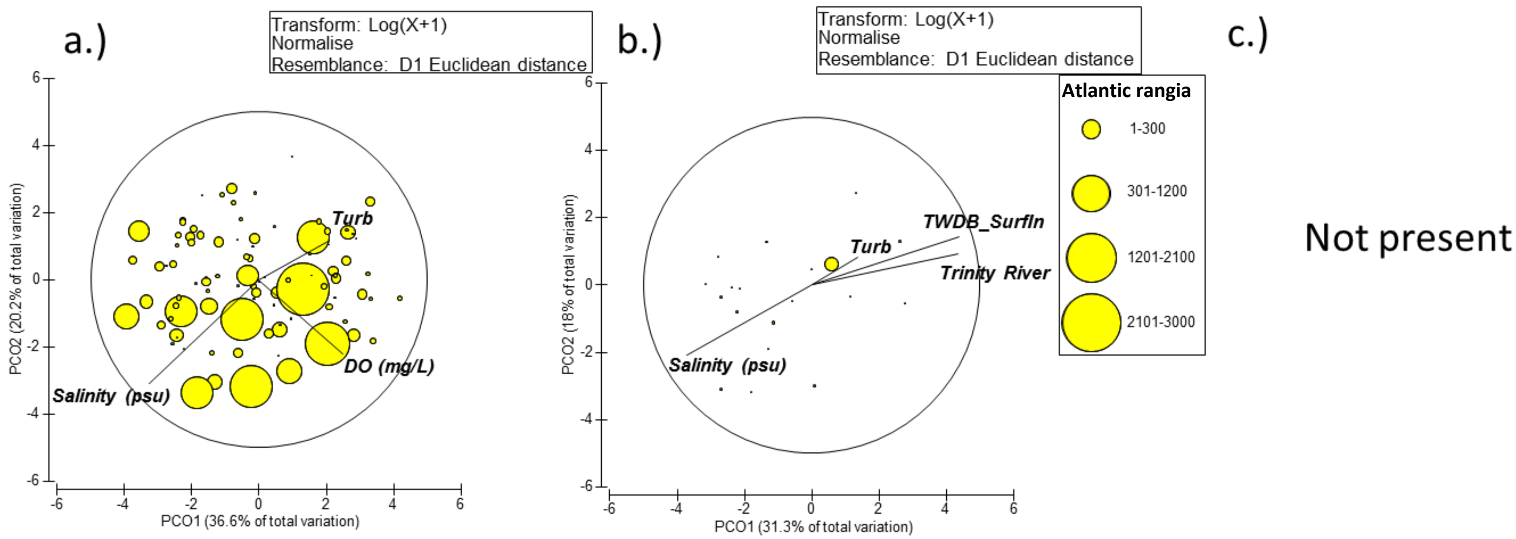

Figure 19 PCO of environmental data with the bubble underlay showing abundance of Atlantic rangia catch data from TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Atlantic rangia abundance in each respective segment

Table 11 Correlation between the abundance of Atlantic rangia to each of the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM test of Atlantic rangia within all segments from organisms collected with the TPWD bay trawl (Gear Type 5).

Subbay -	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
Gear Type	Parameter	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	2416.60	1.62	0.1946	0.01	3865.50	2.69	0.0707	0.08	94.83	0.06	0.9772	0.00	1695.40	1.32	0.2591	0.04	3547.70	2.31	0.0865	0.07
Bay trawl	**DO (mg/L)**	6020.40	4.13	**0.0212**	0.03	2507.30	1.69	0.1769	0.06	3082.10	2.03	0.1344	0.07	4751.90	4.02	**0.0237**	0.12	2056.10	1.29	0.2571	0.04
	Salinity (psu)	5414.70	3.70	**0.0308**	0.03	1325.30	0.87	0.4166	0.03	711.46	0.44	0.6659	0.02	3522.90	2.87	0.0690	0.09	1001.40	0.62	0.5175	0.02
	Turb (NTU)	20910.00	15.64	**0.0001**	0.11	3974.20	2.77	0.0669	0.09	2886.90	1.89	0.1474	0.06	6518.70	5.81	**0.0060**	0.17	6289.70	4.36	**0.0246**	0.13
	NO_3+NO_2 (µM)	126.50	0.08	0.9538	0.00	1094.20	0.71	0.4962	0.02	2144.90	1.38	0.2407	0.05	1728.20	1.34	0.2694	0.04	145.44	0.09	0.9433	0.00
	NH_3 (µM)	2850.90	1.92	0.1437	0.02	588.91	0.38	0.7212	0.01	3939.20	2.64	0.0753	0.08	718.55	0.54	0.5667	0.02	299.00	0.18	0.8384	0.01
	PO_4 (µM)	3479.60	2.35	0.0912	0.02	1469.90	0.97	0.3823	0.03	871.86	0.55	0.5932	0.02	2458.70	1.95	0.1505	0.06	638.32	0.39	0.6624	0.01
	N:P	1588.90	1.06	0.3412	0.01	1032.00	0.67	0.5157	0.02	6122.50	4.32	**0.0205**	0.13	408.67	0.31	0.7383	0.01	138.04	0.08	0.9382	0.00
	Surf. In. (ac-ft/mon^{-1})	2803.20	1.89	0.1469	0.02	1718.80	1.14	0.3235	0.04	2121.70	1.36	0.2544	0.04	257.32	0.19	0.8464	0.01	909.12	0.56	0.5460	0.02
	TR (cfs)	1823.50	1.22	0.2827	0.01	2091.70	1.39	0.2412	0.05	534.34	0.33	0.7510	0.01	1152.80	0.88	0.3960	0.03	275.41	0.17	0.8535	0.01
	SJR (cfs)	1744.80	1.17	0.3004	0.01	1273.40	0.83	0.4334	0.03	474.78	0.29	0.7865	0.01	381.94	0.29	0.7628	0.01	416.88	0.25	0.7820	0.01
UGB	**Temp (°C)**	18.94	0.07	0.9149	0.00	186.56	0.98	0.3228	0.03	186.78	0.53	0.5200	0.02	87.30	0.39	0.4664	0.01	149.52	0.42	0.5153	0.01
Bay Trawl	**DO (mg/L)**	11.02	0.04	0.9489	0.00	0.89	0.00	0.9895	0.00	118.46	0.33	0.5398	0.01	23.07	0.10	0.7719	0.00	106.72	0.30	0.6025	0.01
	Salinity (psu)	1157.40	4.31	**0.0281**	0.03	289.60	1.55	0.2305	0.05	812.74	2.43	0.1275	0.08	874.35	4.45	**0.0415**	0.13	381.92	1.09	0.3077	0.04
	Turb (NTU)	959.46	3.55	**0.0477**	0.03	85.47	0.44	0.5218	0.01	1010.20	3.09	0.0753	0.10	70.88	0.32	0.5829	0.01	167.92	0.47	0.5046	0.02
	NO_3+NO_2 (µM)	35.52	0.13	0.8499	0.00	48.89	0.25	0.6295	0.01	109.03	0.30	0.6820	0.01	511.70	2.45	0.1263	0.08	5.95	0.02	0.9462	0.00
	NH_3 (µM)	420.25	1.53	0.2043	0.01	360.16	1.95	0.1597	0.06	11.06	0.03	0.9531	0.00	3.62	0.02	0.9106	0.00	344.38	0.98	0.3321	0.03
	PO_4 (µM)	256.93	0.93	0.3441	0.01	195.09	1.02	0.3211	0.03	233.09	0.66	0.4690	0.02	138.73	0.62	0.4433	0.02	20.97	0.06	0.8522	0.00
	N:P	2.84	0.01	0.9925	0.00	30.75	0.16	0.7061	0.01	178.15	0.50	0.5573	0.02	58.08	0.26	0.6217	0.01	802.08	2.39	0.1279	0.08
	Surf. In. (ac-ft/mon^{-1})	1997.70	7.63	**0.0033**	0.06	667.24	3.83	0.0549	0.12	980.21	2.99	0.0690	0.09	863.05	4.38	**0.0448**	0.13	4.98	0.01	0.9557	0.00
	TR (cfs)	1262.30	4.71	**0.0225**	0.04	819.48	4.85	**0.0292**	0.14	465.86	1.35	0.2463	0.04	510.05	2.44	0.1256	0.08	0.41	0.00	0.9952	0.00
	SJR (cfs)	93.25	0.34	0.6577	0.00	262.75	1.40	0.2357	0.05	597.25	1.75	0.1917	0.06	25.69	0.11	0.7535	0.00	713.38	2.11	0.1625	0.07
LGB	**Temp (°C)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay Trawl	**DO (mg/L)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Salinity (psu)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Turb (NTU)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NO_3+NO_2 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PO_4 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N:P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Surf. In. (ac-ft/mon^{-1})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SJR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Gulf menhaden (Brevoortia patronus)

Gulf menhaden were collected routinely across all 3 bay segments in the bay trawl and bag seine gear types (Figs. 20 and 21). The distribution of Gulf menhaden collected in the bay trawl and the bag seine samples were seen across all bay segments (Figs. 20 and 21). Both the visual display shown in the PCO (Fig. 22 and 23) and the test of significance run in the DISTLM (Table 12) showed that the Gulf menhaden abundance (bay trawl) was significantly correlated with dissolved oxygen (p<0.001), PO_4 (p<0.001), turbidity (p<0.001), TWDB surface inflow (p<0.05) and DIN:DIP (p<0.05) in TB (Fig. 22a; Table 12). In UGB, the Gulf menhaden abundance (bay trawl) was significantly correlated to turbidity (p<0.01), temperature (p<0.05), dissolved oxygen (p<0.05), PO_4 (p<0.05), DIN:DIP (p<0.05) and TWDB surface inflow (p<0.05) (Fig. 22b; Table 12). In LGB, Gulf menhaden abundance was correlated to decreasing salinities (p<0.001), decreasing PO4 (p<0.001), increasing TWDB surface inflow (p<0.001), increasing TR river discharge (p<0.001), temperature (p<0.05), NO_3^- + NO_2^- (p<0.05), DIN:DIP (p<0.05) and SJR river discharge (p<0.05) (Fig. 22c; Table 12).

Bag seines collected along the shoreline typically target the smaller juvenile stage fish (TPWD, 2012). The Gulf menhaden were collected in bag seines all 3 bay segments. In TB, Gulf menhaden (bag seine) showed an increase in abundance with increasing temperature (p<0.001), dissolved oxygen (p<0.001), NH_3 (p<0.001) and decreasing salinity (p<0.05) (Fig. 23a; Table 12). In UGB Gulf menhaden counts from the bag seines were correlated with TR discharge (p<0.05) and dissolved oxygen (p<0.05) (Fig. 23b; Table 12). In LGB, Gulf menhaden (bag seine) were correlated to temperature (p<0.01) and dissolved oxygen (p<0.01) Fig. 23c; Table 12).

Seasonal variation was observed within the abundances of Gulf menhaden collected within each of the bay segments. In TB, the increased abundance of Gulf menhaden were significantly correlated to decreasing PO4, DIN:DIP, TWDB surface inflow, Trinity and San Jacinto River discharges (Table 12). In the spring the increased Gulf menhaden were significantly correlated to decreasing turbidity and increasing NO3+NO2 (Table 12). During the summer increased Gulf menhaden were significantly correlated to decreasing salinity, turbidity and PO4 Table 12). In the fall the increased Gulf menhaden were significantly correlated to increasing temperatures and decreasing dissolved oxygen (Table 12).

Within UGB the increase of Gulf menhaden was positively correlated to TWDB surface inflow, Trinity and San Jacinto River discharges. In the spring, the increase of menhaden was positively correlated to dissolved oxygen, PO4 and DIN:DIP (Table 12). In the summer there was a positive correlation to dissolved oxygen and PO4.

In LGB, Gulf menhaden were positively correlated to temperature, TWDB surface inflow, Trinity and San Jacinto River discharges and decreasing salinity (Table 12). In the spring there was a positive correlation with temperature, PO4, and TWDB surface inflow and decreasing turbidity (Table 12). IN the summer there was a positive correlation with dissolved oxygen, DIN:DIP and TWDB surface inflow and decreasing temperature and DIN:DIP (Table 12).

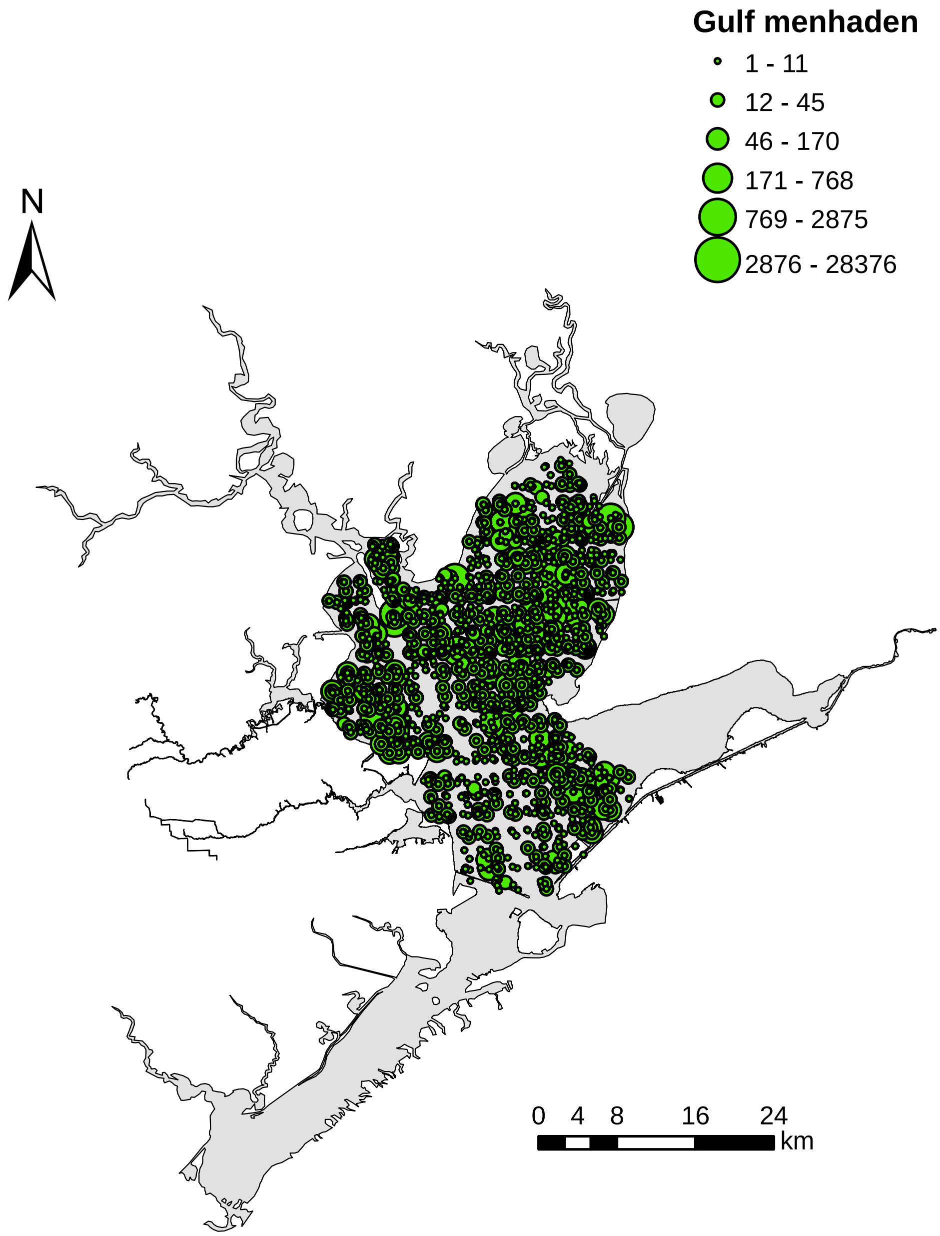

Figure 20 Distribution of each Gulf menhaden collected with the bay trawl 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

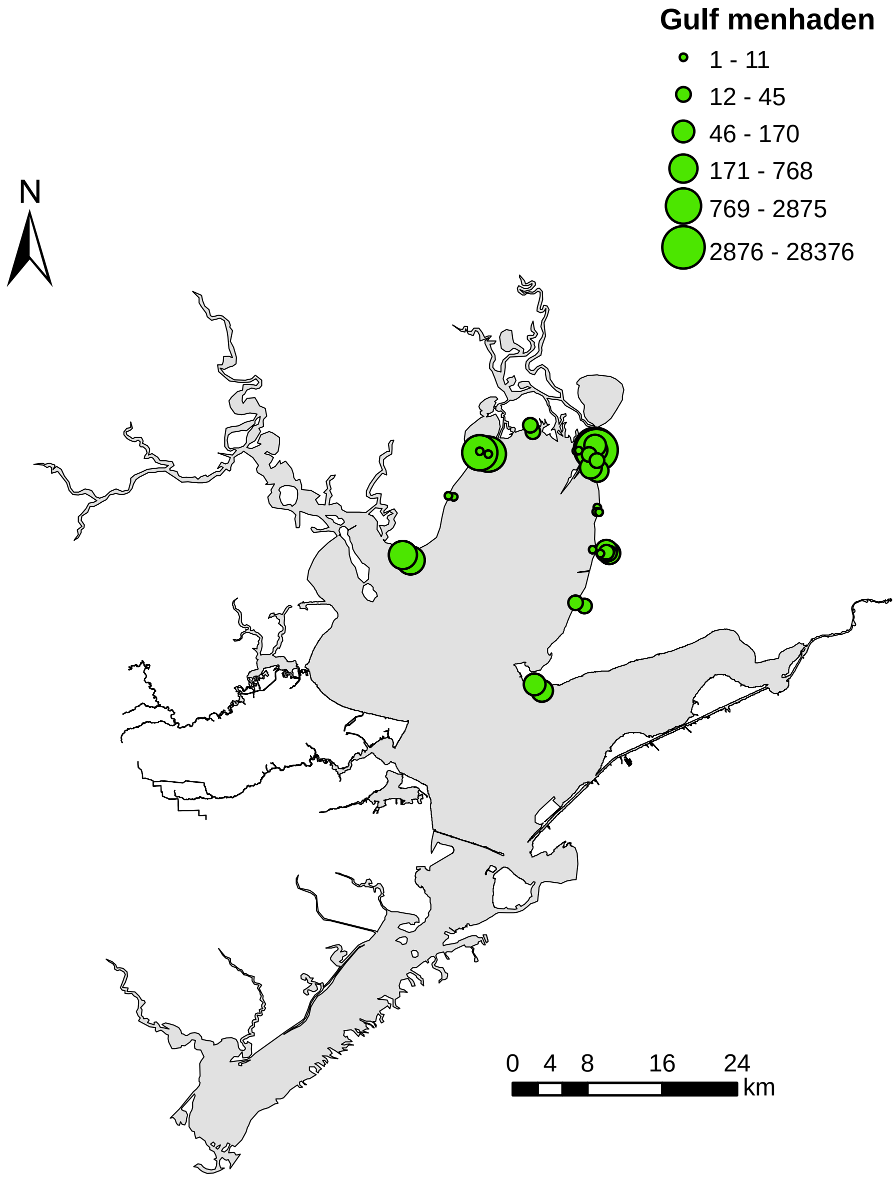

Figure 21 Distribution of each Gulf menhaden collected with the bag seine 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

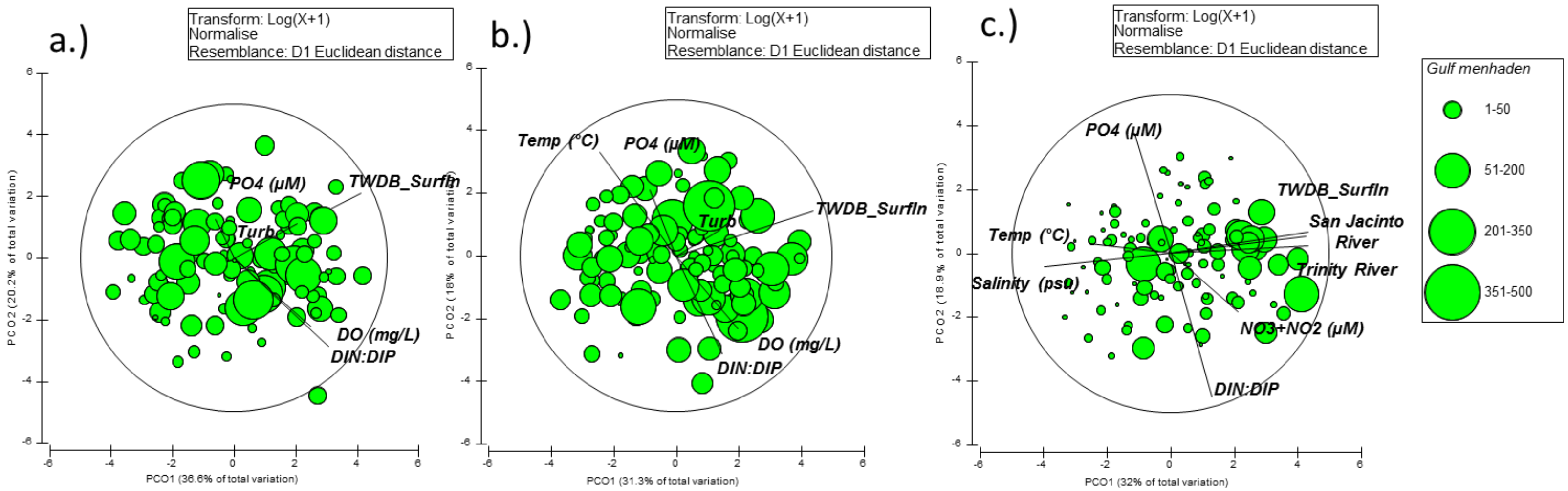

Figure 22 PCO of environmental data with the bubble underlay showing abundance of Gulf menhaden collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Gulf menhaden abundance in each respective segment.

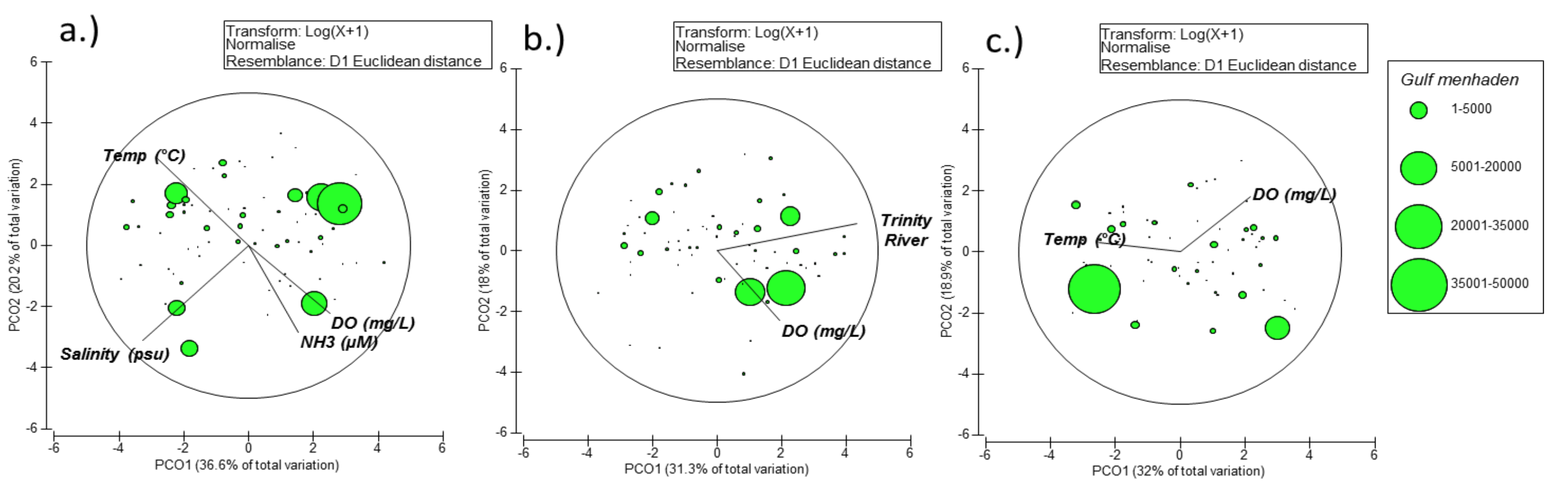

Figure 23 PCO of environmental data with the bubble underlay showing abundance of Gulf menhaden collected in the TPWD bag seine for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Gulf menhaden abundance in each respective segment.

Table 12 Correlation between the abundance of each Gulf menhaden to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM test of each Gulf menhaden within all segments from organisms collected with the TPWD bay trawl and bag seine.

Subbay - Gear Type	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	1667.00	2.52	0.0831	0.02	278.90	0.37	0.6914	0.01	457.47	0.71	0.4928	0.02	2071.90	3.35	0.0542	0.10	4317.70	8.43	**0.0257**	0.23
Bay trawl	**DO (mg/L)**	9306.90	15.54	**0.0001**	0.11	1630.80	2.32	0.1020	0.07	547.97	0.86	0.4289	0.03	8763.20	22.57	**0.0002**	0.44	1955.90	3.29	**0.0488**	0.10
	Salinity (psu)	340.86	0.51	0.5795	0.00	698.07	0.95	0.3829	0.03	721.41	1.14	0.3210	0.04	837.07	1.27	0.2672	0.04	890.08	1.41	0.2214	0.05
	Turb (NTU)	5980.90	9.55	**0.0005**	0.07	686.24	0.93	0.3860	0.03	2817.40	5.03	**0.0135**	0.15	4755.20	9.03	**0.0011**	0.24	1357.40	2.21	0.1267	0.07
	NO_3+NO_2 (µM)	893.32	1.34	0.2584	0.01	551.89	0.74	0.4839	0.03	2521.50	4.42	**0.0168**	0.13	761.83	1.15	0.2346	0.04	113.87	0.17	0.8078	0.01
	NH_3 (µM)	54.62	0.08	0.9357	0.00	599.81	0.81	0.4225	0.03	141.02	0.22	0.8151	0.01	944.52	1.44	0.2295	0.05	455.23	0.71	0.4562	0.02
	PO_4 (µM)	11006.00	18.81	**0.0001**	0.13	4157.50	6.74	**0.0041**	0.19	1481.20	2.44	0.1006	0.08	8629.80	21.97	**0.0001**	0.43	1458.10	2.39	0.1088	0.08
	N:P	4100.50	6.39	**0.0044**	0.05	3730.20	5.90	**0.0091**	0.17	1698.60	2.84	0.0755	0.09	1762.20	2.80	0.0721	0.09	943.39	1.50	0.2235	0.05
	Surf. In. (ac-ft/mon^{-1})	2610.70	3.99	**0.0290**	0.03	3444.40	5.37	**0.0103**	0.16	527.36	0.83	0.4118	0.03	413.08	0.61	0.5241	0.02	104.45	0.16	0.8645	0.01
	TR (cfs)	754.07	1.13	0.3050	0.01	2890.90	4.38	**0.0194**	0.13	230.11	0.35	0.7011	0.01	995.46	1.52	0.2083	0.05	7.58	0.01	0.9965	0.00
	SJR (cfs)	81.77	0.12	0.8943	0.00	2980.60	4.53	**0.0196**	0.14	172.60	0.26	0.7801	0.01	383.68	0.57	0.5380	0.02	103.36	0.16	0.8637	0.01
TB	**Temp (°C)**	15601.00	9.06	**0.0004**	0.07	n/a	n/a	n/a	n/a	1053.40	0.47	0.6654	0.02	2268.20	1.22	0.2832	0.04	1936.10	1.31	0.2627	0.04
Bag seine	**DO (mg/L)**	17390.00	10.18	**0.0001**	0.08	n/a	n/a	n/a	n/a	1781.30	0.81	0.4566	0.03	6051.50	3.49	**0.0271**	0.11	1242.00	0.83	0.3995	0.03
	Salinity (psu)	6664.70	3.71	**0.0246**	0.03	n/a	n/a	n/a	n/a	3549.20	1.65	0.1803	0.05	1627.70	0.86	0.4221	0.03	400.55	0.26	0.7523	0.01
	Turb (NTU)	918.66	0.50	0.6251	0.00	n/a	n/a	n/a	n/a	1314.40	0.59	0.5797	0.02	714.82	0.37	0.7126	0.01	70.95	0.05	0.9690	0.00
	NO_3+NO_2 (µM)	527.56	0.29	0.7959	0.00	n/a	n/a	n/a	n/a	886.03	0.40	0.7218	0.01	2208.10	1.18	0.3141	0.04	292.31	0.19	0.8170	0.01
	NH_3 (µM)	15447.00	8.96	**0.0004**	0.07	n/a	n/a	n/a	n/a	5015.10	2.39	0.0861	0.08	9140.00	5.62	**0.0049**	0.16	1687.70	1.14	0.3036	0.04
	PO_4 (µM)	2823.50	1.55	0.2011	0.01	n/a	n/a	n/a	n/a	1199.30	0.54	0.6161	0.02	4605.00	2.58	0.0771	0.08	3384.30	2.38	0.1125	0.08
	N:P	2939.00	1.61	0.1872	0.01	n/a	n/a	n/a	n/a	1745.20	0.79	0.4680	0.03	1766.20	0.94	0.3795	0.03	323.52	0.21	0.8000	0.01
	Surf. In. (ac-ft/mon^{-1})	2293.20	1.25	0.2703	0.01	n/a	n/a	n/a	n/a	1026.70	0.46	0.6805	0.02	405.40	0.21	0.8564	0.01	450.94	0.30	0.7155	0.01
	TR (cfs)	3344.20	1.83	0.1486	0.01	n/a	n/a	n/a	n/a	2771.00	1.27	0.2787	0.04	1421.80	0.75	0.4797	0.03	2137.40	1.46	0.2191	0.05
	SJR (cfs)	1437.20	0.78	0.4543	0.01	n/a	n/a	n/a	n/a	2367.00	1.08	0.3443	0.04	3097.50	1.69	0.1847	0.06	61.33	0.04	0.9794	0.00
UGB	**Temp (°C)**	2014.20	3.09	**0.0494**	0.02	1318.90	2.00	0.1447	0.06	746.58	1.24	0.2888	0.04	1290.20	1.95	0.1350	0.06	340.05	0.52	0.5248	0.02
Bay Trawl	**DO (mg/L)**	3168.10	4.94	**0.0121**	0.04	787.66	1.16	0.2812	0.04	2844.80	5.39	**0.0199**	**0.16**	5723.30	11.27	**0.0005**	0.28	875.64	1.37	0.2384	0.05
	Salinity (psu)	853.71	1.29	0.2683	0.01	884.98	1.31	0.2582	0.04	674.66	1.12	0.3272	0.04	770.85	1.14	0.3215	0.04	452.36	0.69	0.4649	0.02
	Turb (NTU)	3425.70	5.36	**0.0091**	0.04	1759.90	2.74	0.0775	0.09	53.87	0.09	0.9311	**0.00**	580.62	0.85	0.4151	0.03	1984.10	3.31	**0.0491**	0.10
	NO_3+NO_2 (µM)	1211.10	1.84	0.1572	0.01	905.26	1.35	0.2542	0.04	1166.30	1.99	0.1421	0.06	825.90	1.22	0.2928	0.04	257.67	0.39	0.6564	0.01
	NH_3 (µM)	139.08	0.21	0.8071	0.00	56.78	0.08	0.9404	0.00	455.35	0.75	0.4584	0.03	143.42	0.20	0.8124	0.01	455.23	0.70	0.4851	0.02
	PO_4 (µM)	4793.10	7.63	**0.0012**	0.06	101.29	0.15	0.8848	0.00	2579.80	4.80	**0.0171**	**0.14**	3053.50	5.09	**0.0084**	0.15	1927.30	3.21	0.0535	0.10
	N:P	3089.40	4.81	**0.0136**	0.04	359.67	0.52	0.5742	0.02	2381.20	4.38	**0.0181**	0.13	631.00	0.92	0.3744	0.03	952.95	1.50	0.2209	0.05
	Surf. In. (ac-ft/mon^{-1})	2619.00	4.05	**0.0271**	0.03	2608.40	4.25	**0.0254**	0.13	576.37	0.95	0.3521	0.03	1122.80	1.68	0.1859	0.05	52.99	0.08	0.9348	0.00
	TR (cfs)	754.22	1.14	0.3066	0.01	2702.00	4.43	**0.0247**	0.13	100.46	0.16	0.8606	0.01	1191.40	1.79	0.1652	0.06	37.05	0.06	0.9548	0.00
	SJR (cfs)	822.94	1.25	0.2846	0.01	2681.50	4.39	**0.0230**	0.13	11.17	0.02	0.9920	0.00	285.12	0.41	0.6846	0.01	134.76	0.20	0.8133	0.01
UGB	**Temp (°C)**	2607.80	1.64	0.1888	0.01	1318.90	2.00	0.1447	0.06	363.94	0.18	0.9028	0.01	1870.00	1.21	0.3046	0.04	1564.50	1.49	0.2246	0.05
Bag Seine	**DO (mg/L)**	4723.30	3.01	**0.0482**	0.02	787.66	1.16	0.2812	0.04	441.49	0.22	0.8654	0.01	7571.70	5.61	**0.0101**	0.16	244.09	0.22	0.7815	0.01
	Salinity (psu)	4278.70	2.72	0.0644	0.02	884.98	1.31	0.2582	0.04	754.65	0.37	0.7419	0.01	526.72	0.33	0.6983	0.01	34.25	0.03	0.9820	0.00
	Turb (NTU)	1527.70	0.96	0.3651	0.01	1759.90	2.74	0.0775	0.09	3360.20	1.74	0.1693	0.06	2598.50	1.71	0.1832	0.06	411.81	0.38	0.6566	0.01
	NO_3+NO_2 (µM)	647.47	0.40	0.6875	0.00	905.26	1.35	0.2540	0.04	1292.50	0.65	0.5456	0.02	137.20	0.09	0.9350	0.00	141.42	0.13	0.8890	0.00
	NH_3 (µM)	1447.60	0.91	0.3905	0.01	56.78	0.08	0.9404	0.00	6993.30	3.88	**0.0233**	0.12	815.26	0.52	0.5841	0.02	683.12	0.63	0.4974	0.02
	PO_4 (µM)	4297.30	2.73	0.0635	0.02	101.29	0.14	0.8848	0.00	1849.90	0.94	0.4001	0.03	1984.90	1.29	0.2641	0.04	29.57	0.03	0.9920	0.00
	N:P	3901.30	2.48	0.0814	0.02	359.67	0.52	0.5742	0.02	2058.60	1.04	0.3450	0.03	509.07	0.32	0.7122	0.01	166.11	0.15	0.8683	0.01
	Surf. In. (ac-ft/mon^{-1})	2550.00	1.61	0.1807	0.01	2608.40	4.25	**0.0254**	0.13	1069.20	0.53	0.6309	0.02	846.61	0.54	0.5563	0.02	279.54	0.25	0.7674	0.01
	TR (cfs)	5164.00	3.30	**0.0380**	0.03	2702.00	4.43	**0.0247**	0.13	610.51	0.30	0.8015	0.01	932.99	0.59	0.5400	0.02	869.74	0.81	0.4048	0.03
	SJR (cfs)	97.84	0.06	0.9794	0.00	2681.50	4.39	**0.0230**	0.13	850.97	0.42	0.7093	0.01	351.23	0.22	0.8015	0.01	472.20	0.43	0.6182	0.01
LGB	**Temp (°C)**	6278.20	7.96	**0.0017**	0.06	6321.70	8.46	**0.0020**	0.23	8792.80	15.17	**0.0004**	0.34	4077.20	7.36	**0.0040**	0.20	2141.10	3.37	0.0556	0.10
Bay Trawl	**DO (mg/L)**	1761.40	2.13	0.1216	0.02	103.44	0.11	0.8990	0.00	169.55	0.19	0.8061	0.01	3726.60	6.59	**0.0073**	0.19	1875.90	2.91	0.0781	0.09
	Salinity (psu)	9612.10	12.63	**0.0001**	0.09	3150.50	3.68	**0.0452**	0.11	4441.70	6.09	**0.0083**	0.17	618.73	0.92	0.3760	0.03	347.65	0.50	0.5643	0.02
	Turb (NTU)	67.85	0.08	0.9320	0.00	188.24	0.20	0.8149	0.01	236.23	0.27	0.7452	0.01	787.40	1.18	0.2974	0.04	23.74	0.03	0.9730	0.00
	NO_3+NO_2 (µM)	3839.10	4.75	**0.0172**	0.04	339.80	0.36	0.6681	0.01	1072.00	1.27	0.2676	0.04	871.85	1.31	0.2576	0.04	1261.20	1.89	0.1598	0.06
	NH_3 (µM)	369.03	0.44	0.6100	0.00	109.79	0.11	0.8872	0.00	30.43	0.03	0.9783	0.00	496.36	0.73	0.4486	0.02	1336.30	2.01	0.1470	0.07
	PO_4 (µM)	7990.90	10.32	**0.0006**	0.08	657.15	0.70	0.4697	0.02	4206.90	5.70	**0.0116**	0.16	3368.10	5.83	**0.0077**	0.17	1408.00	2.13	0.1318	0.07
	N:P	6230.60	7.90	**0.0017**	0.06	337.85	0.35	0.6828	0.01	2576.10	3.24	0.0607	0.10	2703.30	4.50	**0.0252**	0.13	1948.00	3.03	0.0628	0.09
	Surf. In. (ac-ft/mon^{-1})	11427.00	15.31	**0.0002**	0.11	4208.50	5.13	**0.0160**	0.15	2758.60	3.50	**0.0527**	0.11	2242.00	3.63	**0.0425**	0.11	600.88	0.87	0.3916	0.03
	TR (cfs)	7678.60	9.88	**0.0008**	0.07	3558.90	4.23	**0.0278**	0.13	1601.50	1.93	0.1478	0.06	1250.00	1.92	0.1528	0.06	394.12	0.57	0.5360	0.02
	SJR (cfs)	4929.80	6.16	**0.0068**	0.05	5464.70	7.04	**0.0056**	0.20	2284.30	2.84	0.0751	0.09	73.07	0.11	0.9206	0.00	201.28	0.29	0.7312	0.01
LGB	**Temp (°C)**	9942.20	6.42	**0.0038**	0.05	1268.40	1.11	0.3119	0.04	2129.50	1.09	0.3292	0.04	2244.70	1.24	0.2894	0.04	114.81	0.13	0.8397	0.00
Bag Seine	**DO (mg/L)**	12110.00	7.91	**0.0012**	0.06	354.72	0.30	0.7285	0.01	1076.40	0.54	0.5965	0.02	2225.20	1.23	0.2917	0.04	590.99	0.69	0.4317	0.02
	Salinity (psu)	4584.80	2.88	0.0596	0.02	410.94	0.35	0.6984	0.01	2106.30	1.07	0.3295	0.04	1646.00	0.90	0.4228	0.03	2558.60	3.25	0.0656	0.10
	Turb (NTU)	764.81	0.47	0.6211	0.00	31.19	0.03	0.9901	0.00	878.99	0.44	0.6533	0.01	1300.50	0.70	0.5035	0.02	218.76	0.25	0.7154	0.01
	NO_3+NO_2 (µM)	1306.50	0.81	0.4388	0.01	756.92	0.65	0.4964	0.02	1108.00	0.55	0.5920	0.02	3405.30	1.92	0.1403	0.06	4278.40	5.88	**0.0130**	0.17
	NH_3 (µM)	140.76	0.09	0.9560	0.00	3361.00	3.14	0.0616	0.10	1589.10	0.80	0.4371	0.03	379.37	0.20	0.8865	0.01	1253.00	1.51	0.2213	0.05
	PO_4 (µM)	2282.40	1.42	0.2199	0.01	264.92	0.23	0.7935	0.01	1037.40	0.52	0.6024	0.02	2019.50	1.11	0.3187	0.04	2273.90	2.86	0.0888	0.09
	N:P	997.71	0.61	0.5275	0.01	71.62	0.06	0.9592	0.00	1092.70	0.55	0.5722	0.02	3018.20	1.69	0.1763	0.06	61.38	0.07	0.9217	0.00
	Surf. In. (ac-ft/mon^{-1})	4027.70	2.52	0.0805	0.02	123.73	0.11	0.9199	0.00	4886.60	2.62	0.0787	0.08	1153.20	0.62	0.5552	0.02	1377.20	1.66	0.1960	0.05
	TR (cfs)	971.21	0.60	0.5430	0.00	138.24	0.12	0.9175	0.00	1268.40	0.64	0.5245	0.02	329.90	0.18	0.9010	0.01	1713.80	2.10	0.1407	0.07
	SJR (cfs)	437.19	0.27	0.7875	0.00	320.53	0.27	0.7673	0.01	2610.20	1.34	0.2456	0.04	603.39	0.32	0.7870	0.01	3332.40	4.39	**0.0318**	0.13

Pinfish (*Lagodon rhomboides*)

Pinfish were collected routinely across all 3 bay segments in the bay trawl and bag seine gear types (Figs. 24 and 25). Pinfish counts were lower in samples collected with the bay trawl compared to the bag seine (Figs. 24 and 25).

Both the visual display shown in the PCO (Fig. 26 and 26) and the test of significance run in the DISTLM (Table 13) showed the Pinfish abundance (bay trawl) in TB significantly correlated with dissolved oxygen (p<0.001) and temperature ((p<0.05) (Fig. 26a; Table 13). In UGB, the Pinfish abundance (bay trawl) was significantly correlated to increasing temperature (p<0.05), decreasing dissolved oxygen (p<0.01) and decreasing NH_3 (p<0.05) (Fig. 26b; Table 13). In LGB, Pinfish abundance was correlated to increasing temperature (p<0.05) and dissolved oxygen (p<0.05) (Fig. 26c; Table 13).

Bag seines collected along the shoreline typically target the smaller juvenile stage fish (TPWD, 2012). The Pinfish were collected in bag seines all 3 bay segments. In TB, Gulf menhaden (bag seine) showed an increase in abundance with increasing temperature (p<0.001), decreasing dissolved oxygen (p<0.001), NH_3 (p<0.01), DIN:DIP (p<0.01), SJR discharge (p<0.01),TR discharger (p<0.05) and NO_3^- + NO_2^- (p<0.05) (Fig. 27a; Table 13). In UGB Pinfish counts from the bag seines were correlated with temperature (p<0.001), SJR discharge (p<0.001), NO_3^- + NO_2^- (p<0.001), dissolved oxygen (p<0.01), DIN:DIP (p<0.01) and TR discharge (p<0.05) (Fig. 27b; Table 13). In LGB, Pinfish (bag seine) were correlated to temperature (p<0.05), turbidity (p<0.05) and DIN:DIP (p<0.05) (Fig. 27c; Table 13).

Seasonal trends were observed with increased Pinfish abundance and increasing DIN:DIP in the Fall in TB (Table 13). In UGB, during the summer there was an increase of Pinfish with decreasing dissolved oxygen. In the fall there was a positive correlation with Pinfish and TWDB surface inflow, Trinity and San Jacinto River discharges and decreasing PO4 (Table 13). In LGB there was a positive correlation between Pinfish and Trinity River discharge in the spring, decreasing NO2+NO3 in the summer and increasing dissolved oxygen in the fall (Table 13).

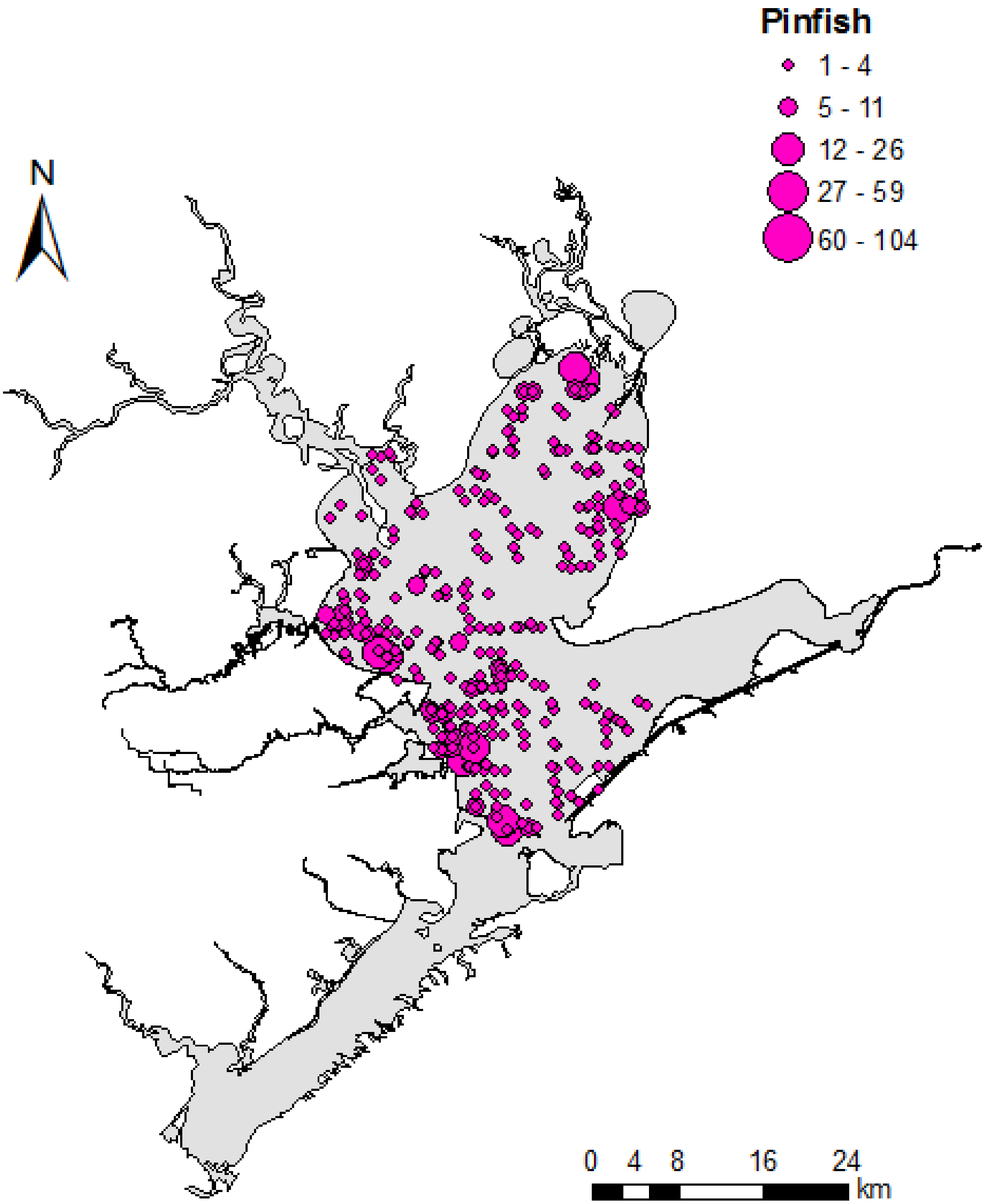

Figure 24 Distribution of Pinfish collected in the bay trawl from 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

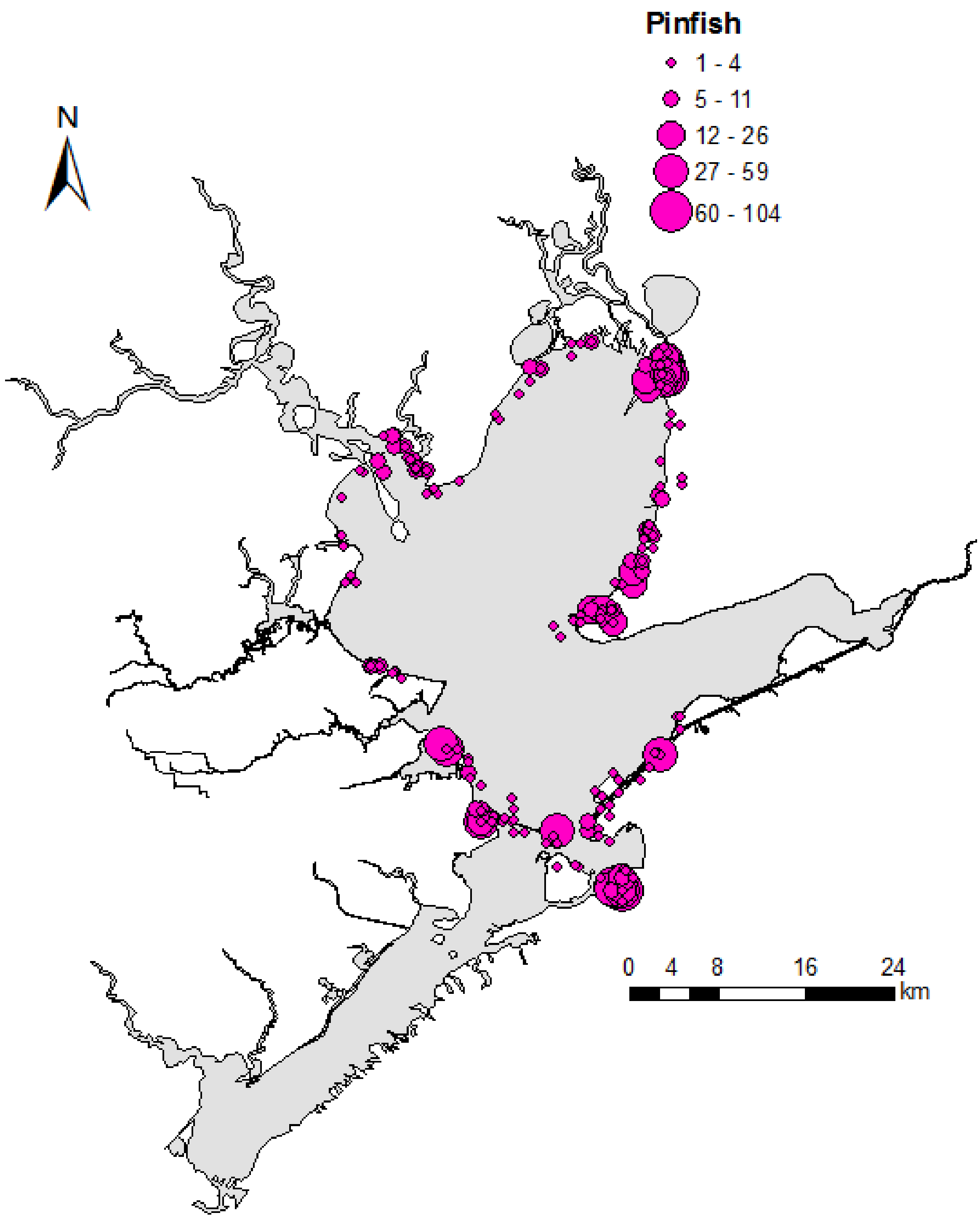

Figure 25 Distribution of Pinfish collected in the bag seine from 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

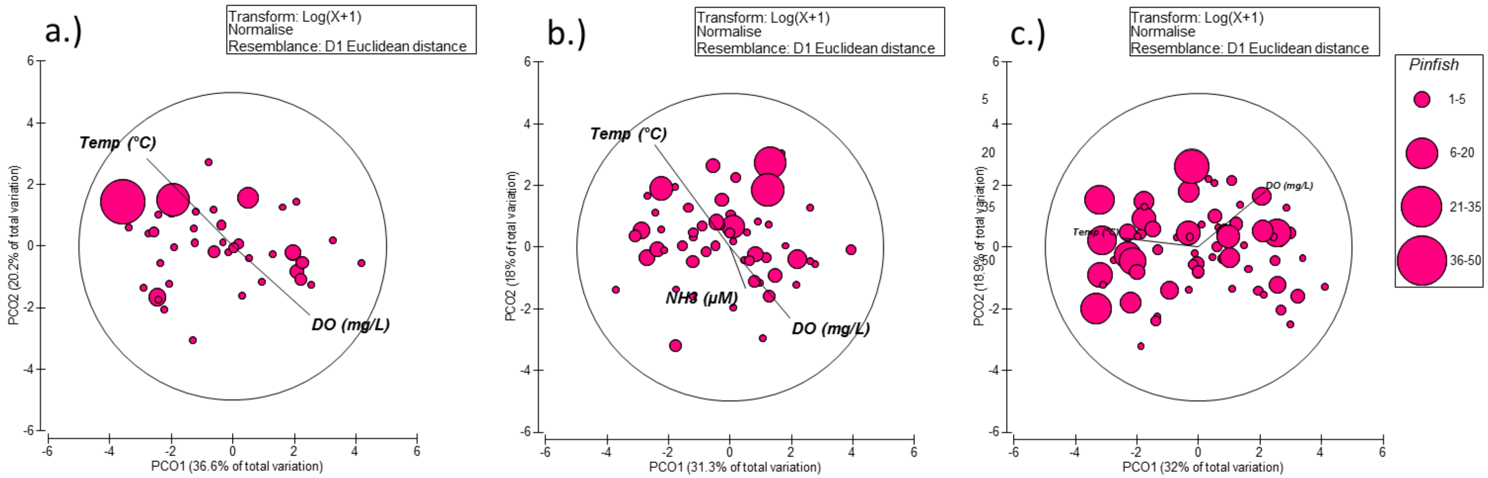

Figure 26 PCO of environmental data with the bubble underlay showing abundance of Pinfish collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Pinfish abundance in each respective segment.

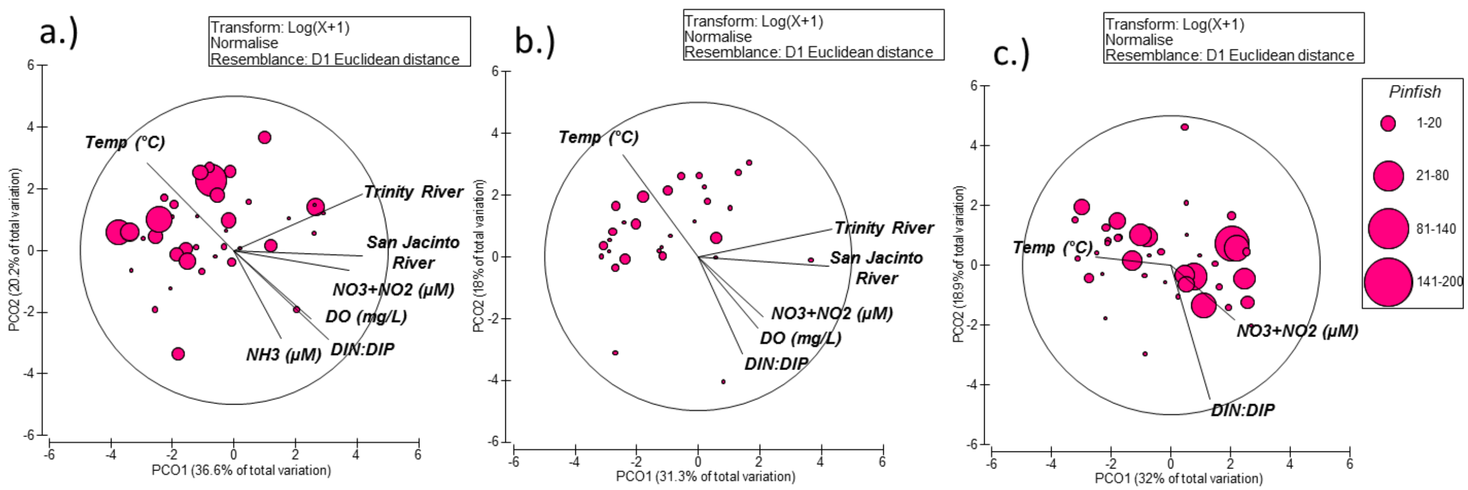

Figure 27 PCO of environmental data with the bubble underlay showing abundance of Pinfish collected in the TPWD bag seine for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Pinfish abundance in each respective segment.

Table 13 Correlation between the abundance of each Pinfish to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM test of Pinfish within all segments from organisms collected with the TPWD bay trawl (Gear Type 5) and bag seine (Gear Type 7).

Subbay - Gear Type	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	1498.70	3.97	**0.0438**	0.03	15.39	0.06	0.8574	0.00	26.10	0.17	0.6938	0.01	517.28	0.82	0.3861	0.03	194.49	0.50	0.6502	0.02
Bay trawl	**DO (mg/L)**	4050.90	11.36	**0.0006**	0.09	471.36	1.81	0.1808	0.06	234.19	1.63	0.2141	0.05	1440.80	2.42	0.1126	0.08	261.78	0.67	0.4293	0.02
	Salinity (psu)	977.30	2.56	0.1009	0.02	266.07	1.00	0.3343	0.03	368.79	2.65	0.1109	0.08	2517.10	4.50	**0.0299**	0.13	649.51	1.72	0.1999	0.06
	Turb (NTU)	1255.50	3.31	0.0612	0.03	844.56	3.42	0.0738	0.11	79.14	0.53	0.4752	0.02	435.54	0.69	0.4563	0.02	206.61	0.53	0.4750	0.02
	NO_3+NO_2 (µM)	341.37	0.88	0.3598	0.01	121.61	0.45	0.5133	0.02	27.86	0.18	0.6782	0.01	957.13	1.56	0.2063	0.05	651.78	1.73	0.2110	0.06
	NH_3 (µM)	228.66	0.59	0.4676	0.00	94.77	0.35	0.5720	0.01	461.63	3.39	0.0754	0.10	233.15	0.37	0.6232	0.01	1081.90	2.99	0.0910	0.09
	PO_4 (µM)	143.50	0.37	0.6010	0.00	98.39	0.36	0.5600	0.01	353.83	2.53	0.1236	0.08	1142.90	1.88	0.1718	0.06	932.59	2.54	0.1209	0.08
	N:P	127.26	0.33	0.6229	0.00	6.23	0.02	0.9155	0.00	1.49	0.01	0.9410	0.00	1215.00	2.01	0.1545	0.06	2436.80	7.73	**0.0091**	0.21
	Surf. In. (ac-ft/mon^{-1})	18.99	0.05	0.9281	0.00	558.33	2.17	0.1434	0.07	170.05	1.16	0.2671	0.04	334.98	0.53	0.5294	0.02	776.37	2.08	0.1593	0.07
	TR (cfs)	933.91	2.44	0.1083	0.02	663.13	2.62	0.1123	0.08	211.79	1.46	0.2352	0.05	163.47	0.26	0.7133	0.01	209.66	0.53	0.4688	0.02
	SJR (cfs)	294.13	0.76	0.3918	0.01	360.28	1.37	0.2479	0.05	463.50	3.41	0.0675	0.11	147.72	0.23	0.7506	0.01	853.05	2.31	0.1378	0.07
TB	**Temp (°C)**	15030.00	26.05	**0.0001**	0.18	80.72	1.17	0.2558	0.04	1520.80	2.18	0.1424	0.07	114.75	0.10	0.8712	0.00	122.02	0.44	0.4871	0.01
Bag Seine	**DO (mg/L)**	11249.00	18.50	**0.0001**	0.13	14.35	0.20	0.5510	0.01	3316.90	5.23	**0.0238**	0.15	190.50	0.17	0.8190	0.01	19.99	0.07	0.8405	0.00
	Salinity (psu)	25.74	0.04	0.9527	0.00	188.43	2.88	0.1652	0.09	2991.40	4.63	**0.0366**	0.14	48.62	0.04	0.9514	0.00	20.00	0.07	0.8369	0.00
	Turb (NTU)	165.75	0.24	0.7012	0.00	12.78	0.18	0.5491	0.01	676.53	0.93	0.3475	0.03	535.72	0.48	0.5392	0.02	8.39	0.03	0.9103	0.00
	NO_3+NO_2 (µM)	3174.80	4.71	**0.0264**	0.04	11.17	0.16	0.8734	0.01	1017.90	1.43	0.2369	0.05	316.39	0.28	0.7311	0.01	136.18	0.49	0.4769	0.02
	NH_3 (µM)	4614.70	6.97	**0.0074**	0.05	20.03	0.28	0.5915	0.01	37.29	0.05	0.9192	0.00	5794.10	6.16	0.0124	0.18	61.90	0.22	0.6654	0.01
	PO_4 (µM)	178.94	0.26	0.6874	0.00	95.43	1.39	0.2297	0.05	907.91	1.26	0.2550	0.04	2977.00	2.87	0.0880	0.09	20.80	0.07	0.8184	0.00
	N:P	5043.20	7.66	**0.0037**	0.06	130.24	1.93	0.1277	0.06	71.89	0.10	0.8609	0.00	1069.00	0.97	0.3412	0.03	0.40	0.00	0.9950	0.00
	Surf. In. (ac-ft/mon^{-1})	283.73	0.41	0.5692	0.00	382.09	6.51	**0.0292**	0.18	1551.00	2.23	0.1348	0.07	213.50	0.19	0.7725	0.01	202.80	0.73	0.4018	0.02
	TR (cfs)	3897.00	5.83	**0.0112**	0.05	241.01	3.79	0.0954	0.12	1306.10	1.86	0.1816	0.06	468.70	0.42	0.6005	0.01	83.59	0.30	0.6044	0.01
	SJR (cfs)	6986.20	10.87	**0.0010**	0.08	409.34	7.09	**0.0316**	0.20	2880.70	4.43	**0.0344**	0.13	368.65	0.33	0.6484	0.01	1.50	0.01	0.9839	0.00
UGB	**Temp (°C)**	2535.50	5.27	**0.0194**	0.04	397.23	1.00	0.3273	0.03	159.70	0.44	0.5073	**0.01**	47.47	0.08	0.8935	0.00	819.41	1.57	0.2171	0.05
Bay Trawl	**DO (mg/L)**	3695.70	7.84	**0.0044**	0.06	890.42	2.34	0.1358	0.07	107.65	0.29	0.5925	**0.01**	2445.70	4.54	**0.0348**	0.14	143.56	0.26	0.6926	0.01
	Salinity (psu)	382.11	0.77	0.3893	0.01	41.85	0.10	0.7951	0.00	13.05	0.04	0.8820	**0.00**	725.81	1.21	0.2758	0.04	841.71	1.61	0.2107	0.05
	Turb (NTU)	44.62	0.09	0.8506	0.00	1259.90	3.43	0.0705	0.11	1316.40	4.06	0.0529	0.12	641.83	1.07	0.3053	0.04	45.75	0.08	0.8795	0.00
	NO_3+NO_2 (µM)	550.22	1.11	0.2923	0.01	25.11	0.06	0.8642	0.00	34.17	0.09	0.7725	**0.00**	70.24	0.11	0.8396	0.00	313.76	0.58	0.4863	0.02
	NH_3 (µM)	2266.90	4.69	**0.0269**	0.04	843.93	2.21	0.1444	0.07	81.43	0.22	0.6480	**0.01**	99.76	0.16	0.7725	0.01	3873.70	9.27	**0.0036**	0.24
	PO_4 (µM)	40.38	0.08	0.8630	0.00	326.85	0.82	0.3665	0.03	272.62	0.76	0.3930	**0.03**	62.63	0.10	0.8498	0.00	34.81	0.06	0.9130	0.00
	N:P	273.02	0.55	0.4848	0.00	22.10	0.05	0.8769	0.00	237.11	0.66	0.4267	**0.02**	32.11	0.05	0.9202	0.00	253.09	0.47	0.5426	0.02
	Surf. In. (ac-ft/mon^{-1})	374.38	0.75	0.3911	0.01	160.48	0.40	0.5475	0.01	1.98	0.01	0.9724	**0.00**	116.75	0.19	0.7507	0.01	5299.40	14.37	**0.0003**	0.33
	TR (cfs)	41.39	0.08	0.8576	0.00	198.40	0.49	0.5002	0.02	22.82	0.06	0.8210	**0.00**	677.76	1.13	0.2877	0.04	3050.00	6.83	**0.0117**	0.19
	SJR (cfs)	54.10	0.11	0.8278	0.00	3.91	0.01	0.9783	0.00	254.96	0.71	0.4125	**0.02**	464.80	0.77	0.3929	0.03	4815.20	12.49	**0.0009**	0.30
UGB	**Temp (°C)**	7258.50	21.06	**0.0001**	0.15	13.53	0.37	0.4160	0.01	112.60	0.25	0.6423	0.01	111.88	0.17	0.7629	0.01	34.61	0.17	0.6640	0.01
Bag Seine	**DO (mg/L)**	2875.50	7.56	**0.0078**	0.06	0.92	0.02	0.9368	0.00	37.98	0.09	0.7989	0.00	173.33	0.27	0.6402	0.01	22.44	0.11	0.7671	0.00
	Salinity (psu)	224.59	0.56	0.4635	0.00	40.42	1.13	0.3552	0.04	1997.20	5.30	**0.0278**	0.15	350.54	0.55	0.4673	0.02	200.79	0.99	0.3268	0.03
	Turb (NTU)	159.40	0.40	0.5346	0.00	29.54	0.82	0.4560	0.03	808.15	1.93	0.1737	0.06	354.41	0.55	0.4702	0.02	0.72	0.00	0.9857	0.00
	NO_3+NO_2 (µM)	5466.20	15.21	**0.0004**	0.11	2.41	0.07	0.9012	0.00	1195.00	2.95	0.0904	0.09	60.11	0.09	0.8201	0.00	1126.90	6.61	**0.0155**	0.19
	NH_3 (µM)	156.34	0.39	0.5531	0.00	364.05	14.80	**0.0368**	0.34	4.46	0.01	0.9777	0.00	1413.20	2.35	0.1300	0.07	670.89	3.60	0.0665	0.11
	PO_4 (µM)	1002.20	2.53	0.1044	0.02	7.00	0.19	0.5809	0.01	82.86	0.19	0.7001	0.01	82.84	0.13	0.7720	0.00	2.68	0.01	0.9520	0.00
	N:P	2625.50	6.86	**0.0092**	0.05	319.52	12.26	**0.0316**	0.30	175.66	0.40	0.5419	0.01	1614.60	2.71	0.1052	0.09	1587.50	10.26	**0.0034**	0.26
	Surf. In. (ac-ft/mon^{-1})	1240.40	3.15	0.0723	0.03	6.06	0.16	0.7381	0.01	2163.10	5.83	**0.0212**	0.17	142.44	0.22	0.6742	0.01	25.42	0.12	0.7422	0.00
	TR (cfs)	2392.70	6.22	**0.0136**	0.05	4.07	0.11	0.7400	0.00	1596.90	4.09	0.0510	0.12	61.47	0.09	0.8244	0.00	14.15	0.07	0.8205	0.00
	SJR (cfs)	6232.10	17.66	**0.0001**	0.13	0.22	0.01	0.9413	0.00	1117.60	2.74	0.1077	0.09	484.17	0.76	0.3840	0.03	173.58	0.85	0.3648	0.03
LGB	**Temp (°C)**	2469.50	3.99	**0.0401**	0.03	30.40	0.07	0.8620	0.00	34.87	0.09	0.7801	0.00	436.25	0.55	0.5104	0.02	367.65	0.58	0.4955	0.02
Bay Trawl	**DO (mg/L)**	3727.80	6.13	**0.0104**	0.05	178.00	0.39	0.5631	0.01	11.24	0.03	0.9036	0.00	1068.40	1.37	0.2679	0.05	2433.80	4.35	**0.0363**	0.13
	Salinity (psu)	270.09	0.42	0.5593	0.00	335.46	0.74	0.4017	0.02	1263.20	3.84	0.0607	0.12	275.60	0.34	0.5975	0.01	80.93	0.13	0.8479	0.00
	Turb (NTU)	1206.60	1.92	0.1565	0.02	58.39	0.13	0.7775	0.00	232.47	0.64	0.4372	0.02	981.35	1.26	0.2733	0.04	70.95	0.11	0.8632	0.00
	NO_3+NO_2 (µM)	156.38	0.25	0.6927	0.00	1.33	0.00	0.9950	0.00	273.53	0.75	0.4048	0.03	2861.90	4.00	**0.0498**	0.12	173.08	0.27	0.7101	0.01
	NH_3 (µM)	727.90	1.15	0.2881	0.01	1179.30	2.77	0.0998	0.09	7.09	0.02	0.9347	0.00	2222.40	3.01	0.0831	0.09	350.82	0.56	0.5171	0.02
	PO_4 (µM)	506.98	0.80	0.3816	0.01	436.40	0.97	0.3306	0.03	80.26	0.22	0.6559	0.01	137.84	0.17	0.7488	0.01	597.09	0.96	0.3501	0.03
	N:P	521.23	0.82	0.3748	0.01	123.96	0.27	0.6233	0.01	8.48	0.02	0.9254	0.00	278.16	0.35	0.5965	0.01	448.42	0.71	0.4327	0.02
	Surf. In. (ac-ft/mon^{-1})	291.03	0.46	0.5387	0.00	546.80	1.22	0.2664	0.04	1043.70	3.10	0.0848	0.10	405.96	0.51	0.5033	0.02	30.40	0.05	0.9401	0.00
	TR (cfs)	1098.00	1.74	0.1833	0.01	710.81	1.61	0.2096	0.05	1385.50	4.26	**0.0499**	0.13	1156.70	1.49	0.2260	0.05	45.81	0.07	0.9032	0.00
	SJR (cfs)	547.59	0.86	0.3665	0.01	185.39	0.40	0.5527	0.01	596.27	1.69	0.2058	0.06	2285.40	3.11	0.0826	0.10	231.19	0.36	0.6330	0.01
LGB	**Temp (°C)**	5377.10	7.52	**0.0036**	0.06	5377.10	7.52	**0.0049**	0.06	375.81	0.32	0.6555	0.01	211.70	0.30	0.6646	0.01	647.12	0.97	0.3378	0.03
Bag Seine	**DO (mg/L)**	1971.50	2.65	0.0889	0.02	1971.50	2.65	0.0883	0.02	4694.80	4.59	**0.0265**	0.14	750.51	1.09	0.3340	0.04	765.00	1.16	0.2958	0.04
	Salinity (psu)	364.50	0.48	0.5464	0.00	364.50	0.48	0.5338	0.00	154.61	0.13	0.8410	0.00	223.87	0.32	0.6512	0.01	1281.00	1.99	0.1620	0.06
	Turb (NTU)	2653.70	3.60	**0.0473**	0.03	2653.70	3.60	**0.0477**	0.03	7338.40	7.87	**0.0033**	0.21	708.05	1.03	0.3234	0.03	382.19	0.57	0.4806	0.02
	NO_3+NO_2 (µM)	1922.90	2.59	0.0976	0.02	1922.90	2.59	0.0989	0.02	2503.90	2.28	0.1322	0.07	1193.00	1.77	0.1810	0.06	420.83	0.62	0.4597	0.02
	NH_3 (µM)	204.85	0.27	0.6949	0.00	204.85	0.27	0.6924	0.00	2352.20	2.13	0.1378	0.07	1033.80	1.52	0.2255	0.05	71.96	0.10	0.8510	0.00
	PO_4 (µM)	1380.80	1.85	0.1639	0.01	1380.80	1.85	0.1644	0.01	232.20	0.20	0.7748	0.01	2871.90	4.67	**0.0309**	0.14	318.36	0.47	0.5323	0.02
	N:P	2985.80	4.07	**0.0314**	0.03	2985.80	4.07	**0.0379**	0.03	2447.30	2.22	0.1346	0.07	3509.20	5.92	**0.0134**	0.17	19.25	0.03	0.9612	0.00
	Surf. In. (ac-ft/mon^{-1})	1788.90	2.40	0.1070	0.02	1788.90	2.40	0.1110	0.02	2257.70	2.04	0.1441	0.07	460.22	0.66	0.4381	0.02	1294.40	2.01	0.1568	0.06
	TR (cfs)	696.80	0.93	0.3532	0.01	745.18	0.99	0.3291	0.01	1767.70	1.57	0.2084	0.05	146.58	0.21	0.7380	0.01	883.04	1.34	0.2526	0.04
	SJR (cfs)	413.68	0.55	0.4950	0.00	338.29	0.45	0.5653	0.00	1515.10	1.34	0.2564	0.04	16.97	0.02	0.9688	0.00	2226.60	3.64	0.0528	0.11

Oyster drill (*Stramonita haemastoma floridana*)

The distribution of Oyster drills collected in the bay trawl samples and oyster dredge was primarily seen in UGB and LGB (Figs. 28 and 29 respectively). The number of Oyster drills collected during a sampling event using both the bay trawl and oyster dredge ranged from 0-18 individuals over the study period (Figs. 28 and 29). The bay trawl is not designed to specifically target Oyster drills and therefore the observed distribution may be skewed because of the sampling method. Oyster drills collected in the bay trawl were primarily located in LGB (Fig. 28). The oyster dredge is utilized to target oyster and is used over oyster reefs. Although the Oyster drill is still technically collected as by catch the oyster dredge should be a more direct sampling method compared to the bay trawl. Oyster drills were collected in the oyster dredge within both UGB and LGB (Figs. 28 and 29).

The PCO (Fig. 30 and 31) showed positive correlation with the Oyster drill (bay trawl and oyster dredge) abundance and temperatures and salinity but no significant correlations were observed in UGB (Fig. 30b and 31b; Table 14). In LGB, Oyster drills displayed a positive correlation between abundance (oyster dredge) and dissolved oxygen (p<0.05) as well as San Jacinto River discharge (p<0.05) (Fig. 31c; Table 14).

Seasonally in LGB there was a significant correlation in the increase in oyster drills with increasing salinity in the summer (Table 14).

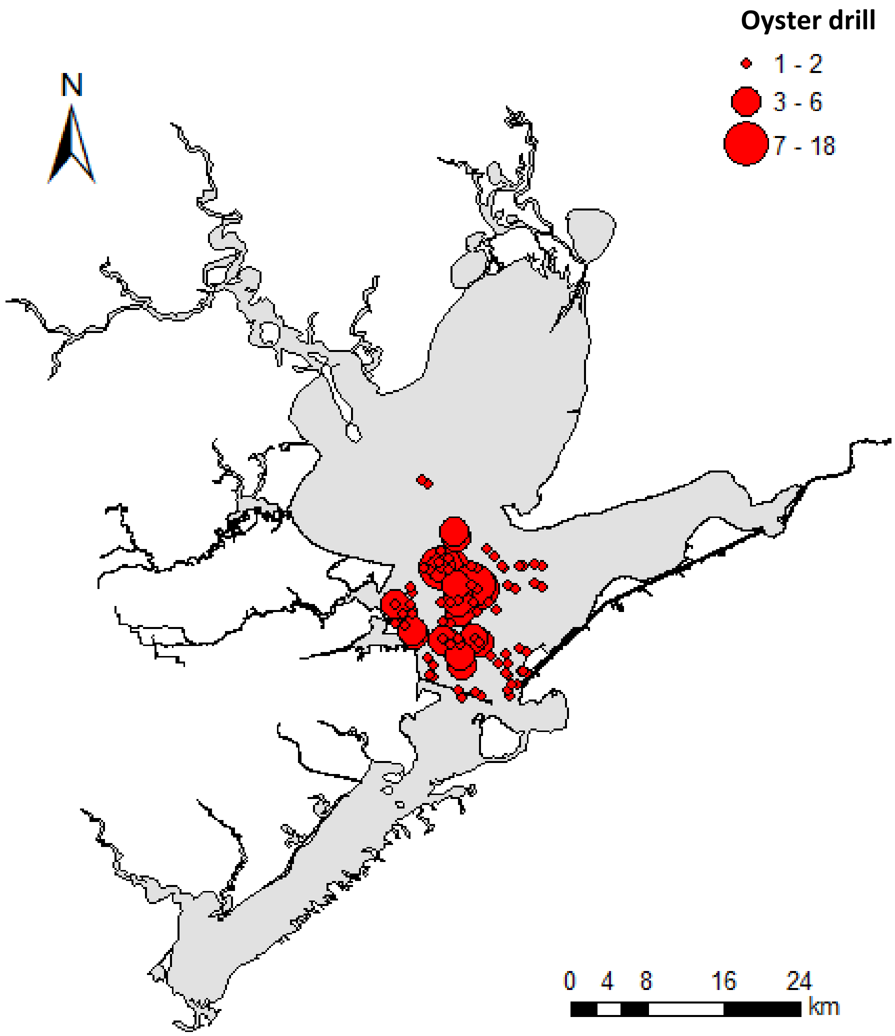

Figure 28 Distribution of Oyster drill collected in the bay trawl from 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

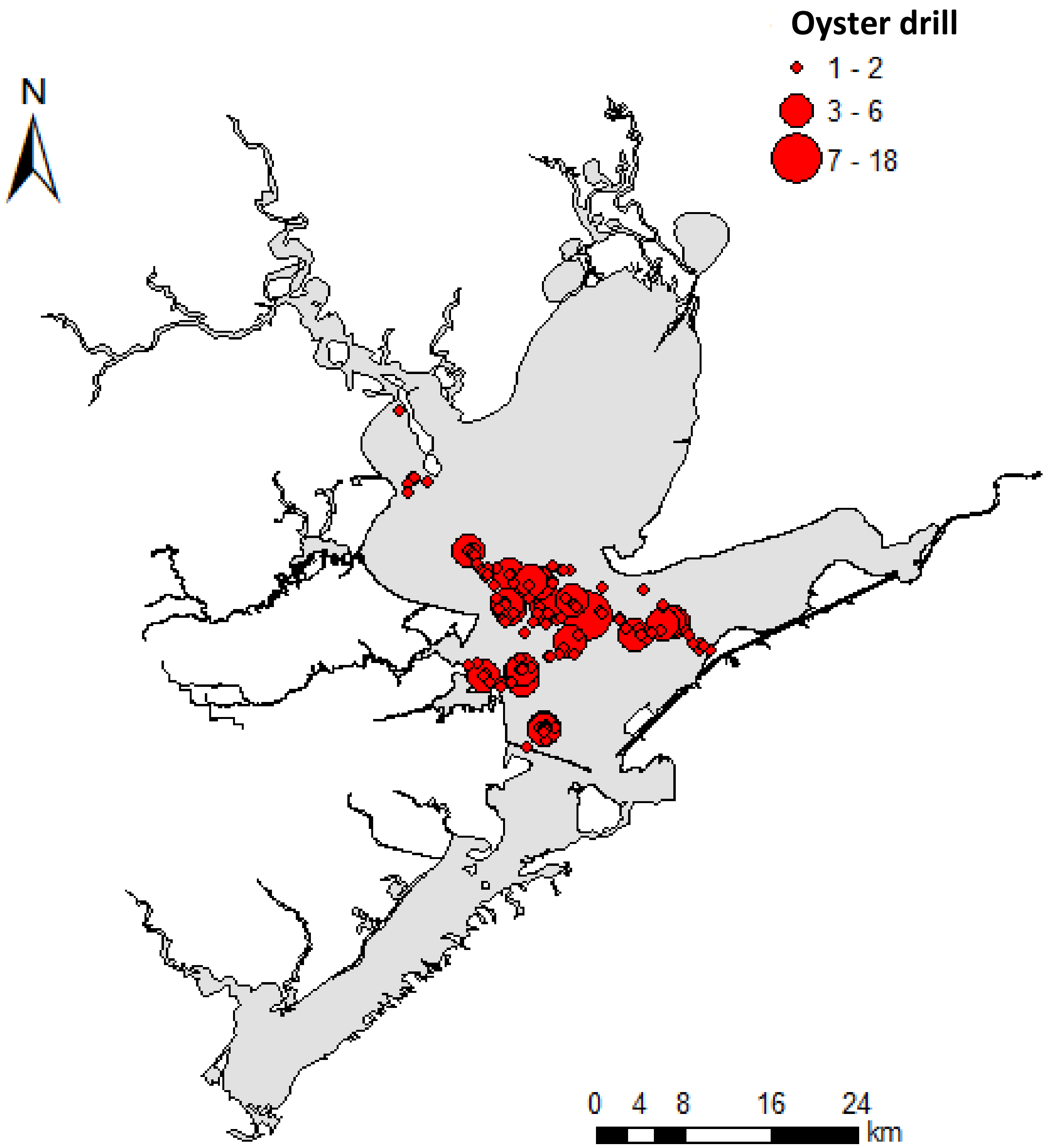

Figure 29 Distribution of Oyster drill collected in the oyster dredge from 1980-2010. Each bubble shows the abundance per sampling event (i.e. not a sum over seasons) within all 3 bay segments: TB, UGB and LGB.

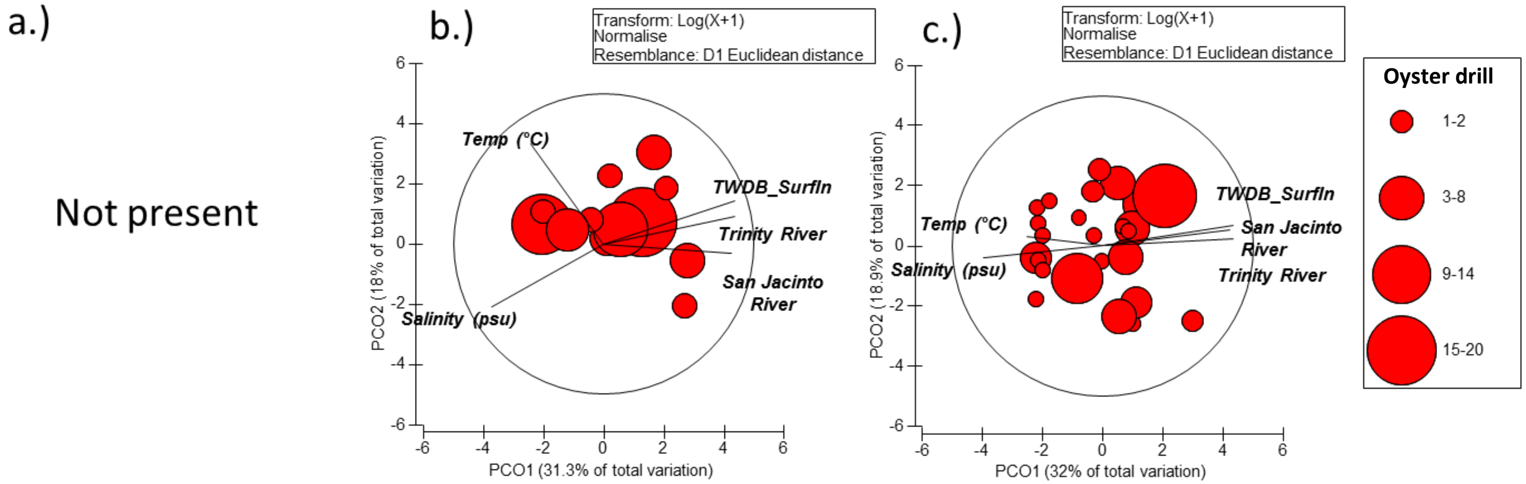

Figure 30 PCO of environmental data with the bubble underlay showing abundance of Oyster drills collected in the TPWD Bay trawl for a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Oyster drill.

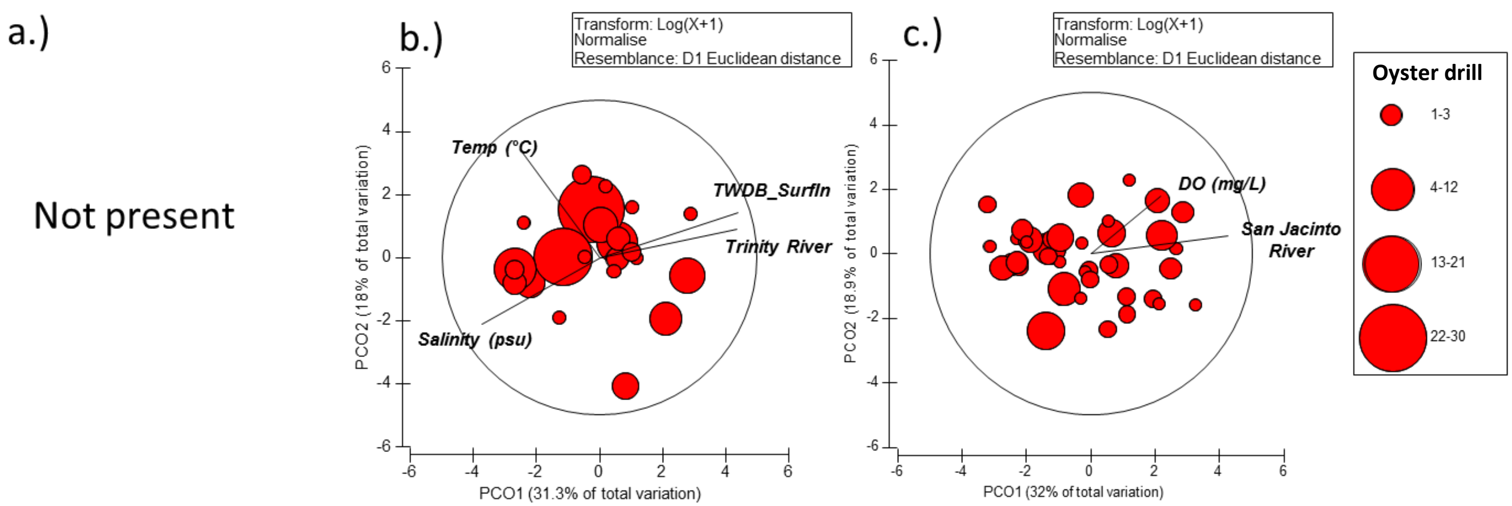

Figure 31 PCO of environmental data with the bubble underlay showing abundance of Oyster drills collected in the TPWD oyster dredge for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Oyster drill.

Table 14 Correlation between the abundance of each Oyster drill to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM test of Oyster drill within all segments from organisms collected with the TPWD bay trawl and oyster dredge.

Subbay -	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
Gear Type	Parameter	SS (Trace	PF	*p*	Prop.	SS (Trace	PF	*p*	Prop.	SS (Trace	PF	*p*	Prop.	SS (Trace	PF	*p*	Prop.	SS (Trace	PF	*p*	Prop.
TB	**Temp (°C)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bay Trawl	**DO (mg/L)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Salinity (psu)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Turb (NTU)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NO_3+NO_2 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PO_4 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N:P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Surf. In. (ac-ft/mon^{-1})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SJR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TB	**Temp (°C)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oyster	**DO (mg/L)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
dredge	**Salinity (psu)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Turb (NTU)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NO_3+NO_2 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NH_3 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PO_4 (µM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N:P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Surf. In. (ac-ft/mon^{-1})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SJR (cfs)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UGB	**Temp (°C)**	148.53	0.91	0.3448	0.01	20.84	0.23	0.5679	0.01	505.06	2.11	0.1568	0.07	666.95	3.04	0.1113	0.09	46.40	0.52	0.3818	0.02
Bay Trawl	**DO (mg/L)**	118.02	0.72	0.3977	0.01	162.51	1.90	0.1472	0.06	272.89	1.10	0.2619	0.04	102.61	0.43	0.5471	0.01	97.00	1.10	0.2879	0.04
	Salinity (psu)	227.34	1.40	0.2340	0.01	257.83	3.13	0.0875	0.10	144.60	0.57	0.4536	0.02	370.98	1.62	0.2128	0.05	0.67	0.01	0.9564	0.00
	Turb (NTU)	280.37	1.73	0.1882	0.01	231.65	2.78	0.0997	0.09	222.57	0.89	0.3534	0.03	91.83	0.38	0.5366	0.01	33.43	0.37	0.5638	0.01
	NO_3+NO_2 (µM)	7.19	0.04	0.8915	0.00	124.79	1.43	0.2511	0.05	111.76	0.44	0.5236	0.02	371.08	1.62	0.2105	0.05	128.00	1.47	0.2242	0.05
	NH_3 (µM)	17.57	0.11	0.7677	0.00	49.13	0.55	0.4746	0.02	326.42	1.33	0.2519	0.04	49.42	0.21	0.6337	0.01	0.12	0.00	0.9887	0.00
	PO_4 (µM)	417.72	2.59	0.1087	0.02	60.68	0.68	0.4274	0.02	706.07	3.04	0.0872	0.09	12.18	0.05	0.8741	0.00	1.79	0.02	0.9408	0.00
	N:P	417.79	2.59	0.1091	0.02	13.77	0.15	0.7108	0.01	840.16	3.68	0.0564	0.11	36.49	0.15	0.7053	0.01	94.71	1.08	0.3563	0.04
	Surf. In. (ac-ft/mon^{-1})	236.05	1.45	0.2304	0.01	87.53	0.99	0.3376	0.03	5.75	0.02	0.9267	0.00	158.21	0.67	0.4305	0.02	64.94	0.73	0.4188	0.02
	TR (cfs)	20.06	0.12	0.7595	0.00	25.39	0.28	0.6499	0.01	1.48	0.01	0.9854	0.00	26.68	0.11	0.7726	0.00	58.82	0.66	0.4471	0.02
	SJR (cfs)	45.52	0.28	0.6176	0.00	54.09	0.60	0.4560	0.02	17.08	0.07	0.8665	0.00	6.71	0.03	0.9163	0.00	190.52	2.25	0.1505	0.07
UGB	**Temp (°C)**	173.54	0.48	0.4956	0.00	2.29	0.01	0.9648	0.00	189.72	0.42	0.5517	0.01	731.52	1.78	0.1725	0.06	2.91	0.01	0.9599	0.00
Oyster	**DO (mg/L)**	36.09	0.10	0.8279	0.00	627.04	2.26	0.1105	0.07	4.30	0.01	0.9770	0.00	262.56	0.62	0.4600	0.02	4.66	0.02	0.9510	0.00
dredge	**Salinity (psu)**	174.47	0.49	0.5097	0.00	22.41	0.08	0.8162	0.00	390.68	0.87	0.3584	0.03	66.35	0.15	0.7980	0.01	209.31	0.70	0.4039	0.02
	Turb (NTU)	364.30	1.02	0.3097	0.01	11.23	0.04	0.8890	0.00	2605.20	7.03	**0.0107**	0.20	15.36	0.04	0.9447	0.00	6.43	0.02	0.9447	0.00
	NO_3+NO_2 (µM)	707.07	2.00	0.1577	0.02	157.83	0.54	0.4882	0.02	76.45	0.17	0.7581	0.01	540.95	1.30	0.2648	0.04	733.20	2.62	0.1136	0.08
	NH_3 (µM)	296.41	0.83	0.3585	0.01	552.24	1.97	0.1551	0.06	63.76	0.14	0.7734	0.00	143.80	0.33	0.5893	0.01	25.37	0.08	0.8108	0.00
	PO_4 (µM)	1081.20	3.08	0.0756	0.02	95.66	0.32	0.5888	0.01	802.29	1.85	0.1840	0.06	93.80	0.22	0.7349	0.01	365.17	1.25	0.2855	0.04
	N:P	14.12	0.04	0.9254	0.00	623.59	2.25	0.1370	0.07	620.86	1.41	0.2421	0.05	19.36	0.04	0.9271	0.00	138.89	0.46	0.5088	0.02
	Surf. In. (ac-ft/mon^{-1})	107.97	0.30	0.6159	0.00	20.05	0.07	0.8387	0.00	140.03	0.31	0.6120	0.01	28.19	0.06	0.9036	0.00	109.12	0.36	0.5652	0.01
	TR (cfs)	210.57	0.59	0.4598	0.00	11.70	0.04	0.8947	0.00	91.68	0.20	0.7127	0.01	5.26	0.01	0.9808	0.00	206.63	0.69	0.4306	0.02
	SJR (cfs)	32.01	0.09	0.8433	0.00	13.24	0.04	0.8956	0.00	14.27	0.03	0.9470	0.00	14.91	0.03	0.9540	0.00	24.46	0.08	0.8206	0.00
LGB	**Temp (°C)**	656.52	2.10	0.1418	0.02	1.95	0.03	0.8543	0.00	1.98	0.00	0.9907	0.00	692.71	2.16	0.1362	0.07	657.66	2.66	0.1082	0.08
Bay Trawl	**DO (mg/L)**	19.57	0.06	0.8708	0.00	8.92	0.13	0.6825	0.00	0.52	0.00	0.9984	0.00	100.44	0.29	0.6063	0.01	1194.50	5.23	0.0320	0.15
	Salinity (psu)	86.86	0.27	0.6360	0.00	65.47	0.94	0.3426	0.03	691.89	1.30	0.2666	0.04	1921.70	6.89	0.0126	0.19	208.57	0.80	0.3814	0.03
	Turb (NTU)	301.16	0.96	0.3345	0.01	15.86	0.22	0.6598	0.01	1183.80	2.30	**0.1411**	0.07	326.08	0.98	0.3392	0.03	45.64	0.17	0.6978	0.01
	NO_3+NO_2 (µM)	48.78	0.15	0.7501	0.00	4.36	0.06	0.8205	0.00	476.26	0.88	0.3645	0.03	376.56	1.13	0.2957	0.04	4.09	0.02	0.9507	0.00
	NH_3 (µM)	382.67	1.22	0.2653	0.01	412.04	7.17	**0.0241**	0.20	3126.40	6.97	0.0128	0.19	30.68	0.09	0.8503	0.00	129.14	0.49	0.5028	0.02
	PO_4 (µM)	512.28	1.63	0.2004	0.01	73.52	1.06	0.3154	0.04	161.21	0.29	0.6190	0.01	322.81	0.97	0.3331	0.03	708.40	2.89	0.1017	0.09
	N:P	1.82	0.01	0.9891	0.00	64.82	0.93	0.3570	0.03	951.23	1.82	0.1767	0.06	183.35	0.54	0.4908	0.02	337.27	1.31	0.2621	0.04
	Surf. In. (ac-ft/mon^{-1})	47.50	0.15	0.7581	0.00	189.72	2.91	0.0892	0.09	84.05	0.15	0.7279	0.01	563.86	1.73	0.1906	0.06	12.77	0.05	**0.8727**	0.00
	TR (cfs)	81.72	0.26	0.6436	0.00	174.38	2.66	0.1000	0.08	48.19	0.09	0.8241	0.00	418.89	1.27	0.2665	0.04	50.84	0.19	0.6899	0.01
	SJR (cfs)	42.48	0.13	0.7723	0.00	127.08	1.89	0.1614	0.06	88.98	0.16	0.7239	0.01	408.30	1.23	0.2751	0.04	12.14	0.05	0.8771	0.00
LGB	**Temp (°C)**	961.34	2.29	0.1299	0.02	707.74	3.40	0.0716	0.11	852.70	1.51	0.2420	0.05	287.93	0.56	0.4938	0.02	27.17	0.08	0.8027	0.00
Oyster	**DO (mg/L)**	2612.50	6.42	**0.0103**	0.05	432.88	1.99	0.1696	0.06	2043.50	3.90	0.0552	0.12	412.94	0.81	0.4323	0.03	997.90	3.28	0.0782	0.10
dredge	**Salinity (psu)**	0.27	0.00	0.9985	0.00	15.23	0.07	0.8176	0.00	394.96	0.68	0.4168	0.02	639.72	1.28	0.2700	0.04	321.55	0.98	0.3322	0.03
	Turb (NTU)	1020.80	2.43	0.1192	0.02	11.13	0.05	0.8493	0.00	769.32	1.36	0.2570	0.04	909.57	1.85	0.1821	0.06	565.32	1.77	0.1930	0.06
	NO_3+NO_2 (µM)	61.41	0.14	0.7323	0.00	28.22	0.12	0.7470	0.00	567.83	0.99	0.3464	0.03	836.02	1.69	0.2028	0.06	201.52	0.61	0.4577	0.02
	NH_3 (µM)	434.42	1.02	0.3231	0.01	329.55	1.49	0.2288	0.05	64.19	0.11	0.7698	0.00	920.66	1.88	0.1785	0.06	364.49	1.12	0.2996	0.04
	PO_4 (µM)	457.03	1.08	0.2974	0.01	8.88	0.04	0.8707	0.00	68.62	0.12	0.7609	0.00	54.66	0.11	0.7829	0.00	1009.90	3.32	0.0763	0.10
	N:P	107.52	0.25	0.6375	0.00	176.57	0.78	0.3942	0.03	31.28	0.05	0.8598	0.00	64.67	0.12	0.7600	0.00	6.10	0.02	0.9431	0.00
	Surf. In. (ac-ft/mon^{-1})	71.54	0.17	0.7132	0.00	132.47	0.58	0.4612	0.02	26.87	0.05	0.8820	0.00	101.43	0.20	0.6811	0.01	403.08	1.24	0.2704	0.04
	TR (cfs)	40.13	0.09	0.8052	0.00	40.30	0.17	0.7004	0.01	10.39	0.02	0.9486	0.00	308.26	0.60	0.4540	0.02	10.66	0.03	0.9059	0.00
	SJR (cfs)	1926.40	4.67	**0.0266**	0.04	94.87	0.41	0.5351	0.01	1438.10	2.64	0.1135	0.08	897.97	1.83	0.1797	0.06	479.79	1.49	0.2286	0.05

Dermo Disease (*Perkinsus marinus;* formerly *Dermocystidium marinum*) (1998-2010)

Oysters were collected from 1998-2010 at 7 reef systems in GB including: (TB) Fisher's reef, Redfish reef (UGB) and April Fool, Lease 403, Lease 415, Hannah's reef and Lease 301 (LGB) (Fig. 32; Table 15) by Dr. Sammy Ray (Texas A&M University at Galveston) and the data was posted to the Oyster Sentinel website (http://www.oystersentinel.org/). During each sampling event up to 30 oysters were collected at a time and then processed to determine the percent of juvenile (<3") and commercial (>3") sized oysters that were infected by the Dermo parasite. A subset of the water quality data that was averaged by season and bay segments for the BBEST – FWBI species was also used in conjunction with the Dermo infected oyster data (Fig. 33). The subset of water quality data was selected for the years in which oyster data was available 1998-2010.

We examined the abiotic environmental factors at the time of the oyster sampling (1998-2010) across the 3 bay segments (Fig. 33). In the winter and spring we saw an increase of TWDB surface inflow, TR and SJR discharge rate, turbidity, NO_3^- + NO_2^-, DIN:DIP and NH_3 (Fig. 33). During the summer and fall there was an increase in temperature, salinity and PO_4 (Fig. 33) relative to the rest of the year. More specifically, in Fig. 33a, PCO axis 1 (PCO1) explained 37.7% of the total variation and the PCO axis 2 (PCO2) explained 18.1% of the total variation (total = 55.8%). In TB the driver of PCO1 was river discharge and nutrients while PCO2 was explained by temperature, dissolved oxygen and salinity (Fig. 33a). In UGB, PCO1 explained 33.9% of the total variation and PCO2 19% (Fig. 33b). In Fig. 33b, PCO1 was predominantly explained by freshwater inflow including river discharge, salinity and PO_4 while along PCO2 data point placement is determined by temperature, dissolved oxygen and salinity. In LGB, PCO1 explained 36.6% of the total variation and is salinity, freshwater discharge and nutrients and PCO2 explained 17.4% of the total variation and is defined by temperature, dissolved oxygen and turbidity (Fig. 33c). Increased temperature and salinity were observed during the summer and fall seasons (Fig. 33). The vectors shown on the PCO for each size class of infected oysters corresponded to variables with a significant correlation to the infection rate (Figs. 35 and 36; Table 16).

By examining all the oysters in each size class for the entire study period of 1998 -2010 we found that typically the commercial sized oysters are more vulnerable to infection by Dermo compared to the juvenile sized oysters (Figs. 34 and 36). The overall percent of juvenile oysters infected at each of the reefs in GB was less than the percentage of commercial sized oysters infected by Dermo. In Figs. 34 and 36, we also show oysters found in east bay and west bay. It appears that regardless of size class, those in west bay were more likely to be infected with Dermo than those in east bay.

PCO results (Figs. 35 and 37) presented here were based on the environmental data (Fig. 33) with corresponding percent of juvenile and commercial sized infected oysters data. A DISTLM test was run for the juvenile size class of oysters and the commercial size oysters infected with Dermo to determine which of the environmental parameters had a significant correlation to the infection rate in oysters (Table 16). The vectors that correspond to the environmental parameters with a significant correlation (p<0.05) were shown in each of the bay segments.

The percentage of juvenile oysters in TB that had been infected with Dermo showed a significant correlation with decreasing TWDB surface inflow (p<0.001), increased salinity (p<0.05) and decreased TR discharge (p<0.05) (Fig. 35a; Table 16). In UGB juvenile size infected oysters were correlated to an increased temperature (p<0.001), decreased dissolved oxygen (p<0.001), and decreased $NO_3^- + NO_2^-$ (µM) (Fig. 35b; Table 16). In LGB juvenile sized oysters displayed a correlation with PO_4 (p<0.01) and DIN:DIP (p<0.05) (Fig. 35c; Table 16).

The percentage of infected commercial sized oysters in TB was significantly correlated to decreased TWDB surface inflow (p<0.05), salinity (p<0.05) and PO_4 (p<0.05) (Fig. 37a; Table 16). The increasing number of commercial size oysters infected with Dermo in UGB showed a significant correlation with increased temperature (p<0.001), decreased dissolved oxygen (p<0.001) and decreased $NO_3^- + NO_2^-$ (p<0.05) (Fig. 37b; Table 16). The number of infected commercial size oysters in LGB correlated with $NO_3^- + NO_2^-$ (p<0.05), NH_3 (p<0.05), PO_4 (p<0.05) and SJR discharge (p<0.05) (Fig. 37c; Table 16).

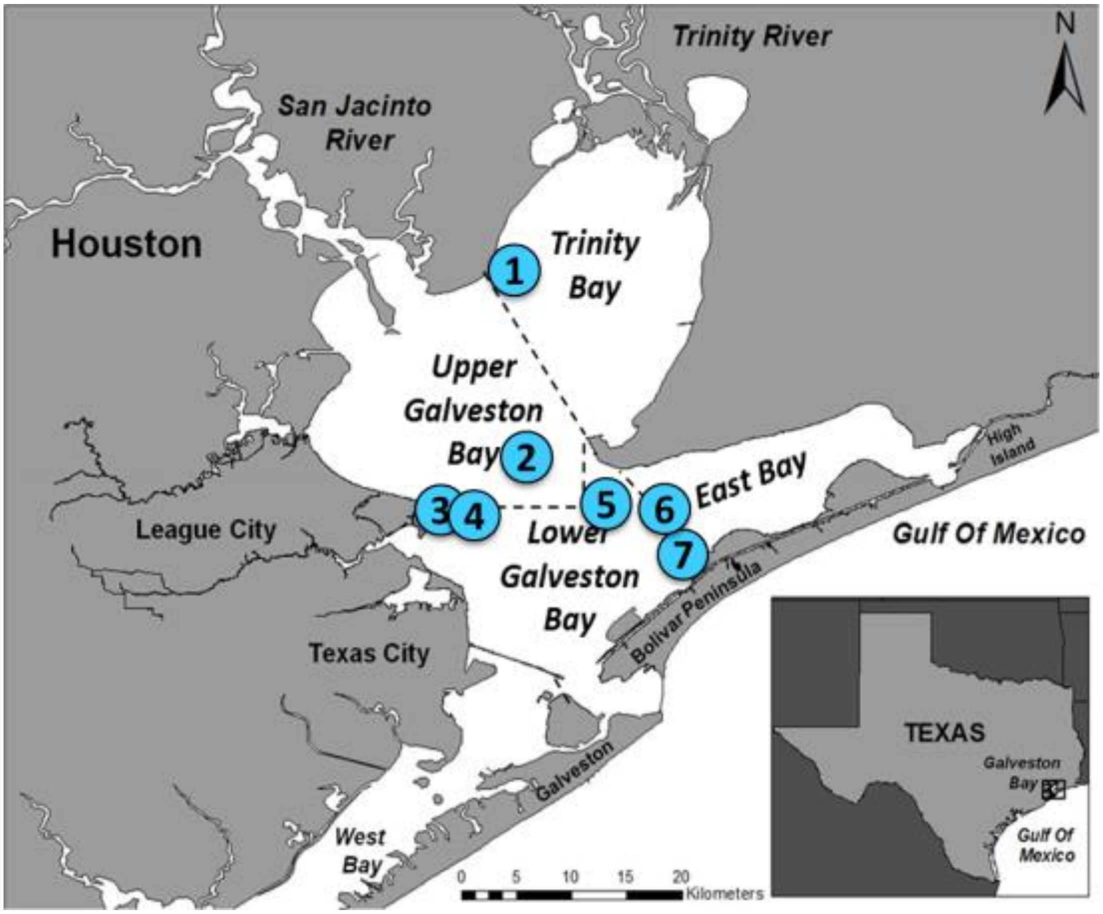

Figure 32 Locations of oyster reefs sampled for the infection of Dermo in juvenile (<3") and commercial (>3") size oysters. Numbers in blue circles correspond to reef name and location provided in Table 15 below.

Table 15 Specific location of oyster reefs sampled included name of reef, latitude and longitude of sample site and station number that corresponds to Fig. 33. *N* indicates the number of samples collected at that location during the study period of 1998-2010.

Station #	Name	*n*	Latitude	Longitude
1	Fishers Reef	37	29.6583	-94.8388
2	Redfish Reef	42	29.5167	-94.8431
3	April Fool Reef	45	29.4767	-94.9143
4	Lease 403	32	29.4722	-94.8886
5	Lease 415	34	29.4814	-94.7750
6	Hannah's Reef	45	29.4785	-94.7262
7	Lease 301	35	29.4468	-94.7097

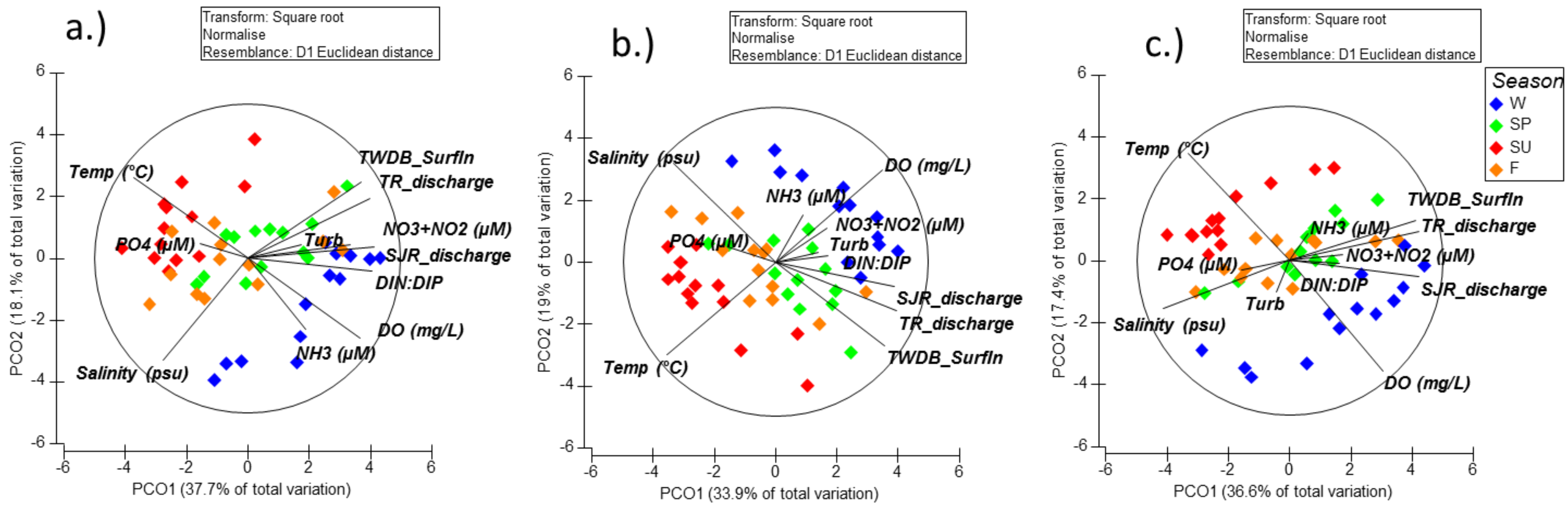

Figure 33 Principal coordinate ordination (PCO) of environmental data collected at the time of oyster collection for each bay segment between 1998-2010 in: a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Each point represents the averages of all water quality parameters for that season and respective year. Data points are colored according to the season that data point: winter (blue), spring (green), summer (red) and fall (orange).

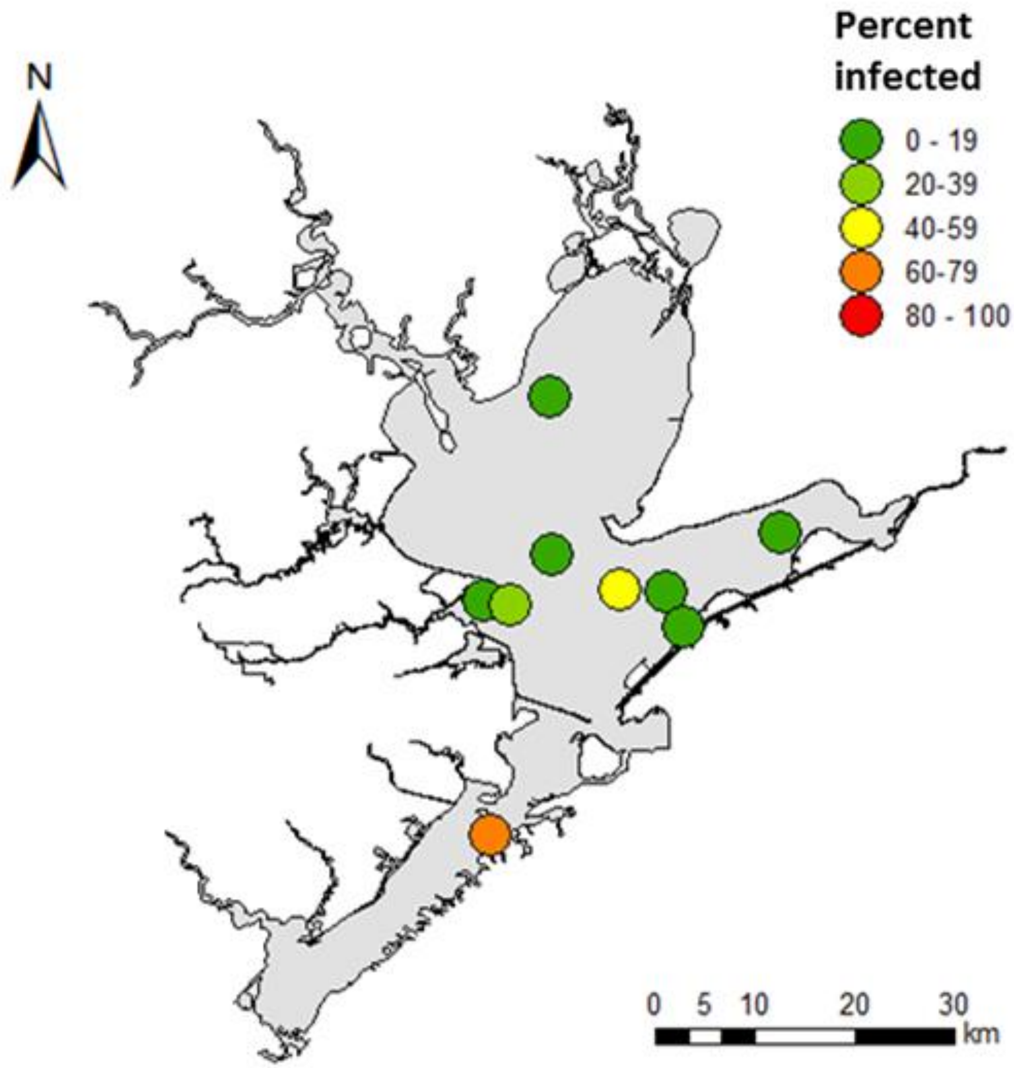

Figure 34 Percent of juvenile sized oysters (<3") sampled at each reef that were infected with Dermo during the study period 1998-2010.

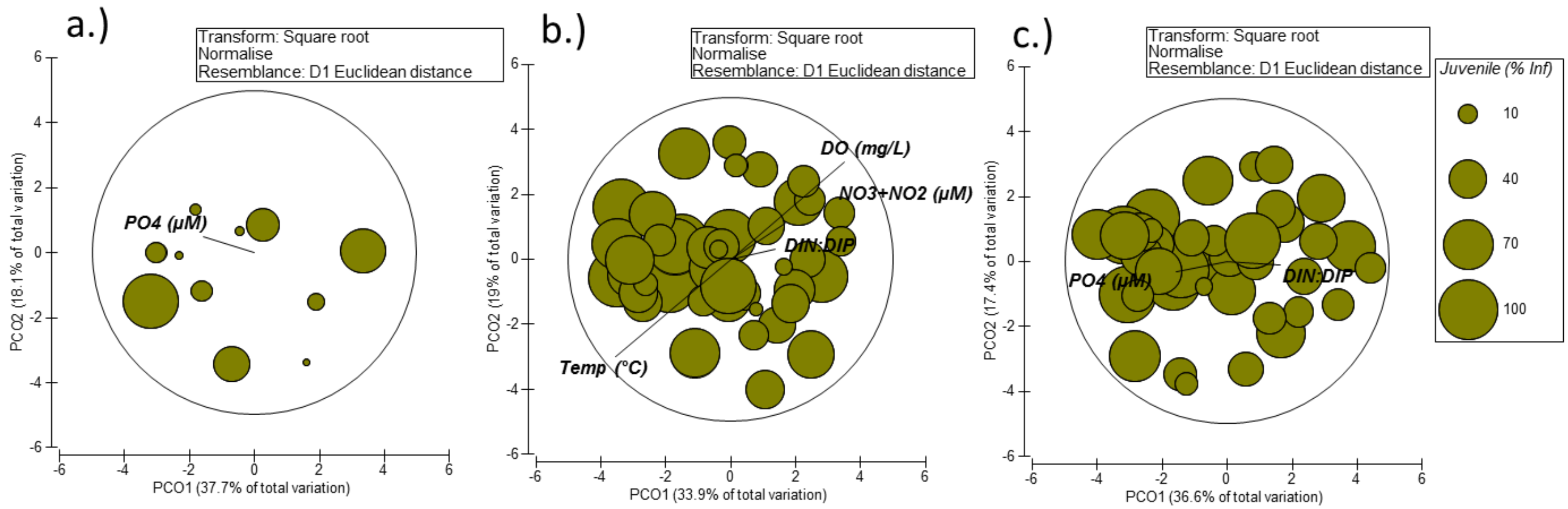

Figure 35 PCO of environmental data with the bubble underlay showing the percentage of juvenile size oysters infected with Dermo at the time of sampling for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with juvenile size oysters infected with Dermo in each respective segment.

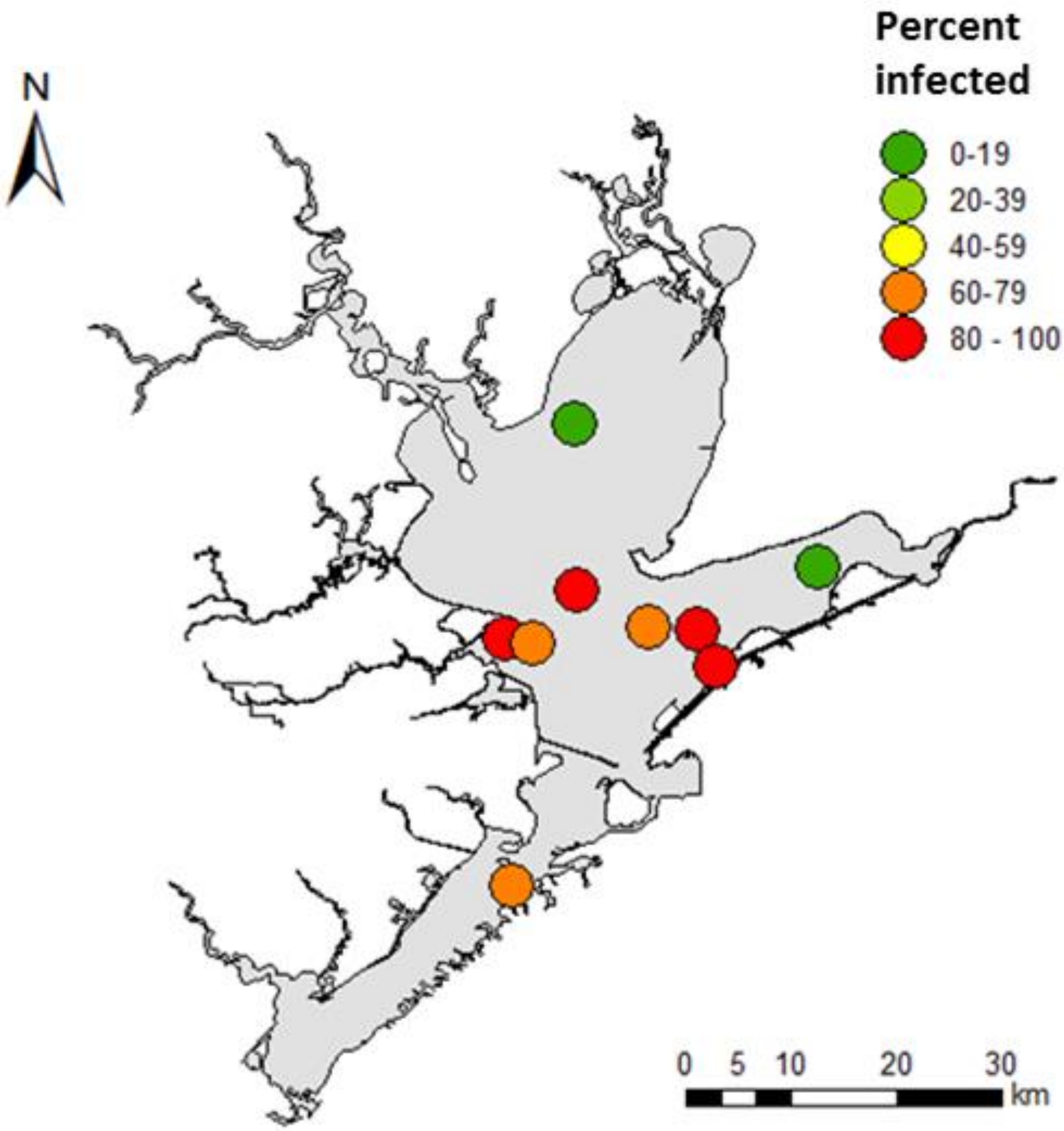

Figure 36 Percent of commercial sized oysters (>3") sampled at each reef that were infected with Dermo.

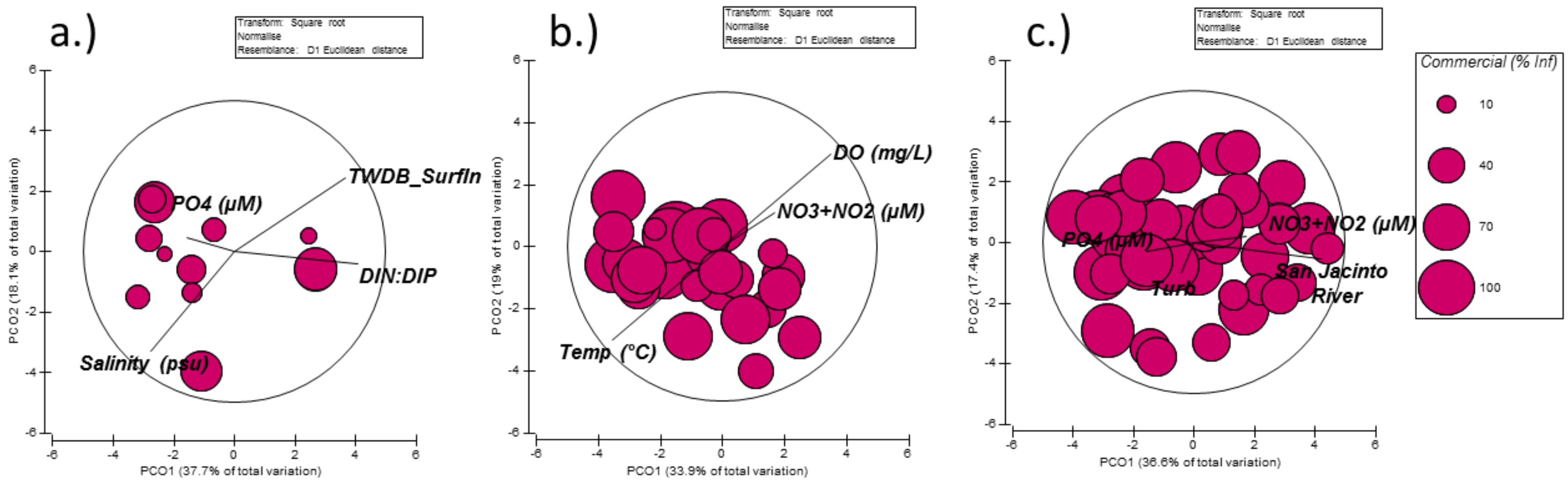

Figure 37 PCO of environmental data with the bubble underlay showing the percentage of commercial size oysters infected with Dermo at the time of sampling for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental

Table 16 Results of DISTLM test on total count of infected oysters and the percent of oysters infected with Dermo compared to environmental factors for each of the 3 bay segments.

Dermo infected	Water Quality Parameter	TB				UGB				LGB			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
Juvenile size (<3")	**Temp (°C)**	136.28	0.46	0.6152	0.01	21414.00	20.70	**0.0001**	0.29	1403.8	1.28	0.261	0.02
	DO (mg/L)	37.26	0.13	0.8673	0.00	13265.00	11.08	**0.0007**	0.18	199.88	0.18	0.828	0.00
	Salinity (PPT)	1403.70	5.23	**0.0177**	0.09	1640.30	1.15	0.2907	0.02	854.28	0.77	0.424	0.02
	Turb	222.34	0.76	0.4050	0.02	2479.50	1.75	0.1761	0.03	2610.9	2.44	0.106	0.05
	NO_3+NO_2 (µM)	543.80	1.90	0.1521	0.04	9689.30	7.64	**0.0046**	0.13	1270.6	1.16	0.291	0.02
	NH_3 (µM)	234.35	0.80	0.3816	0.02	1580.40	1.10	0.3023	0.02	183.61	0.16	0.84	0.00
	PO_4 (µM)	231.50	0.79	0.3623	0.02	3563.40	2.56	0.0971	0.05	7593.2	7.81	**0.003**	0.14
	DIN:DIP	259.20	0.89	0.3350	0.02	3837.70	2.77	0.0838	0.05	4987.2	4.87	**0.017**	0.09
	Surf. In. (ac-ft/mon^{-1})	2138.50	8.42	**0.0008**	0.14	821.71	0.57	0.5104	0.01	289.58	0.26	0.747	0.01
	Trinity River (cfs)	1310.90	4.85	**0.0160**	0.09	1484.40	1.04	0.3217	0.02	231.96	0.21	0.794	0.00
	San Jacinto River (cfs)	525.52	1.84	0.1474	0.04	1410.90	0.98	0.3377	0.02	651.19	0.59	0.514	0.01
Commercial size (>3")	**Temp (°C)**	232.56	0.35	0.6351	0.01	27705.00	25.53	**0.0001**	0.34	2060.70	2.61	0.0774	0.05
	DO (mg/L)	210.51	0.31	0.6499	0.01	19453.00	15.56	**0.0002**	0.24	964.93	1.19	0.3022	0.02
	Salinity (PPT)	2884.30	4.69	**0.0267**	0.09	701.11	0.43	0.5648	0.01	804.13	0.99	0.3698	0.02
	Turb	1563.80	2.44	0.1083	0.05	3613.00	2.31	0.1239	0.04	3092.60	4.03	**0.0234**	0.07
	NO_3+NO_2 (µM)	124.98	0.19	0.7665	0.00	8338.50	5.66	**0.0143**	0.10	3200.70	4.18	**0.0222**	0.08
	NH_3 (µM)	165.75	0.25	0.7048	0.00	2923.40	1.85	0.1655	0.04	370.74	0.45	0.6108	0.01
	PO_4 (µM)	2880.40	4.68	**0.0290**	0.09	3443.30	2.19	0.1294	0.04	3675.30	4.86	**0.0134**	0.09
	DIN:DIP	2105.80	3.34	0.0654	0.06	4860.80	3.15	0.0697	0.06	1503.90	1.88	0.1569	0.04
	Surf. In. (ac-ft/mon^{-1})	2736.40	4.43	**0.0299**	0.08	899.52	0.55	0.4926	0.01	511.24	0.62	0.5218	0.01
	Trinity River (cfs)	1300.60	2.01	0.1575	0.04	448.12	0.27	0.6931	0.01	853.71	1.05	0.3432	0.02
	San Jacinto River (cfs)	1313.00	2.03	0.1514	0.04	1215.10	0.75	0.4141	0.01	2644.70	3.41	**0.0381**	0.06

Potential other bioindicator species

Phytoplankton Pigments (2008-2013)

Samples were collected for phytoplankton pigment analysis on a monthly basis from 6 stations across Galveston Bay from 2008-2013 by the PI on this project (Fig. 3). The phytoplankton pigments for the 2014-2015 time frame have been collected but have not yet been analyzed therefore data will not be shown for those two years. When these samples are processed the data will be made available to TWDB. To determine if phytoplankton pigments groups have the potential of being a FWBI for Galveston Bay, phytoplankton pigment concentrations and water quality parameters over a 6 year time period (2008-2013) were analysed. The statistical analysis follows the same format as explained previously in this report. This series of results is presented for each of the phytoplankton groups which we have defined based on their primary accessorry pigment: Diatoms (Fucoxanthin), Cyanobacteria (Zeaxanthin), Cryptophytes (Alloxanthin), Chlorophytes (chlorophyll *b*), and Dinoflagellates (Peridinin) (listed in order of decreasing overall concentration).

In Fig. 38, the percent composition of each of the phytoplankton groups were presented in a pie chart at each of the 6 stations across GB. Diatoms dominated the phytoplankton community from 2008-2013 and across all 6 stations in Galveston Bay (Fig. 38). Cyanobacteria were the second most dominant group of phytoplankton in terms of concentration followed by chlorophytes, cryptophytes and then the dinoflagellates (Fig. 39).

Figure 39 shows the changes in phytoplankton taxonomic groups over time and how they relate to salinity fluctuations. Again we see that the phytoplankton community is dominated by diatoms within all 3 bay segments and over all seasons. The cyanobacteria concentrations tended to be higher in TB over all seasons and we see the highest concentrations of dinoflagellates in UGB (Fig. 39). During the drought period that began in October 2010 and last through 2011 and into 2012 there is a marked decrease in overall phytoplankton concentration across all phytoplankton taxonomic groups analyzed herein (Fig. 39). During the summer of 2008 there was a bloom shown by the spike in the concentration of peridin representative of the dinoflagellate concentration (red) (Fig. 39). Seasonal spikes are observed in the spring and fall indicative of the natural bloom cycles associated with increased nutrient availability during those times (Fig. 39).

A PCO analysis was conducted for each of the bay segments to show the environmental variabilty in abiotic variables collected concurrently across the bay during the sampling period (Fig. 40). In TB PCO1 explained 42% of the total variation and was driven by nutrient concentations and river discharge (Fig. 40a). PCO2 explained 16.9% of the variation and separated the data points by salinity, temperature and pH (Fig. 40a). In UGB PCO1 described 39.4% of the variation and the data points were separated by temperature, pH and nutrients while PCO2 explained 23.5% of the variation and was defined by TR and SJR river discharge and salinity (Fig. 40b). LGB data points were separated based on nutrient concentrations on PCO1 (32.5%) and PCO2 (19.9%) separated by pH, temperature, salinity and river discharge (Fig. 40c). (Note: TWDB surface inflow was not available from 2012-2013 therefore this parameter was excluded from this analysis. When this data becomes available, we can include this in the pigment analysis. We may infer from other analyses shown in this report that the TR and SJR discharge tend to follow similar trends as the TWDB surface inflow.

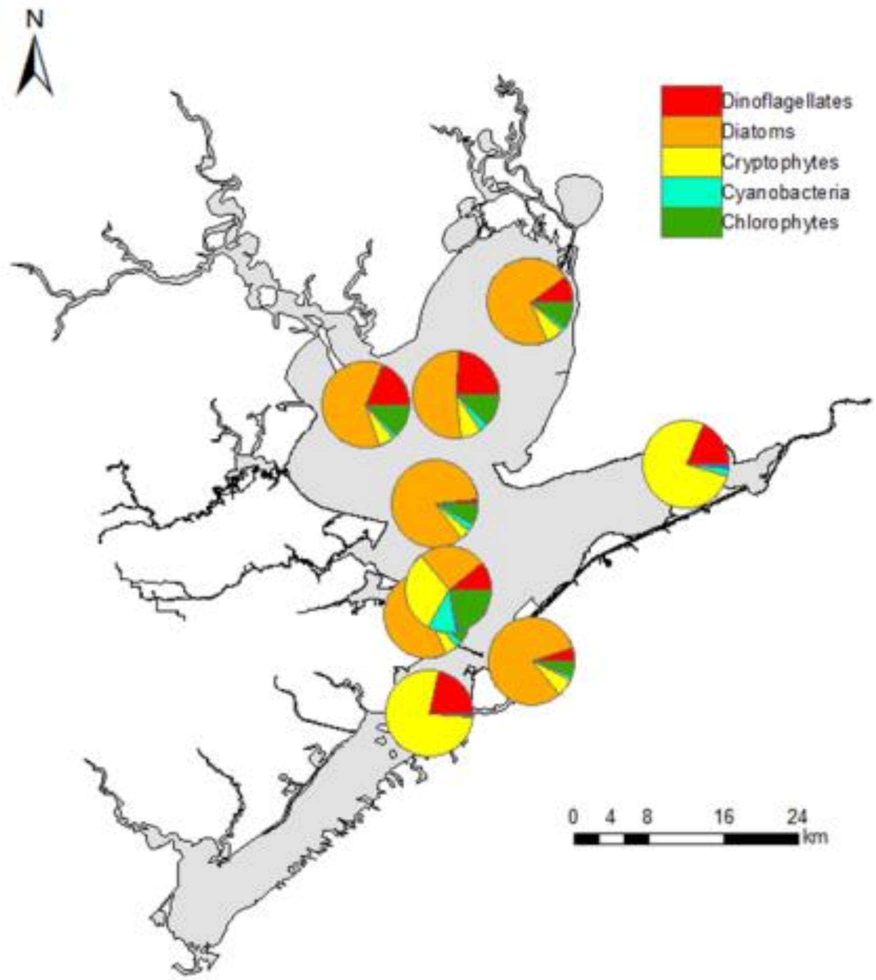

Figure 38 Map of GB showing the average percent composition of phytoplankton groups at each of the 6 stations sampled.

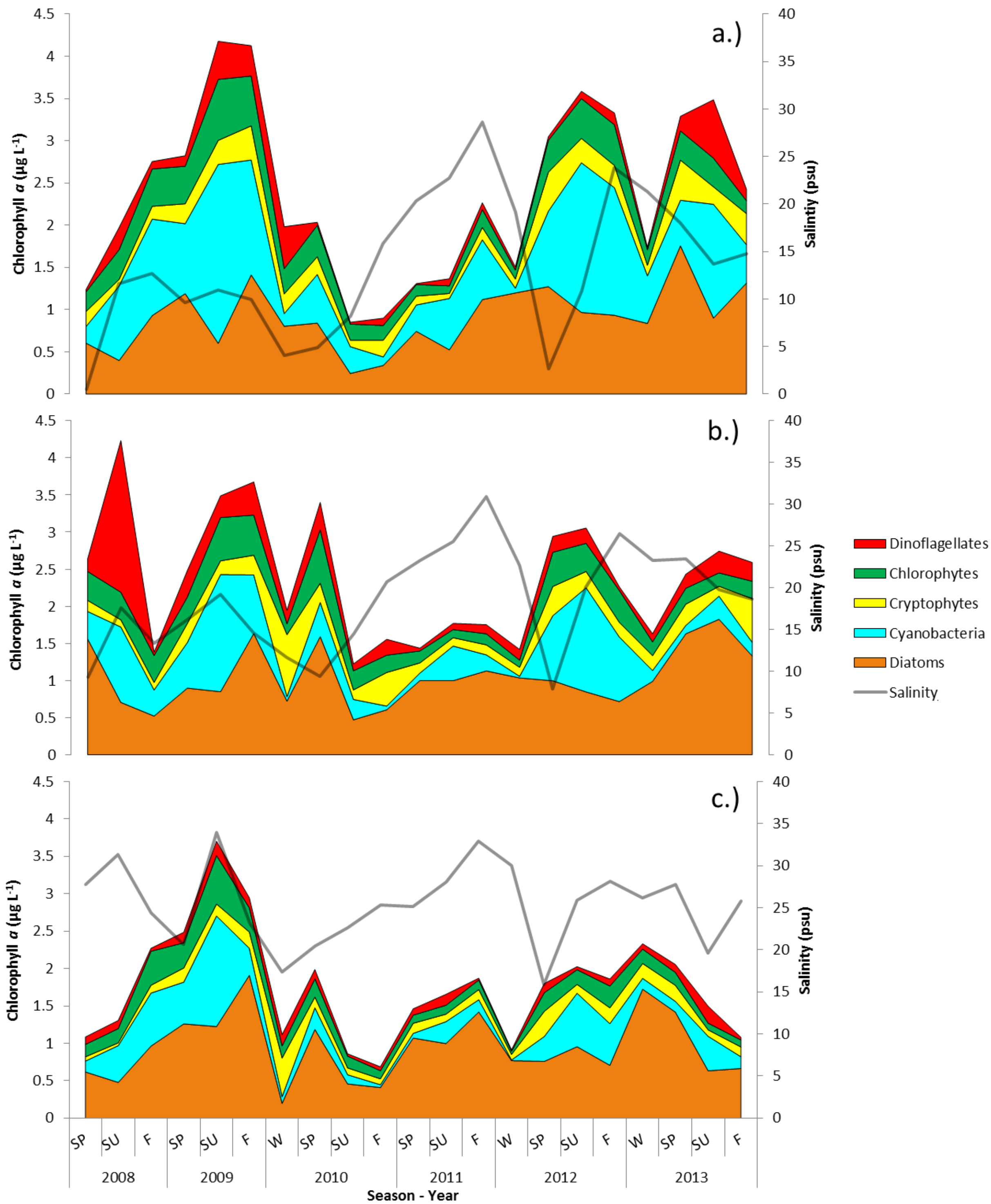

Figure 39 Mean seasonal contribution of diatoms (brown), cyanobacteria (teal), cryptophytes (yellow), chlorophytes (green) and dinoflagellates (red) to total chlorophyll *a* in a.) TB b.) UGB and c.) LGB from 2008-2013. Salinity over time is plotted as the gray line and corresponds with the secondary y-axis.

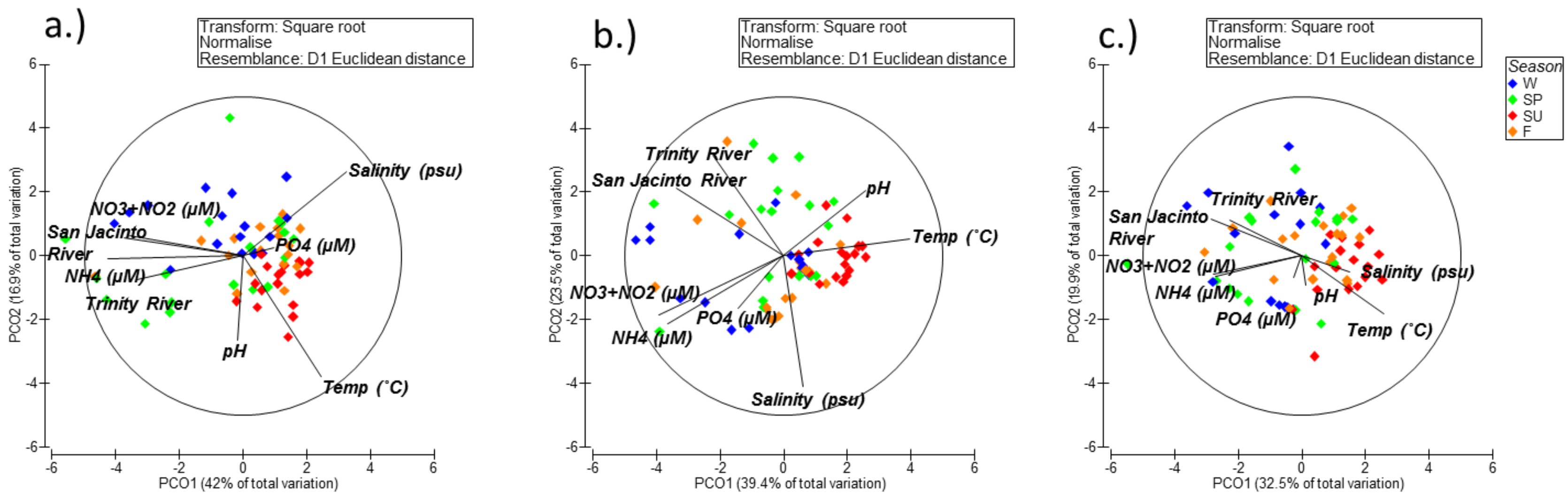

Figure 40 PCO of environmental data collected with phytoplantkon pigment samples for each bay segment 2008-2013 a.) Trinity Bay b.) Upper Galveston Bay c.) Lower Galveston Bay. Each point represents the averages of all water quality parameters for that season and respective year. Data points are colored according to the season that data point: winter (blue), spring (green), summer (red) and fall (orange). Vectors indicate all water quality parameters measured at each of the sample sites.

Diatoms (Fucoxanthin)

Galveston Bay is typically a diatom dominated system bay-wide across all seasons (Fig. 38 and 39). In TB the diatom concentration was explained by the SJR (p<0.001) and TR (p<0.05) river discharge (Fig. 41a; Table17). In UGB the diatoms were influenced by the TR discharge - as the rate increased so did the portion of diatoms (Fig. 41b; Table 17). Diatoms in LGB increased in concentration with decreasing pH (p<0.001), increased salinity (p<0.001), decreasing PO_4 (p<0.01) and decreasing NO_3^- + NO_2^- (p<0.05) (Fig. 41c; Table 17).

Cyanobacteria (Zeaxanthin)

Cyanobacteria were present in higher concentrations in both TB and UGB compared to LGB (Fig. 42). In TB, cyanobacteria increased in concentration with increasing temperature (p<0.001), decreasing NO_3^- + NO_2^- (p<0.001) and NH_4 (p<0.05) (Fig. 42a; Table 18). In UGB, cyanobacteria increased in concentration with increasing temperature (p<0.001), decreasing NO_3^- + NO_2^- (p<0.001) and decreasing NH_4 (p<0.05) (Fig. 42b; Table 18). The cyanobacteria concentration in LGB increased with increasing temperatures (p<0.001), decreasing PO_4 (p<0.05), decreasing NO_3^- + NO_2^- (p<0.05) and decreasing salinity (p<0.05) (Fig. 42c; Table 18).

Chlorophytes (Chlorophyll *b*)

The chlorophytes in TB increased in concentration with decreasing salinity (p<0.01), decreasing temperature (p<0.05) and increasing NO_3^- + NO_2^- (p<0.05) (Fig. 43a; Table 19). In UGB the chlorophytes again increased in concentration with decreasing salinity (p<0.01) and increasing TR discharge (p<0.05) (Fig. 43b; Table 19). Chlorophytes in LGB overall had decreased concentrations and were related to decreasing salinity (p<0.05), decreasing PO_4 (p<0.05) and pH (p<0.05) (Fig. 43c; Table 19).

Cryptophytes (Alloxanthin)

Cryptophytes had highest concentration in UGB and lowest in LGB (Fig. 44). In TB, the cryptophyte concentration increased with decreasing salinity (p<0.01), increasing TR (p<0.01) and SJR (p<0.05) discharge (Fig 44a; Table 20). Interestingly, Cryptophytes in UGB did not have a significant correlation with any of the measured environmental parameters in this study. Salinity, temperature, TR and SJR discharge were selected to show variation in the cryptophyte communities but are not significantly correlated (Fig. 44b; Table 20). In LGB, cryptophytes increased in abundance with decreasing pH (p<0.001), decreasing PO_4 (p<0.01) and decreasing temperatures (p<0.05) (Fig. 44c; Table 20).

Dinoflagellates (Peridinin)

Dinoflagellates were the second most dominate phytoplankton group among all 3 bay segments in Galveston Bay during the study period 2008-2013 (Fig. 38 and 39). The highest dinoflagellate concentrations were observed in TB compared to UGB and then LGB (Fig. 45). In TB the dinoflagellate abundance increased increasing pH (p<0.01) and decreasing $NO_3^- + NO_2^-$ (p<0.01) (Fig. 45a; Table 21). The dinoflagellate concentration in UGB increased with increasing TR discharge (p<0.001) and decreasing salinity (p<0.05) (Fig. 45b; Table 21). The dinoflagellates in LGB were influenced by decreasing PO_4 (p<0.001), increasing TR discharge (p<0.05) and decreasing $NO_3^- + NO_2^-$ (p<0.05) (Fig. 45c; Table 21).

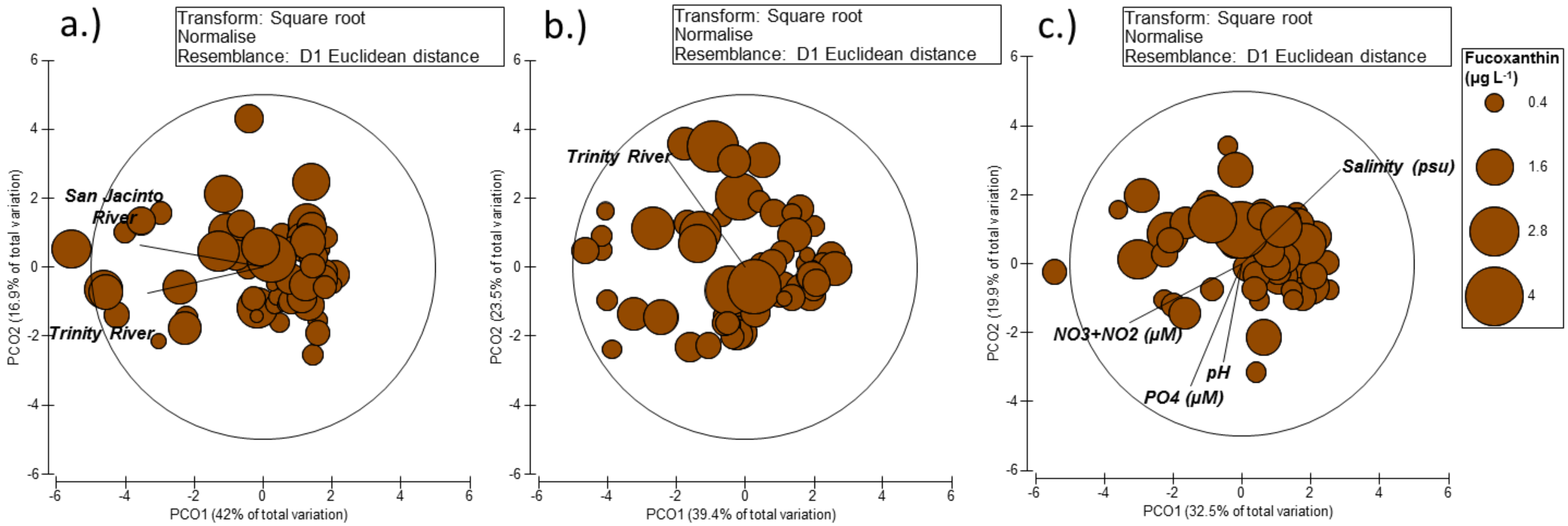

Figure 41 PCO of environmental data with the bubble underlay showing diatom abundance (based on fucoxanthin concentration in μg L^{-1}) 2008-2013 in GB: a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with diatom concentrations in each respective segment.

Table 17 DistLM results displaying the correlation between the diatoms to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 2008-2013.

Subbay	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
	Parameter	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	183.91	1.23	0.2804	0.02	2349.60	17.73	**0.0016**	0.54	241.89	2.53	0.1224	0.14	253.05	4.02	0.0751	0.20	43.50	0.36	0.5869	0.02
	Salinity (psu)	310.70	2.11	0.1452	0.03	170.63	0.61	0.4439	0.04	78.71	0.74	0.4205	0.04	3.56	0.05	0.9146	0.00	12.13	0.10	0.7914	0.01
	pH	269.08	1.82	0.1759	0.03	133.02	0.48	0.5279	0.03	102.07	0.98	0.2635	0.06	2.90	0.04	0.9198	0.00	5.50	0.04	0.9126	0.00
	NO_3+NO_2 (µM)	131.02	0.87	0.3476	0.01	53.51	0.19	0.6818	0.01	26.14	0.24	0.6668	0.01	489.00	10.15	**0.0047**	0.39	64.93	0.55	0.4551	0.04
	NH_3 (µM)	13.73	0.09	0.8277	0.00	20.20	0.07	0.8229	0.00	63.71	0.60	0.4499	0.04	396.40	7.35	**0.0140**	0.31	33.39	0.28	0.5924	0.02
	PO_4 (µM)	7.50	0.05	0.8857	0.00	1465.40	7.65	**0.0141**	0.34	6.12	0.06	0.8412	0.00	40.85	0.54	0.5047	0.03	34.48	0.29	0.6505	0.02
	Trinity River (cfs)	896.60	6.45	**0.0122**	0.09	477.49	1.86	0.1965	0.11	166.72	1.66	0.2141	0.09	4.43	0.06	0.8653	0.00	202.98	1.86	0.1536	0.11
	San Jacinto River (cfs)	908.16	6.55	**0.0095**	0.09	374.23	1.42	0.2546	0.09	235.89	2.46	0.1302	0.13	84.99	1.16	0.2411	0.07	380.97	3.91	0.0634	0.21
UGB	**Temp (°C)**	39.51	0.19	0.7005	0.00	2704.50	20.40	**0.0013**	0.58	4.87	0.03	0.9558	0.00	222.12	2.20	0.1604	0.13	91.40	0.62	0.4623	0.04
	Salinity (psu)	75.32	0.37	0.5622	0.01	45.23	0.15	0.7146	0.01	312.25	1.78	0.2023	0.10	132.75	1.24	0.2804	0.08	3.17	0.02	0.9530	0.00
	pH	454.92	2.31	0.1319	0.03	1935.50	10.53	**0.0057**	0.41	64.33	0.34	0.5393	0.02	17.52	0.15	0.7959	0.01	50.82	0.34	0.5574	0.02
	NO_3+NO_2 (µM)	135.44	0.67	0.4179	0.01	2148.40	12.66	**0.0032**	0.46	95.26	0.50	0.5050	0.03	116.77	1.08	0.3195	0.07	246.00	1.79	0.1930	0.10
	NH_3 (µM)	53.86	0.27	0.6337	0.00	1480.50	6.91	**0.0219**	0.32	413.91	2.44	0.1315	0.13	59.99	0.54	0.4714	0.03	5.75	0.04	0.9257	0.00
	PO_4 (µM)	123.78	0.61	0.4487	0.01	771.00	2.95	0.0918	0.16	49.89	0.26	0.6235	0.02	0.41	0.00	0.9884	0.00	169.22	1.19	0.2542	0.07
	Trinity River (cfs)	794.37	4.13	**0.0386**	0.06	737.59	2.80	0.1196	0.16	13.02	0.07	0.8738	0.00	23.73	0.21	0.6392	0.01	424.57	3.37	0.0692	0.17
	San Jacinto River (cfs)	166.67	0.83	0.3720	0.01	456.89	1.62	0.2213	0.10	9.86	0.05	0.9123	0.00	24.95	0.22	0.5728	0.01	144.02	1.00	0.3342	0.06
LGB	**Temp (°C)**	89.67	0.43	0.5291	0.01	2803.20	14.54	**0.0025**	0.49	51.96	0.37	0.5783	0.02	624.13	14.65	**0.0492**	0.49	459.03	2.73	0.1106	0.15
	Salinity (psu)	1897.80	10.36	**0.0016**	0.13	2041.50	8.38	**0.0111**	0.36	204.15	1.58	0.2422	0.09	241.63	3.55	0.0582	0.19	93.09	0.49	0.5068	0.03
	pH	1940.00	10.63	**0.0012**	0.14	1273.90	4.32	**0.0292**	0.22	226.02	1.77	0.1984	0.10	22.28	0.27	0.6088	0.02	967.24	7.08	**0.0136**	0.31
	NO_3+NO_2 (µM)	1017.60	5.19	**0.0217**	0.07	958.08	3.03	0.0944	0.17	277.17	2.23	0.1418	0.12	67.50	0.85	0.3387	0.05	25.04	0.13	0.7820	0.01
	NH_3 (µM)	259.88	1.25	0.2665	0.02	347.69	0.98	0.3428	0.06	179.22	1.37	0.2517	0.08	61.17	0.76	0.3827	0.05	9.72	0.05	0.8980	0.00
	PO_4 (µM)	1640.00	8.77	**0.0028**	0.11	1189.80	3.96	0.0641	0.21	434.37	3.79	0.0535	0.19	159.59	2.17	0.1127	0.13	9.03	0.05	0.8986	0.00
	Trinity River (cfs)	315.04	1.53	0.2166	0.02	122.99	0.33	0.5998	0.02	20.47	0.15	0.7307	0.01	10.65	0.13	0.7292	0.01	195.88	1.06	0.3205	0.06
	San Jacinto River (cfs)	64.65	0.31	0.5968	0.00	92.76	0.25	0.6402	0.02	354.05	2.96	0.0893	0.16	17.43	0.21	0.5796	0.01	120.92	0.64	0.4425	0.04

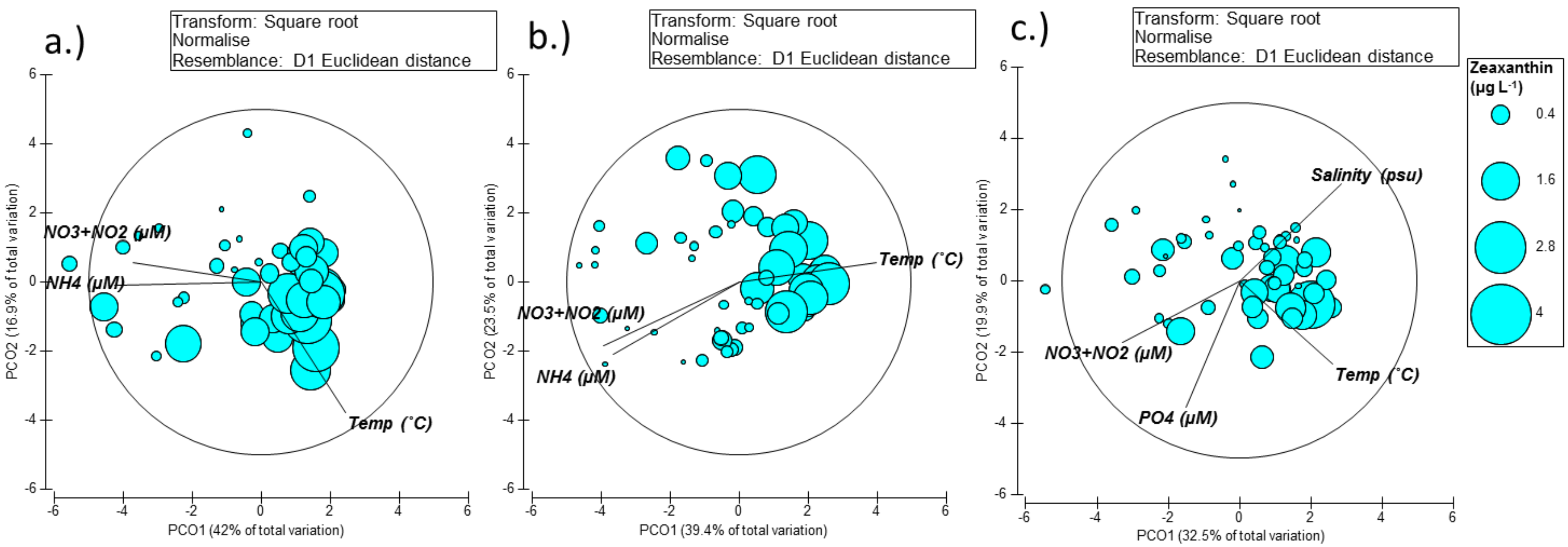

Figure 42 PCO of environmental data with the bubble underlay showing cyanobacteria abundance (based on zeaxanthin concentration in µg L^{-1}) 2008-2013 in GB: a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with cyanobacteria concentrations in each respective segment.

Table 18 DistLM results displaying the correlation between the cyanobacteria to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 2008-2013.

Subbay	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	3096.00	18.67	**0.0002**	0.22	158.52	1.78	0.1977	0.11	93.40	0.83	0.3815	0.05	401.20	2.15	0.2056	0.12	535.65	2.62	0.1241	0.15
	Salinity (psu)	59.75	0.28	0.6122	0.00	38.95	0.40	0.5394	0.03	67.33	0.59	0.4592	0.04	8.26	0.04	0.9124	0.00	113.39	0.49	0.5144	0.03
	pH	433.82	2.12	0.1496	0.03	47.01	0.49	0.5054	0.03	110.19	0.98	0.3458	0.06	76.58	0.37	0.5881	0.02	369.59	1.72	0.2032	0.10
	NO_3+NO_2 (µM)	2560.40	14.74	**0.0004**	0.18	75.21	0.80	0.3910	0.05	5.52	0.05	0.8905	0.00	1585.50	14.08	**0.0038**	0.47	1129.60	6.85	**0.0172**	0.31
	NH_3 (µM)	1214.90	6.28	**0.0126**	0.08	32.04	0.33	0.5913	0.02	5.62	0.05	0.8779	0.00	1240.90	9.25	**0.0077**	0.37	680.36	3.49	0.0761	0.19
	PO_4 (µM)	74.31	0.35	0.5815	0.01	209.86	2.46	0.1308	0.14	146.93	1.34	0.2557	0.08	375.90	2.00	0.1764	0.11	900.91	5.00	**0.0361**	0.25
	Trinity River (cfs)	152.83	0.73	0.3998	0.01	92.98	1.00	0.3319	0.06	14.18	0.12	0.7731	0.01	22.94	0.11	0.7859	0.01	39.23	0.17	0.7412	0.01
	San Jacinto River (cfs)	208.81	1.00	0.3323	0.01	89.63	0.96	0.3443	0.06	105.67	0.94	0.3440	0.06	140.22	0.69	0.3707	0.04	123.22	0.53	0.4910	0.03
UGB	**Temp (°C)**	2247.00	14.91	**0.0003**	0.18	260.23	10.04	**0.0058**	0.40	843.01	8.66	**0.0095**	0.35	228.35	1.06	0.3119	0.07	117.44	0.76	0.4016	0.05
	Salinity (psu)	314.96	1.76	0.1839	0.03	0.94	0.02	0.9077	0.00	996.69	11.36	**0.0042**	0.42	153.74	0.70	0.4182	0.04	41.44	0.26	0.6439	0.02
	pH	644.60	3.70	0.0537	0.05	77.41	2.03	0.1756	0.12	257.56	1.92	0.1930	0.11	736.25	4.07	0.0608	0.21	24.34	0.15	0.7418	0.01
	NO_3+NO_2 (µM)	1804.40	11.48	**0.0008**	0.14	38.07	0.93	0.3538	0.06	561.87	4.89	**0.0410**	0.23	2713.30	55.11	**0.0001**	0.79	78.87	0.50	0.5104	0.03
	NH_3 (µM)	1062.00	6.32	**0.0131**	0.09	13.32	0.31	0.5889	0.02	628.13	5.67	**0.0289**	0.26	187.56	0.86	0.3687	0.05	269.48	1.85	0.1855	0.10
	PO_4 (µM)	72.14	0.39	0.5460	0.01	4.93	0.11	0.7592	0.01	181.47	1.31	0.2767	0.08	126.01	0.57	0.4820	0.04	351.16	2.49	0.1248	0.13
	Trinity River (cfs)	84.72	0.46	0.5075	0.01	72.01	1.87	0.1927	0.11	29.88	0.20	0.6894	0.01	1.31	0.01	0.9853	0.00	172.69	1.14	0.2867	0.07
	San Jacinto River (cfs)	60.38	0.33	0.5751	0.00	54.22	1.37	0.2595	0.08	6.43	0.04	0.9093	0.00	174.97	0.80	0.4000	0.05	155.99	1.02	0.3230	0.06
LGB	**Temp (°C)**	1170.80	10.05	**0.0022**	0.13	354.99	14.65	**0.0023**	0.49	222.84	3.42	0.0774	0.18	453.20	3.80	0.0951	0.20	65.72	0.48	0.4986	0.03
	Salinity (psu)	568.07	4.53	**0.0347**	0.06	111.62	2.76	0.1128	0.16	57.62	0.76	0.3909	0.05	643.91	6.04	**0.0243**	0.29	53.62	0.39	0.5540	0.02
	pH	57.18	0.43	0.5280	0.01	136.66	3.52	0.0671	0.19	15.07	0.19	0.6837	0.01	152.47	1.09	0.3046	0.07	104.38	0.78	0.3938	0.05
	NO_3+NO_2 (µM)	575.96	4.60	**0.0325**	0.06	99.23	2.40	0.1380	0.14	32.51	0.42	0.5365	0.03	130.57	0.93	0.3459	0.06	5.28	0.04	0.8993	0.00
	NH_3 (µM)	464.81	3.66	0.0584	0.05	27.27	0.59	0.4580	0.04	38.42	0.50	0.4932	0.03	28.12	0.19	0.7106	0.01	2.50	0.02	0.9495	0.00
	PO_4 (µM)	669.68	5.41	**0.0198**	0.07	291.11	10.22	**0.0053**	0.41	15.74	0.20	0.6800	0.01	639.11	5.98	**0.0295**	0.29	180.57	1.39	0.2576	0.08
	Trinity River (cfs)	26.99	0.20	0.6772	0.00	33.74	0.74	0.4070	0.05	13.11	0.17	0.7163	0.01	4.01	0.03	0.9374	0.00	1.19	0.01	0.9786	0.00
	San Jacinto River (cfs)	175.54	1.34	0.2470	0.02	41.18	0.91	0.3607	0.06	83.64	1.13	0.2969	0.07	37.55	0.26	0.5746	0.02	29.58	0.21	0.6681	0.01

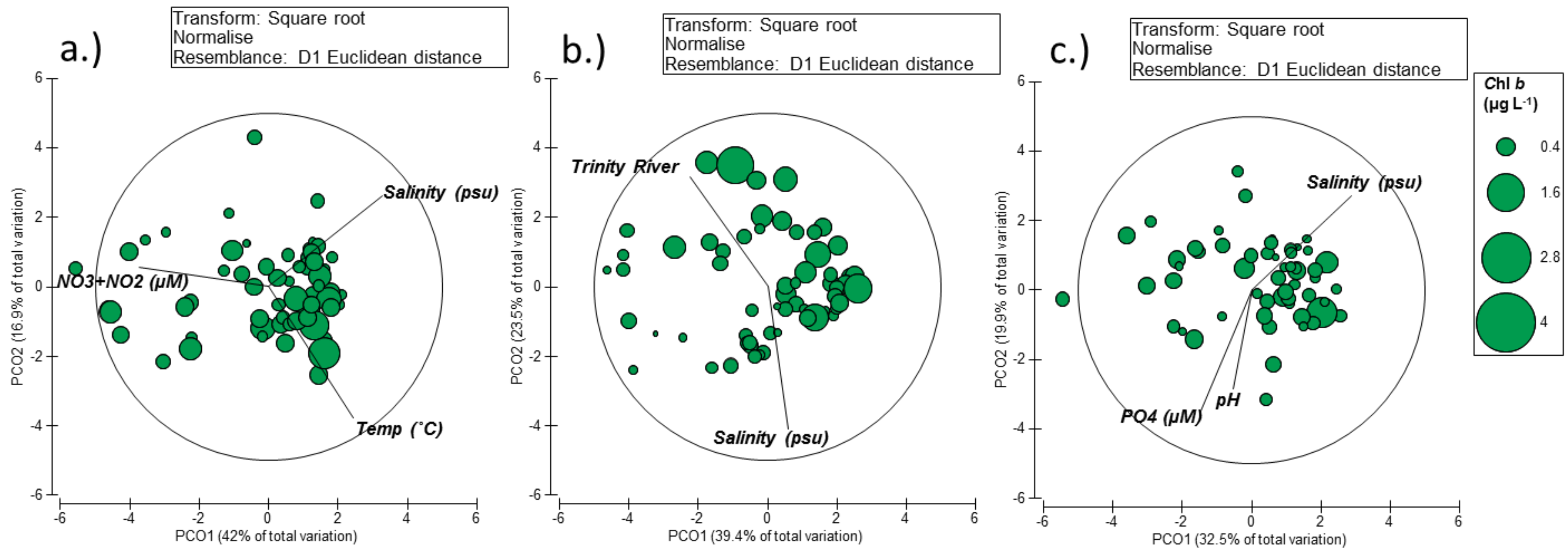

Figure 43 PCO of environmental data with the bubble underlay showing Chlorophyte abundance (based on chlorophyll *b* concentration in µg L^{-1}) 2008-2013 in GB: a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Chlorophyte concentrations in each respective segment.

Table 19 DistLM results displaying the correlation between the chlorophytes to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 2008-2013.

Subbay	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
	Parameter	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	325.71	4.55	**0.0347**	0.06	580.76	10.70	**0.0067**	0.42	580.76	10.70	**0.0067**	0.42	329.62	7.32	**0.0121**	0.33	329.62	7.32	**0.0127**	0.33
	Salinity (psu)	543.78	7.95	**0.0057**	0.10	309.90	4.28	0.0554	0.22	309.90	4.28	0.0554	0.22	1.46	0.02	0.9231	0.00	1.46	0.02	0.9258	0.00
	pH	50.44	0.67	0.4115	0.01	3.28	0.04	0.8728	0.00	3.28	0.04	0.8728	0.00	149.36	2.62	0.1201	0.15	149.36	2.62	0.1299	0.15
	NO_3+NO_2 (μM)	375.63	5.30	**0.0201**	0.07	48.38	0.54	0.4752	0.03	48.38	0.54	0.4752	0.03	162.93	2.90	0.1104	0.16	162.93	2.90	0.1028	0.16
	NH_3 (μM)	77.73	1.03	0.3191	0.02	1.26	0.01	0.9359	0.00	1.26	0.01	0.9359	0.00	73.83	1.19	0.2675	0.07	73.83	1.19	0.2678	0.07
	PO_4 (μM)	11.30	0.15	0.7110	0.00	601.74	11.40	**0.0038**	0.43	601.74	11.40	**0.0038**	0.43	3.80	0.06	0.8673	0.00	3.80	0.06	0.8641	0.00
	Trinity River (cfs)	200.37	2.73	0.0978	0.04	340.30	4.84	**0.0404**	0.24	340.30	4.84	**0.0404**	0.24	12.22	0.18	0.6550	0.01	12.22	0.18	0.6534	0.01
	San Jacinto River (cfs)	170.27	2.30	0.1328	0.03	372.32	5.46	**0.0332**	0.27	372.32	5.46	**0.0332**	0.27	32.36	0.50	0.4943	0.03	32.36	0.50	0.4959	0.03
UGB	**Temp (°C)**	145.44	1.63	0.2049	0.02	693.96	25.12	**0.0008**	0.63	1.90	0.02	0.9639	0.00	226.93	4.81	**0.0448**	0.24	18.45	0.25	0.6436	0.02
	Salinity (psu)	617.46	7.51	**0.0071**	0.10	15.86	0.22	0.6492	0.01	583.67	9.74	**0.0040**	0.38	19.11	0.31	0.6023	0.02	105.96	1.55	0.2296	0.09
	pH	35.92	0.40	0.5406	0.01	309.04	5.80	**0.0290**	0.28	55.08	0.59	0.3997	0.04	182.14	3.63	0.0692	0.19	6.60	0.09	0.7876	0.01
	NO_3+NO_2 (μM)	220.48	2.50	0.1125	0.04	207.70	3.46	0.0825	0.19	207.48	2.49	0.1307	0.13	456.27	14.30	**0.0011**	0.49	17.70	0.24	0.6333	0.01
	NH_3 (μM)	254.33	2.90	0.0892	0.04	86.32	1.27	0.2693	0.08	151.18	1.74	0.1976	0.10	108.23	1.96	0.1694	0.12	4.72	0.06	0.8483	0.00
	PO_4 (μM)	21.78	0.24	0.6406	0.00	0.82	0.01	0.9518	0.00	66.37	0.72	0.3942	0.04	5.37	0.09	0.7806	0.01	27.43	0.37	0.4937	0.02
	Trinity River (cfs)	460.68	5.45	**0.0180**	0.07	219.11	3.70	0.0736	0.20	105.54	1.17	0.2900	0.07	4.21	0.07	0.8171	0.00	236.49	3.93	0.0541	0.20
	San Jacinto River (cfs)	140.62	1.58	0.2160	0.02	186.02	3.03	0.1009	0.17	73.42	0.80	0.3881	0.05	67.73	1.17	0.2514	0.07	89.70	1.29	0.2775	0.07
LGB	**Temp (°C)**	40.27	0.55	0.4634	0.01	676.53	15.32	**0.0024**	0.51	0.65	0.01	0.9466	0.00	318.92	9.24	0.0283	0.38	63.66	0.89	0.3572	0.05
	Salinity (psu)	349.30	5.09	**0.0256**	0.07	223.84	3.01	0.0970	0.17	2.12	0.05	0.8524	0.00	318.16	9.20	**0.0041**	0.38	27.16	0.37	0.5563	0.02
	pH	349.68	5.09	**0.0258**	0.07	409.23	6.60	**0.0041**	0.31	79.54	1.94	0.1781	0.11	62.02	1.20	0.2818	0.07	143.47	2.16	0.1582	0.12
	NO_3+NO_2 (μM)	190.11	2.68	0.1018	0.04	155.42	1.97	0.1801	0.12	5.34	0.12	0.7469	0.01	30.20	0.56	0.4474	0.04	0.70	0.01	0.9664	0.00
	NH_3 (μM)	22.16	0.30	0.6005	0.00	188.24	2.45	0.1392	0.14	0.35	0.01	0.9660	0.00	66.39	1.29	0.2608	0.08	27.56	0.37	0.5495	0.02
	PO_4 (μM)	421.86	6.24	**0.0150**	0.08	471.08	8.14	**0.0117**	0.35	52.11	1.22	0.2872	0.07	14.52	0.26	0.5598	0.02	1.06	0.01	0.9459	0.00
	Trinity River (cfs)	109.89	1.52	0.2259	0.02	70.09	0.83	0.3733	0.05	70.60	1.70	0.2119	0.10	12.41	0.23	0.6000	0.01	23.27	0.31	0.6051	0.02
	San Jacinto River (cfs)	12.86	0.17	0.6929	0.00	68.46	0.81	0.3804	0.05	23.61	0.53	0.4810	0.03	2.68	0.05	0.8163	0.00	7.05	0.09	0.7718	0.01

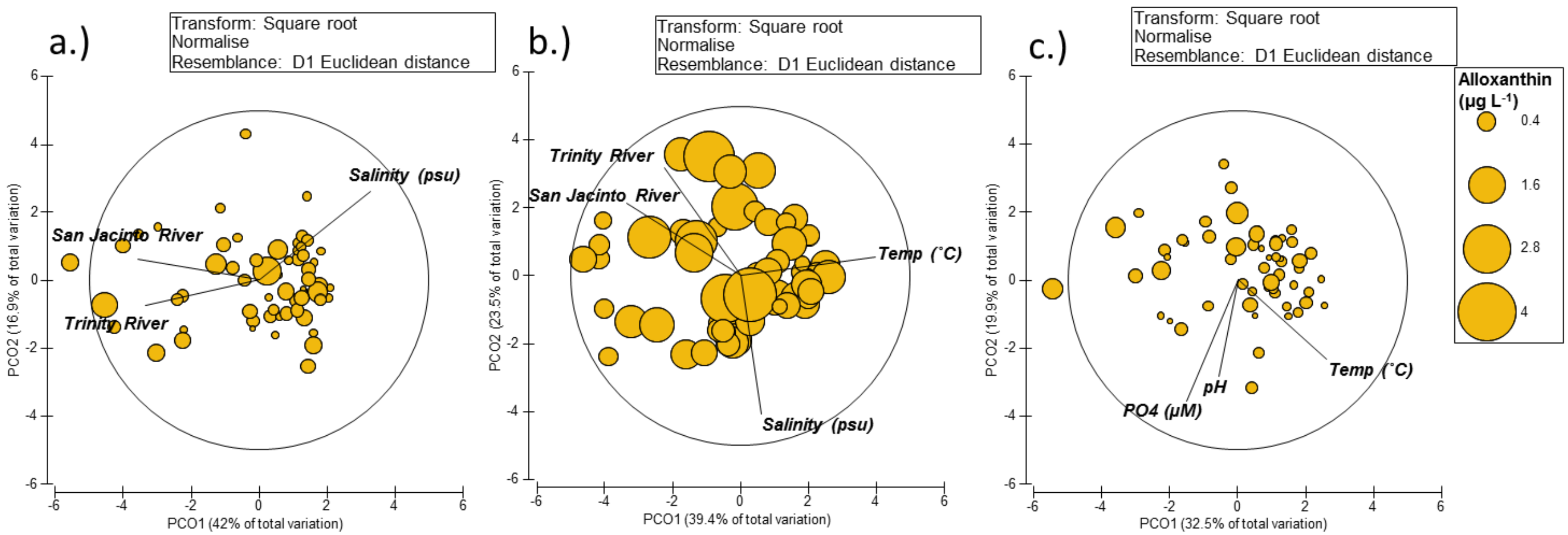

Figure 44 PCO of environmental data with the bubble underlay showing cryptophyte abundance (based on alloxanthin concentration in µg L^{-1}) 2008-2013 in GB: a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with cryptophyte concentrations in each respective segment.

Table 20 DistLM results displaying the correlation between the cryptophytes to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 2008-2013.

Subbay	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	12.25	0.20	0.6669	0.00	569.90	18.29	**0.0014**	0.55	3.59	0.06	0.8804	0.00	150.32	4.57	**0.0466**	0.22	16.77	0.33	0.5867	0.02
	Salinity (psu)	544.52	10.48	**0.0021**	0.13	245.97	4.66	0.0512	0.24	185.80	4.05	0.0569	0.20	11.19	0.27	0.6068	0.02	10.63	0.21	0.6565	0.01
	pH	2.13	0.04	0.8859	0.00	0.55	0.01	0.9551	0.00	2.09	0.04	0.8466	0.00	4.06	0.10	0.7804	0.01	5.70	0.11	0.7622	0.01
	NO_3+NO_2 (µM)	10.15	0.17	0.7001	0.00	5.01	0.07	0.7903	0.00	119.00	2.38	0.1380	0.13	181.82	5.88	**0.0266**	0.27	2.65	0.05	0.8510	0.00
	NH_3 (µM)	50.45	0.85	0.3540	0.01	8.66	0.13	0.7339	0.01	156.77	3.29	0.0904	0.17	118.55	3.40	0.0820	0.18	1.56	0.03	0.8966	0.00
	PO_4 (µM)	3.57	0.06	0.8350	0.00	418.38	10.10	**0.0062**	0.40	4.35	0.08	0.7075	0.00	4.77	0.11	0.7556	0.01	36.45	0.74	0.4181	0.05
	Trinity River (cfs)	501.21	9.53	**0.0036**	0.12	295.78	5.98	**0.0248**	0.29	119.54	2.39	0.1372	0.13	4.52	0.11	0.7590	0.01	78.05	1.68	0.2024	0.10
	San Jacinto River (cfs)	311.92	5.63	**0.0198**	0.08	308.68	6.35	**0.0230**	0.30	81.41	1.55	0.2237	0.09	67.92	1.78	0.1826	0.10	32.12	0.65	0.4348	0.04
UGB	**Temp (°C)**	152.33	1.99	0.1602	0.03	1230.10	20.61	**0.0001**	0.58	2.63	0.04	0.8849	0.00	177.92	13.52	**0.0094**	0.47	185.92	2.73	0.1128	0.15
	Salinity (psu)	222.65	2.95	0.0942	0.04	19.93	0.14	0.7575	0.01	214.39	4.47	**0.0440**	0.22	4.42	0.18	0.6981	0.01	34.33	0.44	0.5173	0.03
	pH	62.10	0.80	0.3672	0.01	83.31	0.61	0.4548	0.04	3.26	0.05	0.8229	0.00	0.25	0.01	0.9706	0.00	13.69	0.17	0.6942	0.01
	NO_3+NO_2 (µM)	18.74	0.24	0.6596	0.00	93.64	0.69	0.4522	0.04	15.27	0.25	0.6304	0.02	69.92	3.43	0.0764	0.19	5.64	0.07	0.8415	0.00
	NH_3 (µM)	126.04	1.64	0.2023	0.02	46.81	0.34	0.6093	0.02	37.29	0.63	0.4239	0.04	26.17	1.12	0.2944	0.07	23.64	0.30	0.6051	0.02
	PO_4 (µM)	27.12	0.35	0.5723	0.01	466.35	4.22	0.0687	0.22	3.76	0.06	0.8184	0.00	19.89	0.84	0.3199	0.05	312.58	5.20	**0.0353**	0.25
	Trinity River (cfs)	260.17	3.48	0.0622	0.05	166.65	1.28	0.2489	0.08	10.87	0.18	0.6888	0.01	8.64	0.35	0.5035	0.02	118.21	1.64	0.2123	0.09
	San Jacinto River (cfs)	82.16	1.06	0.3014	0.02	190.54	1.48	0.2410	0.09	15.00	0.25	0.6386	0.02	4.41	0.18	0.6105	0.01	1.84	0.02	0.9605	0.00
LGB	**Temp (°C)**	226.87	4.20	**0.0459**	0.06	1125.20	28.71	**0.0004**	0.66	25.70	0.52	0.4855	0.03	126.75	10.10	**0.0427**	0.40	141.45	3.39	0.0811	0.17
	Salinity (psu)	129.15	2.33	0.1279	0.03	322.40	3.48	0.0866	0.19	3.27	0.06	0.8309	0.00	27.03	1.41	0.2620	0.09	0.22	0.00	0.9823	0.00
	pH	766.45	16.65	**0.0004**	0.20	271.33	2.82	0.0940	0.16	268.17	7.91	**0.0139**	0.33	15.52	0.78	0.3839	0.05	239.56	6.73	**0.0177**	0.30
	NO_3+NO_2 (µM)	129.18	2.33	0.1340	0.03	539.47	6.90	**0.0186**	0.31	11.29	0.23	0.6517	0.01	33.04	1.76	0.2001	0.10	4.41	0.09	0.7866	0.01
	NH_3 (µM)	23.41	0.41	0.5347	0.01	3.31	0.03	0.8985	0.00	3.75	0.07	0.8193	0.00	10.14	0.50	0.4794	0.03	1.99	0.04	0.8765	0.00
	PO_4 (µM)	467.30	9.26	**0.0031**	0.12	1264.80	42.33	**0.0001**	0.74	93.86	2.09	0.1623	0.12	0.41	0.02	0.8981	0.00	6.52	0.13	0.7350	0.01
	Trinity River (cfs)	176.53	3.23	0.0748	0.05	143.66	1.37	0.2647	0.08	16.55	0.33	0.5945	0.02	1.14	0.05	0.8249	0.00	21.80	0.44	0.5400	0.03
	San Jacinto River (cfs)	26.43	0.46	0.5172	0.01	217.53	2.18	0.1551	0.13	24.31	0.49	0.4935	0.03	1.74	0.08	0.7735	0.01	0.15	0.00	0.9885	0.00

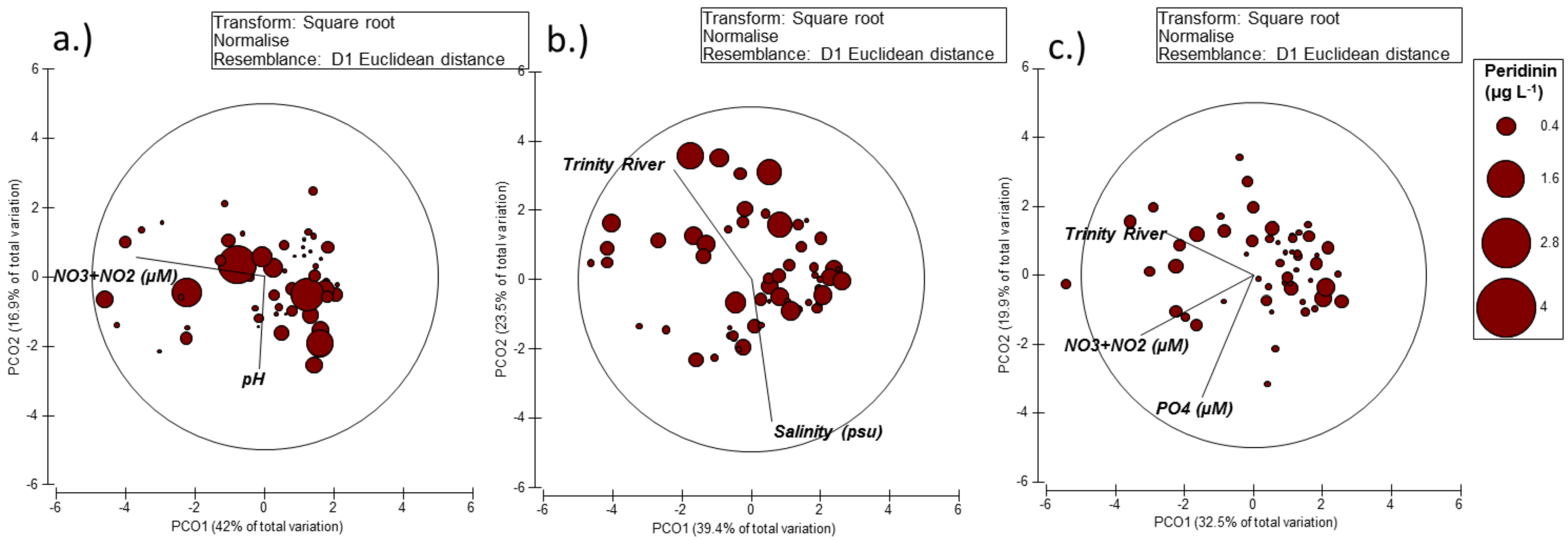

Figure 45 PCO of environmental data with the bubble underlay displaying dinoflagellate abundance (based on peridinin concentration in µg L^{-1}) 2008-2013 in GB: a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with dinoflagellate concentrations in each respective segment.

Table 21 DistLM results displaying the correlation between the dinoflagellate to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 2008-2013.

Subbay	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
	Parameter	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	50.26	0.55	0.4675	0.01	767.61	7.17	0.0132	0.32	18.82	0.35	0.5723	0.02	94.33	0.89	0.3762	0.05	123.46	3.26	0.0921	0.18
	Salinity (psu)	88.90	0.98	0.3182	0.01	943.26	9.90	0.0067	0.40	8.30	0.15	0.7167	0.01	3.01	0.03	0.9340	0.00	46.33	1.08	0.3106	0.07
	pH	780.37	9.70	**0.0028**	0.13	260.01	1.85	0.1858	0.11	103.46	2.11	0.1612	0.12	344.12	3.80	0.0635	0.19	7.14	0.16	0.7100	0.01
	NO_3+NO_2 (µM)	571.41	6.84	**0.0091**	0.09	201.21	1.39	0.2492	0.08	43.29	0.82	0.3713	0.05	291.79	3.11	0.0882	0.16	13.75	0.30	0.5948	0.02
	NH_3 (µM)	316.51	3.63	**0.0576**	0.05	56.77	0.37	0.5732	0.02	43.30	0.82	0.3919	0.05	211.77	2.14	0.1543	0.12	3.33	0.07	0.8058	0.00
	PO_4 (µM)	54.68	0.60	0.4523	0.01	1430.20	22.80	0.0008	0.60	0.59	0.01	0.9508	0.00	18.31	0.17	0.7216	0.01	6.70	0.15	0.7070	0.01
	Trinity River (cfs)	24.03	0.26	0.6276	0.00	536.07	4.38	**0.0474**	0.23	0.74	0.01	0.9542	0.00	30.50	0.28	0.6167	0.02	158.77	4.47	**0.0490**	0.23
	San Jacinto River (cfs)	257.75	2.93	**0.0896**	0.04	711.15	6.42	**0.0207**	0.30	41.15	0.78	0.3987	0.05	55.35	0.51	0.4911	0.03	24.63	0.55	0.4679	0.04
UGB	**Temp (°C)**	1.99	0.03	0.9172	0.00	798.83	37.02	**0.0004**	0.71	28.62	0.26	0.6128	0.02	199.53	5.53	0.0315	0.27	32.61	0.41	0.5463	0.02
	Salinity (psu)	457.43	6.42	**0.0128**	0.09	28.66	0.39	0.5455	0.03	501.54	6.37	0.0222	0.28	4.71	0.10	0.7792	0.01	105.01	1.39	0.2500	0.08
	pH	36.37	0.47	0.5007	0.01	251.38	4.33	0.0559	0.22	136.08	1.34	0.2769	0.08	1.35	0.03	0.9129	0.00	105.44	1.39	0.2610	0.08
	NO_3+NO_2 (µM)	42.57	0.55	0.4597	0.01	133.87	2.03	0.1694	0.12	96.44	0.93	0.3501	0.05	54.34	1.19	0.2964	0.07	0.71	0.01	0.9723	0.00
	NH_3 (µM)	137.40	1.81	0.1871	0.03	69.78	0.99	0.3303	0.06	88.48	0.85	0.3864	0.05	32.56	0.69	0.4227	0.04	131.32	1.77	0.1995	0.10
	PO_4 (µM)	5.10	0.07	0.8291	0.00	11.21	0.15	0.7441	0.01	26.71	0.25	0.6507	0.02	0.39	0.01	0.9642	0.00	19.61	0.24	0.6554	0.01
	Trinity River (cfs)	862.14	13.21	**0.0004**	0.16	254.19	4.39	**0.0496**	0.23	250.63	2.66	0.1192	0.14	4.79	0.10	0.7631	0.01	540.35	11.12	0.0025	0.41
	San Jacinto River (cfs)	255.81	3.45	0.0648	0.05	235.05	3.97	0.0676	0.21	328.30	3.67	0.0677	0.19	1.43	0.03	0.8898	0.00	12.17	0.15	0.7223	0.01
LGB	**Temp (°C)**	3.79	0.09	0.7839	0.00	426.84	13.80	**0.0030**	0.48	81.56	2.57	0.1250	0.14	178.03	5.82	**0.0232**	0.28	44.79	1.86	0.1951	0.10
	Salinity (psu)	96.14	2.28	0.1391	0.03	142.22	2.85	0.1102	0.16	3.15	0.09	0.7816	0.01	46.74	1.19	0.2887	0.07	5.19	0.20	0.6682	0.01
	pH	148.16	3.58	0.0629	0.05	132.54	2.62	0.0971	0.15	61.35	1.86	0.1905	0.10	93.81	2.59	0.1262	0.15	120.10	6.21	**0.0217**	0.28
	NO_3+NO_2 (µM)	207.80	5.13	**0.0250**	0.07	375.26	10.92	**0.0056**	0.42	0.94	0.03	0.9086	0.00	126.49	3.72	0.0659	0.20	25.27	1.00	0.3344	0.06
	NH_3 (µM)	44.96	1.05	0.3144	0.02	8.78	0.15	0.7085	0.01	2.47	0.07	0.8179	0.00	38.67	0.97	0.3481	0.06	1.19	0.04	0.8492	0.00
	PO_4 (µM)	502.09	13.86	**0.0005**	0.17	637.26	37.70	**0.0002**	0.72	31.96	0.92	0.3474	0.05	86.70	2.36	0.1461	0.14	5.47	0.21	0.6545	0.01
	Trinity River (cfs)	242.56	6.06	**0.0160**	0.08	91.97	1.73	0.2081	0.10	117.48	3.99	0.0615	0.20	0.01	0.00	0.9987	0.00	58.71	2.53	0.1249	0.14
	San Jacinto River (cfs)	1.14	0.03	0.8997	0.00	134.33	2.66	0.1301	0.15	5.84	0.16	0.7054	0.01	20.77	0.51	0.5098	0.03	0.26	0.01	0.9515	0.00

Other fauna

The following PCOs (Figs. 46-49) correspond to those shown above for the abiotic environmental variables used over the sampling period of 1980-2010 (Fig. 11). As a review in TB the first axis separates the data primarily on freshwater inflow and river discharge and PCO2 by temperature and nutrient concentration (Fig. 11a, 46-49a). PCO axis 1 (PCO1) explains 36.6% of the total variation and the PCO axis 2 (PCO2) explains 20.2% of the total variation. In UGB, PCO1 explains 31.3% of the total variation and PCO2 18%. In Figs. 11b and 46-49b, PCO1 is predominantly explained by freshwater inflow including river discharge and PCO2 by temperature and nutrient concentration similar to TB. In LGB, PCO1 explains 32% of the total variation and is defined by freshwater inflow and temperature while PCO2 explains 18.9% and is defined by nutrient concentration (Figs. 11c and 46-49c). Higher temperatures and higher salinities were observed during the seasons that were grouped within the higher salinity range (Fig. 12). The vectors displayed in Figs. 46-49 are the environmental factors that had a significant correlation to the abundance data for each species.

Atlantic croaker (Micropogonias undulates)

Higher abundances of Atlantic croaker were recorded in TB compared to UGB and LGB for the study period (1980-2010) (Fig. 46). In TB all of the environmental parameters displayed had a significant correlation with Atlantic croaker abundance including: TWDB surface inflow (p<0.001), TR discharge (p<0.001), temperature (p<0.001), dissolved oxygen (p<0.001), turbidity (p<0.001), PO4 (p<0.001), DIN:DIP (p<0.001), salinity (p<0.01), SJR discharge (p<0.01) and NO_3^- + NO_2^- (p<0.001) (Fig. 46a; Table 22). In UGB, the Atlantic croaker abundances correlated with salinity (p<0.001), temperature (p<0.001), dissolved oxygen (p<0.001), turbidity (p<0.001), PO4 (p<0.001), TWDB surface inflow (p<0.01), TR discharge (p<0.01), SJR discharge (p<0.05), DIN:DIP (p<0.05) and NO_3^- + NO_2^- (p<0.05) (Fig. 46b; Table 22). The Atlantic croaker in LGB correlated with dissolved oxygen (p<0.001), TR discharge (p<0.01), TWDB surface inflow (p<0.01), temperature (p<0.01) and salinity (p<0.05) (Fig. 46c; Table 22).

Spotted seatrout (Cynoscion nebulosus)

Spotted seatrout in TB displayed a significant correlation in increasing abundance with decreasing temperatures (p<0.001), increasing SJR discharge (p<0.001), increasing DIN:DIP (p<0.01), decreasing PO_4 (p<0.05) and increasing NO_3^- + NO_2^- (p<0.05) (Fig. 47a; Table 23). In UGB Spotted seatrout increased in abundance with decreasing temperatures (p<0.001), increasing dissolved oxygen (p<0.001), increasing SJR discharge (p<0.001), increasing NO_3^- + NO_2^- (p<0.05), increasing TR discharge (p<0.05) and decreasing PO_4 (p<0.05) (Fig. 47b; Table 23). In LGB, Spotted seatrout increased in abundance with decreasing temperature (p<0.001), increasing SJR discharge (p<0.001), increasing dissolved oxygen (p<0.01), TWDB surface inflow (p<0.05) and TR discharge (p<0.05) (Fig. 47c; Table 23).

Southern flounder (Paralichthys lethostigma)

The abundance of Southern flounder collected in the bay trawl was highest in TB compared to UGB and LGB (Fig. 48). In TB, increased Southern flounder abundance was significantly correlated to increasing TR discharge (p<0.01), temperature (p<0.01), TWDB surface inflow (p<0.05), decreasing salinity (p<0.05), dissolved oxygen (p<0.05) and increasing NO_3^- + NO_2^- (p<0.05) (Fig. 48a; Table 24). Increasing abundance of Southern flounder in UGB was significantly correlated to decreasing salinity (p<0.01), increasing TR discharge (p<0.01) and increasing TWDB surface inflow (p<0.01) (Fig. 48b; Table 24). In LGB the abundance of Southern flounder increased with increasing TR discharge (p<0.001), increasing SJR discharge (p<0.01), increasing TWDB surface inflow (p<0.01) and decreasing salinity (p<0.05) (Fig. 48c; Table 24).

Blue crab (Callinectes sapidus)

The abundance of blue crab per bay trawl sample collection was higher in TB compared to UGB and LGB (Fig. 49). In TB the increase in abundance of Blue crab was significantly correlated with temperature (p<0.01), PO_4 (p<0.001), dissolved oxygen (p<0.05) and increasing turbidity (p<0.05) (Fig. 49a; Table 25). In UGB the Blue crab abundance increased with decreasing salinity (p<0.001), increasing TR discharge (p<0.05) and decreasing NH4+ (p<0.05)

(Fig. 49b; Table 25). In LGB the Blue crab abundance is significantly correlated to salinity (p<0.01), TR discharge (p<0.05) and NO_3^- + NO_2^-, (p<0.05) (Fig. 49c; Table 25).

Brown shrimp (Farfantepenaeus aztecus)

The Brown shrimp abundance per bay trawl collection was highest in UGB compared to TB and LGB (Fig. 50). In TB, Brown shrimp abundance is significantly correlated to increasing temperatures (p<0.001), decreasing dissolved oxygen (p<0.001), decreasing SJR discharge (p<0.01) and decreasing DIN:DIP (p<0.05) (Fig. 50a; Table 26). In UGB, Brown shrimp increased in abundance with increasing temperatures (p<0.001), decreased SJR discharge (p<0.001), decreased dissolved oxygen (p<0.001) and decreased NO_3^- + NO_2^-, (p<0.01) (Fig. 50b; Table 26). In LGB, Brown shrimp abundance increased with increasing temperatures (p<0.001), increasing dissolved oxygen (p<0.001) and decreasing NH4+ (p<0.05) (Fig. 50c; Table 26).

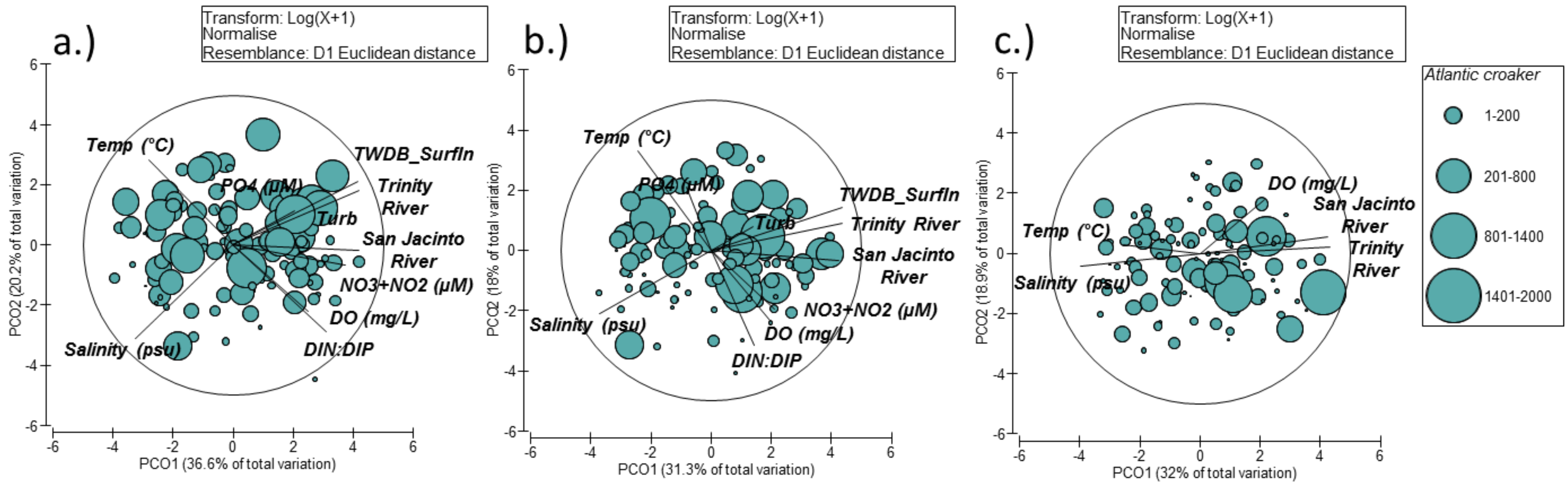

Figure 46 PCO of environmental data with the bubble underlay showing abundance of Atlantic croaker collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Atlantic croaker abundance in each respective segment.

Table 22 DISTLM test results Correlation between the abundance of each Atlantic croaker to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl.

Subbay and	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
Gear Type	**Parameter**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**
TB	**Temp (°C)**	21183.00	15.17	**0.0001**	0.11	672.94	0.74	0.4677	0.02	1539.80	1.31	0.2341	0.04	4999.40	4.79	**0.0052**	0.14	7209.60	6.63	**0.0192**	0.19
Bay Trawl	**DO (mg/L)**	17646.00	12.38	**0.0001**	0.09	2366.60	2.78	0.0724	0.09	1154.70	0.97	0.4057	0.03	9518.00	10.72	**0.0007**	0.27	2271.10	1.81	0.1025	0.06
	Salinity (psu)	7477.30	4.95	**0.0010**	0.04	927.63	1.03	0.3463	0.03	2442.10	2.14	0.0672	0.07	3082.50	2.78	**0.0326**	0.09	1996.60	1.58	0.1440	0.05
	Turb (NTU)	10374.00	6.98	**0.0001**	0.05	548.32	0.60	0.5418	0.02	1524.60	1.30	0.2416	0.04	5164.10	4.98	**0.0011**	0.15	4004.20	3.34	**0.0157**	0.10
	NO_3+NO_2 (μM)	4794.10	3.13	**0.0084**	0.03	1691.60	1.93	0.1491	0.06	1329.60	1.13	0.3206	0.04	772.11	0.65	0.5989	0.02	2556.60	2.05	0.0787	0.07
	NH_3 (μM)	1310.00	0.84	0.5252	0.01	150.26	0.16	0.8509	0.01	1721.90	1.48	0.1953	0.05	980.41	0.83	0.4592	0.03	1905.30	1.50	0.1874	0.05
	PO_4 (μM)	14810.00	10.22	**0.0001**	0.08	3885.40	4.86	**0.0185**	0.14	3056.90	2.73	**0.0365**	0.09	6613.40	6.70	0.0021	0.19	2903.60	2.35	0.0603	0.07
	N:P	7569.60	5.02	**0.0005**	0.04	4020.40	5.06	**0.0160**	0.15	2373.40	2.08	0.0795	0.07	2471.90	2.19	0.0566	0.07	3800.30	3.15	**0.0207**	0.10
	Surf. In. (ac-ft/mon^{-1})	8964.80	5.99	**0.0001**	0.05	3872.40	4.84	**0.0153**	0.14	2047.10	1.77	0.1133	0.06	1473.70	1.27	0.2612	0.04	1903.50	1.50	0.1908	0.05
	TR (cfs)	7668.60	5.09	**0.0003**	0.04	2617.20	3.10	0.0559	0.10	1095.10	0.92	0.4156	0.03	1247.00	1.06	0.3292	0.04	835.15	0.64	0.6697	0.02
	SJR (cfs)	6587.90	4.34	**0.0012**	0.03	3278.80	4.00	**0.0274**	0.12	538.08	0.45	0.8366	0.02	1077.00	0.91	0.4467	0.03	2473.60	1.98	0.0875	0.06
UGB	**Temp (°C)**	20262.00	14.43	**0.0001**	0.11	1877.00	1.16	0.3129	0.04	147.37	0.18	0.8327	0.01	1380.10	1.87	0.1292	0.06	422.95	0.65	0.4757	0.02
Bay Trawl	**DO (mg/L)**	17509.00	12.27	**0.0001**	0.09	3313.80	2.11	0.0534	0.07	5253.90	8.43	**0.0017**	0.23	3208.00	4.76	**0.0186**	0.14	25.56	0.04	0.9747	0.00
	Salinity (psu)	8029.70	5.34	**0.0005**	0.04	2948.50	1.86	0.0756	0.06	577.96	0.74	0.4724	0.02	178.40	0.23	0.8095	0.01	115.01	0.17	0.8530	0.01
	Turb (NTU)	10186.00	6.85	**0.0003**	0.05	2866.20	1.80	0.1004	0.06	269.48	0.34	0.7114	0.01	397.89	0.52	0.5877	0.02	484.44	0.75	0.4543	0.03
	NO_3+NO_2 (μM)	4630.30	3.02	**0.0118**	0.02	1852.00	1.14	0.3247	0.04	1607.00	2.15	0.1290	0.07	514.66	0.67	0.4990	0.02	105.54	0.16	0.8633	0.01
	NH_3 (μM)	1251.80	0.80	0.5571	0.01	693.74	0.42	0.8799	0.01	291.31	0.37	0.6983	0.01	2204.00	3.11	0.0652	0.10	300.53	0.46	0.6229	0.02
	PO_4 (μM)	17724.00	12.44	**0.0001**	0.09	8131.80	5.78	**0.0019**	0.17	3201.20	4.61	**0.0144**	0.14	1659.50	2.28	0.1087	0.07	892.32	1.40	0.2453	0.05
	N:P	4089.00	2.66	**0.0301**	0.02	1229.80	0.75	0.4591	0.03	2456.60	3.41	**0.0403**	0.11	531.12	0.69	0.4778	0.02	775.82	1.21	0.2847	0.04
	Surf. In. (ac-ft/mon^{-1})	7782.50	5.17	**0.0011**	0.04	4027.80	2.60	0.0341	0.08	574.40	0.73	0.4467	0.02	362.20	0.47	0.6211	0.02	680.31	1.06	0.3405	0.04
	TR (cfs)	7391.80	4.90	**0.0012**	0.04	3475.00	2.22	0.0543	0.07	386.27	0.49	0.6111	0.02	419.47	0.54	0.5632	0.02	369.67	0.57	0.5705	0.02
	SJR (cfs)	4468.00	2.91	**0.0177**	0.02	4149.30	2.69	**0.0200**	0.08	645.20	0.82	0.4423	0.03	665.71	0.87	0.4139	0.03	659.08	1.02	0.3553	0.03
LGB	**Temp (°C)**	6162.20	6.31	**0.0040**	0.05	1918.90	2.56	0.0987	0.08	5926.30	9.08	**0.0027**	0.24	319.99	0.42	0.6087	0.01	4477.30	8.34	**0.0027**	0.22
Bay Trawl	**DO (mg/L)**	10640.00	11.32	**0.0001**	0.08	290.45	0.36	0.6810	0.01	1113.10	1.36	0.2310	0.04	5598.70	9.76	**0.0191**	0.25	495.59	0.74	0.4659	0.02
	Salinity (psu)	4997.40	5.07	**0.0104**	0.04	2046.40	2.74	0.0736	0.09	2281.20	2.93	0.0562	0.09	207.62	0.27	0.7652	0.01	31.10	0.05	0.9731	0.00
	Turb (NTU)	332.06	0.32	0.7485	0.00	222.04	0.27	0.7512	0.01	1203.10	1.48	0.1774	0.05	920.60	1.25	0.2611	0.04	539.47	0.80	0.3960	0.03
	NO_3+NO_2 (μM)	282.44	0.28	0.7597	0.00	1500.70	1.96	0.1537	0.06	484.48	0.58	0.4010	0.02	633.47	0.85	0.4113	0.03	1058.70	1.62	0.1926	0.05
	NH_3 (μM)	1214.20	1.19	0.2956	0.01	1516.20	1.98	0.1516	0.06	182.02	0.21	0.8287	0.01	267.55	0.35	0.6562	0.01	378.15	0.56	0.5479	0.02
	PO_4 (μM)	2296.30	2.28	0.1000	0.02	221.92	0.27	0.7550	0.01	5302.30	7.86	**0.0005**	0.21	1879.20	2.68	0.0762	0.08	1156.40	1.78	0.1681	0.06
	N:P	1116.90	1.10	0.3173	0.01	303.19	0.38	0.6707	0.01	1027.50	1.25	0.2826	0.04	315.35	0.42	0.6383	0.01	512.57	0.76	0.4523	0.03
	Surf. In. (ac-ft/mon^{-1})	5748.40	5.86	**0.0057**	0.05	3907.90	5.73	**0.0129**	0.17	1446.00	1.79	0.1552	0.06	434.12	0.58	0.5646	0.02	383.28	0.57	0.5550	0.02
	TR (cfs)	7077.30	7.30	**0.0016**	0.06	3279.30	4.66	**0.0199**	0.14	1074.20	1.31	0.2624	0.04	420.30	0.56	0.5596	0.02	114.94	0.17	0.8614	0.01
	SJR (cfs)	331.17	0.32	0.7456	0.00	2190.80	2.96	0.0652	0.09	462.15	0.55	0.6051	0.02	643.91	0.87	0.3906	0.03	238.06	0.35	0.7102	0.01

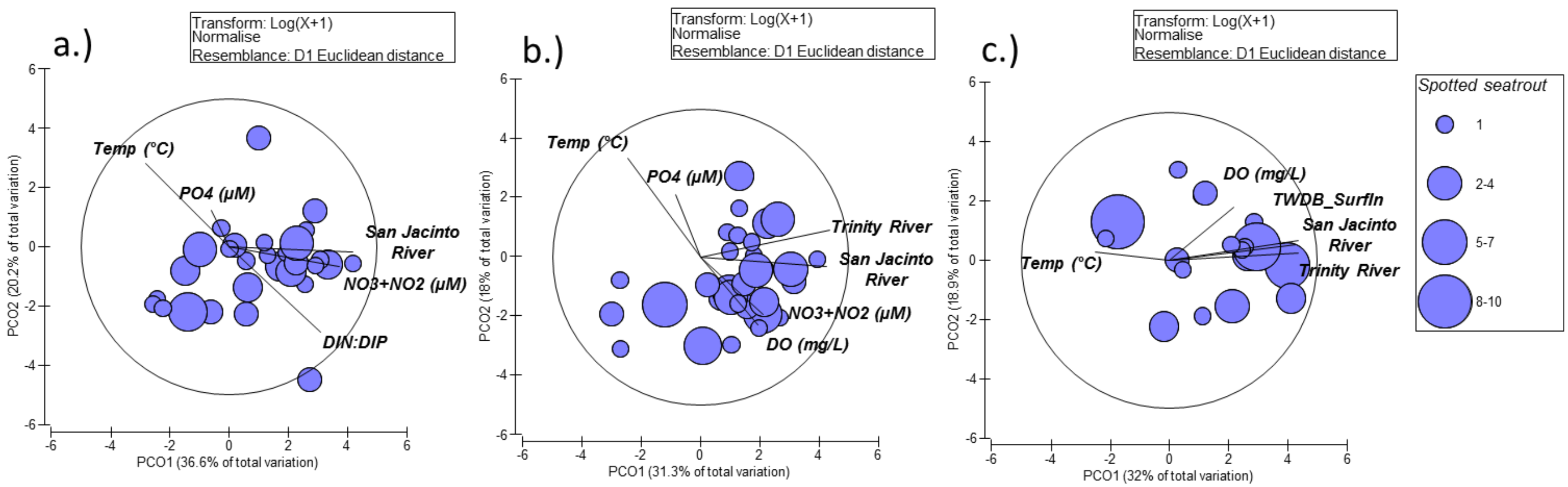

Figure 47 PCO of environmental data with the bubble underlay showing abundance of Spotted seatrout collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Spotted seatrout abundance in each respective segment.

Table 23 DISTLM test results Correlation between the abundance of each Spotted seatrout to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl.

Subbay and	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
Gear Type	Parameter	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	6836.30	28.86	**0.0001**	0.19	9.10	0.02	0.9404	0.00	192.30	1.01	0.3306	0.03	23.14	0.41	0.5512	0.01	193.91	0.78	0.2959	0.03
Bay Trawl	**DO (mg/L)**	943.25	3.31	0.0712	0.03	1530.80	3.72	0.0620	0.11	272.63	1.46	0.2300	0.05	0.68	0.01	0.9082	0.00	152.77	0.61	0.4455	0.02
	Salinity (psu)	135.53	0.46	0.5018	0.00	77.97	0.17	0.6963	0.01	1.04	0.01	0.9687	0.00	224.49	4.53	0.0970	0.14	150.08	0.60	0.4566	0.02
	Turb (NTU)	4.60	0.02	0.9422	0.00	215.77	0.47	0.5043	0.02	520.42	2.92	0.0907	0.09	68.24	1.24	0.3229	0.04	49.93	0.20	0.6738	0.01
	NO_3+NO_2 (µM)	1224.10	4.33	**0.0395**	0.03	66.62	0.14	0.7367	0.00	32.43	0.17	0.6874	0.01	8.46	0.15	0.7102	0.01	1319.10	6.27	**0.0237**	0.18
	NH_3 (µM)	206.82	0.71	0.4135	0.01	103.13	0.22	0.6645	0.01	34.55	0.18	0.6925	0.01	34.36	0.61	0.4553	0.02	7.39	0.03	0.9003	0.00
	PO_4 (µM)	1772.50	6.37	**0.0124**	0.05	1734.90	4.28	**0.0470**	0.13	83.88	0.43	0.5204	0.01	28.96	0.51	0.4832	0.02	45.16	0.18	0.6828	0.01
	N:P	1994.20	7.21	**0.0080**	0.06	175.02	0.38	0.5586	0.01	2.27	0.01	0.9388	0.00	10.71	0.19	0.6497	0.01	43.82	0.17	0.6902	0.01
	Surf. In. (ac-ft/mon^{-1})	589.42	2.05	0.1583	0.02	23.40	0.05	0.8628	0.00	13.29	0.07	0.7881	0.00	190.26	3.75	**0.0312**	0.11	193.02	0.77	0.3938	0.03
	TR (cfs)	697.36	2.43	0.1219	0.02	9.74	0.02	0.9402	0.00	79.17	0.41	0.5314	0.01	532.84	13.70	**0.0326**	0.32	159.46	0.64	0.4362	0.02
	SJR (cfs)	3090.10	11.55	**0.0007**	0.09	67.50	0.15	0.7269	0.01	0.95	0.00	0.9734	0.00	165.38	3.21	0.0917	0.10	1062.60	4.85	**0.0322**	0.14
UGB	**Temp (°C)**	12485.00	53.60	**0.0001**	0.31	1231.70	2.68	0.1071	0.08	377.02	1.21	0.2831	0.04	n/a	n/a	n/a	n/a	76.23	0.43	0.4504	0.01
Bay Trawl	**DO (mg/L)**	4266.00	14.21	**0.0002**	0.10	3.67	0.01	0.9841	0.00	79.23	0.25	0.6306	0.01	n/a	n/a	n/a	n/a	156.64	0.90	0.3429	0.03
	Salinity (psu)	362.39	1.09	0.3005	0.01	181.95	0.37	0.5626	0.01	230.39	0.73	0.4114	0.02	n/a	n/a	n/a	n/a	1270.30	9.31	**0.0088**	0.24
	Turb (NTU)	1197.10	3.68	0.0592	0.03	808.67	1.70	0.1918	0.06	96.98	0.30	0.6030	0.01	n/a	n/a	n/a	n/a	37.76	0.21	0.6587	0.01
	NO_3+NO_2 (µM)	1539.50	4.77	**0.0268**	0.04	2.70	0.01	0.9868	0.00	127.86	0.40	0.5384	0.01	n/a	n/a	n/a	n/a	121.92	0.69	0.4118	0.02
	NH_3 (µM)	16.31	0.05	0.8706	0.00	6.06	0.01	0.9740	0.00	0.69	0.00	0.9917	0.00	n/a	n/a	n/a	n/a	259.36	1.51	0.2219	0.05
	PO_4 (µM)	1404.60	4.34	**0.0391**	0.03	31.25	0.06	0.8694	0.00	1134.10	3.98	**0.0493**	0.12	n/a	n/a	n/a	n/a	2.39	0.01	0.9577	0.00
	N:P	845.49	2.58	0.1050	0.02	206.83	0.42	0.5416	0.01	997.47	3.44	0.0694	0.11	n/a	n/a	n/a	n/a	466.45	2.84	0.1047	0.09
	Surf. In. (ac-ft/mon^{-1})	1012.90	3.10	0.0825	0.02	27.73	0.06	0.8785	0.00	177.31	0.56	0.4678	0.02	n/a	n/a	n/a	n/a	242.12	1.41	0.2541	0.05
	TR (cfs)	1475.50	4.57	**0.0346**	0.04	52.62	0.11	0.7998	0.00	48.21	0.15	0.7114	0.01	n/a	n/a	n/a	n/a	278.53	1.63	0.2262	0.05
	SJR (cfs)	5414.10	18.61	**0.0002**	0.13	12.79	0.03	0.9464	0.00	145.23	0.46	0.5203	0.02	n/a	n/a	n/a	n/a	1027.00	7.09	0.0099	0.20
LGB	**Temp (°C)**	8361.70	50.83	**0.0001**	0.29	3939.00	9.40	**0.0033**	0.24	172.95	1.32	0.2467	0.04	n/a		n/a	n/a	n/a	0.24	0.5889	0.01
Bay Trawl	**DO (mg/L)**	1960.60	9.04	**0.0037**	0.07	81.90	0.15	0.7522	0.01	26.63	0.20	0.6032	0.01	n/a		n/a	n/a	n/a	0.04	0.8681	0.00
	Salinity (psu)	665.87	2.93	0.0859	0.02	50.79	0.09	0.8317	0.00	75.65	0.56	0.4562	0.02	n/a		n/a	n/a	n/a	10.32	**0.0108**	0.26
	Turb (NTU)	128.72	0.55	0.4575	0.00	169.04	0.31	0.6083	0.01	120.01	0.90	0.3291	0.03	n/a		n/a	n/a	n/a	0.07	0.7959	0.00
	NO_3+NO_2 (µM)	132.66	0.57	0.4474	0.00	458.35	0.85	0.3636	0.03	165.89	1.27	0.2240	0.04	n/a		n/a	n/a	n/a	0.05	0.7844	0.00
	NH_3 (µM)	93.37	0.40	0.5354	0.00	37.70	0.07	0.8678	0.00	20.45	0.15	0.7083	0.01	n/a		n/a	n/a	n/a	0.43	0.4927	0.01
	PO_4 (µM)	180.02	0.78	0.3869	0.01	22.91	0.04	0.9149	0.00	30.37	0.22	0.6398	0.01	n/a		n/a	n/a	n/a	0.08	0.8129	0.00
	N:P	94.33	0.41	0.5375	0.00	209.68	0.38	0.5593	0.01	110.27	0.83	0.3795	0.03	n/a		n/a	n/a	n/a	0.30	0.5943	0.01
	Surf. In. (ac-ft/mon^{-1})	1084.20	4.84	**0.0297**	0.04	888.90	1.70	0.1977	0.06	22.68	0.17	0.6768	0.01	n/a		n/a	n/a	n/a	3.13	0.0818	0.10
	TR (cfs)	919.01	4.08	**0.0406**	0.03	416.00	0.77	0.3912	0.03	13.74	0.10	0.7700	0.00	n/a		n/a	n/a	n/a	1.12	0.3266	0.04
	SJR (cfs)	2516.60	11.85	**0.0009**	0.09	862.45	1.64	0.2116	0.05	27.71	0.20	0.6842	0.01	n/a		n/a	n/a	n/a	2.91	0.1070	0.09

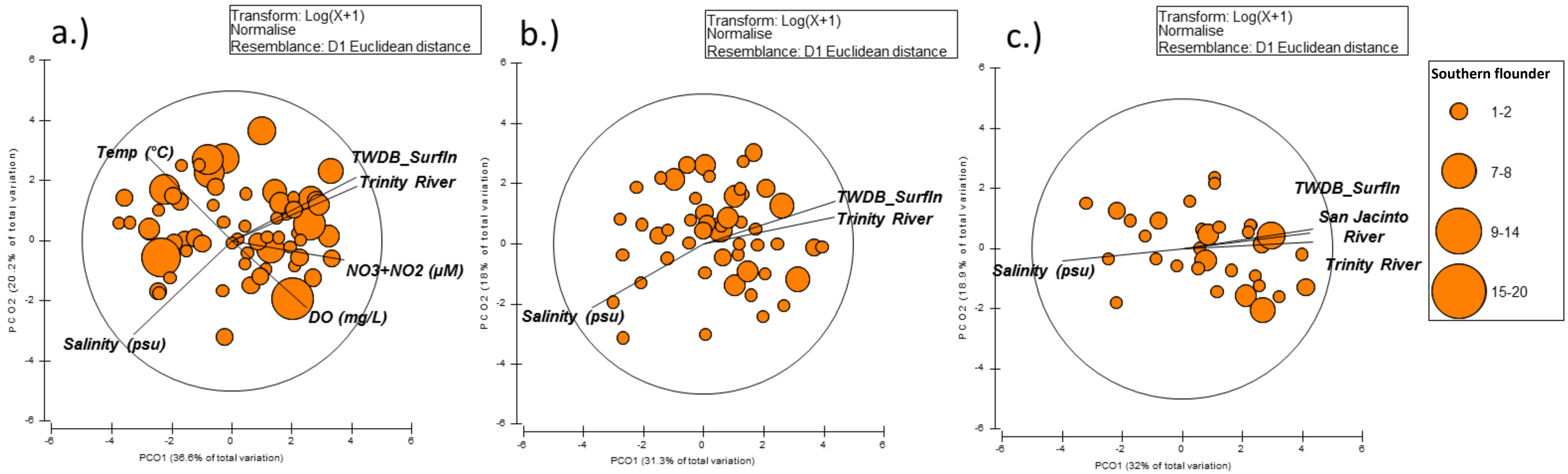

Figure 48 PCO of environmental data with the bubble underlay showing abundance of Southern flounder collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Southern flounder abundance in each respective segment.

Table 24 DISTLM test results Correlation between the abundance of each Southern flounder to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl.

Subbay and	Water Quality	All Seasons				Winter				Spring				Summer				Fall			
Gear Type	**Parameter**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**	**SS (Trace)**	**PF**	***p***	**Prop.**
TB	**Temp (°C)**	4667.10	10.80	**0.0014**	0.08	42.57	0.13	0.7369	0.00	27.58	0.06	0.8977	0.00	2497.90	6.31	**0.0164**	0.18	84.53	0.20	0.7985	0.01
Bay Trawl	**DO (mg/L)**	2254.10	4.99	**0.0245**	0.04	66.98	0.20	0.6711	0.01	456.08	0.97	0.3390	0.03	65.18	0.14	0.7949	0.00	28.68	0.07	0.8879	0.00
	Salinity (psu)	2831.30	6.33	**0.0121**	0.05	169.46	0.52	0.4736	0.02	1268.00	2.88	0.0984	0.09	231.20	0.49	0.5079	0.02	18.67	0.04	0.9167	0.00
	Turb (NTU)	51.01	0.11	0.7836	0.00	265.96	0.82	0.3697	0.03	263.44	0.55	0.4893	0.02	572.22	1.24	0.2716	0.04	189.85	0.45	0.5264	0.02
	NO_3+NO_2 (µM)	2188.10	4.84	**0.0286**	0.04	1207.30	4.14	0.0536	0.12	1590.00	3.70	0.0574	0.11	383.89	0.82	0.4069	0.03	2197.00	6.19	**0.0131**	0.18
	NH_3 (µM)	314.06	0.67	0.4177	0.01	198.18	0.61	0.4570	0.02	45.40	0.09	0.8390	0.00	88.32	0.18	0.7216	0.01	358.53	0.86	0.3595	0.03
	PO_4 (µM)	709.13	1.53	0.2144	0.01	63.66	0.19	0.6739	0.01	48.16	0.10	0.8352	0.00	51.78	0.11	0.8093	0.00	88.40	0.21	0.6933	0.01
	N:P	26.31	0.06	0.8813	0.00	26.37	0.08	0.7889	0.00	557.13	1.20	0.2832	0.04	60.98	0.13	0.7882	0.00	600.43	1.46	0.2364	0.05
	Surf. In. (ac-ft/mon^{-1})	2953.90	6.62	**0.0113**	0.05	666.64	2.15	0.1526	0.07	1486.10	3.43	0.0652	0.11	360.28	0.77	0.3897	0.03	659.43	1.62	0.2131	0.05
	TR (cfs)	4127.20	9.46	**0.0023**	0.07	706.26	2.29	0.1419	0.07	3741.50	10.52	**0.0018**	0.27	1239.40	2.82	0.1029	0.09	473.57	1.14	0.2949	0.04
	SJR (cfs)	569.77	1.22	0.2684	0.01	1036.90	3.49	0.0692	0.11	376.63	0.80	0.3776	0.03	3.84	0.01	0.9835	0.00	3074.70	9.47	**0.0028**	0.25
UGB	**Temp (°C)**	780.44	2.23	0.1299	0.02	98.88	0.34	0.5722	0.01	214.82	0.56	0.4619	0.02	664.04	1.79	0.2005	0.06	50.54	0.17	0.6821	0.01
Bay Trawl	**DO (mg/L)**	463.42	1.32	0.2501	0.01	74.07	0.25	0.6324	0.01	73.82	0.19	0.6916	0.01	305.11	0.79	0.3938	0.03	16.81	0.06	0.8390	0.00
	Salinity (psu)	3723.90	11.44	**0.0012**	0.09	67.53	0.23	0.6435	0.01	3.96	0.01	0.9686	0.00	1719.30	5.12	**0.0322**	0.15	1669.90	6.96	**0.0118**	0.19
	Turb (NTU)	201.47	0.57	0.4544	0.00	525.36	1.90	0.1730	0.06	20.45	0.05	0.8575	0.00	14.07	0.04	0.8911	0.00	555.85	2.00	0.1610	0.06
	NO_3+NO_2 (µM)	3.18	0.01	0.9649	0.00	9.06	0.03	0.9148	0.00	468.99	1.25	0.2721	0.04	35.19	0.09	0.7933	0.00	13.17	0.04	0.8747	0.00
	NH_3 (µM)	371.60	1.05	0.3018	0.01	19.08	0.07	0.8383	0.00	51.50	0.13	0.7365	0.00	616.76	1.65	0.2120	0.05	903.53	3.39	0.0780	0.10
	PO_4 (µM)	434.21	1.23	0.2627	0.01	406.05	1.45	0.2417	0.05	814.73	2.25	0.1426	0.07	9.85	0.03	0.9169	0.00	2.46	0.01	0.9736	0.00
	N:P	15.63	0.04	0.8701	0.00	518.77	1.88	0.1731	0.06	635.46	1.72	0.1994	0.06	787.02	2.14	0.1550	0.07	104.93	0.36	0.5583	0.01
	Surf. In. (ac-ft/mon^{-1})	2398.20	7.13	**0.0068**	0.06	60.10	0.21	0.6670	0.01	16.77	0.04	0.8816	0.00	1217.60	3.45	0.0739	0.11	1504.20	6.13	**0.0185**	0.17
	TR (cfs)	3237.00	9.83	**0.0012**	0.07	13.19	0.05	0.8752	0.00	211.02	0.55	0.4664	0.02	2881.40	9.75	**0.0049**	0.25	714.88	2.62	0.1150	0.08
	SJR (cfs)	435.24	1.24	0.2585	0.01	139.07	0.48	0.4979	0.02	10.99	0.03	0.9159	0.00	37.34	0.09	0.7788	0.00	1662.20	6.93	**0.0135**	0.19
LGB	**Temp (°C)**	636.25	2.39	0.1236	0.02	238.80	0.59	0.4525	0.02	37.23	0.13	0.7350	0.00	12.34	0.05	0.8406	0.00	9.55	0.09	0.7396	0.00
Bay Trawl	**DO (mg/L)**	157.78	0.58	0.4416	0.00	177.49	0.43	0.5198	0.01	220.17	0.79	0.3849	0.03	138.72	0.54	0.4902	0.02	83.40	0.83	0.3755	0.03
	Salinity (psu)	1151.90	4.39	**0.0369**	0.03	220.73	0.54	0.4807	0.02	777.15	2.98	0.0923	0.09	0.59	0.00	0.9836	0.00	99.93	1.00	0.3248	0.03
	Turb (NTU)	543.45	2.03	0.1615	0.02	1367.10	3.71	0.0615	0.11	220.13	0.79	0.3852	0.03	3.93	0.02	0.9235	0.00	20.30	0.20	0.6565	0.01
	NO_3+NO_2 (µM)	752.74	2.83	0.0968	0.02	1351.20	3.66	0.0655	0.11	9.61	0.03	0.8728	0.00	387.46	1.57	0.2215	0.05	353.32	3.86	**0.0446**	0.12
	NH_3 (µM)	119.52	0.44	0.5106	0.00	104.50	0.25	0.6348	0.01	79.03	0.28	0.6079	0.01	117.03	0.46	0.5119	0.02	6.41	0.06	0.8136	0.00
	PO_4 (µM)	33.07	0.12	0.7459	0.00	22.56	0.05	0.8674	0.00	138.70	0.49	0.4918	0.02	6.18	0.02	0.8924	0.00	188.32	1.93	0.1868	0.06
	N:P	90.08	0.33	0.5720	0.00	712.46	1.82	0.1838	0.06	226.04	0.81	0.3713	0.03	195.85	0.77	0.3795	0.03	164.72	1.68	0.2079	0.05
	Surf. In. (ac-ft/mon^{-1})	1890.60	7.38	**0.0072**	0.06	666.94	1.70	0.2016	0.06	894.38	3.48	0.0694	0.11	31.46	0.12	0.7375	0.00	147.99	1.50	0.2410	0.05
	TR (cfs)	2948.80	11.91	**0.0007**	0.09	935.15	2.44	0.1234	0.08	1055.90	4.20	**0.0471**	0.13	144.37	0.57	0.4620	0.02	149.41	1.51	0.2344	0.05
	SJR (cfs)	2157.80	8.49	**0.0033**	0.07	696.05	1.78	0.1934	0.06	771.74	2.96	0.0949	0.09	3.42	0.01	0.9305	0.00	575.95	6.86	**0.0133**	0.19

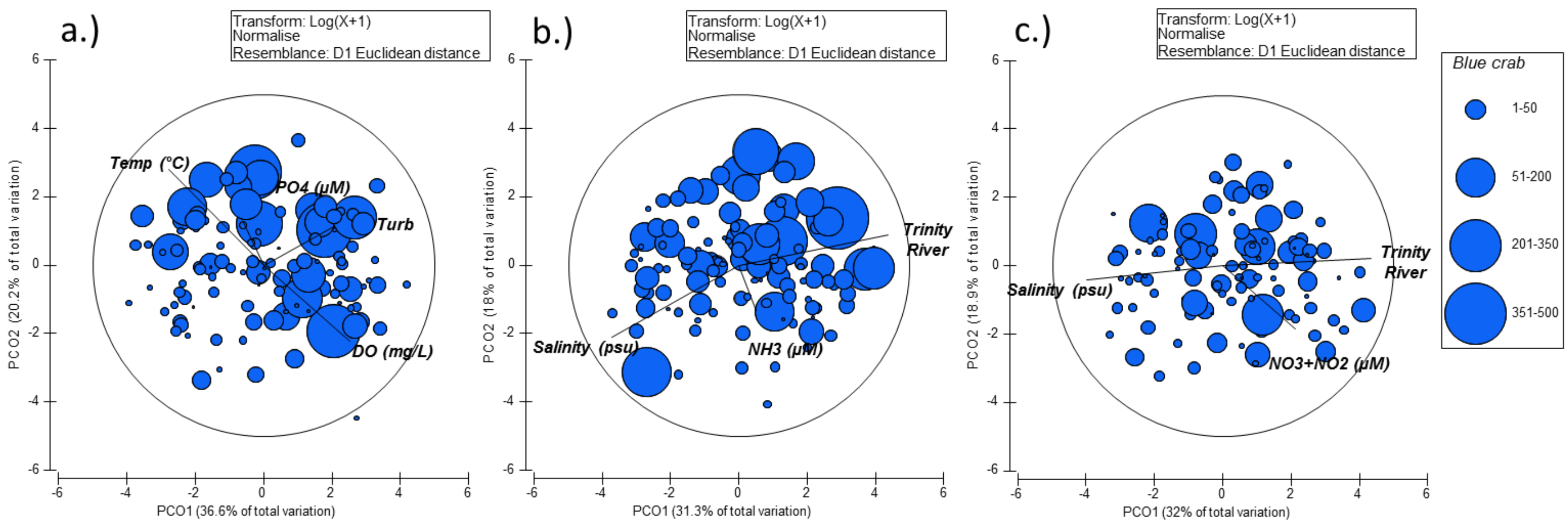

Figure 49 PCO of environmental data with the bubble underlay showing abundance of blue crab collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Blue crab abundance in each respective segment.

Table 25 DISTLM test results Correlation between the abundance of each Blue crab to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl.

Subbay and Gear Type	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	4787.40	5.87	**0.0061**	0.05	25.84	0.04	0.9688	0.00	46.76	0.04	0.9789	0.00	4775.40	6.84	**0.0040**	0.19	2465.60	4.25	**0.0430**	0.13
Bay Trawl	**DO (mg/L)**	3934.20	4.78	**0.0118**	0.04	811.31	1.21	0.2739	0.04	1669.10	1.66	0.1824	0.05	3562.00	4.81	**0.0204**	0.14	1193.40	1.91	0.1590	0.06
	Salinity (psu)	2326.90	2.78	0.0684	0.02	49.53	0.07	0.9238	0.00	111.60	0.11	0.9231	0.00	1808.80	2.26	0.1162	0.07	336.02	0.51	0.5545	0.02
	Turb (NTU)	3122.60	3.76	**0.0309**	0.03	262.74	0.38	0.6427	0.01	589.47	0.57	0.5632	0.02	1928.10	2.42	0.1004	0.08	1562.80	2.56	0.0950	0.08
	NO_3+NO_2 (µM)	1357.80	1.61	0.1959	0.01	1081.20	1.64	0.1945	0.05	1153.50	1.13	0.3103	0.04	1001.20	1.21	0.2789	0.04	100.75	0.15	0.8397	0.01
	NH_3 (µM)	544.74	0.64	0.5070	0.01	474.10	0.70	0.4539	0.02	1677.10	1.67	0.1930	0.05	106.13	0.12	0.8846	0.00	582.54	0.90	0.3861	0.03
	PO_4 (µM)	7804.80	9.86	**0.0003**	0.07	481.10	0.71	0.4524	0.02	2245.30	2.28	0.1127	0.07	4899.30	7.06	**0.0036**	0.20	1024.20	1.63	0.1990	0.05
	N:P	1114.30	1.32	0.2581	0.01	975.41	1.47	0.2267	0.05	1298.10	1.28	0.2695	0.04	1444.80	1.78	0.1672	0.06	271.71	0.41	0.6201	0.01
	Surf. In. (ac-ft/mon^{-1})	848.66	1.00	0.3522	0.01	596.19	0.88	0.3777	0.03	94.08	0.09	0.9380	0.00	657.97	0.78	0.4433	0.03	61.43	0.09	0.9157	0.00
	TR (cfs)	2239.10	2.68	0.0736	0.02	870.62	1.31	0.2561	0.04	284.33	0.27	0.7690	0.01	1871.90	2.34	0.1001	0.07	25.45	0.04	0.9722	0.00
	SJR (cfs)	194.67	0.23	0.8000	0.00	1225.10	1.87	0.1650	0.06	1379.50	1.36	0.2519	0.04	77.84	0.09	0.9356	0.00	711.38	1.11	0.3105	0.04
UGB	**Temp (°C)**	2022.30	2.41	0.0944	0.02	270.09	0.49	0.5618	0.02	91.81	0.10	0.9290	0.00	4356.20	6.26	**0.0090**	0.18	676.92	0.82	0.4081	0.03
Bay Trawl	**DO (mg/L)**	1495.90	1.78	0.1640	0.01	306.22	0.56	0.5429	0.02	2764.90	3.21	0.0592	0.10	2468.90	3.25	0.0523	0.10	1908.70	2.45	0.1040	0.08
	Salinity (psu)	7579.30	9.57	**0.0006**	0.07	260.95	0.47	0.5771	0.02	441.20	0.47	0.6229	0.02	3318.90	4.54	**0.0210**	0.14	861.91	1.06	0.3215	0.04
	Turb (NTU)	2687.60	3.23	0.0516	0.03	739.07	1.38	0.2421	0.05	63.34	0.07	0.9567	0.00	1972.30	2.54	0.0932	0.08	674.30	0.82	0.4054	0.03
	NO_3+NO_2 (µM)	758.39	0.89	0.3864	0.01	377.26	0.69	0.4624	0.02	663.25	0.71	0.4853	0.02	989.70	1.22	0.2867	0.04	85.39	0.10	0.8942	0.00
	NH_3 (µM)	2719.70	3.27	0.0463	0.03	1498.60	2.94	0.0764	0.09	44.21	0.05	0.9752	0.00	1656.60	2.10	0.1297	0.07	735.17	0.90	0.3875	0.03
	PO_4 (µM)	1882.30	2.24	0.1171	0.02	188.91	0.34	0.6719	0.01	773.62	0.83	0.4205	0.03	2261.20	2.95	0.0622	0.09	258.88	0.31	0.6984	0.01
	N:P	2364.60	2.83	0.0653	0.02	348.89	0.64	0.4752	0.02	613.49	0.66	0.5125	0.02	3134.80	4.25	**0.0269**	0.13	519.20	0.63	0.5009	0.02
	Surf. In. (ac-ft/mon^{-1})	1728.30	2.06	0.1280	0.02	292.93	0.53	0.5432	0.02	211.59	0.22	0.8010	0.01	648.66	0.79	0.4453	0.03	226.64	0.27	0.7208	0.01
	TR (cfs)	4062.50	4.95	**0.0142**	0.04	644.01	1.20	0.2835	0.04	801.40	0.86	0.4185	0.03	2282.00	2.97	0.0642	0.09	266.07	0.32	0.6989	0.01
	SJR (cfs)	1115.30	1.32	0.2512	0.01	675.90	1.26	0.2605	0.04	225.09	0.24	0.8102	0.01	327.05	0.39	0.6685	0.01	1673.30	2.12	0.1346	0.07
LGB	**Temp (°C)**	1281.00	1.42	0.2256	0.01	545.12	1.01	0.3399	0.03	3493.70	4.35	**0.0261**	0.13	4037.20	5.71	**0.0122**	0.16	5439.10	6.06	**0.0135**	0.17
Bay Trawl	**DO (mg/L)**	175.09	0.19	0.8098	0.00	96.82	0.17	0.8137	0.01	1128.90	1.28	0.2697	0.04	944.97	1.16	0.2818	0.04	1674.40	1.63	0.2114	0.05
	Salinity (psu)	7632.20	9.00	**0.0011**	0.07	97.66	0.18	0.8097	0.01	1532.90	1.76	0.1865	0.06	3139.50	4.26	**0.0264**	0.13	1405.60	1.36	0.2471	0.04
	Turb (NTU)	314.06	0.35	0.6783	0.00	385.58	0.70	0.4443	0.02	350.43	0.38	0.6482	0.01	1424.30	1.79	0.1680	0.06	1359.30	1.31	0.2537	0.04
	NO_3+NO_2 (µM)	3750.60	4.26	**0.0279**	0.03	116.74	0.21	0.7777	0.01	3206.50	3.94	**0.0373**	0.12	1578.50	1.99	0.1471	0.06	4350.50	4.65	**0.0308**	0.14
	NH_3 (µM)	1470.60	1.64	0.1952	0.01	939.06	1.78	0.1784	0.06	63.28	0.07	0.9472	0.00	787.82	0.96	0.3636	0.03	206.70	0.19	0.7679	0.01
	PO_4 (µM)	1329.20	1.48	0.2178	0.01	32.87	0.06	0.9466	0.00	451.45	0.50	0.5778	0.02	888.17	1.09	0.3291	0.04	789.27	0.75	0.4071	0.03
	N:P	1501.30	1.67	0.1790	0.01	65.07	0.12	0.8755	0.00	499.57	0.55	0.5523	0.02	296.49	0.35	0.6873	0.01	2179.60	2.16	0.1334	0.07
	Surf. In. (ac-ft/mon^{-1})	2706.60	3.05	0.0571	0.02	539.28	1.00	0.3420	0.03	399.91	0.44	0.6122	0.01	252.71	0.30	0.7407	0.01	161.66	0.15	0.8174	0.01
	TR (cfs)	4763.40	5.46	**0.0101**	0.04	763.43	1.43	0.2356	0.05	927.26	1.04	0.3365	0.03	1060.00	1.31	0.2688	0.04	57.43	0.05	0.9362	0.00
	SJR (cfs)	2578.70	2.90	0.0706	0.02	1374.20	2.68	0.0975	0.08	1611.80	1.86	0.1619	0.06	64.63	0.08	0.9411	0.00	1537.90	1.49	0.2239	0.05

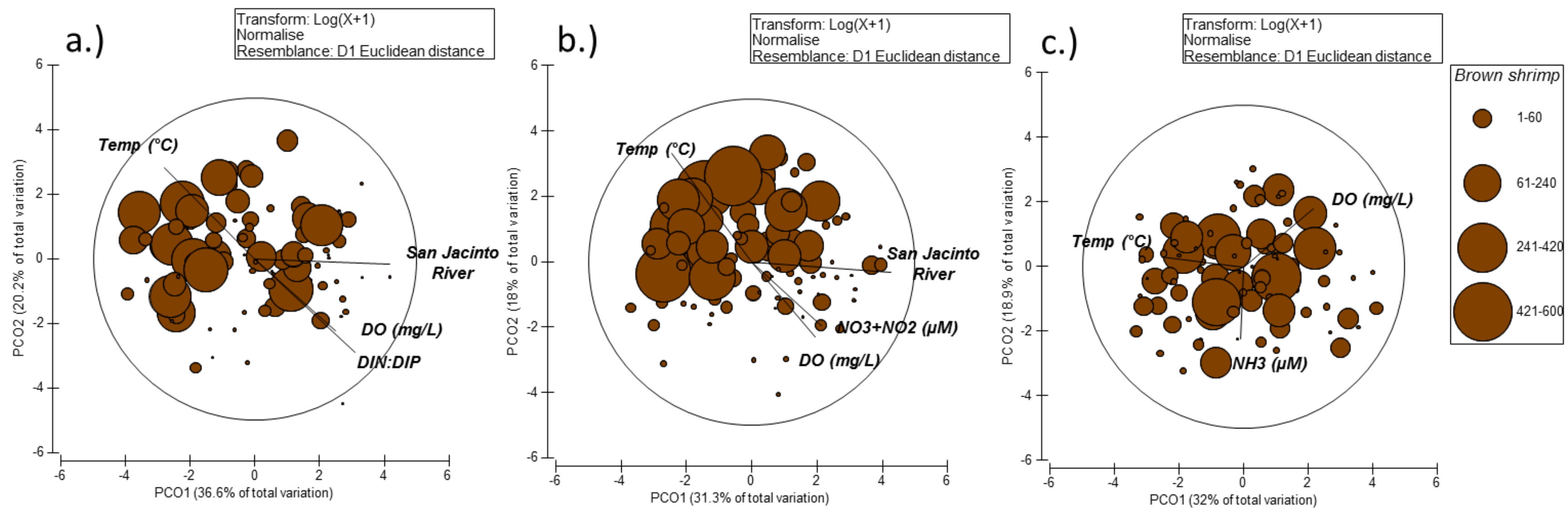

Figure 50 PCO of environmental data with the bubble underlay showing abundance of Brown shrimp collected in the TPWD bay trawl for a.) Trinity Bay b.) Upper Galveston Bay and c.) Lower Galveston Bay. Vectors correspond to environmental variables that showed a significant correlation with Brown shrimp abundance in each respective segment.

Table 26 test results Correlation between the abundance of each Brown shrimp to the respective environmental factors across the all seasons for Trinity Bay (TB), Upper Galveston Bay (UGB) and Lower Galveston Bay (LGB) from 1980-2010. Results of the DISTLM routine on indicator species within all segments from organisms collected with the TPWD bay trawl.

Subbay and Gear Type	Water Quality Parameter	All Seasons				Winter				Spring				Summer				Fall			
		SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.	SS (Trace)	PF	*p*	Prop.
TB	**Temp (°C)**	51406.00	51.60	**0.0001**	0.30	583.18	1.19	0.2798	0.04	6446.90	5.71	**0.0113**	0.16	1283.40	1.30	0.2663	0.04	1150.40	1.21	0.3088	0.04
Bay trawl	**DO (mg/L)**	33904.00	29.75	**0.0001**	0.20	363.88	0.73	0.4122	0.02	912.24	0.69	0.4663	0.02	4267.40	4.82	**0.0239**	0.14	224.46	0.23	0.7991	0.01
	Salinity (psu)	1271.50	0.90	0.3706	0.01	117.69	0.23	0.6897	0.01	4522.90	3.78	**0.0410**	0.12	3834.50	4.26	**0.0266**	0.13	3037.60	3.44	**0.0468**	0.11
	Turb (NTU)	1495.00	1.06	0.3138	0.01	348.59	0.70	0.4255	0.02	1168.00	0.89	0.3820	0.03	1959.10	2.03	0.1402	0.07	3026.50	3.42	**0.0457**	0.11
	NO_3+NO_2 (µM)	2573.90	1.84	0.1565	0.01	479.72	0.97	0.3335	0.03	506.56	0.38	0.6619	0.01	946.53	0.95	0.3398	0.03	393.56	0.40	0.6421	0.01
	NH_3 (µM)	2093.80	1.50	0.2146	0.01	442.59	0.89	0.3613	0.03	250.59	0.19	0.8238	0.01	79.72	0.08	0.9366	0.00	142.21	0.14	0.8747	0.00
	PO_4 (µM)	1239.10	0.88	0.3830	0.01	239.28	0.48	0.5185	0.02	3837.70	3.15	0.0642	0.10	3270.00	3.56	**0.0396**	0.11	520.09	0.54	0.5629	0.02
	N:P	5177.20	3.76	**0.0344**	0.03	547.12	1.11	0.3099	0.04	1693.60	1.31	0.2645	0.04	1826.30	1.89	0.1602	0.06	161.48	0.16	0.8572	0.01
	Surf. In. (ac-ft/mon^{-1})	2467.70	1.77	0.1734	0.01	4.50	0.01	0.9866	0.00	3425.70	2.78	0.0820	0.09	801.95	0.80	0.4389	0.03	389.72	0.40	0.6584	0.01
	TR (cfs)	1999.50	1.43	0.2283	0.01	11.27	0.02	0.9605	0.00	2518.30	1.99	0.1434	0.06	559.05	0.55	0.5612	0.02	212.33	0.22	0.8163	0.01
	SJR (cfs)	10950.00	8.25	**0.0027**	0.06	87.90	0.17	0.7530	0.01	2013.40	1.57	0.2075	0.05	631.05	0.62	0.5280	0.02	485.94	0.50	0.5892	0.02
UGB	**Temp (°C)**	44948.00	50.54	**0.0001**	0.29	2.71	0.00	0.9959	0.00	4453.70	4.78	**0.0227**	0.14	1935.70	2.39	0.1040	0.08	70.14	0.09	0.8981	0.00
Bay Trawl	**DO (mg/L)**	33043.00	33.48	**0.0001**	0.22	101.26	0.18	0.7970	0.01	4864.20	5.30	**0.0120**	0.15	1980.00	2.45	0.0935	0.08	381.17	0.52	0.5681	0.02
	Salinity (psu)	771.40	0.62	0.5183	0.01	73.22	0.13	0.8367	0.00	546.74	0.51	0.5797	0.02	75.28	0.09	0.9441	0.00	666.35	0.92	0.3756	0.03
	Turb (NTU)	1365.40	1.10	0.3140	0.01	510.37	0.90	0.3643	0.03	637.57	0.60	0.5222	0.02	664.65	0.78	0.4539	0.03	1371.00	1.95	0.1531	0.06
	NO_3+NO_2 (µM)	7106.80	5.92	**0.0060**	0.05	289.05	0.51	0.5387	0.02	438.90	0.41	0.6417	0.01	1463.90	1.77	0.1724	0.06	235.38	0.32	0.7105	0.01
	NH_3 (µM)	549.69	0.44	0.6333	0.00	319.63	0.56	0.4987	0.02	4030.40	4.26	**0.0292**	0.13	1713.40	2.10	0.1254	0.07	63.58	0.09	0.9234	0.00
	PO_4 (µM)	2479.80	2.00	0.1374	0.02	400.52	0.71	0.4327	0.02	682.30	0.64	0.5027	0.02	1318.30	1.59	0.2053	0.05	252.50	0.34	0.6845	0.01
	N:P	3427.80	2.79	0.0660	0.02	103.06	0.18	0.7857	0.01	837.73	0.79	0.4292	0.03	1989.00	2.46	0.0998	0.08	350.43	0.48	0.5879	0.02
	Surf. In. (ac-ft/mon^{-1})	125.64	0.10	0.9275	0.00	270.53	0.47	0.5585	0.02	509.38	0.48	0.6012	0.02	152.45	0.18	0.8652	0.01	446.35	0.61	0.5089	0.02
	TR (cfs)	143.42	0.11	0.9126	0.00	302.09	0.53	0.5272	0.02	122.26	0.11	0.9111	0.00	147.11	0.17	0.8514	0.01	105.77	0.14	0.8686	0.00
	SJR (cfs)	11090.00	9.50	**0.0005**	0.07	256.62	0.45	0.5701	0.02	227.53	0.21	0.8127	0.01	198.89	0.23	0.8172	0.01	31.89	0.04	0.9702	0.00
LGB	**Temp (°C)**	30642.00	33.93	**0.0001**	0.22	30.11	0.05	0.8986	0.00	3629.50	4.50	**0.0212**	0.13	4033.70	4.91	**0.0164**	0.14	1849.20	3.33	0.0531	0.10
Bay Trawl	**DO (mg/L)**	25258.00	26.67	**0.0001**	0.18	71.74	0.12	0.7901	0.00	880.49	0.98	0.3661	0.03	3044.00	3.56	0.0606	0.11	344.34	0.57	0.5465	0.02
	Salinity (psu)	1619.10	1.42	0.2306	0.01	471.59	0.80	0.3753	0.03	1159.60	1.30	0.2779	0.04	3242.10	3.82	**0.0395**	0.12	555.39	0.92	0.3770	0.03
	Turb (NTU)	402.87	0.35	0.6956	0.00	173.05	0.29	0.6216	0.01	346.18	0.38	0.6809	0.01	821.37	0.88	0.3985	0.03	47.13	0.08	0.9394	0.00
	NO_3+NO_2 (µM)	588.55	0.51	0.5834	0.00	25.53	0.04	0.9091	0.00	164.60	0.18	0.8403	0.01	1175.90	1.28	0.2618	0.04	3816.50	7.82	**0.0020**	0.21
	NH_3 (µM)	5262.80	4.74	**0.0149**	0.04	563.11	0.96	0.3416	0.03	611.41	0.67	0.4896	0.02	1195.40	1.30	0.2679	0.04	238.87	0.39	0.6726	0.01
	PO_4 (µM)	632.42	0.55	0.5500	0.00	137.03	0.23	0.6695	0.01	2138.90	2.49	0.0914	0.08	1299.00	1.42	0.2364	0.05	1172.10	2.02	0.1427	0.07
	N:P	1351.20	1.18	0.2876	0.01	167.84	0.28	0.6268	0.01	1802.00	2.07	0.1370	0.07	1973.60	2.21	0.1107	0.07	2333.20	4.33	**0.0235**	0.13
	Surf. In. (ac-ft/mon^{-1})	1174.70	1.03	0.3380	0.01	819.75	1.42	0.2438	0.05	1033.20	1.15	0.3073	0.04	1568.80	1.73	0.1724	0.06	46.65	0.08	0.9375	0.00
	TR (cfs)	1911.60	1.68	0.1836	0.01	1077.90	1.90	0.1821	0.06	1543.70	1.76	0.1734	0.06	2246.60	2.55	0.0845	0.08	39.14	0.06	0.9551	0.00
	SJR (cfs)	2563.10	2.26	0.1049	0.02	1628.70	2.97	0.0912	0.09	466.64	0.51	0.6015	0.02	962.84	1.04	0.3435	0.03	396.01	0.65	0.4907	0.02

Temporal and spatial distributions of water quality parameters

The physio-chemical parameters mapped in Galveston Bay are shown in the figures below. After sensor calibration and blank correction, data was imported into Surfer (Version 8.0), a 3D contouring and surface plotting program (using the default kriging method). Water temperatures (ºC) are generally homogenous throughout Galveston Bay (Fig. 51). The temperature scale below ranges from 6-36ºC with cooler temperatures in cyan and then warmest temperatures in red. Water temperatures range from 6-10 °C in January up to 28-30 °C in September, with temperatures much higher in the middle of summer, up to 36 °C. These temperature changes in the bay were driven by natural seasonal cycles.

Salinities as shown in Fig. 52, on the other hand, were driven mostly by freshwater inflows. Salinities herein were presented on the Practical Salinity Unit scale and so are unit-less from 0 to 36. In May/June/July 2015, a large freshet of water entered Galveston Bay after a period of significant rainfall in the upper watershed (see Fig. 52). The influence of this event was observed in the Trinity River basin and slowly extending towards the middle of the Bay by May 2015 as can be seen by the lighter colors (which reflect fresher waters). For the same time frame a year earlier, the bay experienced significantly higher salinities throughout, consistent with the generally lower freshwater inflows into that bay late in spring/early summer.

Galveston Bay is a shallow system and is subjected to wind mixing and turbid conditions. These water clarity maps are often an inverted view of the salinity maps, especially in the Trinity River delta where freshets from the river can dramatically increase the turbidity (Figs. 52 and 53). A good example of this can be seen in May, June and July 2015 salinity and water clarity maps respectively. Higher freshwater inflows into the Bay lowered salinities but increased turbidity, especially in the upper part of the bay. In general, transmittance values closer to 0 indicate low water clarity (high particulate load) while those closer to 5 suggest high water clarity (low particulate load). In times when large freshets were observed (>10,000 cfs), the water clarity generally decreased (and we see more brown in the river basins) as the freshwater brings with it sediment, particulates and silts (Fig. 53). During periods of low flow and calm weather, the water clarity tended to improve as was observed in July 2014 and progressively into October 2014 (Fig. 53).

Chlorophyll *a* concentration is often used a proxy for phytoplankton biomass. While it is known that phytoplankton will respond to nutrient inputs via freshwater inflows, the magnitude of the response will be offset by abiotic and biotic factors such as water clarity, wind mixing and predation, amongst others. This was reflected in the spatial and temporal patterns of chlorophyll *a* observed during the study (Fig. 54). It was anticipated that highest chlorophyll a concentrations would be observed on the eastern side of Galveston Bay, that is, nearest to the largest input of freshwater and hence nutrients. However, we found that in most cases, highest chlorophyll *a* concentrations were instead measured in the San Jacinto River basin (Fig. 54). It appeared that this area may be a hot spot of phytoplankton growth (Fig. 54). The lower parts of Galveston Bay were found to be frequently low in chlorophyll concentrations, especially compared to the upper portions.

CDOM in Galveston Bay has two sources: allochthonous (from the catchment) and autochthonous (produced within the system). The distribution of DOM in an estuarine system provides details on the efficiency of carbon cycling in that system, by both the phototrophic community (that produce it) and the heterotrophic community (that consume it). DOM concentrations in Galveston Bay were relatively low during the study period as seen in Fig. 55, which shows that in most cases the DOM concentration was < 0.25 ug L^{-1}). This is consistent with low allochthonous inputs (low freshwater inflows). In East Bay, the higher DOM concentrations were thought to be associated with inputs from nearby wetlands. In May, June and July 2015 we observed an increase in DOM concentrations in conjunction with the increased freshwater inflow (i.e., lower salinities; Figs. 52 and 55).

Phycoerythrin is an accessory pigment that is commonly associated with cryptophytes in particular although it can also be found in some cyanobacteria and xanthophytes (Jeffrey et al. 1997). From the maps below, it appeared that certain conditions favor phytoplankton which utilize this pigment (Fig. 56). In particular, hotspots appear after major freshets – see May, June and July 2015 but less so during months of higher salinities (Figs. 52 and 56).

Phycocyanin is an accessory pigment that is commonly associated with cyanobacteria (Jeffrey et al. 1997). From the maps below, it appeared that certain conditions also favor phytoplankton which utilize this pigment (Fig. 57). In particular, hotspots appear after major freshets – May, June and July 2015 as well as during the summer months in the upper western side of Galveston Bay (Fig. 57).

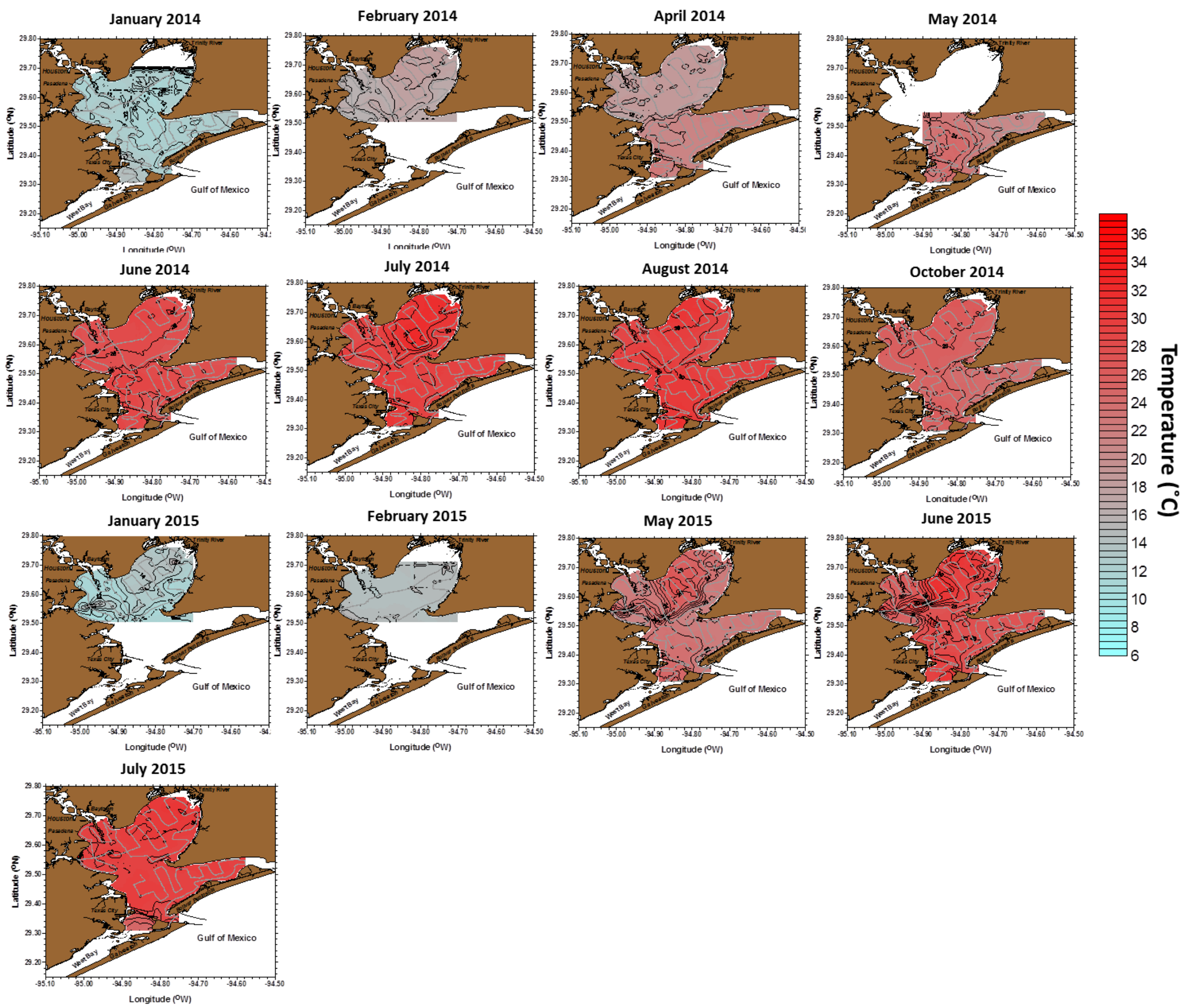

Figure 51 High spatial and temporal resolution maps of temperature (°C) measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales are the same for all maps and the temperature range is 6-36°C (teal to red respectively).

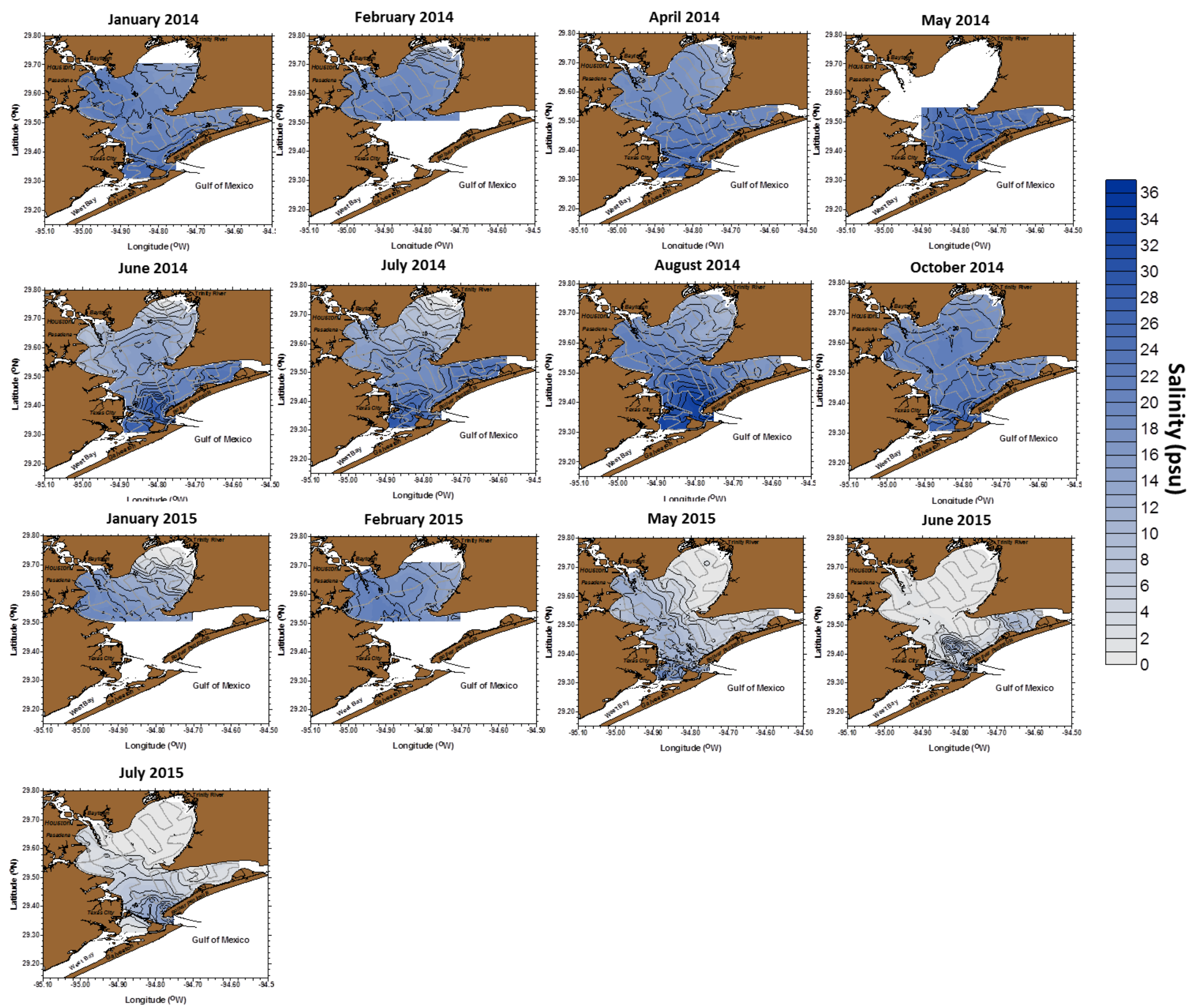

Figure 52 High spatial and temporal resolution maps of salinity measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the salinity range is 0-36 (white to blue respectively)

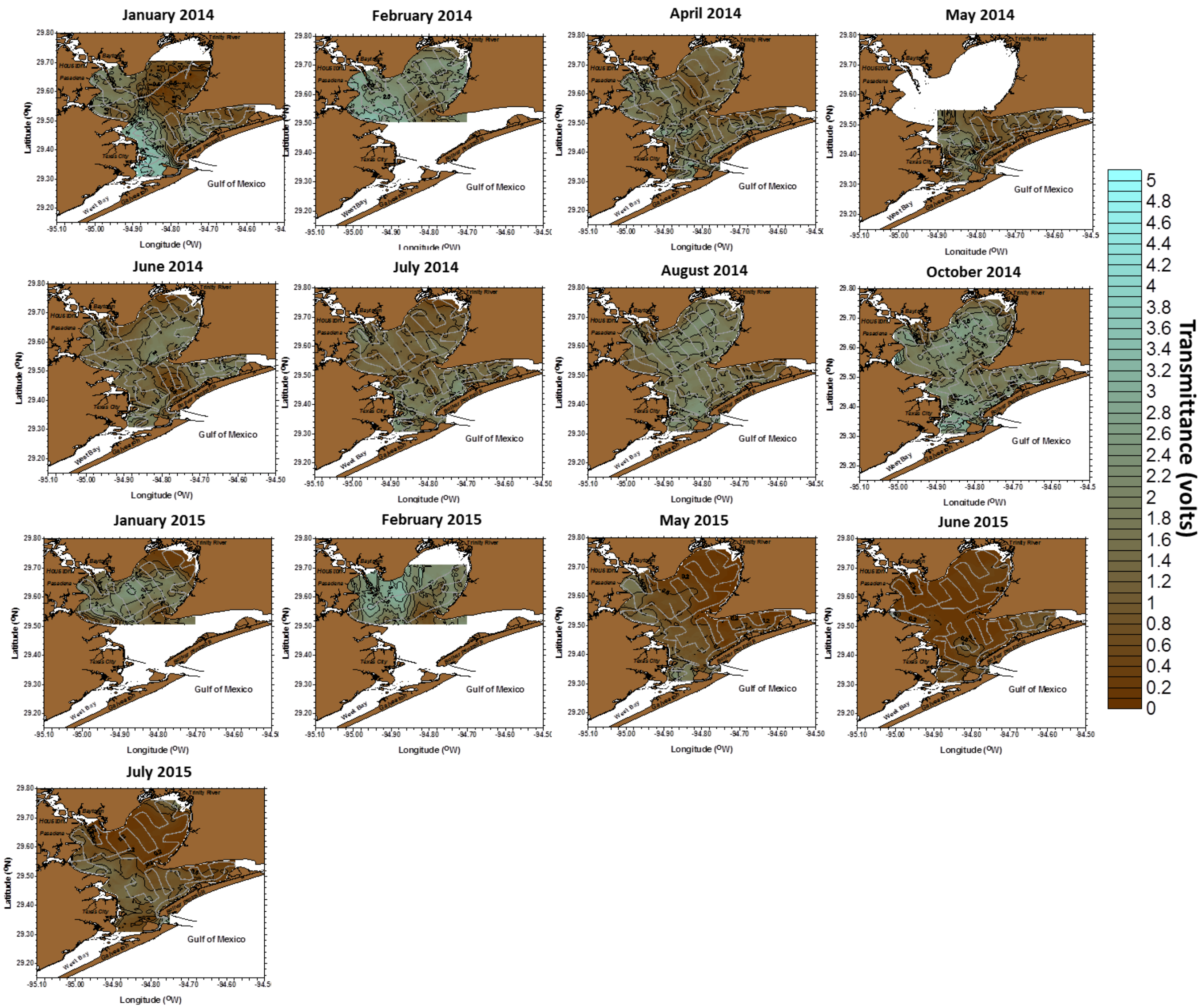

Figure 53 High spatial and temporal resolution maps of water clarity (beam transmittance), measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the water clarity range is 0-5 volts (brown to cyan).

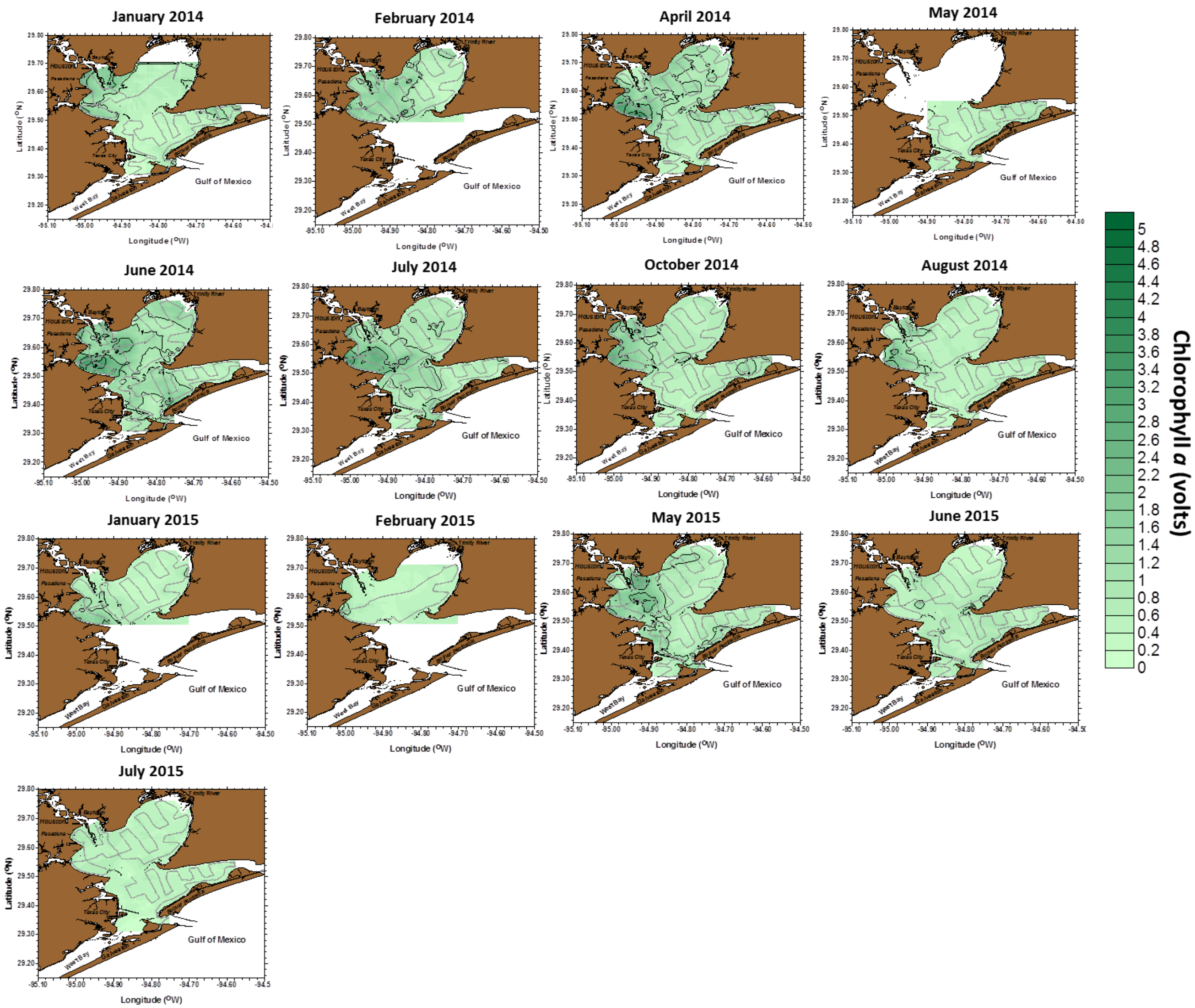

Figure 54 High spatial and temporal resolution maps of chlorophyll *a* measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the DOM range is 0-5 volts (light green to dark green respectively). *Please note: the units herein are volts; we will not be able convert to concentrations for final report as the standard is still not available.*

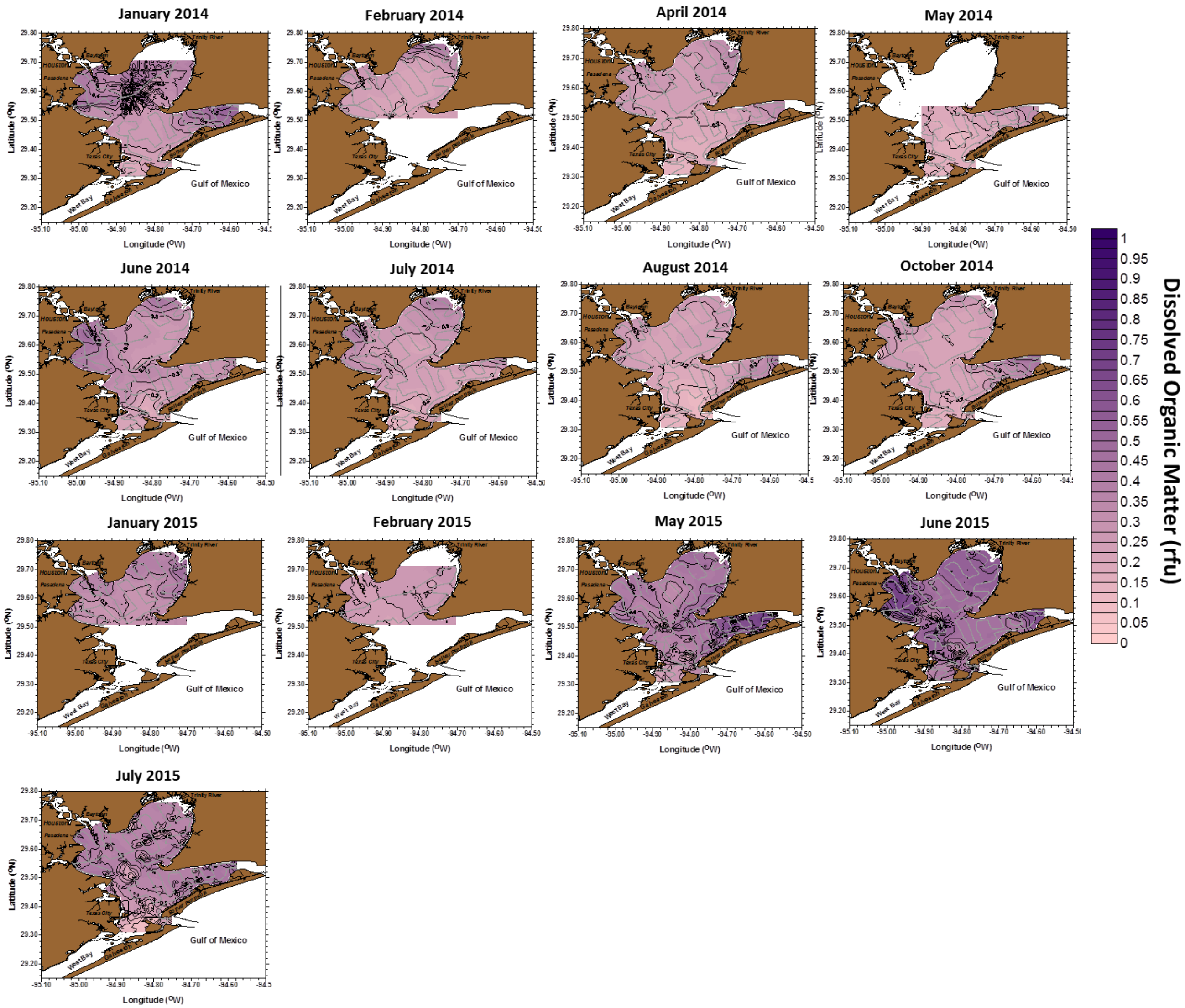

Figure 55 High spatial and temporal resolution maps of dissolved organic matter (DOM) measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the DOM range is 0-5 volts (pink to purple respectively). Please note: the units herein are volts; we will not be able convert to concentrations for final report as the standard is still not available.

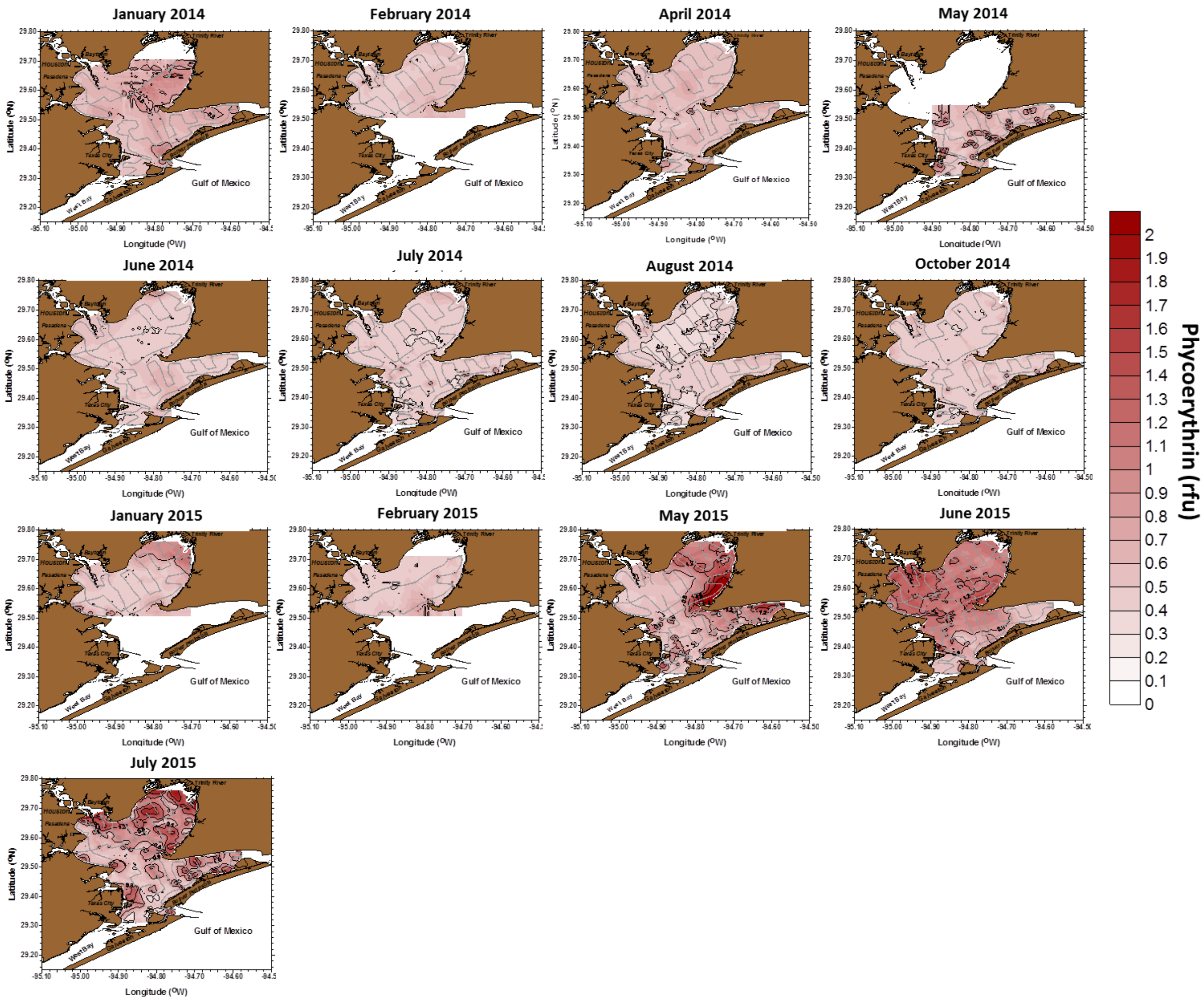

Figure 56 High spatial and temporal resolution maps of phycoerythrin measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the 0-2 volts (white to maroon respectively). Please note: the units herein are volts; we will not be able to convert to concentrations for final report as the standard is still not available.

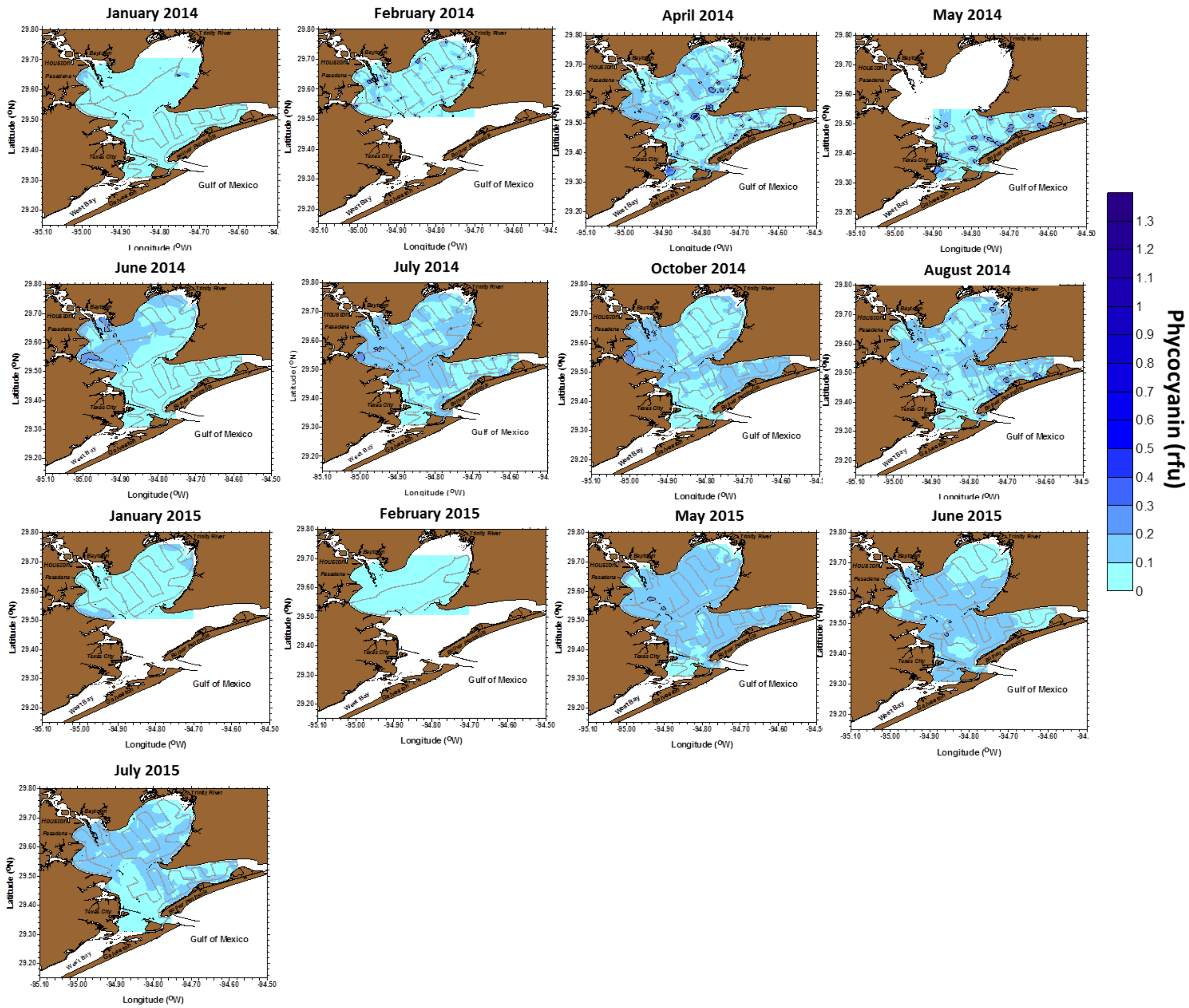

Figure 57 High spatial and temporal resolution maps of phycocyanin measured monthly in surface waters of Galveston Bay from January 2014 to July 2015. Scales were the same for all maps and the 0-1.3 volts (cyan to dark blue respectively). Please note: the units herein are volts; we will not be able convert to concentrations for final report as the standard is still not available.

DISCUSSION

Galveston Bay is influenced by the freshwater inflows of the Trinity River (55%) and San Jacinto River (16%) resulting in lower salinities in the bay segments of TB and UGB respectively across all seasons compared to LGB (Table 8). Due to the influence of freshwater in these bay segments it is expected that the biological community will vary in response to freshwater inflows, freshets, and the corresponding salinities. This freshwater brings with it nutrients, sediments and organic matter, all important to the survival and well-being of the flora and fauna which reside in the estuary (Lester and Gonzalez 2011; Roelke et al. 2013; Dorado et al. 2015; Palmer and Montagna, 2013). Freshwater inflows can affect estuarine systems by enhancing primary productivity, species biodiversity and energy transfer between trophic levels enhancing the integrity and sustainability of the ecosystem (Roelke et al., 2013; Flemer and Champ, 2006). The integrity, function and biodiversity of an ecosystem provide a measure of ecological health (Flemer and Champ, 2006). By depicting trends of the biotic community in response to FWI we are working towards better understanding of the ecological health of Galveston Bay.

But how much freshwater in enough? In this report, we presented the PCO figures to aid in the visualization of the abundance of various species along the gradient of environmental variables. The method of the DistLM analysis can be used in the future to monitor the significant trends among various FWBI species in correlation to the abiotic parameters within the bay. *We have deemed species as appropriate FWBI species based on the correlations of increasing or decreasing abundance with increasing or decreasing freshwater inflows (TWDB Surface Inflow, Trinity River discharge, San Jacinto River discharge) and salinities*. Increasing nutrient concentrations and turbidity were positively correlated with FWI and decreasing salinities but this relationship increased in complexity downstream of the major riverine inputs. For this report, only freshwater inflows and salinity correlations were used as factors in determining the appropriateness of FWBI species for Galveston Bay.

Vallisneria was only identified a limited amount of times with Galveston Bay over the 30 time period and therefore was not included in the analysis. In addition, *Vallisneria* (wild celery) had not been observed from 2011- 2014 in Galveston Bay (Parnell et al. 2011; pers. obs., authors). Recently (August 2015) however, *Vallisneria* was observed again (Personal communication with Scott Alford, USDA – Natural Resources Conservation Service) in the Trinity River Delta. Preceding this observation, Trinity Bay experienced increased freshet events during the spring of 2015 and even modest flooding conditions (pers. obs). With the return of *Vallisneria* in conjunction with the increased river discharge and subsequent lowered salinities in the Trinity River Delta, further analysis of this submerged aquatic vegetation is required before a decision is made on the validity of it as a FWBI.

By exploring the bioindicators established for different bays and estuaries in Texas (Fig. 58; Table 28) (summarized in Palmer and Montagna 2013), we examined additional potential bioindicators which could also be applied to Galveston Bay. We explored published bioindicators from previous studies, particularly those developed for other Gulf state ecosystems to determine both potential new bioindicators and approaches to defining bioindicators as we move forward. Several finish species have the potential of being applied as bioindicators of freshwater in Galveston Bay based on other literature and statistics run in this analysis. These include Atlantic croaker, Southern flounder, Spotted seatrout, Blue crab and Brown shrimp (Table 28). Further analyses and monitoring is required to determine the applicability of these species as FWBI in Galveston Bay.

For the potential FWBI proposed herein, the species chosen were based on similar studies conducted by the other BBEST within Texas which is summarized by Palmer and Montagna (2013). Various types of species have been selected as appropriate FWBI for other Texas bays in response to Senate Bill 3 and have the potential to be used in Galveston Bay as well (Palmer and Montagna, 2013; Table 5). We have chosen to analyze the data from the bay trawl gear type because this gear type provides the most spatial coverage of Galveston Bay over the study period of 1980-2010. Future analysis could include multiple gear types and additional species. The species that we chose to analyze as potential FWBI for GB include the Atlantic croaker, Spotted seatrout, Southern flounder, blue crab and Brown shrimp (Table 5 and 27). Atlantic croaker are currently listed as FWBI for the Colorado-Lavaca, and Nueces River basins (Table 28). Spotted seatrout are used as no currently used as a FWBI in Texas but the juveniles require lower salinities. Southern flounder are used as a FWBI in the Rio Grande River basin (Table 28). Blue crabs are currently used as a FWBI in the Sabine-Neches, Colorado-Lavaca, Guadalupe-San Antonio, Nueces and Rio Grande River Basins (Table 28). Brown shrimp are currently used as a FWBI in the Colorado-Lavaca River basin (Table 28).

The results of this report were formulated based on a similar criteria presented in the TSJ-BBEST report, specifically considering inflows, water quality, and indicator (flora or fauna) data that was historical collected by a range of agencies over the last few decades (1980-2010). More specifically we have applied a variety of statistical approaches to disentangle the effect of inflows over other abiotic factors in impacting potential bioindicators. To do so, we employed multi-variate multi-dimensional statistical approaches as well as GIS and more traditional approaches. This study provides recommendations for each of the FWBI species based on the correlation between each of the species and the suite of environmental parameters measured in Galveston Bay from 1980-2010 (Table 27). These correlations depict trends in species abundance in relation to each of the environmental parameters.

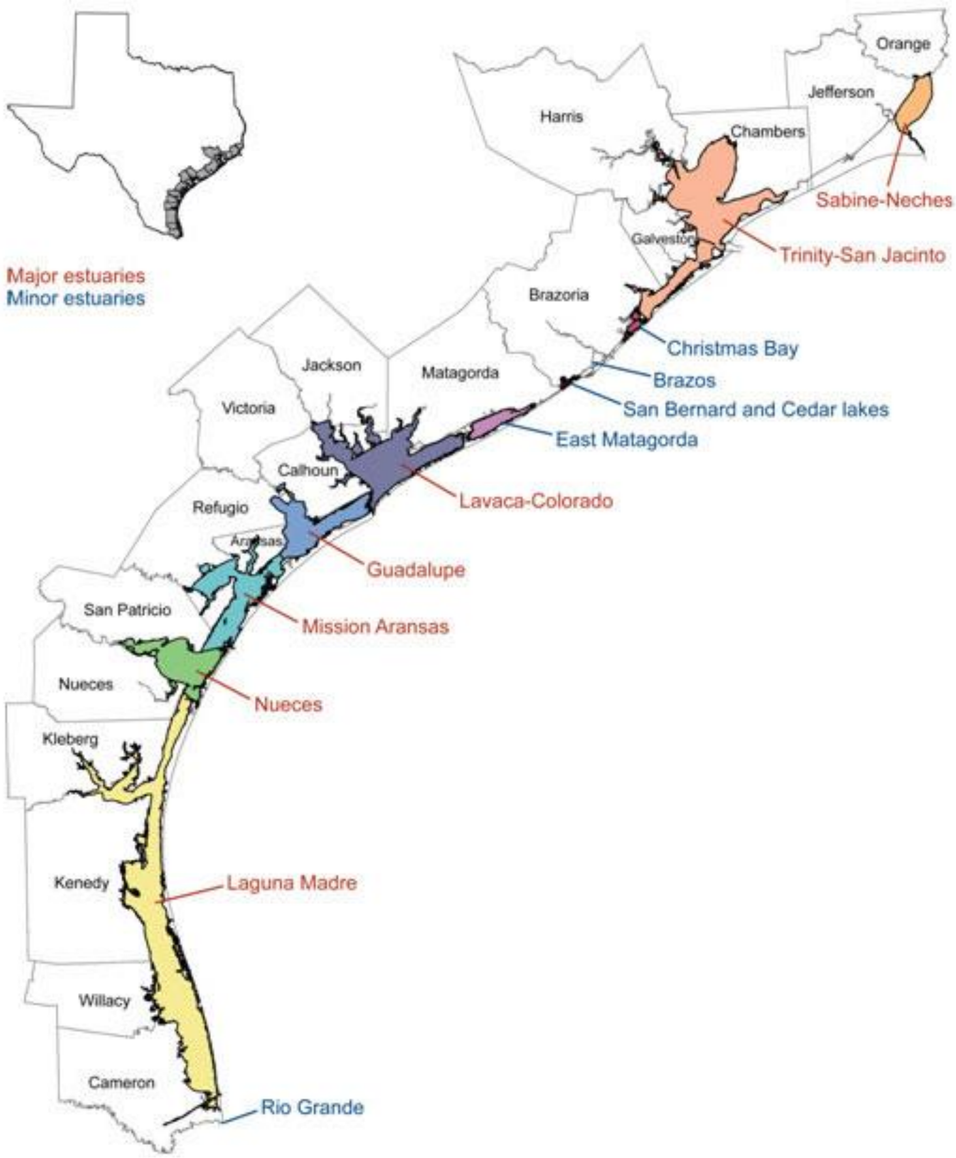

Figure 58 Map of all major and minor estuaries along the Texas coast (source TWDB; ttp://www.twdb.texas.gov/surfacewater/bays/)

Table 27 Heat map showing the strength of significant correlations between each species included in the TSJ-BBEST Espey et al., 2009 report. The darker black shaded squares represent strongest significant correlations of p<0.001, dark gray shading

represents significant correlations of p<0.01 and the light gray shaded areas indicate significant correlations of p<0.05. Correlations are shown for each parameter for each season for each species in the respective bay segment (TB, UGB, LGB).

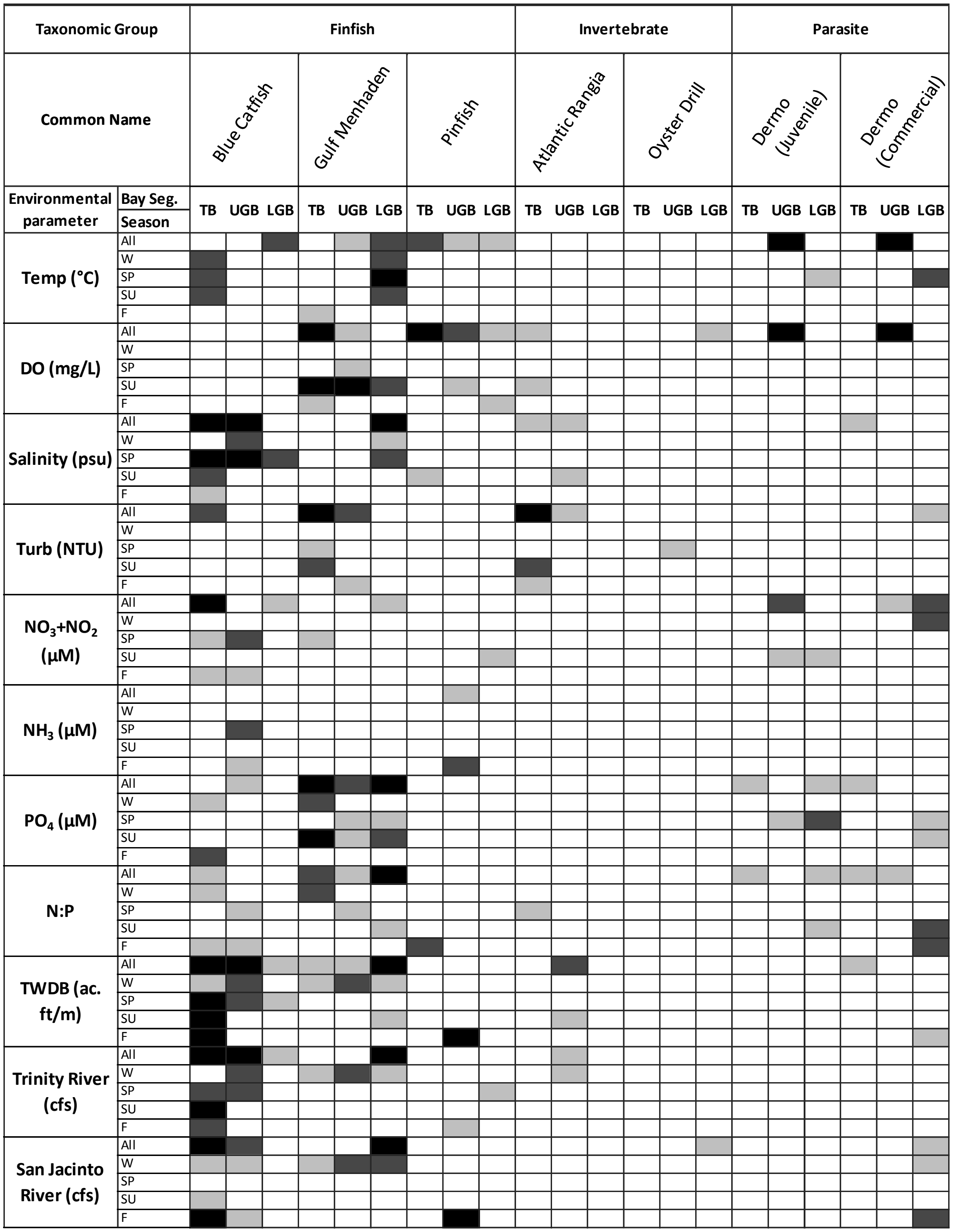

Table 28 List of current FWBI species used in all estuary systems along the Texas Coast compiled from Palmer and Montagna, 2013. Tolerated salinity range of FWBI is noted by L (0-24) or H (>24) respectively. All FWBI species included in this study are in

Common Name	Scientific Name	Sabine-Neches	Trinity-San Jacinto	Colorado-Lavaca	Guad-San Anton-Aran	Nueces	Rio Grande	L/H salinity indicator	Evaulated in this study for GB
Atlantic croaker	*Micropogonias undulatus*			x		x		L	x
Atlantic rangia	*Rangia cuneata*	x	x		x	x		L	x
Blue catfish	*Ictalurus furcatus*		x					L	x
Blue crab	*Callinectes sapidus*	x		x	x	x	x	L	x
Brown rangia	*Rangia flexuosa*				x			L	
Brown shrimp	*Farfantepenaeus aztecus*			x				L	x
Dermo	*Perkinus marinus*		x	x				H	x
Eastern oyster	*Crassostrea virginica*	x			x	x		L	
Gulf menhaden	*Brevoortia patronus*		x	x				L	x
Mantis shrimp	*Squilla empusa*		x					H	n/a
Olney bulrush*	*Scripus americanus*	x						L	
Oyster drill	*Stramonita haemastoma floridana*		x					H	x
Pinfish	*Lagodon rhomboides*		x					H	x
Smooth cordgrass	*Spartina alterniflora*					x		L	
Snook	*Centropomus undecimalis*						x	H	
Southern flounder	*Paralichthyhys lethostigma*						x	L	x
Tarpon	*Megalops atlanticus*						x	H	
White shrimp	*Litopenaeus setiferus*			x	x			L	
Wild celery	*Vallisneria americana*		x					L	n/a

*(adult/seedlings)

Recommendations for FWBI in Galveston Bay – Sessile and Motile organisms

Blue catfish are a migratory fish species and typically prefer open waters of large reservoirs and flowing rivers with a strong current where waters are turbid (Graham, 1999). This species is native to Texas and exhibits a wide distribution having the potential to be a freshwater indicator species for multiple estuaries (Graham, 1999). For a freshwater species, Blue catfish have a moderately high tolerance of salinities of up to 8 psu but not exceeding 8 psu for an extended period of time (Graham, 1999). They have been known to tolerate salinities of up to 11-14 psu in estuarine environments (Perry, 1968; Allen and Avault, 1970). The low salinity tolerances of the Blue catfish make it an excellent freshwater inflow bioindicator. The majority of Blue catfish collected during this study period were in TB with fewer in UGB. The increased abundance of Blue catfish in TB was significantly related to decreased salinities in the spring, summer and fall seasons (Table 10). Increasing surface water inflow was also significantly correlated to increased abundances of Blue catfish across all seasons in TB and during the winter in UGB (Tables 10 and 27). *The TSJ-BBEST recommended that Blue catfish be used as an indicator of freshwater inflow to Galveston Bay (TSJ-BBEST report). With the proportion of variation that explains the increased abundance in response to increased freshwater inflow and salinities in TB and UGB, Blue catfish acts as a beneficial freshwater bioindicator for GB. The results of this study support the use of Blue catfish as a FWBI species in Galveston Bay.*

The eggs and larvae of Gulf menhaden are euryhaline, tolerating salinities of 6-36psu (VanderKooy et al., 2011). For the larvae to complete metamorphosis to the deeper bodied juvenile/adult form they require lower salinity waters (5-13 psu) (VanderKooy et al., 2011). During the post-larval stage, Gulf menhaden inhabit quiet, low salinity (5-13 psu) waters at depths <6.5’ (Fore and Baxter, 1972). After they enter the juvenile life stage they will remain in the nearshore estuaries until they reach an approximate length of ~100mm in fork length (Lassuy, 1983). The TPWD bag seine data would be the most appropriate gear type to target the juvenile size class in the nearshore environment (based on current data options). In this analysis we did not find a significant correlation of Gulf menhaden collected in the bag seine to lower salinities or freshwater inflow in TB when looking at each of the seasons independently of each other. However when considering all seasons together there was significant proportion of variation within the abundance of Gulf menhaden present in TB that is explained by salinity fluctuations Gulf menhaden (Tables 12 and 27). The bay trawl samples were collected over the open areas of the bay and the number of sampling events that collected Gulf menhaden was higher than that of the bag seine (Figs. 22 and 23). *The abundance of Gulf menhaden collected with the bay trawl in winter across all 3 bay segments was significantly correlated to surface water inflow (TWDB), TR and SJR discharge (Tables 12 and 27). Utilizing the TPWD fisheries data, Gulf menhaden collected in the bay trawl gear type does appear to be a beneficial* *indicator of freshwater inflow. The results of this study support the use of Gulf menhaden as a FWBI species in Galveston Bay.*

Estuaries play an important role in the metamorphosis of the Pinfish (Shervette et al., 2007). Adult Pinfish spawn offshore and then post-larvae stage individuals are transported into estuaries where they undergo metamorphosis and live through their juvenile stage of their life cycle (Caldwell 1957, Darcy 1985, Shervette et al., 2007). During the summer months, in both TB and UGB there was a significant correlation between increased abundance of Pinfish (collected in the bay trawl) and salinity (Table 13). In LGB, Pinfish collected in the bay trawl had a significant correlation between increased abundance and decreased TR discharge in the spring (Tables 13 and 27). When Pinfish were collected with the bag seine, there was a significant correlation between higher salinity and increased abundance (Fig. 27; Tables 13 and 27). Pinfish (collected in the bag seine) in TB showed a significant correlation with increased abundance and decreased freshwater inflow (surface inflow and SJR discharge) in the winter and with SJR discharge in the spring (Fig. 27; Tables 13 and 27). *The increased abundance of Pinfish in UGB was significantly related to a decrease surface water inflow (Fig. 27; Tables 13 and 27). The results of the analysis of Pinfish to salinity and freshwater inflow did definitively support the use of this species as a FWBI as recommended by the TSJ-BBEST.*

The brackish water clam, Atlantic rangia is native to the upper Texas estuaries and is generally found in waters with salinities of 15 psu or less (Hopkins et al., 1973).
The Atlantic rangia was selected by the TSJ-BBEST as a benthic indicator of low salinities in Galveston Bay (Tables 1 and 27). The increased abundance of Atlantic rangia that were collected in the bay trawls in TB had a significant correlation with increasing salinity when all seasons were analyzed together but not when the seasons were analyzed independently (Tables 11 and 27). In UGB the Atlantic rangia that were collected in the bay trawl did show a significant correlation with increasing salinity in the summer months (Tables 11 and 27). This is an unexpected result as we expected to see an increase in the abundance of Atlantic rangia with decreasing salinities. The Atlantic rangia collected in the bay trawl were incidental catch numbers and may have resulted in this unexpected correlation between the clams and salinity. The results of the Atlantic rangia abundance in relation to environmental variables should be

interpreted with caution as this gear type is not designed to target these organisms. *Further analysis should be conducted to target Atlantic rangia specifically to determine the true correlation with environmental variables that are characteristic of freshwater inflow fluctuation.*

The eastern oyster (*Crassostrea virginica*) is a euryhaline species that has a higher tolerance of salinity fluctuation than other oyster species (Berquist et al. 2006). The optimal salinity for growth and reproduction is 10 - 28 psu (Wilson et al. 2005). While the oysters in Galveston Bay have a wide salinity tolerance, the parasites and predators on these animals have higher salinity requirements and when present in high abundance may indicate when salinities greater than optimal for bay health. The Oyster drill was collected along with oysters in the oyster dredge gear type. *Oyster drill was absent in TB but was collected in higher abundances in UGB and LGB. There was a significant correlation between increased Oyster drill abundance with decreased SJR discharge in LGB* (Tables 14 and 27). *The results of this study support the use of the Oyster drill as a FWBI species in Galveston Bay as their abundances increased in response to decreased freshwater inflows and increasing salinities.*

Dermo is a disease in oysters caused by the parasite *Perkinsus marinus* that infects and can result in the mortality of eastern oysters (Ray, 1996). In TB we saw that the number of juveniles infected with Dermo was significantly correlated to increasing salinity and decreasing surface water inflow and TR discharge (Tables 16 and 27). In UGB temperature and dissolved oxygen were significantly related to the increase in the number of juvenile and commercial sized oysters infected with Dermo (Tables 16 and 27). And in LGB there was a significant increase in the number of commercial sized oysters infected with decreasing SJR discharge (Tables 16 and 27). *Overall the highest number of oysters infected (both juvenile and commercial sized) were collected in LGB where we saw highest salinities in Galveston Bay* (Tables 8 and 27). *The results of this study support the use of the Dermo as a FWBI species in Galveston Bay, indicative of decreased freshwater inflows and increased salinities.*

Phytoplankton pigments as indicators of freshwater inflow

Phytoplankton have fast growth rates and are able to rapidly respond to changing environmental conditions including chemical (pollutants, nutrients etc) and physical (turbulence, light availability etc.) factors. Changes at the phytoplankton level (community composition, biomass, productivity) tend to precede large scale events such as fluctuations in the oxygen balance, food webs and fisheries and habitat (Paerl et al., 2003). Phytoplankton have been used as indicators of physical, chemical and biotic disturbances in various estuaries (Paerl et al., 2003). Phytoplankton pigment concentrations have successfully been used to determine the phytoplankton community structure or phytoplankton taxonomic groups (Jeffrey et al., 1997; Paerl et al., 2003).

For this study we standardized the pigment concentrations to the chl *a* concentration to gain an understanding of the contribution of each phytoplankton taxonomic group. In October of 2010 through the end of 2011 Texas experienced exceptional drought conditions. In Fig. 39 there is a decline in overall phytoplankton concentration during that time. Fig. 45 shows a corresponding decrease in phytoplankton biomass during the drought period. Average discharge rate from the Trinity River from 2008-2013 was ~5500 cfs and through the drought the average discharge rate fell to ~2300 cfs. This decreased surface inflow and increased salinities resulted in overall lower phytoplankton concentration within each of the 3 bay segments (Fig. 45).

In TB, the diatom and the cryptophyte concentrations increases were significantly correlated to TR and SJR discharges (Tables 18 and 20). Chlorophytes, cyanobacteria and dinoflagellates show significant increases related to decreasing NO_3^-+NO_2^- (Figs. 40, 42 and 44; Tables 17, 19 and 21). In the winter, there is a significant correlation between increasing PO_4, TR and SJR discharge and decreasing concentration of chlorophytes, cyanobacteria and dinoflagellates (Fig. 45). During the summer season there is a significant correlation of fluctuating NO_3^-+NO_2^- concentrations and the cryptophyte, cyanobacteria and diatom concentrations.

In UGB there is a significant correlation among increasing dinoflagellate and chlorophyte concentrations and increasing TR discharge and decreasing salinities (Figs. 40b and 44b). The diatoms also show a significant correlation between increasing concentration and increasing TR discharge (Fig. 43b). During the time of the spring bloom (times of high freshwater inflow), we see a significant correlation between all pigment group, except the diatoms, and salinity variation (Tables 17-21).

In LGB there is a significant correlation between increasing chlorophytes and cyanobacteria abundance and salinity in the summer months (Table 40 and 42). When all seasons are combined there is a significant correlation between salinity and the abundance of cyanobacteria, chlorophytes and diatoms (Tables 17, 19 and 20).

Further work needs to be done to determine the applicability of phytoplankton pigments as FWBI for Galveston Bay. Based on this 5 year analysis, when FWI is greatly decreased there is a responding decrease in phytoplankton biomass (Fig. 45). During the period of the recent drought, there was a greater increase in the concentration of the dinoflagellates, chlorophytes and cryptophytes than of diatoms, although diatoms remained the dominant pigment group. *We suggest that phytoplankton pigments have the potential to be included as FWBI in Galveston Bay but more data must be obtained covering a longer period of time to make a better assessment.*

Potential indicators of freshwater inflows

In addition to evaluating the species listed in the TSJ-BBEST report and phytoplankton pigments as FWBI, we analyzed additional species fish and invertebrate species serving as indicators in other Texas Bays using the same statistical methods. This process was conducted to determine the potential inclusion of these species as FWBI for Galveston Bay. Using PRIMER, we are able to show that some bioindicators summarized by Palmer and Montagna (2013), including *Atlantic croaker and Southern flounder, are correlated with lower salinity waters and increased freshwater inflow in TB* (Figs. 46 and 48; Tables 22 and 24).

Overall across all seasons, there was a significant correlation between Atlantic croaker and salinity, TWDB surface inflow, and TR and SJR discharge across all 3 bay segments (excluding SJR discharge in LGB) (Table 22). During the winter months, Atlantic croaker abundance has a significant correlation with TWDB surface inflow and TR discharge in all 3 bay segments (Table 22). Southern flounder were also significantly correlated to salinity, TWDB surface inflow, TR and SJR discharge when seasons were combined in all 3 bay segments (excluding SJR discharge in LGB) (Table 24). Blue crab abundance was significantly correlated to salinity and TR discharge in both UGB and LGB (Table 25). *Based on these results, we suggest* *that Atlantic croaker, Southern flounder and Blue crabs be considered as potential FWBI for Galveston Bay as their abundances increased in response to increased freshwater inflows and subsequent decreasing salinities.* Increased abundances of Spotted seatrout were significantly correlated to increasing SJR discharge in TB (Fig. 47a.; Table 23). In UGB the increased abundance was significantly correlated to increasing TR and SJR river discharge (Fig. 47b; Table 23). In LGB the increase in Spotted seatrout was significantly correlated to increased TWDB surface inflow and TR discharge (Fig. 47c; Table 23). *Based on these findings we believe that Spotted seatrout had the potential to be used as an indicator of increased FWI to GB, but further analysis is necessary.* From the preliminary results pertaining to Brown shrimp there is an increase in abundance with decreasing SJR discharge in both TB and UGB. The preliminary data regarding the Brown shrimp did not provide sufficient correlation to be recommended as an indicator of FWI without further analysis.

FUTURE DIRECTIONS

Now that the correlations between the FWBI species have been described, it is important to determine the specific ranges of the environmental parameters associated with changes of abundance in segments of Galveston Bay receiving freshwater inflow. This will assist in formulating critical limits for environmental parameters related to freshwater inflows. Analysis of defined size ranges or life history stages (beyond gear type) of the fish, invertebrates and shellfish species may unravel undetected trends in the FWBI species that have been analyzed here. The phytoplankton pigment analysis can be expanded to include species information to correlate with biological community changes in addition to the fluctuations of freshwater inflows. Galveston Bay is a complex system with many parameters changing temporally and spatially. The most appropriate course of action for the determination and selection of FWBI for Galveston Bay may need to be a spatially segmented and seasonal approach. This work has developed a foundation upon which this approach may be built and provides opportunity for future development and modification of the FWBI selection.

PUBLIC RELEVANCE

Water resources are at the base of human health and prosperity. Acknowledging the importance of freshwater inflow to the coast, the Texas Legislature passed Senate Bill 3 in 2007, which requires identification of environmental flow regimes to maintain the ecological health of bays and estuaries. This information may be provided to resource managers as information needed to educate policy- and decision-makers as well as the public about principal coastal problems, and strategies available for their protection and adaptive management. Through the efforts of project participants with local, state and federal agencies (including committees, presentations, reports, web pages), we have worked towards increasing the awareness of issues facing Texas as they relate to water resources.

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