USE OF HISTORICAL DATA TO ASSESS CLIMATE CHANGE EFFECTS: NUECES DELTA

Final Report

Publication CBBEP – 184
Project Number – 2425

1 August 2024

Prepared by:
Berit E. Batterton, B.A.
Monroe A. Person, B.S.
and
Kenneth H. Dunton, Ph.D.

University of Texas at Austin Marine Science Institute
750 Channel View Drive, Port Aransas, TX 78373
Phone: (361) 749-6744
Fax: (361) 749-6777
E-mail: ken.dunton@utexas.edu

Submitted to:
Coastal Bend Bays & Estuaries Program
1305 N. Shoreline Blvd., Suite 205
Corpus Christi, TX 78401

USE OF HISTORICAL DATA TO ASSESS CLIMATE CHANGE EFFECTS: NUECES DELTA

Final Report to Coastal Bend Bays & Estuaries Program
Project 2425

1 August 2024

Berit E. Batterton, Monroe A. Person, and Kenneth H. Dunton

Table of Contents

List of Figures

List of Tables

Appendices

List of Abbreviations

Abbreviation	Definition
CBBEP	Coastal Bend Bays and Estuaries Program
CBI	Conrad Blucher Institute at Texas A&M University-Corpus Christi
CO-OPS	Center for Operational Oceanographic Products and Services
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NCEI	National Centers for Environmental Information
NH_4^+	Ammonium
NO_3^-	Nitrate
NO_2^-	Nitrite
PO_4^{3-}	Phosphate
rSLR	relative Sea Level Rise
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SOM	Soil Organic Matter
TAMU-CC	Texas A&M University- Corpus Christi
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids

EXECUTIVE SUMMARY

The purpose of this study is to provide CBBEP and resource agencies with the information needed to determine and plan for the impacts of future environmental change on marsh habitats in the Nueces Delta. This work is a subset of research by scientists at the University of Texas Marine Science Institute to implement long-term monitoring to detect environmental changes, focusing on the ecological integrity of marsh vegetation communities. Long-term ecological monitoring is an extremely valuable tool for evaluating ecological baselines, assessing historical ecological change, and making informed and effective decisions for adaptive management of water and habitat resources. The primary questions addressed include: 1) “What are the characteristics of Nueces Delta marsh vegetation communities, including their species composition and percent cover?”, 2) “How are changes in marsh condition and environmental quality related to climate?”, and 3) “What are the characteristics of the current body of scientific literature regarding the Nueces Delta?”.

Marsh vegetation covered a sizable portion of all six monitoring sites (73.1%). Dominant plant species included *Salicornia virginica*, *Borrichia frutescens*, and *Batis maritima*. However, significant losses in vegetated marsh area due to erosion or increases in water level have occurred over time. Mean porewater salinity values frequently met or exceeded thresholds for hypersalinity (>35), and nearly all water quality parameters displayed high variability and extreme values. Many shifts in both vegetation community composition and water quality correspond to patterns in climatic conditions, especially within the ten-year period from 2007-2017. Based on monitoring data gathered in this study, both hypersalinity caused by drought conditions and erosional losses have the potential to be the most critical stressors and drivers of vegetation change and overall marsh resilience in the Nueces Delta.

Addressing complex ecological questions, such as the quantitative impacts of climate on vegetation dynamics, is extremely data-intensive. Additional sources of data are often needed to supplement in-situ measurements for statistical analyses. Thus, publicly accessible sources of data are extremely valuable for ecological research. Our proposed solution, a web-based dashboard (Shiny app), will increase the accessibility of our long-term monitoring dataset and significantly improve ease of use and engagement with the data for researchers and the public alike.

The Nueces Delta is the southernmost marsh system in Texas and the Gulf Coast. South Texas is experiencing a drought that has persisted for over three decades and has deeply impacted coastal ecosystems. For the Nueces Delta, management strategies for conservation of the dynamic vegetative landscape and its productivity should include the replenishment of sediments, improved freshwater inflow management (i.e., water diversion, etc.), and shoreline erosion abatement (e.g., living shorelines). Continued research priorities should include diverse taxa (i.e., fish, shorebirds, etc.), ecosystem functions (i.e., carbon sequestration, wave attenuation, etc.), and long-term processes (e.g., impacts of climate change on community dynamics).

INTRODUCTION

Since 1995, members of the University of Texas Marine Science Institute (UTMSI), with support from CBBEP and other agencies, have been monitoring the quality and condition of six sites within the Nueces Delta marsh ecosystem. Long-term ecological monitoring offers data and tools to evaluate ecological baselines and make informed and effective decisions for adaptive management of water and habitat resources (Montagna et al., 2009). The magnitude and longevity of long-term datasets, such as in the Nueces Delta, makes them extremely valuable for assessing historical change in ecological condition and predicting future responses to climate change stressors. Nueces Delta data have been used to assess short-term ecosystem responses to drivers such as riverine discharge (Stachelek & Dunton, 2013) or erosion disturbance (Dunton et al., 2019), but impacts of long-term stresses (e.g., drought, sea level rise) have not yet been quantified.

Research and conservation efforts should seek to develop a knowledge base that outlines the linkages amongst marsh ecosystem components and indicators of climate or anthropogenic stressors to assess marsh condition, stability, and resilience at various temporal and spatial scales. Marsh stability is a key factor in ecological resilience to climate change. South Texas marshes are highly variable and stressful environments with regards to salinity and water availability, due to low precipitation and high evaporation. The Texas coast represents a “zone of ecological instability” in which small disturbances can cause drastic shifts in vegetation cover and community composition (Osland et al., 2019). Changes in freshwater availability and salinity may lead to cascading effects on plant community composition and therefore overall marsh productivity, stability, and critical ecosystem functions and/or services (Osland et al., 2018; Spivak et al., 2019). Human activity, such as upstream watershed modifications, agriculture, industry, and coastal development, intensify these threats to marshes. Accelerated sea-level rise will also likely have a large impact on coastal marshes (Fagherazzi et al., 2020; Saintilan et al., 2022). Historical and projected rates of relative sea-level rise (rSLR) along the Texas coast are among the highest globally due to land subsidence (0.47-0.79 m projected rSLR by 2050; (Sweet et al., 2022). Increases in sea levels are expected to push salinity gradients upslope and upstream, exacerbating hypersalinity and causing loss of marsh vegetation (Osland et al., 2022).

Studies funded by a variety of local, state, and federal agencies have examined several aspects of marsh health, such as freshwater inflow and plant community dynamics, within the Delta (Alexander & Dunton, 2002, 2006; Dunton et al., 2001, 2019; Forbes & Dunton, 2006; Henley et al., 1981; Hill et al., 2011; Montagna et al., 2017; Stachelek & Dunton, 2013). Large efforts have been made to improve freshwater inflow to the Delta, the most significant of which was the Rincon Bayou Demonstration project overflow channel construction (Dunton, Ward, Montagna, Whitledge et al., 2000). These studies provide an abundance of data from several sources, including measurements of meteorology and climate, water quality, and vegetation. However, a significant portion of this data is either not yet publicly available or is difficult to navigate and access. Ensuring data accessibility is not just a crucial component of open science practices, but also facilitates cross-collaboration and synthesis, public engagement with research, and more informed management decisions in dynamic ecosystems.

The objectives of this study were to (1) gather and synthesize the multitudes of data from the Nueces Delta to characterize drivers of marsh ecological condition, (2) continue and expand upon long-term data collection through a marsh vegetation monitoring program, and (3) address accessibility issues by synthesizing multiple data sources to provide CBBEP and resource agencies with the information needed to plan for the impacts of future environmental change on marsh habitats in the Nueces Delta. This approach allows us to identify relevant datasets, contribute to the continued generation and management of critical data, and analyze gaps and trends in previous research in the Nueces Delta in order to make recommendations for future studies and management action. It is vitally important that we understand and quantify how vegetation and ecological functioning in the Nueces Delta marsh has changed over time, so that we may make informed decisions in the face of rapid climate change.

The primary questions addressed by vegetation monitoring and data synthesis include:

1) What are the characteristics of Nueces Delta marsh vegetation communities, including their species composition and percent cover?
2) How are changes in marsh condition and environmental quality related to climate?
3) What are the characteristics of the current body of scientific literature regarding the Nueces Delta?

METHODS

Vegetation Monitoring Sampling Summary

Six sites within the Nueces Delta (254, 270, 271, 450, 451, 463) have been monitored from 1995 until present (no data collection June 2019-Jan 2023). For statistical rigor, we utilize a repeated measures design with fixed sampling stations to maximize ability to detect change. Transects were re-established in Feb 2023, with subsequent measurements collected at all sites in May, Aug, and Nov 2023, and Feb, Mar, and June 2024. Monitoring protocols are consistent with Texas Commission on Environmental Quality (TCEQ) and Environmental Protection Agency (EPA)-approved methods historically conducted by UTMSI (EPA Q-TRAK#: 24-093).

Hydrographic measurements of temperature, salinity, conductivity, dissolved oxygen, chlorophyll-*a* fluorescence, and pH were collected with a YSI 6920 data sonde in tidal creeks/open water adjacent to each site. Water samples were obtained at each station for determination of Total Suspended Solids (TSS) and water column nutrient concentrations (ammonium (NH_4^+), nitrate + nitrite (NO_3^- + NO_2^-), phosphate (PO_4^{3-})). All sonde measurements and water samples were obtained after sediment resuspension due to boat disturbance ceased. Soil cores were taken every 10 m along four transects, starting at 0 m (or the shoreline, if the 0 m point was underwater) for analysis of (1) soil nutrients, (2) soil moisture, and (3) porewater chemistry. Lastly, two soil cores were taken along the shoreline of each site for analysis of soil organic matter (SOM) content.

At each site, species composition and percent cover were obtained from a quadrat sample collected every 2 m along the 20 m transects (every 4 m from 24-50 m at site 463). Percsent cover of species area was estimated via visual observation using a 0.25 m^{-2} quadrat frame subdivided into 100 cells. Components assessed with percent cover included vegetation, wrack, bare substrate (i.e., cyanobacterial mat, mud flat, etc.), and water.

Data Synthesis Summary

Data synthesis comprised of the following tasks: (1) compiling long-term vegetation monitoring data collected by UTMSI researchers, (2) compiling long-term environmental monitoring data collected by Conrad Blucher Institute (CBI) at Texas A&M University-Corpus Christi staff (TAMU-CC), (3) performing a web search to identify and collate literature related to the Nueces Delta, and (4) synthesizing these multitudes of data.

Long-term vegetation monitoring data were downloaded from lab data management software (UT Box) or the CBI data portal (https://lighthouse.tamucc.edu/overview/), cleaned, and formatted using R Statistical Software (v4.3.2; R Core Team, 2023). All figures were made using the ggplot2 package (v3.5.0; Wickham, 2024).

Publications were identified via a web search of peer-reviewed (i.e., journal articles, books, etc.) and gray literature (i.e., reports, pre-prints, dissertations, etc.) using Google Scholar, Web of Science, and the University of Texas Libraries system. Combinations of keywords, such as "Nueces", "Nueces Delta", "Nueces Bay", "Rincon Bayou", and "Rincon Delta", were used to filter and select potential sources. Furthermore, we performed a manual search of print materials stored within labs and libraries at UTMSI. After compiling an initial database of sources in the open-source reference manager Zotero (Corporation for Digital Scholarship, 2024), we filtered out irrelevant sources, extracted metadata for all sources, and organized information into a Microsoft Excel database. Lastly, we performed a meta-analysis on the compiled database of literature to characterize patterns in publication type, date of publication, authorship, focus, and methodology.

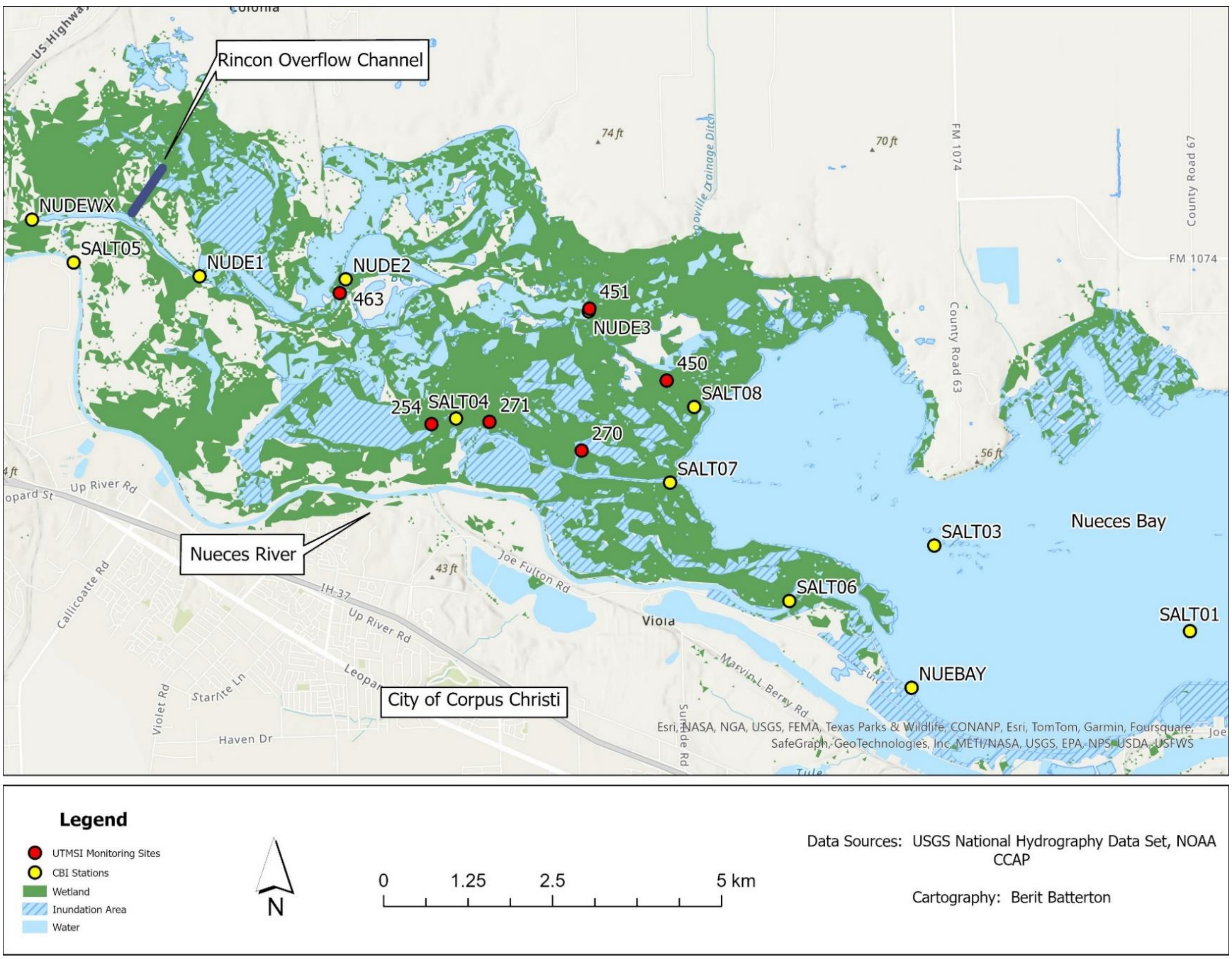


Figure 1. Map of long-term monitoring sites managed by UTMSI (vegetation, soil, water) and CBI (water, weather) in the Nueces Delta.

RESULTS

Water and Soil Quality

Within the 2023-2024 sampling period, tidal creeks adjacent to monitoring sites had a mean water temperature of 25.28 ± 7.74 °C (mean ± standard deviation) and salinity of 31.13 ± 6.62. These are both higher than the long-term averages (**Table 1**). Dissolved oxygen concentrations were 8.56 ± 3.37 mg L^{-1} with an oxygen saturation of 116.53 ± 29.66 % (**Table 1**). No hypoxic (≤ 2 mg L^{-1}) or low oxygen (≤ 3 mg L^{-1}) conditions have been documented since August 2010 (2.62 mg L^{-1}). Mean pH values were 7.74 ± 0.49, lower than the long-term average (**Table 1**). All stations had pH values over 7.7 during the winter sampling, while pH values decreased at all stations during spring sampling (6.79-7.77). Chlorophyll-a concentrations varied widely from 4.3 to 41.6 mg L^{-1}. Water column nutrient concentrations were 0.80 ± 1.06 µM and 0.00 ± 0.00 µM for NH_4^+ and NO_3^- + NO_2^-, respectively. Mean TSS values were 61.95 ± 59.08 mg L^{-1}, lower than the long-term average (**Table 1**). Stations located higher along the Rincon Bayou (451, 463) had much lower variability in tidal creek temperature than other stations, likely due to the reduced influence of tides from Nueces Bay with distance upstream (**Figure 1**). However, conductivity and salinity were highly variable at the end-most sites 463 and 270 (**Table 1**; **Figure 1**). Overall, the stations were quite similar in general characteristics.

Soil at vegetation monitoring sites had a mean water content (moisture) of 43.95 ± 7.45 % and porewater salinity of 46.33 ± 23.69 in 2023-2024. Porewater salinity values frequently met or exceeded thresholds for hypersalinity (>35), and many values greater than 100 were recorded. Moisture and salinity were both more stressful (drier, saltier) within the past year than the long-term average (**Table 2**). Mean porewater NH_4^+ concentrations were 65.73 ± 13.20 µM (**Table 2**). Lastly, SOM content in 2023-2024 averaged 8.36 ± 2.14 %, with site 271 having the highest value (11.73%; **Table 2**). Site 451 is the most extreme site, as it had the lowest soil moisture (33.4%), highest porewater salinity (92.4), and the greatest variability in both parameters (6.49% and 50.2, respectively). Overall, stations exhibited greater spatial and temporal variability in soil parameters versus corresponding tidal creek parameters, indicating the influence of both above and belowground factors (vegetation, microbial processes, elevation, etc.).

Table 1. Summary of tidal creek hydrographic parameters from 2001-2024. Site with highest average per parameter in bold. *Note:* $NH_4^+/NO_3^-+NO_2^-$*: 2007-2018, 2023-2024,* PO_4^{3-}*: 2017-2019, TSS: 2023-2024.*

	Temperature (°C)	**Specific Conductance (mS cm^{-1})**	**Conductivity (mS cm^{-1})**	**Salinity**	**DO Conc. (mg L^{-1})**	**DO Saturation (%)**	**pH**	**Chl *a* (µg L^{-1})**	**NH_4^+ (µM)**	**NO_3^- + NO_2^- (µM)**	**PO_4^{3-} (µM)**	**TSS (mg L^{-1})**
254												
Mean	22.08	37.53	38.11	22.38	7.81	99.31	8.19	**39.13**	**18.46**	**20.49**	4.78	116.38
Std. Dev.	6.38	18.42	16.58	12.89	2.34	26.42	0.37	30.51	49.18	50.38	2.51	111.92
270												
Mean	24.20	36.16	32.45	24.98	8.52	**107.48**	7.95	11.02	2.86	1.09	6.15	61.37
Std. Dev.	6.36	14.87	13.47	12.74	1.69	28.42	0.43	9.90	4.87	4.20	3.99	39.83
271												
Mean	23.73	38.97	35.21	23.32	7.92	105.19	7.91	17.92	8.29	1.44	6.20	87.96
Std. Dev.	6.92	16.51	14.73	12.99	1.64	18.03	0.42	11.39	22.75	5.04	2.11	49.16
450												
Mean	22.13	31.06	41.58	23.34	**11.04**	90.17	8.01	17.76	2.57	0.31	6.07	74.44
Std. Dev.	6.17	18.42	16.55	13.18	54.72	16.31	0.33	13.40	3.85	0.77	4.46	39.92
451												
Mean	22.23	**39.81**	**41.70**	24.41	7.37	90.49	8.05	22.40	2.35	1.40	**6.61**	72.54
Std. Dev.	6.05	19.60	19.07	14.80	5.74	18.28	0.61	15.91	4.41	8.23	3.43	41.54
463												
Mean	**24.33**	22.17	35.96	**26.52**	9.18	106.99	**8.28**	32.92	2.79	2.43	4.26	**117.54**
Std. Dev.	6.00	17.10	26.22	18.38	11.20	21.35	0.40	21.63	4.48	9.25	5.00	63.84
Total												
Mean	22.50	32.71	39.38	24.24	8.78	95.59	8.10	27.04	5.95	4.04	5.68	88.37
Std. Dev.	6.23	18.10	19.41	14.46	29.29	21.82	0.46	22.92	22.23	20.75	3.67	64.66

Table 2. Summary of soil parameters from 1995-2024. Site with highest average per parameter in bold. *Note: Moisture: 2001-2019, 2023-2024, Salinity: 1995-1997, 1999-2019, 2023-2024,* NH_4^+*: 2007-2018, 2023-2024,* $NO_3^-+NO_2^-$*: 2007-2017, 2023-2024, SOM: 2023-2024.*

		Soil Moisture (%)	**Porewater Salinity**	**Porewater NH_4^+ (µM)**	**Porewater NO_3^- + NO_2^- (µM)**	**Soil Organic Matter (%)**
254						
	Mean	46.22	39.83	105.21	16.17	10.57
	Std. Dev.	7.10	23.18	85.06	30.90	2.56
270						
	Mean	52.72	35.03	92.20	20.68	11.34
	Std. Dev.	6.11	21.12	76.92	57.27	2.53
271						
	Mean	**54.08**	38.89	**123.40**	28.52	12.82
	Std. Dev.	6.24	20.42	99.21	95.62	3.04
450						
	Mean	50.35	39.80	96.33	29.95	10.08
	Std. Dev.	6.24	19.88	71.16	64.89	3.18
451						
	Mean	37.19	**63.64**	83.48	34.44	8.06
	Std. Dev.	7.56	47.51	58.98	80.90	1.87
463						
	Mean	41.76	53.55	85.92	**43.06**	**11.42**
	Std. Dev.	7.50	42.15	124.58	90.51	6.75
Total						
	Mean	46.12	45.72	95.90	31.70	10.82
	Std. Dev.	9.16	33.60	95.65	75.47	4.13

Marsh Vegetation Cover and Species Distributions

The mean vegetation cover in 2024 for all sites in the Nueces Delta was 73.11 ± 42.89 %, comparable to the long-term average of ~74-75% (**Table 3**). The dominant plant species, *Salicornia virginica*, *Borrichia frutescens*, and *Batis maritima*, covered 39.32 ± 39.34 %, 14.18 ± 30.07 %, and 12.03 ± 22.68 % on average, respectively. While *Salicornia virginica* is dominant at every site, the relative dominance of *B. maritima* and *B. frutescens* varied widely between sites (7.10-27.95% and 1.55-27.18%, respectively), due to environmental conditions such as distance upstream, elevation, and salinity. These three species are consistently dominant long-term (**Table 3**). As in recent years, no *Limonium nashii*, *Suaeda linearis*, *Scirpus maritimus*, *Spartina spartinae*, *Iva frutescens*, or *Aster* spp. were found in 2024. One *Salicornia bigelovii* individual was found in a plot at site 451 during spring sampling. Additionally, *Monanthochloe littoralis* is only found in abundance at sites 451 and 463, and *Spartina alterniflora* is only found at sites 270 and 450 (**Table 3**; see **Appendix A** for species abbreviations). Overall, each monitoring site has a distinct and characteristic vegetation community based on its position within the Delta (**Figure 1**).

Despite the consistent dominance by three major species across the Delta, the vegetation community is not static. While the relative abundance of many of the rare species (i.e., *Aster* spp., *S. maritimus*, *S. spartinae*, *I. frutescens*, *L. nashii*) is consistently low (**Figure 2**), the proportions of more dominant species show unique patterns through the years. The three major species (*B. maritima*, *B. frutescens*, *S. virginica*) all show periods of change between 2002 and 2007. While *S. virginica* and *B. maritima* decrease during that period, *B. frutescens* increases. Other interesting patterns include the large decline in bare ground from ~2007-2009 followed by recovery until 2017, the high variability in *Distichlis spicata* coverage, and the decline in *S. alterniflora* from ~2007-present (**Figure 2**). In addition to long-term changes over time, rapid shifts in vegetation cover and composition have been observed after weather events (i.e., floods, Hurricane Harvey, etc.). Spring sampling in 2024 occurred both before and after Tropical Storm Alberto (~4 inches rainfall, 46 mph wind gusts, 3 ft storm surge; National Hurricane Center, 2024), allowing for observations of flooding impacts. All sites visited after the storm (270, 271, 254) had standing water levels upwards of 8 cm within the marsh and evidence of sediment overflow onto the marsh platform (**Figure 3a, 3b**). Furthermore, large bare patches at sites 270, 271, 451, and 463 continue to be observed under both flooded and dry conditions (**Figure 3b**). Abundant cyanobacterial mats were observed covering sizable portions of bare ground. Significant losses due to erosion or increases in water level continue to occur at sites 270, 450, and 463. At site 270, between 2 and 10 m of transects marsh have eroded from the historical shoreline. The presence of *S. alterniflora* has been reduced to an approximately 2 m band between the 6 and 8 m lines (**Figure 3c**). At site 450, the 0 m transect line has been underwater since approximately 2015, and the 2 m line is continuing to show signs of erosional collapse. At site 463, the 0 m line is underwater along four of the five transects, and the 50 m line along the Rincon Bayou is potentially at risk of erosion as well.

Table 3. Summary of plant areal percent cover (%) from 1995-2024. Three most dominant cover types in bold. *Note: does not include 2020-2022.*

		BM	BF	DS	LN	LC	ML	SB	SV	SA	SL	SM	SS	IF	AT	Other	Wrack	Bare
254																		
	Mean	**16.76**	**17.18**	9.30	0.01	0.56	0.13	0.42	**40.30**	3.59	0.95	0.001	0	0.02	0.01	0.17	8.55	2.0
	Std. Dev.	25.59	29.24	19.27	0.31	2.98	2.03	3.80	36.62	15.14	6.00	0.06	0	0.84	0.12	2.89	23.3	8.97
270																		
	Mean	11.01	**27.29**	3.86	0.05	1.51	0.003	0.04	**26.12**	8.49	0.63	0.71	0	0.21	0.003	2.09	4.85	**12.84**
	Std. Dev.	18.62	32.26	11.71	1.11	5.94	0.14	1.58	33.88	23.57	4.96	6.36	0	3.11	0.11	13.64	15.79	34.34
271																		
	Mean	**14.84**	**22.95**	3.39	0.07	0.18	0.003	0.03	**39.48**	0.07	0.31	0.005	0.04	0	0.02	0.10	8.35	10.21
	Std. Dev.	25.56	34.08	12.54	0.27	1.40	0.13	0.41	39.53	1.97	3.62	0.16	1.30	0	0.89	1.72	24.02	25.57
450																		
	Mean	**13.38**	**24.73**	2.99	0.07	0.40	0	0.01	**41.75**	4.0	0.90	0	0	0.14	0.02	0.37	6.26	4.65
	Std. Dev.	19.67	33.52	9.19	0.75	2.10	0	0.37	35.56	13.56	5.19	0	0	2.94	0.61	4.80	18.35	17.45
451																		
	Mean	7.08	**11.79**	1.91	0.26	3.43	3.69	2.73	**8.05**	0.11	1.65	0	0	0.01	0.10	6.62	4.73	**47.82**
	Std. Dev.	16.18	28.35	9.96	3.62	12.71	15.82	11.15	21.40	3.08	7.95	0	0	0.43	2.05	24.13	15.81	45.16
463																		
	Mean	**15.41**	12.03	2.74	0.15	3.74	**13.13**	3.14	9.74	0.003	1.55	0.001	0.10	0.01	0.34	3.70	3.99	**30.19**
	Std. Dev.	23.31	27.44	11.32	1.12	11.84	27.45	12.64	24.03	0.23	7.80	0.04	1.90	0.47	3.89	16.24	14.55	38.62
Total																		
	Mean	13.41	**18.31**	3.85	0.10	1.93	4.28	1.35	**25.07**	2.33	1.08	0.10	0.03	0.06	0.12	2.39	5.82	**19.67**
	Std. Dev.	22.22	31.53	12.77	1.59	8.51	16.83	8.23	34.67	12.23	6.40	2.42	1.13	1.68	2.26	13.95	18.53	35.70

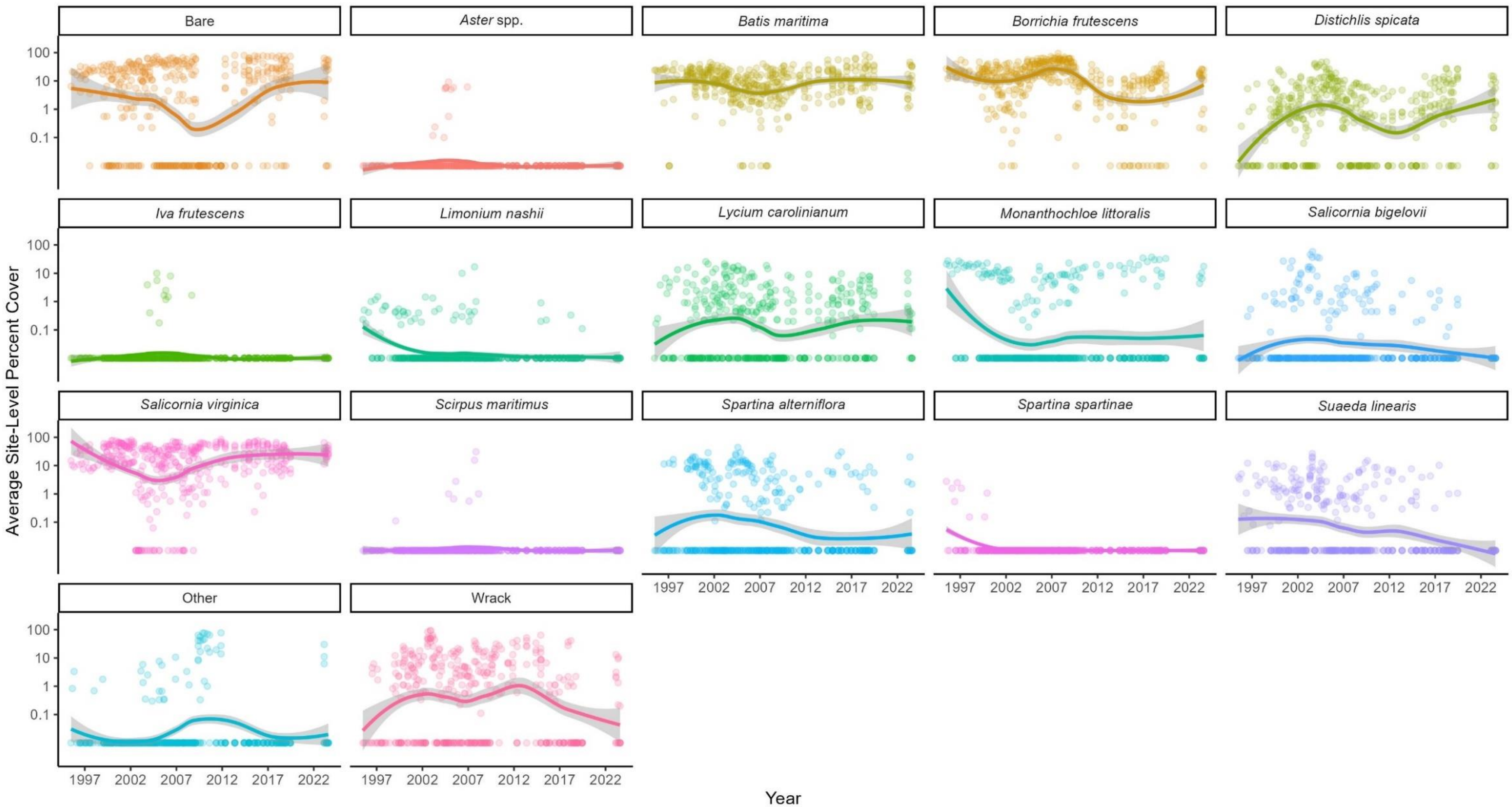


Figure 2. Long-term trends in vegetation percent cover at UTMSI monitoring sites in the Nueces Delta. Points represent site-level percent cover values across all sites for each plant species. Overall trends are represented by ribbons (mean, 95% confidence interval).

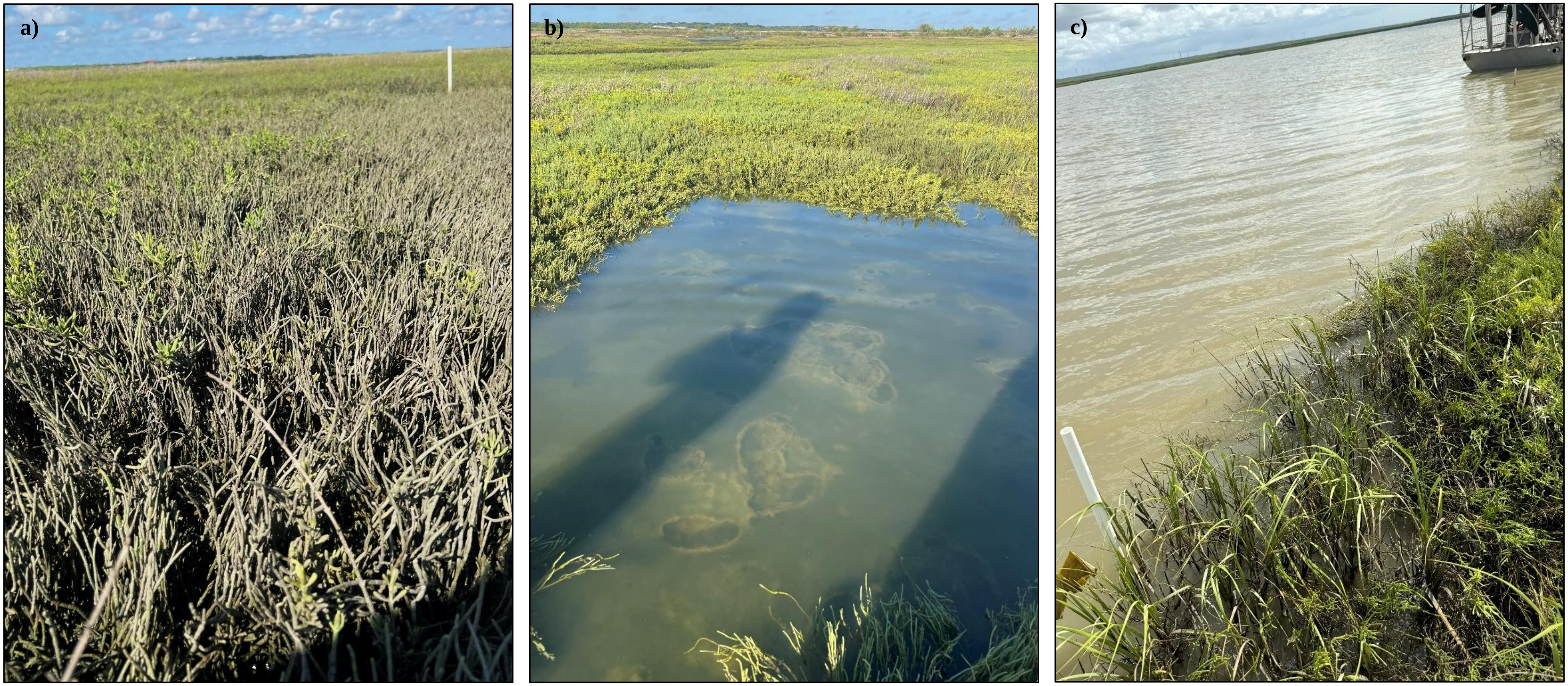


Figure 3. a) Sediment washover deposited from flooding during Tropical Storm Alberto (June 2024) on *Salicornia virginica* and *Batis maritima* plants near the 20 m mark at site 254, b) Cyanobacterial mats under ~8 cm of flood water at site 254 after Tropical Storm Alberto, c) PVC poles marking former plot locations along the shoreline of site 270 (foreground pole: 2 m mark on Transect 1, background pole: 6 m mark on Transect 5).

Data Synthesis

Data Accessibility Challenges and Solutions

UTMSI and CBI are both organizations with long-standing monitoring networks within the Nueces Delta. Despite the demonstrated value of long-term monitoring data, neither of these databases are easily accessible. The vegetation, soil, and water quality data collected by UTMSI has never previously been published in full. This database will be published on the NOAA National Centers for Environmental Information (NCEI) data management site (DOI forthcoming). While the CBI environmental data is published in a web portal, the difficulty of web navigation and data download reduces access. For example, it was challenging to find information on inactive sites that may have previous data and to manage data downloads, as the server would often fail to complete the request. It took several attempts to fine-tune the proper query parameters to retrieve data from the web portal, and this only allowed for downloads of a few years of data at a time. After retrieving ten individual files, each had to be extensively cleaned before they became useful. These challenges are not insurmountable for someone experienced with data management and/or web scraping, but they may be preventative for a broader public audience. Furthermore, both databases are only available for download in spreadsheet format, which is ideal for researchers but further reduces the ability for a lay audience to learn from the efforts of the monitoring programs. We propose implementing a dashboard-style approach, via a Shiny app, to improve public engagement with the data (Chang et al., 2024). Shiny apps implement open science practices by using easily reproducible R code to process and publish data in an interactive dashboard and allowing web visitors to execute R commands and view results without needing prior coding experience (**Figure 4**).

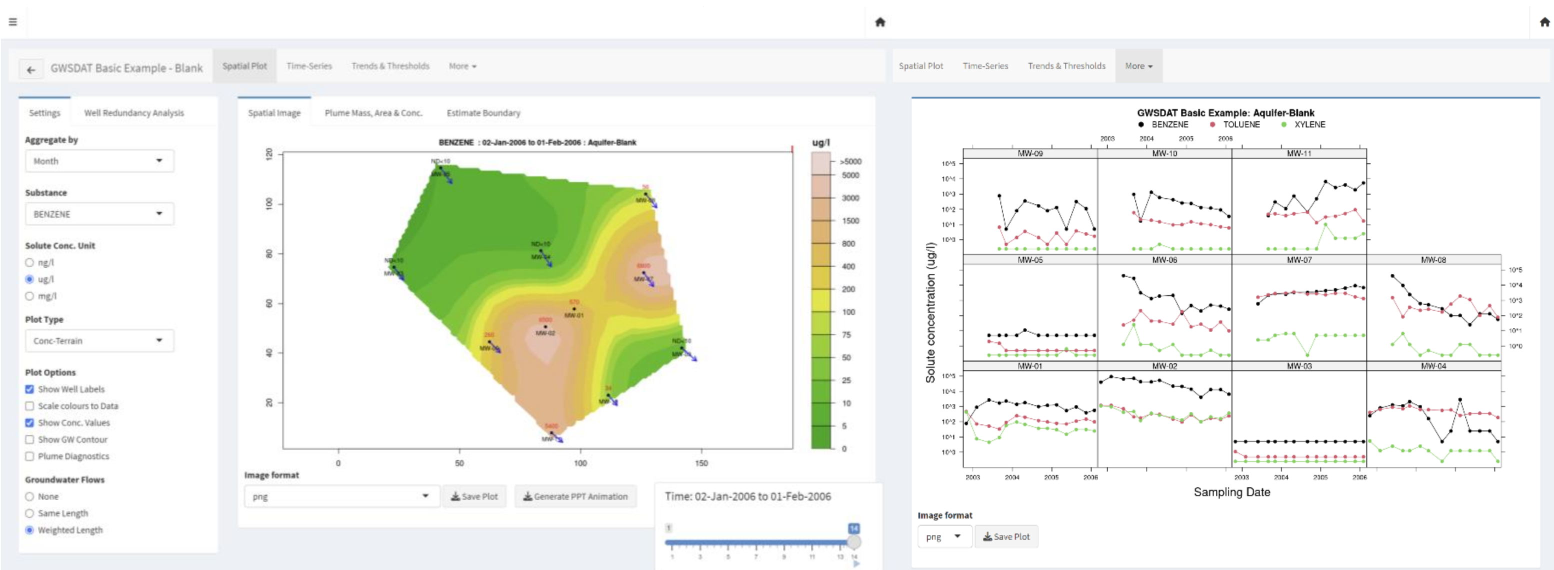


Figure 4. GWSDAT is an example of proposed Shiny dashboard app for visualization, analysis, and reporting of groundwater monitoring data (Jones et al., 2014).

Comparing Uses for UTMSI and CBI Data

As mentioned above, the UTMSI and CBI datasets are both extremely valuable based on their longevity and consistency. However, each dataset is best suited for specific purposes. For example, CBI takes a broad thematic approach, aiming for wide spatial coverage and sampling general environmental quality parameters (**Table 4**). The UTMSI dataset, on the other hand, focuses solely on vegetation marsh habitats and the soil and water parameters that are most relevant for these critical areas, filling a major gap in monitoring (**Table 4**). While CBI data is collected at high frequency across a wide range of sites throughout the Delta, several of these sites are missing data for multiple years at a time or for multiple months within a year, leading to inconsistent spatiotemporal coverage. In fact, since 2020, there are only two active stations within the Delta, both located far up the Rincon Bayou (NUDE2 and NUDEWX; **Figure 1**; **Appendix B**). In contrast, the UTMSI dataset has fewer sites and less frequent sampling but has consistent temporal coverage across those sites, facilitating easier spatiotemporal analyses of change. Overall, both sources of data act synergistically to provide a holistic assessment of vegetation, soil, water, and weather over the past several decades.

Table 4. Characteristics of UTMSI and CBI datasets. See **Appendix B** for more information.

UTMSI	CBI
Vegetation-focused monitoring	General environmental monitoring
Consistent temporal coverage across sites	Temporal coverage across sites is inconsistent
Good spatial coverage within delta habitats	Broader spatial coverage across delta, river, and bay habitats
No meteorological data	Weather station provides meteorological data
Monthly to quarterly sampling frequency	Hourly sampling frequency

Assessing Effects of Climate Change through Monitoring Data

By combining the UTMSI and CBI datasets, we can begin to understand how vegetation and ecological functioning in the Nueces Delta has changed over time and how that change is related to climate. Firstly, water quality parameters collected by UTMSI largely match with data from CBI sites within the Delta. For example, tidal creek salinity and water temperature measurements follow very similar patterns within Delta sites (**Figure 5a-5d**). However, the UTMSI values seem to have higher variability and greater extremes across most parameters. The Bay and River CBI sites typically have lower salinity and DO, but higher pH, than the Delta sites (**Figure 5a, 5c, 5d**). Most notably, the salinity in the Delta ranges from 0 to nearly 100, while the Bay salinity rarely deviates outside of 10-45 (**Figure 5a**). In general, the Delta sites have greater variability in water quality, pointing to the dynamic and extreme nature of the Delta marsh system.

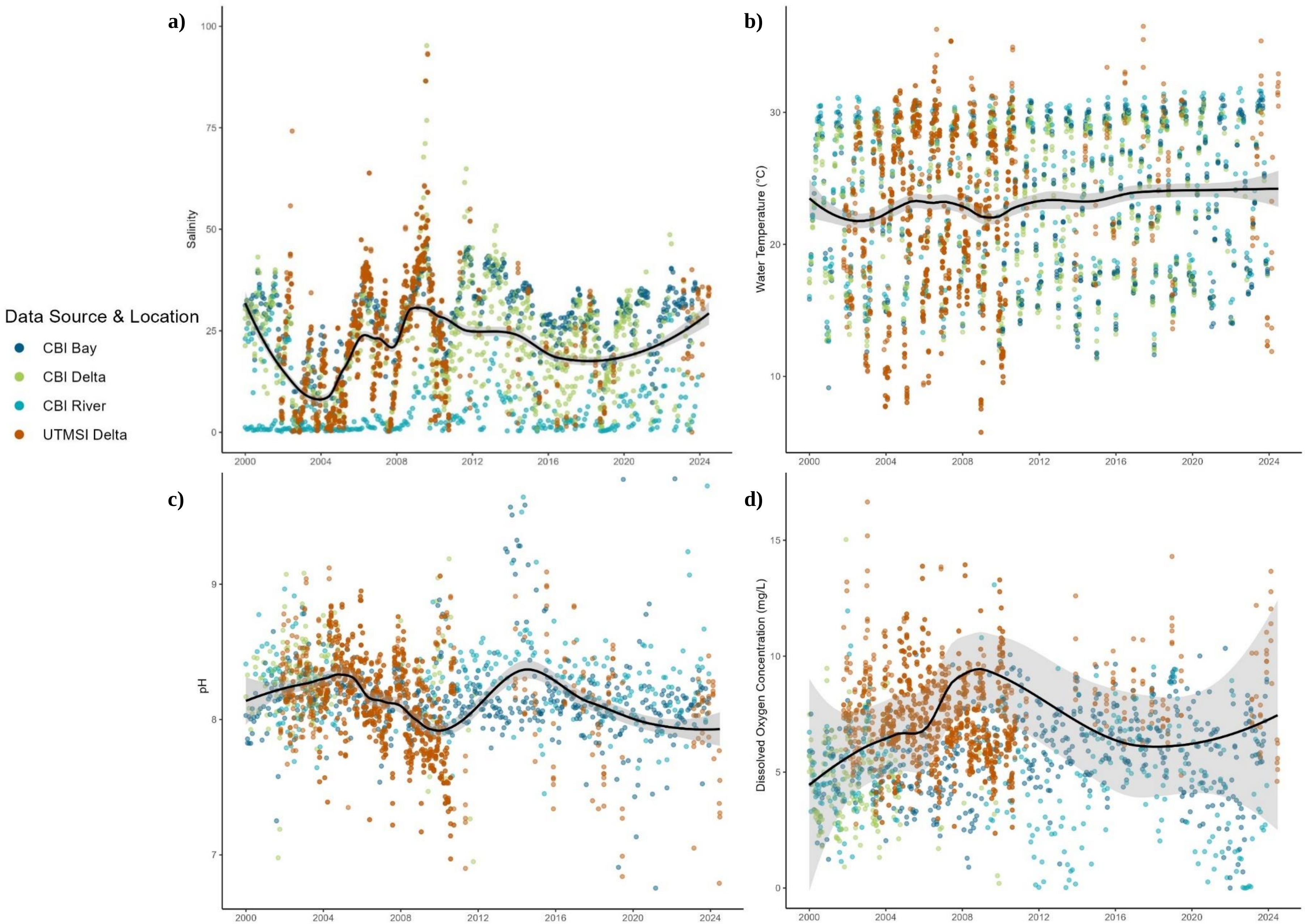


Figure 5. Long-term change in key water quality parameters at CBI and UTMSI monitoring sites: a) Salinity, b) Water Temperature, c) pH, d) Dissolved Oxygen Concentration. Data points are color-coded by organization and general location. Overall trends are represented by ribbons (mean, 95% confidence interval).

Key water quality and meteorological parameters also demonstrate interesting temporal patterns. Nearly all parameters show changepoints around 2007, 2012, and/or 2017. The largest changes occurred in salinity, precipitation, relative humidity, and wind speed (**Figure 5, Figure 6**). Notably, salinity experienced two extreme oscillations from low to high values between 2004 and 2012 (**Figure 5a**). These increases correspond to extreme droughts experienced throughout the region. Furthermore, trends in the precipitation data at the CBI weather station follow this pattern, as precipitation was zero in 2009, 2011, and 2012, when salinities spiked (**Figure 6b**). Additional smaller spikes in the salinity data also match up with periods of no recorded precipitation at the weather station. Relative humidity values steadily declined to extremely low values from 2008 to 2014, these were consistently around 75-90% until 2023, and have begun to decline again (**Figure 6d**). It is unclear what drives this pattern, but it is likely related to drought conditions as relative humidity is determined by the temperature and water content of the air (Lawrence, 2005). Lastly, wind speed values in the Bay dropped from 2015-2017 (**Figure 6e**).

Many of the shifts observed in water quality and meteorological parameters correspond to observed shifts in the vegetative community within the Delta. At the landscape-scale, species such as *B. maritima*, *B. frutescens*, *D. spicata*, *L. carolinianum*, *M. littoralis,* and *S. bigelovii,* and unvegetated cover types, like wrack and bare, appear to demonstrate varying levels of change in relative abundance around 2007, 2012, and/or 2017 (**Figure 2**). This ten-year period seems to be one of high variability and change within the Delta. Furthermore, vegetative assemblages may display stronger correlations to environmental parameters at the individual site level, as we've demonstrated that position within the Delta plays an important role in structuring communities.

Findings from Literature Search

We identified approximately 150 initial sources of interest, ranging from the mid-1900s to present. After manually filtering out sources that did not explicitly focus on or provide data on the Nueces watershed system, we ended up with 125 final sources (**Appendix D**). Of those, the vast majority were published journal articles (n = 57) and reports (n = 50; **Table 5**). Most reports were written for and published by state agencies, such as Texas General Land Office, or resources managers, such as CBBEP or Texas Water Development Board. The major focus on the Nueces Delta was launched by the influx of federal funding from the U.S. Bureau of Reclamation in the mid-1990s, resulting in several publications and reports throughout the early 21st century (n = 112; **Table 5**). Many of these studies have been published by the same authors or groups of authors (Montagna, Dunton, Tunnell, Palmer, and Hill) from UTMSI and Harte Research Institute for Gulf of Mexico Studies at TAMU-CC (**Appendix E**). Furthermore, many studies have focused on the changes in or impacts of hydrology/freshwater inflows (n = 53), the geologic history of the estuary (n = 32), and the wetland habitats (n = 25). Studies on fish, reptiles, birds (n = 7 total), and pollution (n = 5) seem to be underrepresented within the body of literature (**Table 5**). Lastly, salinity (n = 68), weather (n = 124), and water quality (n = 187) are commonly measured parameters throughout most studies (**Table 5**).

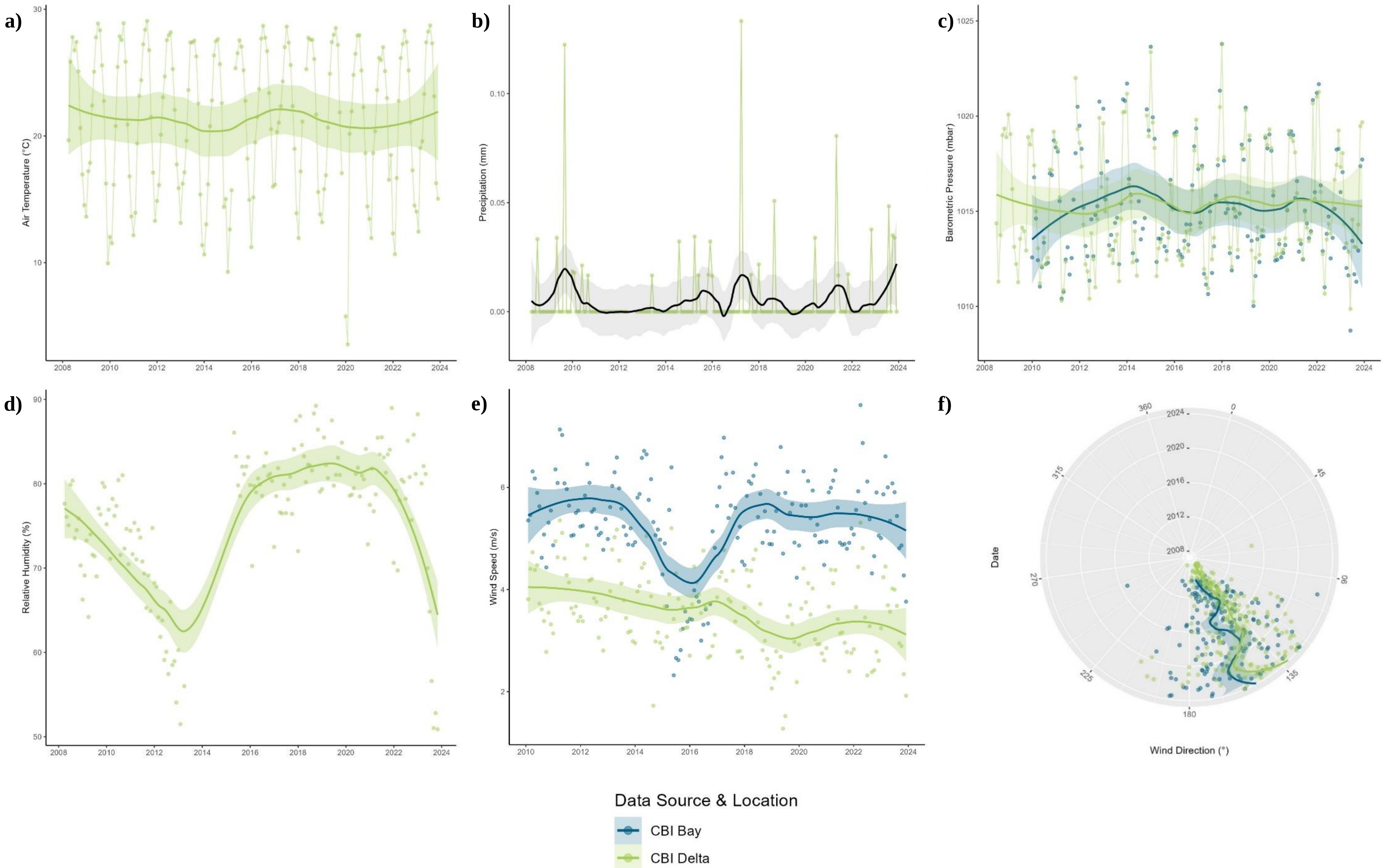


Figure 6. Long-term change in meteorological parameters at CBI monitoring sites: a) Air Temperature, b) Precipitation, c) Barometric Pressure, d) Relative Humidity, e) Wind Speed, f) Wind Direction. Data points are color-coded by organization and general location. Overall trends are represented by ribbons (mean, 95% confidence interval).

Table 5. Key characteristics of the Nueces Delta body of literature, including publication type, date of publication, focus, and methodology.

Source Type	Count
Journal Article	57
Report	50
Thesis	8
Dissertation	5
Book	3
Conference Paper	2

Publication Date	Count
1960s and earlier	0
1970s	1
1980s	4
1990s	8
2000s	45
2010s	53
2020s	14

Study Focus	Count
Hydrology/Inflows	53
Geology	32
Wetlands	25
Monitoring/Restoration/Management	24
Salinity	20
Invertebrates	13
Sediments	14
Plankton	12
Fish/Reptiles	6
Pollutants	5
Climate	4
Birds	1

Measurements	Count
Salinity	68
Precipitation	41
Temperature	39
Water Depth	37
Dissolved Oxygen	34
pH	31
Nutrients	24
Inflow	26
Biomass	20
Wind Speed/Direction	19
Vegetation Percent Cover	14
Barometric Pressure	10
Chlorophyll *a*	12
Isotopes	10
Relative Humidity	8
Solar Radiation	7
Respiration	6
Evaporation	4
Total Suspended Solids	4
Photosynthesis	3

CONCLUSIONS

Marsh Abiotic and Biotic Conditions

Overall, water and soil quality at the vegetation monitoring sites appear to be within an acceptable range for a productive marsh. There is no evidence of either excessive nutrient loading (low tidal creek nutrient levels and high dissolved oxygen concentrations observed) or nutrient limitation (sufficient porewater ammonium concentrations observed). While water column temperature, salinity, and pH are all within normal ranges for the Texas Coastal Bend, these parameters all have extremely high variability within the Delta. TSS represents potential sediment delivery to marsh sites. Values of TSS were generally high, indicating turbid waters, but were highly variable across sites and over time, justifying the need for continued sampling. Soil moisture and porewater salinity are inversely related. Drier sites tend to have higher salinities due to reduced tidal flushing and high evaporation. Porewater salinity reached extreme values (>100) for extended periods at many sites. Spatial parameters, such as distance upstream and elevation, are likely the key factors in explaining these differences in water and soil quality between sites. Furthermore, climatic conditions, such as precipitation, seem to be likely drivers of changes in abiotic factors, such as salinity and soil moisture, in the marsh. Hypersalinity caused by drought has the potential to be the most critical stressor and driver of vegetation change in the Nueces Delta.

Each monitoring site displayed unique communities of marsh vegetation. This variation is reflective of differences in abiotic factors, such as salinity, moisture, and nutrient concentrations. Ultimately, differences in these factors are a result of fine-scale spatial heterogeneity in elevation or topography, freshwater inflow, and tidal influence. We observed an increase in high marsh species (i.e., *M. littoralis, S. linearis*) with distance upstream (sites 451 and 463). Intertidal species, such as *S. alterniflora*, were only observed at low elevations at sites nearest to Nueces Bay. It appears that *S. alterniflora* and other low marsh species may all but disappear from the monitoring sites in the future. The brackish species *S. maritimus* has already been lost and has not been recorded at any sites since 2008.

At all sites, significant changes in both vegetation cover and community composition have been observed over time. Many of the shifts correspond to changes in water quality and climate. At the landscape-scale, the ten-year period from 2007-2017 seems to be one of high variability and change within the Delta. While the community may be shifting in composition, a more worrying trend is the loss of vegetation altogether due to erosion and/or increases in water level. Multiple sites have already lost anywhere from 2-10 m of shoreline that could be potential low marsh colonization area, the most severe example being site 270 (~8-10 m retreat). Site 270 is among the closest sites to the wave action of Nueces Bay and has the lowest concentration of TSS in the water column, indicating potential sediment starvation. In addition, persistent high salinities can lead to vegetation dieback, expansion of interior bare patches, and the reduction of sediment stabilization via belowground biomass. Recolonization of saline bare patches will only occur in the most disturbance- or salinity-tolerant species (i.e., *S. bigelovii*, *D. spicata*) or when salinities are ameliorated by freshwater events. Low, intertidal species can colonize new ground after erosion and an increase in water levels, but shorelines within the Nueces Delta may be too steep due to erosion. Marsh management efforts should focus not only on sediment delivery, but also on preserving vegetation abundance and productivity. Strategies may include freshwater inflows management, thin layer placement, and living shorelines.

Data Synthesis Discussion and Future Recommendations

Linking marsh vegetation dynamics to climate is a data-intensive process. Data from environmental monitoring stations, such as those managed by CBI, provide environmental parameters useful for contextualizing vegetation change, but they are not enough to perform an in-depth statistical modeling effort, due to previously mentioned limitations in spatial and/or temporal coverage. Additional sources of data such as PRISM (Oregon State University, 2014) and NOAA (NOS CO-OPS, 2013) are needed to supplement in-situ measurements for further characterizations of the environmental drivers of marsh vegetation community composition over time. These datasets are publicly available and easily accessible, further demonstrating their value and emphasizing the need to improve accessibility of our Nueces Delta datasets. Our proposed solution, a web-based Shiny app, will significantly improve ease of use and increase engagement with the data for researchers and the public alike.

In completing a literature search, we learned that most studies in the Nueces Delta have focused on freshwater inflows and salinity. This is clearly an important research topic given their demonstrated impact on many different habitats and populations. However, there is a stark lack of representation of fish, reptiles, birds, and other fauna within the identified body of literature. Furthermore, it appears that there are very few studies analyzing the vast amounts of monitoring data on longer time scales. Long-term analyses are extremely important for validating trends observed in short-term studies and for predicting future change, and therefore, collecting consistent long-term monitoring data is even more important. Coastal marshes are well-known for the critical ecosystem functions they perform, but research quantifying levels of various ecosystem functions, such as primary productivity, carbon sequestration, and wave attenuation, are scarce. Although the publication rate in the Nueces Delta has waned in recent years, there remains an urgent need to understand the ecological processes within this dynamic system so that we may make informed decisions in the face of threats from rapid climate change.

Future research efforts should prioritize a focus on higher trophic levels, ecosystem functions, and improvement of long-term data quality and accessibility. The utility of long-term data is limited not only by access, but also by the quality and consistency of data collection and management. If high-quality environmental data were made easily accessible, it would reduce the barriers for many studies to proceed, filling several gaps in the literature. Implementation of an in-depth data management plan should be a prerequisite for any future programs funded within the Nueces Delta.

APPENDIX

Appendix A. Description of species abbreviations in **Table 3** and **Figure 2**.

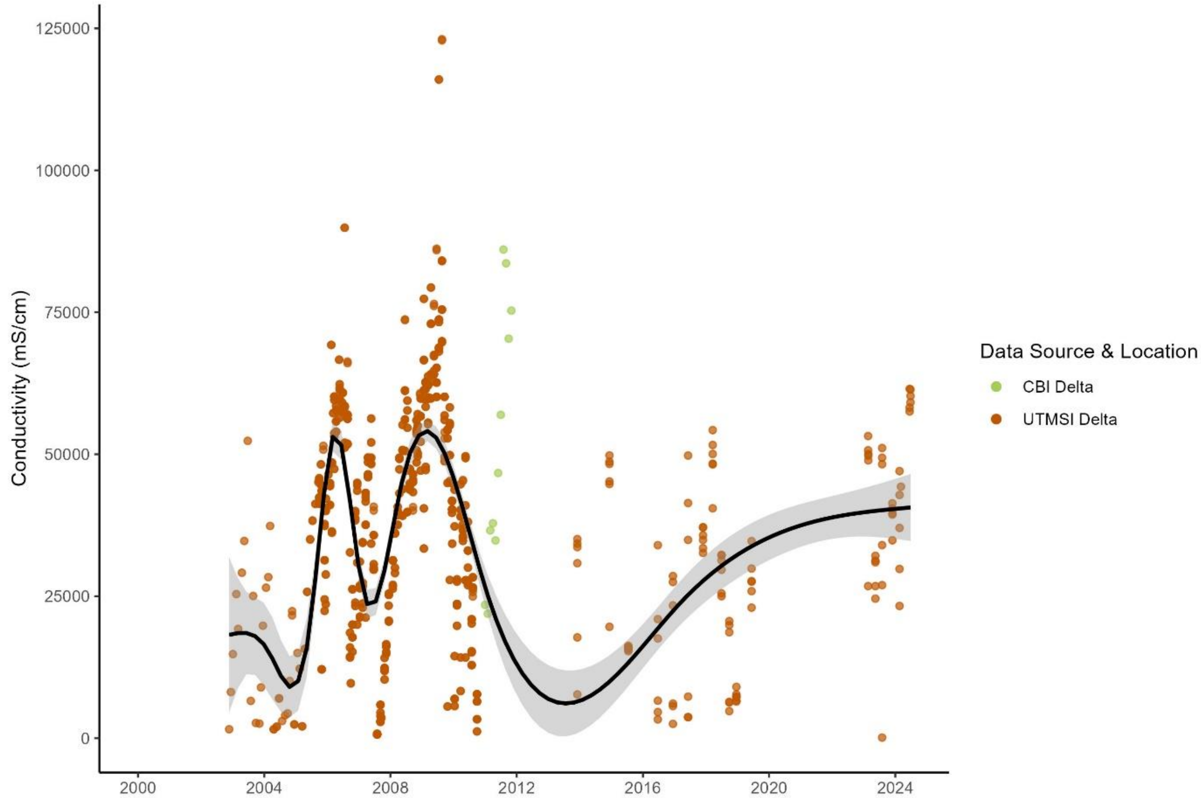
Abbreviation	Species Name
BM	*Batis maritima*
BF	*Borrichia frutescens*
DS	*Distichlis spicata*
LN	*Limonium nashii*
LC	*Lycium carolinianum*
ML	*Monanthochloe littoralis*
SB	*Salicornia bigelovii*
SV	*Salicornia virginica*
SA	*Spartina alterniflora*
SS	*Spartina spartinae*
SL	*Suaeda linearis*
SM	*Scirpus maritimus*
IF	*Iva frutescens*
AT	*Asteridae*
Bare	No vegetation
Wrack	Dead vegetation
Other	Transient species

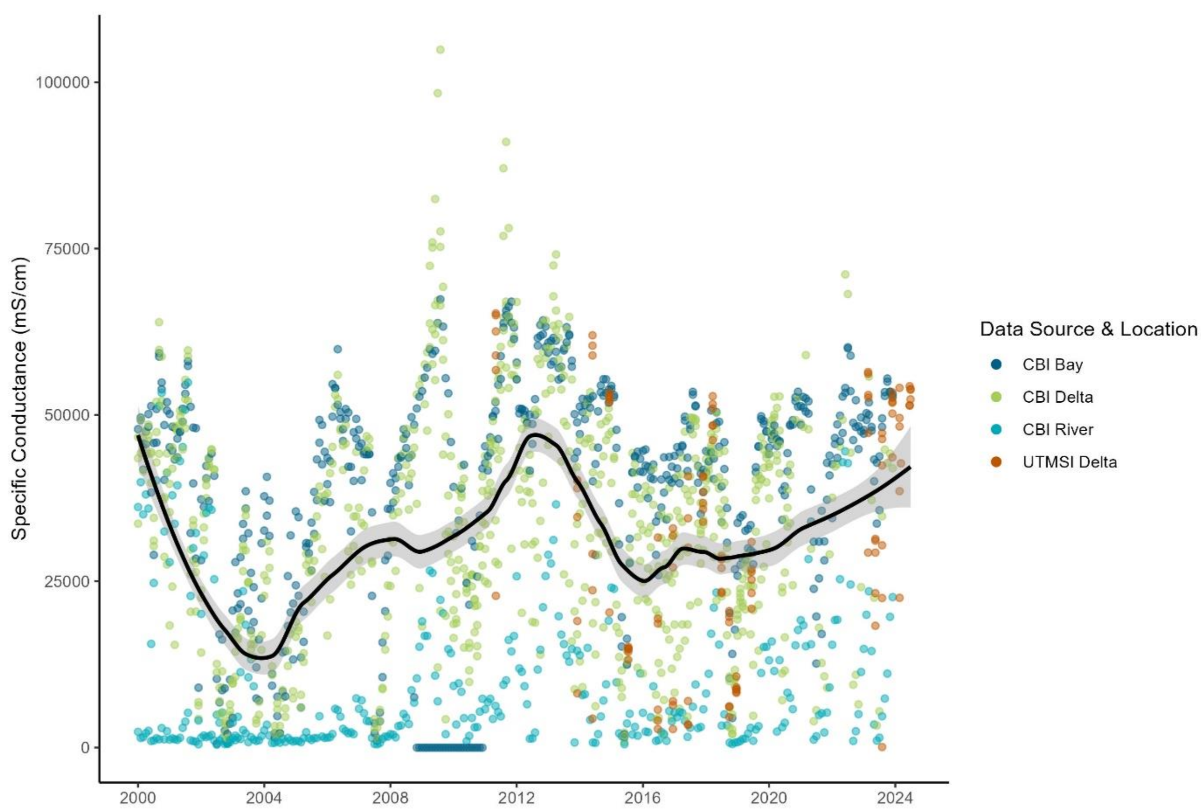
Appendix B. Spatial and temporal metadata for CBI environmental monitoring stations.

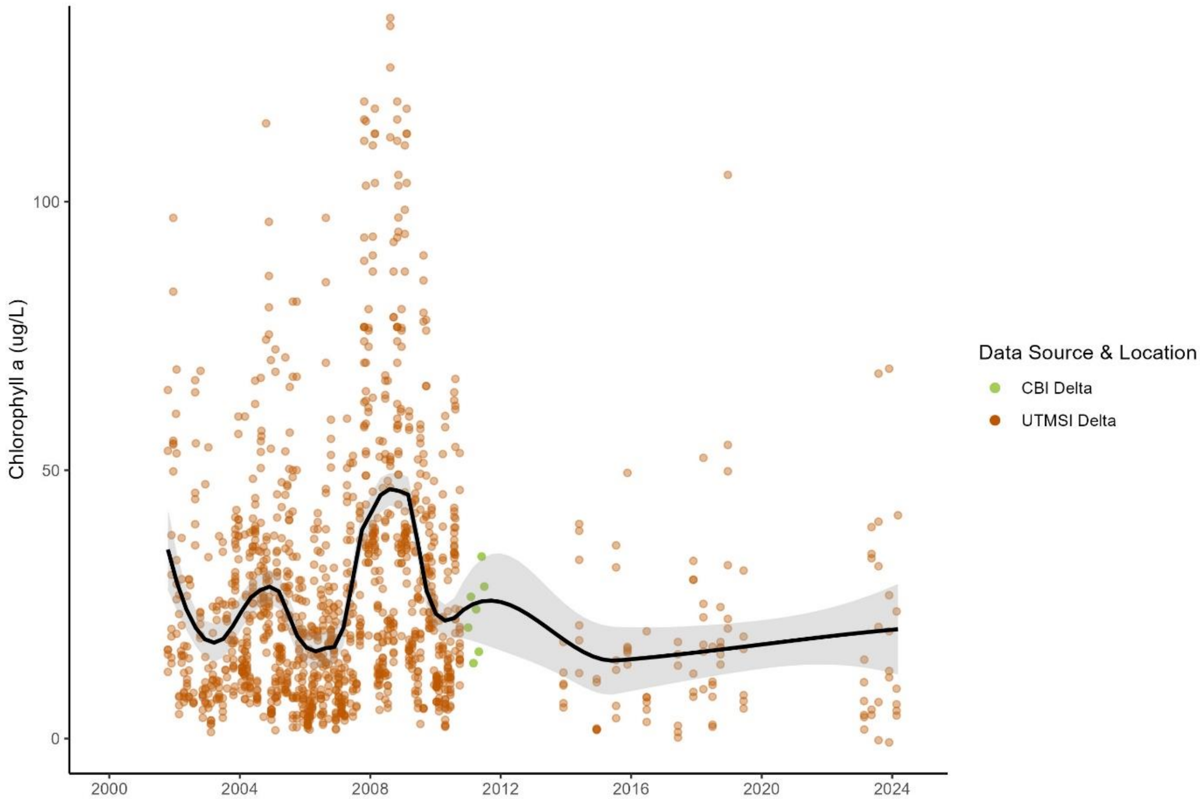
Site #	Site Name	Latitude	Longitude	Parameter	Date Range
41	NUDE1	27.88944	-97.59139	Water temperature	2009-2011
				Salinity	2009-2011
				Specific conductance	2009-2011
				pH	2009
				DO concentration	2009
				DO saturation	2009
				Water depth	2009-2011
42	NUDE2	27.88861	-97.56944	Water temperature	2009-2023
				Salinity	2009-2023
				Specific conductance	2009-2023
				Conductivity	2011
				pH	2009-2011
				Chlorophyll *a*	2011
				Water depth	2009-2012, 2014-2018, 2023
43	NUDE3	27.88361	-97.53306	Water temperature	2009-2020
				Salinity	2009-2020
				Specific conductance	2009-2020
				Water depth	2009-2018
72	SALT01	27.83917	-97.44389	Water temperature	2000-2023
				Salinity	2000-2023
				Specific conductance	2000-2023
				pH	2000-2023
				DO concentration	2000-2023
				DO saturation	2000-2023
				Water depth	2002-2018
74	SALT03	27.85139	-97.48194	Water temperature	2000-2023
				Salinity	2000-2023
				Specific conductance	2000-2023
				pH	2000-2023
				DO concentration	2000-2023
				DO saturation	2000-2023
				Water depth	2001-2018
75	SALT04	27.86972	-97.55333	Water temperature	2000-2009, 2016-2020
				Salinity	2000-2009, 2016-2020
				Specific conductance	2000-2009, 2016-2020
				pH	2000-2004, 2008
				DO concentration	2000-2004, 2006, 2008
				DO saturation	2000-2004, 2008
				Water depth	2002-2009, 2016-2018

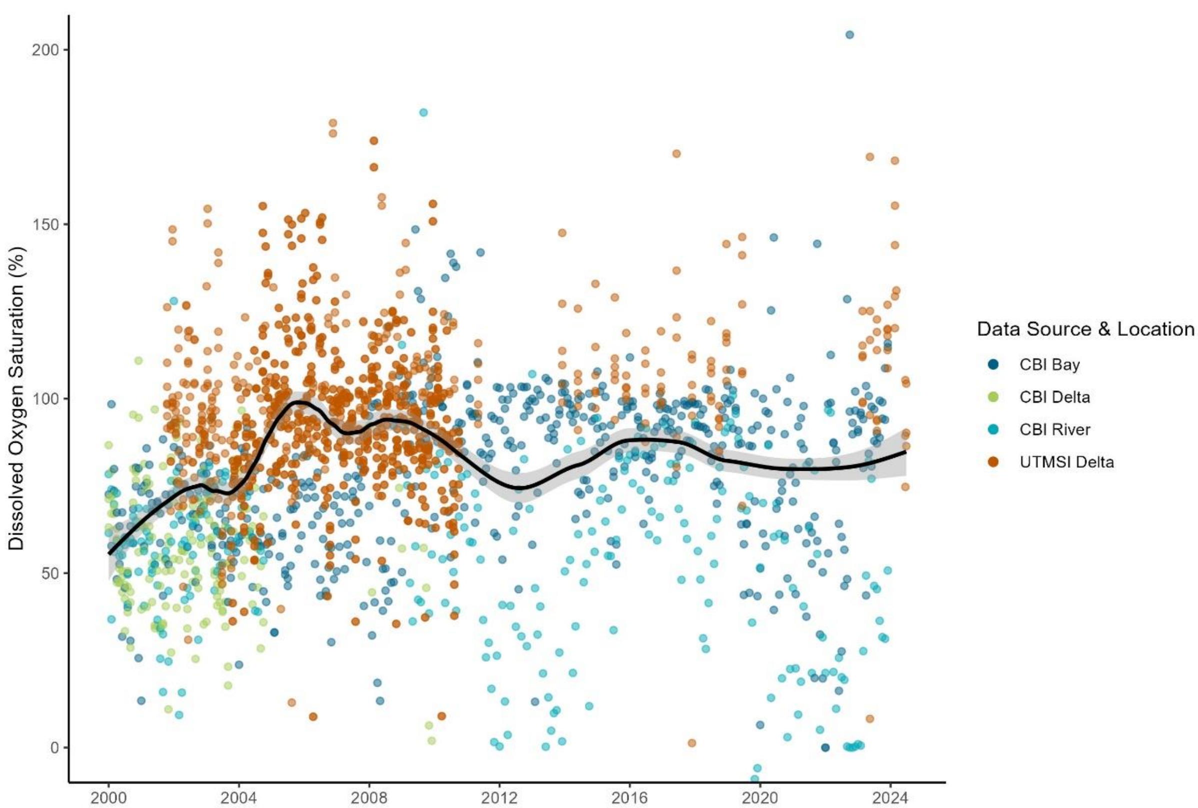
Site #	Site Name	Latitude	Longitude	Parameter	Date Range
76	SALT05	27.89167	-97.61028	Water temperature	2000-2023
				Salinity	2000-2023
				Specific conductance	2000-2023
				pH	2000-2004, 2009-2023
				DO concentration	2000-2004, 2009-2023
				DO saturation	2000-2004, 2009-2023
				Water depth	2016-2018
77	SALT06	27.84444	-97.50389	Water temperature	2000-2003
				Salinity	2000-2003
				Specific conductance	2000-2003
				pH	2001-2003
				DO concentration	2000-2003
				DO saturation	2000-2003
				Water depth	2001-2003
78	SALT07	27.86056	-97.52139	Water temperature	2000-2003
				Salinity	2000-2003
				Specific conductance	2000-2003
				pH	2001-2003
				DO concentration	2000-2003
				DO saturation	2000-2003
				Water depth	2001-2003
79	SALT08	27.87056	-97.51750	Water temperature	2000-2020
				Salinity	2000-2020
				Specific conductance	2000-2020
				pH	2001-2004, 2009
				DO concentration	2000-2004, 2009
				DO saturation	2000-2004, 2009
				Water depth	2001-2018
100	NUDEWX	27.89750	-97.61639	Wind speed	2008-2023
				Wind gust	2008-2023
				Wind direction	2008-2023
				Barometric pressure	2008-2023
				Rainfall	2008-2023
				Air temperature	2008-2023
				Relative humidity	2008-2023
185	NUEBAY	27.83250	-97.48583	Water temperature	2010-2020, 2022-2023
				Water level	2010-2023
				Wind speed	2010-2023
				Wind gust	2010-2023
				Wind direction	2010-2023
				Barometric pressure	2010-2023
				High-high water level	2010-2015
				High water level	2010-2015
				Low water level	2010-2013
				Low-low water level	2010-2013

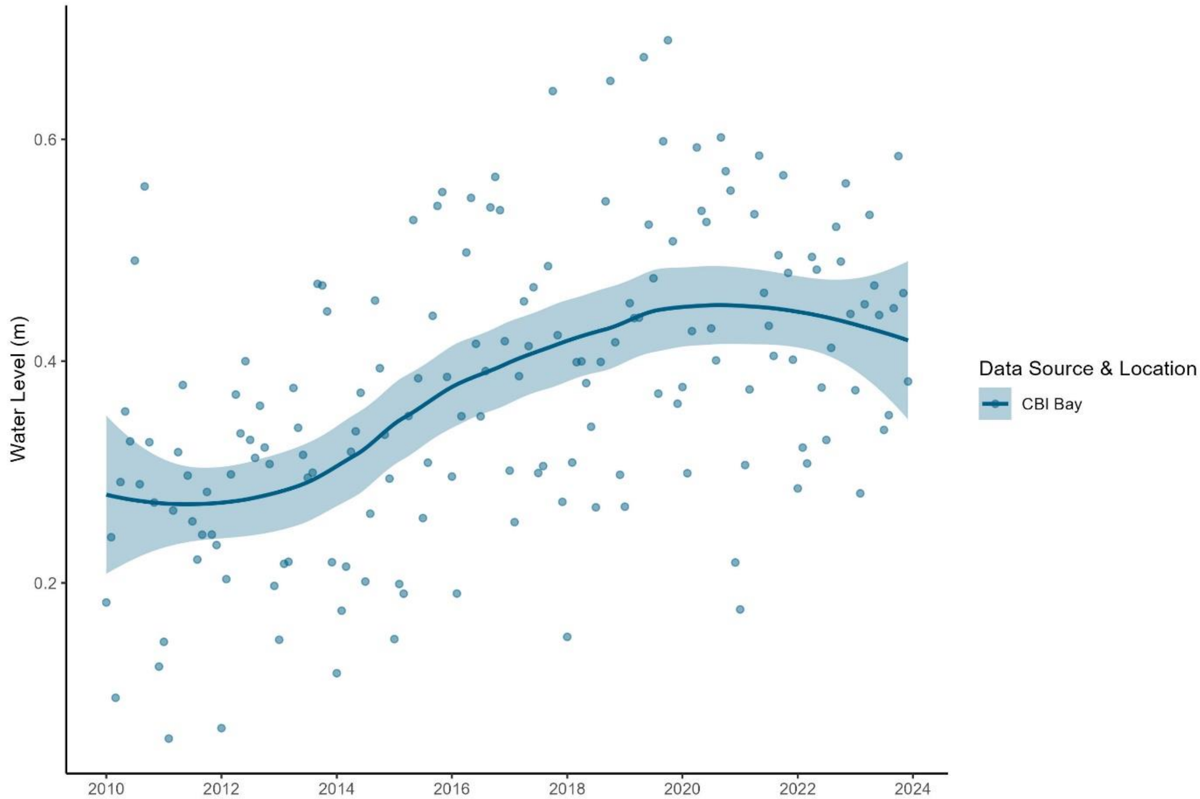
Appendix C. Additional data from CBI and UTMSI monitoring sites. Stations are color-coded by organization and general location.



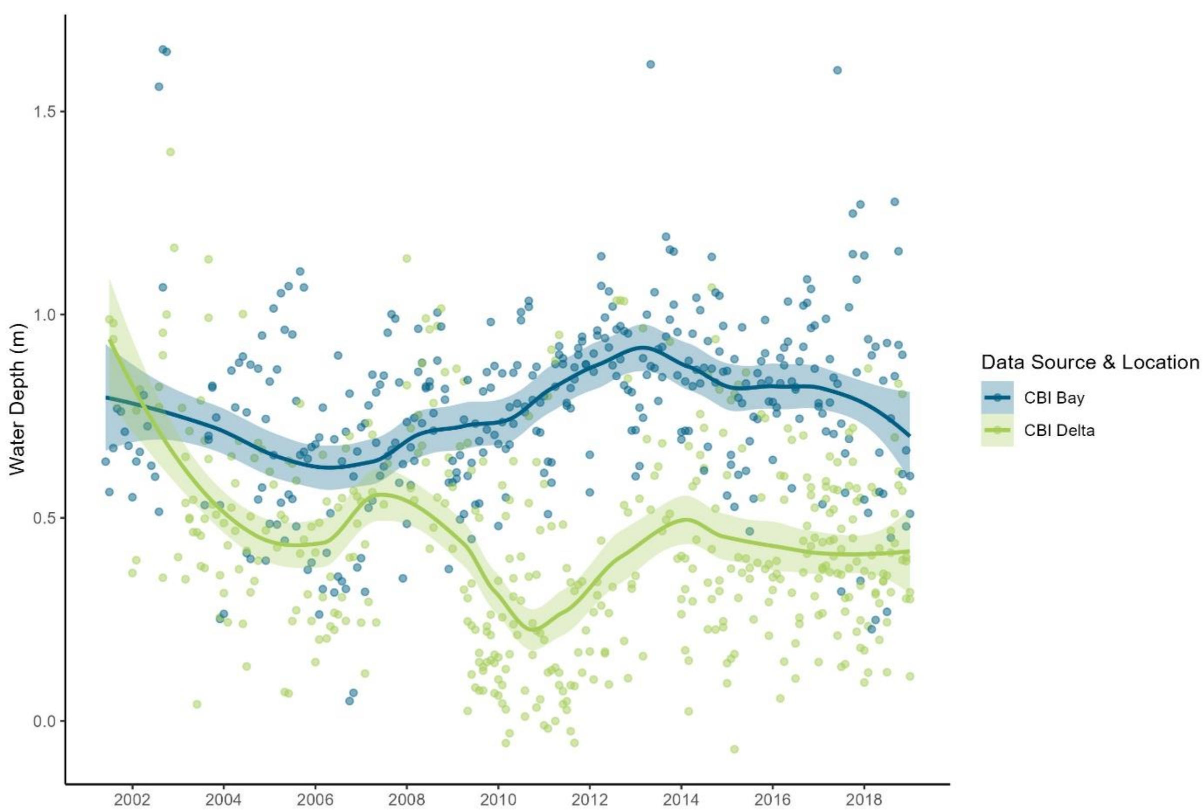



Chlorophyll a (ug/L)
0
50
100
2000
2004
2008
2012
2016
2020
2024
Data Source & Location
CBI Delta
UTMSI Delta


Dissolved Oxygen Saturation (%)
0
50
100
150
200
2000
2004
2008
2012
2016
2020
2024
Data Source & Location
CBI Bay
CBI Delta
CBI River
UTMSI Delta



Site 185 “NUEBAY” Only



Appendix D. Raw results from Nueces Delta literature search. Excel spreadsheet will be provided.

Source Type	Author(s)	Title	Year	Data Range	Parameters Measured	Concluding Remarks
Journal Article	White, WA Morton, RA Holmes, CB	A comparison of factors controlling sedimentation rates and wetland loss	2002		Core sediment texture, salinity, sedimentation and accretion rates, sea-level rise, precipitation, basin size, suspended sediment, mud thickness, wetland loss	
Report	Buzan, D	Alternative methods to add freshwater to the Nueces Delta	2017		Tidal diversions, inner harbor additions, Hondo Creek realignment, deep water wells, mine ponds	
Journal Article	Zhang, H Zimba, PV	Analyzing the effects of estuarine freshwater fluxes on fish abundance using artificial neural network ensembles	2017		Streamflow, evaporation, precipitation, species, predicted catch rate, observed catch rate	The ANN model has improved predictive performance and can be widely used in decision-making processes of freshwater regulation.
Journal Article	Ray, LE Murray, HE Giam, CS	Analysis of water and sediment from the Nueces Estuary/Corpus Christi Bay (Texas) for selected organic pollutants	1983		Organic pollutant concentrations	This study identified suitable sites for use in forthcoming studies on the biological effects of marine pollutants.
Book	Funicelli, NA	Assessing and managing effects of reduced freshwater inflow to two Texas estuaries	1984		Flow, flood volume, occurrences	Fishery harvest + marsh inundation approach has the advantage of transition to economic impact
Journal Article	Abdulla, H	Assessment of organic pollutants in Nueces Bay's petroleum brine impacted sediment	2021		Salinity, pH, temperature, conductivity, DO, PAHs	
Journal Article	Simms, AR Rodriguez, AB Anderson, JB	Bayhead deltas and shorelines: Insights from modern and ancient examples	2018		Clinoform thickness, depth	
Journal Article	Heinsch, FA Heilman, JL McInnes, KJ Cobos, DR Zuberer, DA Roelke, DL	Carbon dioxide exchange in a high marsh on the Texas Gulf Coast: effects of freshwater availability	2004		Precipitation, water depth, respiration, net ecosystem exchange, gross ecosystem production, diel fluctuations in NEE	In its present state, with limited and intermittent freshwater inflow and high salinity, the high marsh of the Nueces River Delta behaves more as a dryland ecosystem than a wetland.
Book	Montagna, PA Brenner, J Gibeaut, J Morehead, S Schmandt, J North, GR Clarkson, J	Chapter 4. Coastal Impacts	2011		Rates of sea-level rise	
Report	Ward, JA Tennant, M Wiles, K Heideman, G	Characterization of Potential Health Risks Associated with Consumption of Fish and Shellfish from Nueces Bay	2005	2005	Arsenic, Cadmium, Zinc, inorganic contaminants, PCBs, pesticides	Oysters contain zinc at levels that could result in systemic adverse health effects. Spotted seatrout, red drum, and blue crabs do not contain quantities of organic or inorganic substances in excess.
Dissertation	Buyukates, Y	Characterization of the plankton community in the lower Rincon Delta: Investigations regarding new approaches to management	2003	2001	Biovolume, chlorophyll, abundance, dissolved inorganic nutrients, salinity, temperature, pH, DO, turb, depth	
Report	Schoenbaechler, C Guthrie, CG Lu, Q	Coastal Hydrology for the Nueces Estuary: Hydrology for Version #TWDB201101 with Updates to Diversion and Return Data for 2000-2009	2011		Net diversions, precipitation, evaporation, surface inflow	

Journal Article	Brusati, ED DuBowy, PJ Lacher, TE	Comparing Ecological Functions of Natural and Created Wetlands for Shorebirds in Texas	2001	1997-1999	Invertebrate biomass	
Report	Guthrie, CG Schoenbaechler, C Matsumoto, J Lu, Q	Comparison of Two Hydrology Datasets, as Applied to the TxBLEND Model, on Salinity Condition in Nueces Bay	2011		Average salinity, annual inflow, flow rate	
Journal Article	Liu, Z Breecker, D Zhong, J	Composition of size-fractioned sedimentary organic matter in coastal environments is affected by difference in physical forcing strength	2013		Water depth, wind speed, tidal range, tidal current, sediment texture (sand), THAA, functional groups	SOM in size fractions showed increasing degradation with decreasing size
Journal Article	Rice, JA Simms, AR Buzas-Stephens, P Steel, E Livsey, D	Deltaic response to climate change: The Holocene history of the Nueces Delta	2020		Core depth, C14 age, sediment and biological characteristics, facies interpretation, core descriptions, mouth-bar thickness	Natural coastal systems are very dynamic and can retreat and prograde at rates exceeding 10 m/yr in the absence of global fluctuations in sea level
Journal Article	Breier, JA Edmonds, HN Breier, CF	Detecting submarine groundwater discharge with synoptic surveys of sediment resistivity, radium, and salinity	2005		Conductivity, salinity, temperature, DO, depth, distance	Groundwater discharge or leakage into Nueces Bay occurs largely in one, possibly two, relatively localized areas.
Report	Montagna, PA Adams, L DelRosario, E Kalke, RD Turner, EL	Determining Optimal Pumped Flows to Nueces Delta	2016		Temperature, pH, DO, depth, salinity, inflow, macroinfauna abundance, biomass, diversity, total # of species	Although lower salinities have been maintained in Rincon Bayou due to pumping activities, lower diversity and high fluctuations of abundance and biomass are indicative of a very disturbed ecosystem.
Report	Eldridge, PM Cifuentes, LA Kaldy, JE	Development of a stable-isotope constraint system for estuarine food-web models	2005		DIC, DOC, flux, biomass, stable isotope ratios, exchange matrices (flow & isotope ratio), dependency of food-web compartments	Infaunal production increased with freshwater inundations. Infauna is a good bio-indicator of Nueces Bay food-web processes.
Journal Article	Baxter, AS	Diamondback Terrapin Paired Crab Trap Study in the Nueces Estuary, Texas	2013	2012-2013	Number of species (terrapin & blue crab), mean carapace width, CPUE	BRDs reduce diamondback terrapin mortality in crab traps without impacting blue crab fishery
Journal Article	Palmer, TA Montagna, PA Kalke, RD	Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA	2002	1998-1999	Salinity, distance from river, biomass, abundance, diversity	Response indicates ecological function was restored, but only for short time periods because freshwater volumes are low and events episodic.
Thesis	DelRosario, E	Ecosystem response to freshwater inflow: determining a link between freshwater pumping regimes, salinity, and benthic macrofauna	2016	2007-2015	Temp, depth, salinity, species composition, dry weight, minimum pumping capacity, inflow, discharge, rainfall	Salinity and depth can be altered from RBP in direct response to management actions
Journal Article	Montagna, PA Kalke, RD Ritter, C	Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA	2001	1994-1999	Rainfall, gaged inflow, salinity, biomass, abundance, diversity, # of species	Increased productivity and ameliorated stresses on biodiversity. Re-opening of the channel is largely justified.
Dissertation	Heinsch, FA	Effects of freshwater inflow on carbon dioxide exchange in a coastal wetland	2022		Temperature, precipitation, water depth, PAR, NCE, photosynthesis, respiration	Freshwater affects NCE and Ps. Plants respond positively to water when photosynthesizing
Journal Article	Forbes, MG Alexander, HD Dunton, KH	Effects of pulsed riverine versus non-pulsed wastewater inputs of freshwater on plant community structure in a semi-arid salt marsh	2008		Net freshwater budget, pore water salinity, relative frequency, species richness	Importance of considering regional climatic and hydrologic cycles when designing and managing restoration projects.
Report	Montagna, PA	Effects of Pumped Flows into Rincon Bayou on Water Quality and Benthic Macrofauna	2015		Temperature, DO, pH, depth, salinity, inflow, discharge, rainfall, macrofauna abundance, biomass, diversity	Inflows should be a continuous trickle, and not dependent on pass-through requirements
Report	Tunnell, JW Lloyd, L	Effects of Rincon Bayou Pipeline Inflows on Salinity Structure Within the Nueces Delta, Texas	2011		Pumping duration, inflow, salinity	

Journal Article	DelRosario, E Montagna, PA	Effects of the Rincon Bayou Pipeline on salinity in the upper Nueces Delta	2018		Percent occurrence of salinity ranges, inflow, rainfall, percent occurrence for natural flow rate	A lower magnitude, longer duration pumping strategy would create a more stable environment
Report	Montagna, PA Chaloupka, C DelRosario, E Gordon, A Turner, EL	Effects on Benthic Macrofauna from Pumped Flows to Rincon Bayou	2016		Salinity, conductivity, DO, temperature, pH, water depth, sediment grain size, macroinfauna and epifauna abundance, biomass, and diversity	Pump when salinities are high, i.e., over 25 PSU, and use one pump only to move the fresh water into Rincon Bayou in a slow trickle rather than a flood.
Journal Article	Rasser, MK Fowler, NL Dunton, KH	Elevation and plant community distribution in a microtidal salt marsh of the western Gulf of Mexico	2013	2003-2006	Elevation, distance from bay, percent cover, cluster analysis of species abundances and bare area	If sea level predictions of 0.5 m to 1.0 m prove true, the entire plant community in the Nueces Marsh will be influenced by higher water levels.
Journal Article	Heilman, JL Heinsch, FA McInnes, KJ	Energy balance of a high marsh on the Texas Gulf Coast: Effect of water availability	2000	1998	Rainfall, water depth, storage heat flux, net radiation, temperature	When ponds were flooded, latent heat flux consumed, on average, 67% of daily net radiation, while sensible heat flux consumed 30%.
Report	Bay Area Stakeholders Committee	Environmental Flow Standards and Strategies Recommendations Report	2012		Resources of Interest, Development of Recs, Recs for Env Flow Standards, Recs for Potential Strategies to Meet Standards, Work Plan and Adaptive Management	
Report	Dunton, KH Arsuffi, T Hoeinghaus, D Stewart, L Tunnell, JW	Environmental Flows Recommendations Report	2011		Overview of Watersheds and Bays, Instream Flow Analyses, Freshwater Inflow and Estuary Analyses, Integration of Instream Flow and Freshwater Inflow Regimes, Environmental Flow Regime Recommendations	
Journal Article	Ward, GH Irlbeck, MJ Montagna, PA	Experimental River Diversion for Marsh Enhancement	2002	1994-1999	Rainfall, flow volume, event mean stage, salinity, duration	
Conference Paper	Su, L Gibeaut, J	Extracting Surface Features of the Nueces River Delta Using LiDAR Points	2009	2007	Lidar point density, elevation, and intensity	Approach can successfully classify lidar points as water or land in estuary areas.
Journal Article	Montagna, PA McKinney, L Yoskowitz, D	Focused Flows to Maintain Natural Nursery Habitats	2021		Volume, surface inflow, inflow balance, flushing rate, naturalized and regulated flows at outlet, percent regulated flow	
Thesis	Gordon, AM	Freshwater inflow effects on mobile epifauna and estuarine dependent crustaceans in Rincon Bayou in the Nueces Delta	2016	2010-2015	Depth, temperature, salinity, DO, pH, inflow, abundance, biomass, species richness, diversity	Rincon Bayou is not just a salinity-stressed environment, but there are overall effects due to all water quality parameters.
Journal Article	Stachelek, JJ Dunton, KH	Freshwater inflow requirements for the Nueces Delta, Texas: *Spartina alterniflora* as an indicator of ecosystem condition	2013	1999-2011	Discharge, salinity, porewater ammonium, soil moisture, distance to tidal creek, distance to Nueces Bay, percent cover	*S. virginica* will likely replace *Spartina* and make up a greater proportion of the overall community, decreasing sediment stabilization
Thesis	Stachelek, JJ	Freshwater inflows in the Nueces Delta, TX: impacts on porewater salinity and estimation of needs	2012	2001-2010	Precipitation, inflow, tidal level, porewater salinity, discharge, percent cover	Declines in freshwater reduce low salinity periods that are critical for plant communities.
Journal Article	Alexander, HD Dunton, KH	Freshwater inundation effects on emergent vegetation of a hypersaline salt marsh	2002		Flow, precipitation, salinity, elevation, distance	Hydrologic events determine vegetation community structure and patterns
Journal Article	Roelke, D Augustine, S Buyukates, Y	Fundamental Predictability in Multispecies Competition: The Influence of Large Disturbance	2003		Total flushing, maximum specific growth rate, half-saturation coefficient, substrate concentration of the source, and cellular substrate content	
Report	Kindinger, J Morton, RA Ferina, N	High-resolution Holocene stratigraphy of the Nueces River Bayhead Delta and incised valley of the Southwestern Texas Gulf Coast	2003		Depth, elevation, travel time	Holocene sea-level rise was series of high frequency events like what may occur during future changes of sea level
Journal Article	Morton, RA Paine, JG	Historical Shoreline Changes in Corpus Christi, Nueces, and Oso Bays	1983		Relative sea level rise, depth	

Report	Venable, C Palmer, TA Montagna, PA Sutton, G	Historical Review of the Nueces Estuary in the 20th Century	2011		Mean/median balanced inflow	
Report	Hill, EM Nicolau, BA Zimba, PV	History of Water and Habitat Improvement in the Nueces Estuary, Texas, USA	2011		Precipitation, inflow	
Report	Tolan, JM Newstead, DJ	Ichthyoplankton Recruitment to the Delta Nursery Areas of Nueces Bay	2005	2003	Air temperature, salinity, pH, DO, Secchi depth, total fish density, length, discharge	Pulsed freshwater inflow events that flush the marsh are important for larval fish recruitment
Journal Article	Baxter, AS	Identifying Diamondback Terrapin nesting habitat in the Nueces Estuary, Texas	2015	2015	Sediment grain size, elevation, distance from water, percent vegetative cover, slope, nest depth	Nest site characterization should allow for identification of nesting sites for other populations
Journal Article	Murgulet, D Murgulet, V Spalt, N Douglas, A Hay, R	Impact of hydrological alterations on river-groundwater exchange and water quality in a semi-arid area: Nueces River, Texas	2016		Rainfall, SC, discharge, gage height, O, D, C isotopes and DIC of porewater, surface water, and shallow groundwater, Na and SO4 molar ratios, Cl concentrations, calcite saturation index, % water and type	Techniques can be used to assess large spatial and temporal scales allowing for a comprehensive understanding of hydrologic alterations effects on rivers.
Thesis	Davis, JC	Implementation of a hydrodynamic model for salinity in Nueces and Corpus Christi Bays	2013	2008-2011	Salinity, flow, m above MSL, water temperature, wind speed, wind direction	Model was not accurate down river and in Nueces Bay.
Journal Article	Buyukates, Y Roelke, D	Influence of Pulsed Inflows and Nutrient Loading on Zooplankton and Phytoplankton Community Structure and Biomass in Microcosm Experiments Using Estuarine Assemblages	2005	2001	Biovolume, nutrients, inflows	Pulsed inflows might alter plankton dynamics by stimulating energy transfer up the food web (greater zooplankton), preventing excessive phytoplankton, and maintaining diversity
Journal Article	Buyukates, Y Roelke, D	Investigating System Characteristics of a Southeast Texas Wetland: Nutrient and Plankton Dynamics of a Tidal Creek in Lower Nueces Delta	2005	2001	Temperature, pH, ORP, DO, turb, salinity, Secchi depth, nitrogen, phosphate, silicate, N:P, biovolume, chlorophyll a, abundance	Confirmed freshwater input to a wetland is important to maintain the environmental health of a marsh ecosystem
Journal Article	Tolan, JM	Larval Fish Assemblage Response to Freshwater Inflows: A Synthesis of Five Years of Ichthyo-Plankton Monitoring Within Nueces Bay, Texas	2008	1999–2004	Daily discharge, temperature, salinity, DO, abundance, density, frequency, length, taxonomic diversity	Allowed for an examination of the ichthyofaunal response at both ends of the inflow spectrum.
Report	Montagna, PA	Management Strategies for the Rincon Bayou Pipeline	2019	1994-2017	Salinity, temperature, depth, DO, abundance, biomass, diversity, richness, evenness, inflow	Pumping at a trickle when salinities are high should improve conditions
Conference Paper	Montagna, PA Chaloupka, C DelRosario, E	Managing Environmental Flows and Water Resources	2018	2014-2016	Salinity, temperature, pH, DO, depth, inflow, abundance, N1 diversity	Future adaptive management efforts should advocate for a more continuous pumping schedule to reduce salinity fluctuations
Journal Article	Schalles, JF Hladik, CM	Mapping phytoplankton chlorophyll in turbid, Case 2 estuarine and coastal waters	2012	2002-2010	Temperature, precipitation, tides, TIN, TSS, Secchi, salinity, depth, wavelength	Case 2 algorithms for phytoplankton chlorophyll perform well with variable CDOM and/or PM
Journal Article	Ward, GH	Marsh Enhancement by Freshwater Diversion	1985	94-99	Flow, salinity, rainfall, stage, duration, flow volume	Location of inflow is as important as volume
Journal Article	Fejes, E Roelke, D Gable, G Heilman, JL McInnes, KJ Zeberer, D	Microalgal productivity, community composition, and pelagic food web dynamics in a subtropical, turbid salt marsh isolated from freshwater inflow	2005	2001-2003	Productivity, respiration, depth, wind speed, salinity, water temperature, nutrients, chlorophyll, biovolume	Nutrient availability in the upper Nueces Delta was most likely a function of recycling processes.
Report	Rony, SM Ren, J Buskey, E Sinha, T Lynn, T	Modeling Freshwater Inflows, Nutrient Dynamics and their Relationships to Algal Bloom in Nueces Bay, Texas	2020	2016-2020	Temperature, salinity, pH, chlorophyll, wave height, water level, nitrogen, wind speed	Provided an analysis tool for better understanding the mechanisms and dynamics of algal growth/blooms which can be an effective means to manage other similar estuaries or coastal waters.

Report	Ryan, AJ Hodges, BR	Modeling hydrodynamic fluxes in the Nueces River Delta	2011		Tides (TCOON), salinity (CBI), precipitation (NOAA), wind (NOAA), inflow (USGS), RBP pumping (NRA)	Model captures tidal propagation up through the marsh and freshwater fluxes down the Rincon
Journal Article	Li, Z Hodges, BR Shen, X	Modeling hypersalinity caused by evaporation and surface–subsurface exchange in a coastal marsh	2023	2012-2013	Simulation scenarios: specific storage, porosity, residual water content, dispersivity, molecular diffusivity	
Thesis	Rony, SM	Modeling Nutrient Dynamics and Algal Blooms Using Delft3d-Flow, Wave and WAQ, in Nueces Bay, Texas	2020		Water depth, wave height, total nitrogen, chlorophyll, temperature, wind speed	
Journal Article	Li, Z Hodges, BR	Modeling subgrid-scale topographic effects on shallow marsh hydrodynamics and salinity transport	2019		Inundation area, flow rate, salinity	Sub-grid model is suitable for shallow marsh modeling if surface connectivity is not interrupted.
Journal Article	Montagna, PA Sadovski, AL King, SA Nelson, KK Palmer, TA Dunton, KH	Modeling the effect of water level on the Nueces Delta marsh community	2017		Flood volume, change in cover, percent cover, change in marsh areal extent	Diffusion equations allowed for dispersal of plants but did not account for competition or rapid colonization.
Journal Article	Brock, DA	Nitrogen budget for low and high freshwater inflows, Nueces Estuary, Texas	2001		Bay surface area, volume, inflow, precipitation, evaporation, total nitrogen budget	
Dissertation	Seguin, RJ	Nitrogenous compounds in the Nueces River and Bay and the impact of a sewage treatment plant: The development of field instrumentation using ion selective electrodes	1996	1993-1995	River width and depth, nutrients, salinity, particulates, flow rate	Additional monitoring of DON and PON needed. CP&L plant cooling waters need to be closely monitored for both volume and nitrogen content.
Journal Article	Palmer, TA Breaux, NJ Pollack, JB	Nueces Bay Demonstration/Restoration Oyster Reef Project	2023	2022	Water depth, temperature, conductivity, dissolved oxygen, salinity, pH, and turbidity, live and dead oyster density, rock coverage, oyster height, Dermo infection	Oyster settlement is substrate limited, and introducing more rock may help populations.
Report	Smee, DL	Nueces Bay Marsh Restoration – Post Construction Assessment	2016	2015	Salinity, temperature, DO, turbidity, pH, shrimp and fish abundance and biomass, *Spartina* stem density	Vegetation density was not significantly different between restored and natural marsh sites
Report	Nicolau, BA Nunez, AX	Nueces Bay Total Maximum Daily Load Project	2005	2004-2005	Depth, temperature, DO, cond., salinity, pH, TSS, wind, rainfall, relative humidity, zinc, TOC, grain size	Spatial differences in zinc, but none between depths.
Report	Steffan, D	Nueces Bay Total Maximum Daily Load Project	2023	22-23	Rainfall, RBP pumping, salinity, depth, conductivity	Salinity diminished during a large pumping event.
Report	Hill, EM Besonen, M Tissot, P	Nueces Bay Zinc in Sediment Profiling Assessment	2014	2013	Water temperature, dissolved oxygen, conductivity, salinity, pH, Secchi depth, TOC, % carbonate, lead radium, and zinc concentrations, sediment accumulation	Hotspots of zinc release to the water column via disturbance. Future projects that disturb sediments can be better managed in areas with high zinc
Report	Montagna, PA Sadovski, AL King, SA Nelson, KK Palmer, TA Dunton, KH	Nueces Delta Ecological Modeling for Nueces River and Tributaries Texas	2013	1996-2006	Total coverage, change in cover, percent clonal dominant and stress tolerant, cover and change in marsh areal extent for three climate regime simulations	Connectivity and marsh growth are synergistic because marshes provide the critical habitat that the estuarine dependent species require. Must be sufficient water flow to flush the marsh from Nueces River to Nueces Bay.
Report	Rizzo, J Burch, D	Nueces Delta Environmental Monitoring Project	2020	2019-2020	Wind speed, barometric pressure, precipitation, relative humidity, solar radiation, pumping duration, salinity	RBP is an effective tool for managing salinities within the Rincon Bayou.
Report	Steffan, D	Nueces Delta Environmental Monitoring Project	2022	2021-2022	Wind speed, barometric pressure, precipitation, relative humidity, solar radiation, pumping duration, salinity	Salinity diminished during heavy rains.
Report	Hodges, BR Dunton, KH Montagna, PA Ward, GH	Nueces Delta Restoration Study	2012	1994-2011	Percent cover, elevation (Lidar DEM), marsh pore water salinity, tidal level/elevation, freshwater inflow, precipitation, inundation areas	Restoration approaches: 1) pumping freshwater through the RBP, 2) diverting more of the Nueces River back into the delta

Report	Lloyd, L Tunnell, JW Everett, A	Nueces Delta Salinity Effects from Pumping Freshwater into the Rincon Bayou: 2009 to 2013	2013	2009-2013	Depth, temperature, wind speed, rainfall, humidity, radiation, RBP pumping, salinity, conductivity, pH, DO	Banking water for future use during high salinity times is crucial for managing salinity gradient during dry conditions.
Report	Lloyd, L	Nueces Delta Salinity Effects from Pumping Freshwater into the Rincon Bayou: 2009 to 2018	2018	2009-2018	Depth, temperature, wind speed, rainfall, humidity, radiation, RBP pumping, salinity, conductivity, pH, DO	Less total pumped water via the RBP. Pumping events were small
Report	Rizzo, J Burch, D	Nueces Delta Salinity Effects from Pumping Freshwater into the Rincon Bayou: 2009 to 2019	2019	2009-2019	Depth, temperature, wind speed, rainfall, humidity, radiation, RBP pumping, salinity, conductivity, pH, DO	Pumping events were large. Salinities dropped to below 5 shortly after initiating the pumps.
Report	Zimba, PV	Nueces Delta Wetland Functionality Study	2017	2016	C, N, S isotopes, fish food preferences, fish densities	Detrital pathway for higher trophic levels
Report	Montagna, PA Hutchison, LM Scholz, D Palmer, T Arismendez, S Yoskowitz, D	Nueces Estuary Ecosystem Management Initiative: An Ecosystem Services-based Plan	2011	2011	Habitats of projects area, Threats and risks to the area, Project approach and process, Ecosystem service and valuation of habitats, Inventory and prioritization of areas for protection/restoration/creation, Future outcomes and next steps	
Report	Nueces BBASC	Nueces River and Corpus Christi and Baffin Bays Basin and Bay Area Stakeholders Committee Work Plan for Adaptive Management	2011		Work Plan Purpose, Timeline for Standards and Recs Review, Strategies to Meet Env Flow Standards, Adaptive Management	BBASC is a committee that creates environmental flow plans for the Nueces River basin.
Report	Vaugh, S Freund, R Arsuffi, T Buzan, D Dunton, KH Hodges, BR Hoeinghaus, D Smith, R Stewart, L Stunz, G Tunnell, JW Williams, L	Nueces River and Corpus Christi and Baffin Bays Environmental Flows Recommendation Report	2011	1900s-2011	Geographic Scope, Hydrology-Based Environmental Flow Regimes, Biology Overlay, Water Quality, Geomorphology (Sediment Transport), Riparian Zone, Hydrology, Salinity, and Inflow Characterization Methodology, Salinity Gradient Methodology, Focal Species and Indicators of Estuarine Health, Drought Criteria Methodology, Freshwater Inflow Needs, Nutrient & sediment Considerations, Environmental Flow Regime Recommendations, Adaptive Management	This Environmental Flows Recommendations Report is the primary deliverable of the Nueces River and Corpus Christi and Baffin Bays Basin and Bay Expert Science Team (Nueces BBEST) and is written to serve as a useful technical resource.
Journal Article	Aranow, S	Nueces River Delta Plain of Pleistocene Beaumont Formation, Corpus Christi Region, Texas	1971		Morphology, grain size	Sediments of the Beaumont-age Nueces Delta are largely fine grained.
Report	Montagna, PA Nelson, KK	Observation Data Model (ODM) For Rincon Bayou, Nueces Delta	2009		Barometric pressure, precip, humidity, temp, wind speed, chlorophyll, nutrients, DO, pH, depth, salinity, isotopes, percent cover	Limitations: lab method metadata, replicate samples, and hierarchy of biological names
Report	Dunton, KH Whiteaker, T Rasser, MK	Patterns of Emergent Vegetation in the Rincon Bayou Delta, 2005-2016	2019		Marsh vegetation percent cover, area of cover class, porewater salinity, shoreline erosion	Species replacements and dissolution of zonation occur during drought or flooding.
Journal Article	Baxter, AS Hill, EM Withers, K	Population Assessment of Texas Diamondback Terrapin (*Malaclemys Terrapin* Littoralis) in the Nueces Estuary, Texas	2013		Salinity, CPUE, turtle population parameters	
Report	Smith, EH Calnan, TR Cox, SA	Potential Sites for Wetland Restoration, Enhancement, and Creation: Corpus Christi/Nueces Bay Area	1997	1995-1996	General Setting, Site Descriptions and Plans, Site Selection Considerations, Functional Assessments, Potential Funding Programs	
Report	Santschi, PH Yaeger, KM	Quantification of Terrestrial and Marine Sediment Sources to a Managed Fluvial, Deltaic, and Estuarine System: The Nueces-Corpus Christi Estuary, Texas	2004	2002-2003	Sediment grain size, radioisotopes, alluvial sediment distance upstream, sediment accumulation rates	Sediment supply is dominated by terrestrial inputs, based on sediment grain size distributions, radioisotopes, and sediment accumulation rates

Journal Article	Ward, JA Bush, S Wiles, K Tennant, M Williams, L Beauchamp, RA	Quantitative Risk Characterization: Nueces Bay Nueces County, TX	2003	2002	Inorganic contaminants in fish and shellfish, hazard ratios for Zinc contamination, allowable meals for fish and shellfish	Oysters had high zinc levels. Consumption of spotted seatrout is a public health hazard, but blue crabs or other finfish are fine.
Report	Batterton, BE Swanson, K Dunton, KH	Relative Sea Level Rise and Habitat Assessment in the Nueces Delta	2023	2018-2023	Temperature, salinity, conductivity, DO, chlorophyll, pH, TSS, soil moisture, nutrients, percent cover, surface elevation change, vertical accretion	High rates of vegetation loss from erosion. SET measurements indicate an increase in overall marsh surface elevation
Dissertation	Li, Z	Representing effects of subgrid-scale topography on coarse-grid hydrodynamic models for shallow coastal marshes	2019		Salinity, water surface elevations, inundation area, absolute flow rate + error	Accuracy of wet/dry status, conservation of cell volume, maintenance of high-resolution surface connectivity patterns at coarse grids.
Journal Article	Forbes, MG Dunton, KH	Response of a subtropical estuarine marsh to local climatic change in the southwestern Gulf of Mexico	2006		Salinity, temperature, nutrients, percent cover	Annuals play a larger role in the maintenance of vegetation cover with large scale annual flooding
Report	Montagna, PA Palmer, TA Gil, M Hill, EM Nicolau, BA Dunton, KH	Response of the Nueces Estuarine Marsh System to Freshwater Inflow: An Integrative Data Synthesis of Baseline Conditions for Faunal Communities	2009		Flow duration, discharge, wet periods, inflow, salinity, dissolved oxygen, chlorophyll, nutrients, benthic macrofaunal community	
Report	U.S. Bureau of Reclamation	Rincon Bayou Demonstration Project: concluding report	2000		Precipitation, flow, salinity, inundation events, water column productivity, benthic communities, vegetation	
Report	Adams, JS Tunnell, JW	Rincon Bayou Salinity Monitoring Report	2010		Inflow, salinity, discharge, water depth, wind speed	
Journal Article	Montagna, PA Hill, EM Moulton, B	Role of science-based and adaptive management in allocating environmental flows to the Nueces Estuary, Texas, USA	2009		Info on Rincon Bayou demonstration project, overflow channel reopening, Calallen pipeline diversion, Allison Wastewater Treatment Plant diversion	
Report	Shockley, C	Salinity Monitoring and Real Time (SMART) Inflow Management in the Nueces Bay and Delta	2014		Seasonal targets, trigger levels, safe yields, annual bay inflow	
Report	Pulich, Jr, W	Chapter: Texas Coastal Bend	2007		Background, Statewide Seagrass Status, Causes	
Journal Article	Razzaque, S Heckman, RW Juenger, TE	Seed size variation impacts local adaptation and life-history strategies in a perennial grass	2023		Biomass, precipitation, elevation, temperature, germination time, shoot length, root length, seedling counts + adult counts	
Journal Article	Ritter, C Montagna, PA Applebaum, S	Short-term succession dynamics of macrobenthos in a salinity-stressed estuary	2005		Salinity, dissolved oxygen, temperature, benthic community abundance	
Journal Article	Schweitzer, MD Withers, K	Size and Distribution of Blue Crabs (Callinectes sapidus) With Regard to Salinity in the Upper Nueces Estuary, Texas	2009	2006-2007	Sex and # of crabs, carapace width, salinity, CPUE	
Journal Article	Mannino, A Montagna, PA	Small-scale spatial variation of macrobenthic community structure	1997	1993	TOC, TN, biomass, community structure, temperature, salinity, pH, DO, depth, nutrients, chlorophyll	
Book	Montagna, P Gibeaut, J Tunnell, Jr, J	South Texas Climate 2100: Coastal Impacts	2007		Habitat area, shoreline change, sea level rise, rainfall, inflow, salinity, freshwater replacement time, species changes	Alterations in freshwater inflows, changes in ecosystem functioning, intense droughts, extreme salinities, reductions in estuarine species
Journal Article	Hill, E Tunnell, JW	Spatial and temporal effects of the Rincon Bayou Pipeline on hypersaline conditions in the Lower Nueces Delta, Texas, USA	2015	1998-2011	Monthly inflow, salinity, pipeline capacity/flow, pumping duration	Hot/dry climate + variable rainfall = reverse estuary. RBP pumping relieved hypersalinity and created an estuarine salinity gradient

Thesis	Wallace, SC	Spatial and temporal variation in trophic structure of the Nueces Marsh, TX	2011	2002-2010	Temperature, salinity, DO, pH, depth, nutrients, discharge, C/N isotopes	Isotopes from emergent vegetation, plankton, macroalgae, POM, sediments, benthos, nekton
Report	Hill, EM Tunnell, JW Lloyd, L	Spatial Effects of Rincon Bayou Pipeline Freshwater Inflows on Salinity in the Lower Nueces Delta, Texas	2012		Salinity, water level, temperature, wind speed, rainfall, barometric pressure, relative humidity, solar radiation, RBP pumping events, duration, acre-ft pumped	Hot/dry climate + variable rainfall = reverse estuary. RBP pumping relieved hypersalinity and created an estuarine salinity gradient
Report	Tolan, JM Newstead, DJ	Spring 2003 Ichthyoplankton Recruitment to the Delta Nursery Areas of Nueces Bay, Texas	2004	2003	Ichthyoplankton, density, larvae #, ID, length, temperature, salinity, DO, pH, turbidity, discharge	Quantified recruitment of larvae to nursery areas and compared distribution to discharge location
Thesis	Hebert, EM	Spring phytoplankton dynamics in a shallow, turbid coastal salt marsh system undergoing extreme salinity variation, South Texas	2004	2001-2003	GPP and respiration, salinity, temperature, nutrients, TSS, water depth, wind speed, plankton community composition, biovolume, chlorophyll, phaeophytin	High spring productivity/biovolume. Sediment resuspension and salinity influenced productivity, abundance, and community composition.
Journal Article	Hutchison, LM Montagna, PA Yoskowitz, D Tunnell, JW	Stakeholder Perceptions of Coastal Habitat Ecosystem Services	2015	2010	Survey of ecosystem services provided by habitats in the Coastal Bend: supportive functions and structures, regulating services, provisioning services, cultural services	(a) Incorporating ecosystem services into management decisions, (b) Documenting services to better inform identification, quantification, (c) Identifying education/ research needs
Report	White, WA Tremblay, TA Waldinger, RL Calnan, TR	Status and Trends of Emergent and Submerged Vegetated Habitats, Gulf of Mexico, USA	1992		Inventories of Coastal Habitats, Functions and Values of Gulf Coastal Habitats, Quality of Coastal Habitats, Living Resources, Case Histories, Conclusions	
Journal Article	Tremblay, TA Vincent, JS Calnan, TR	Status and Trends of Inland Wetland and Aquatic Habitats in the Corpus Christi Bay Area	2008	2002-2004	Current and historical distribution of wetlands using color infrared photos	
Report	White, WA Calnan, TR	Sedimentation and Historical Changes in Fluvial-Deltaic Wetlands Along the Texas Gulf Coast with Emphasis on the Colorado and Trinity River Deltas	1990		Change in vegetated wetland area, shoreline changes and accretion	
Report	Sugarek, S	Surface Water Monitoring and Bathymetric Data Collection Study for the Nueces Tidal Special Study	2003	2002-2003	Depth, temperature, DO, pH, conductivity, salinity, wind speed, streamflow, bathymetry, tides, discharge	Routine hydrological data to monitor the effects of high and low flow conditions
Journal Article	Montagna, PA Kalke, RD	The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces Estuaries, Texas	1992	1987	Salinity, macrofauna/meiofauna biomass, density, and taxa, tissue TOC/TON, sediment grain size, freshwater inflow balance	Macrofauna respond positively to inflow, and meiofauna respond negatively
Journal Article	Wang, Z Liu, Z Liu, M Xu, K Mayer, LM	The impact of drying on structure of sedimentary organic matter in wetlands: Probing with native and amended polycyclic aromatic hydrocarbons	2016	2011	Black carbon content, TOC, DOC, specific mineral surface area, grain size, PAH type, concentration, and release	Insights into structural changes of SOM upon drying and help predict the fate of compounds such as organic contaminants during drought/flood oscillations.
Journal Article	Garrison Jr, JR Mccoy, B	The Nueces Incised Valley Revisited: A Reinterpretation of the Sedimentology and Depositional Sequence Stratigraphy of Preserved Pleistocene and Holocene Valley-Fill Sediments	2007		Sedimentology, Reinterpretation of Seismic Data, Depositional Sequence Stratigraphy, Valley Evolution, Implications for the Interpretation of Ancient Incised Valleys	
Journal Article	Yeager, KM Santschi, PH Schindler, KJ Andres, MJ Weaver, EA	The Relative Importance of Terrestrial versus Marine Sediment Sources to the Nueces-Corpus Christi Estuary, Texas: An Isotopic Approach	2006	2002-2003	Sediment core radioisotope ratios and activity concentrations, sedimentation rates, grain size, sediment supply/source	Overwhelming majority of sediments are from terrestrial sources. The Nueces-Corpus Christi Estuary is microtidal, has an extensive barrier island system, and is not significantly affected by ocean currents.
Dissertation	Rasser, MK	The role of biotic and abiotic processes in the zonation of salt marsh plants in the Nueces River Delta, Texas	2009	2004-2009	Elevation, aerial imagery, percent cover, image metrics, nutrients, salinity, soil moisture, plant survival and growth, fluorescence yield response, shoreline erosion	

Thesis	Cramer, NC	Thermal properties of an upper tidal flat sediment on the Texas Gulf Coast	2006		Soil bulk/particle density, moisture, salinity, thermal conductivity, heat capacity, thermal diffusivity	
Journal Article	Heilman, JL Cobos, DR Heinsch, FA Campbell, CS McInnes, KJ	Tower-based conditional sampling for measuring ecosystem-scale carbon dioxide exchange in coastal wetlands	1999	1997	3D wind flux, 3D CO2 flux, 3D H2O flux, ecosystem net CO2 exchange, photosynthesis, respiration	CO2 flux was altered by freshwater inflow, recession, and drying on a diurnal, daily, and season basis. Fresh water inflow increased NCE by increasing CO2 assimilation and decreasing CO2 efflux.
Journal Article	Alexander, HD Dunton, KH	Treated Wastewater Effluent as an Alternative Freshwater Source in a Hypersaline Salt Marsh: Impacts on Salinity, Inorganic Nitrogen, and Emergent Vegetation	2006	1996-2002	Salinity, nutrients, percent cover, vegetation species richness/C:N/15N	Wastewater diversions lowered salinity, increased nutrients, and increased cover of less salt-tolerant vegetation species near the diversion but was restricted to a limited area.
Report	Schoenbaechler, C Guthrie, CG Matsumoto, J Lu, Q Negusse, S	TxBLEND Model Calibration and Validation for the Nueces Estuary	2011		Daily inflows (gaged, runoff, diversion, return, etc.), tide elevations, meteorology (wind, temperature, precipitation, evaporation), salinity, velocity, discharge	TxBLEND predicts long-term trends well. Deep navigational channels and strong winds generates 3D circulation features that inherently cannot be captured by a 2D model
Journal Article	Riera, P Montagna, PA Kalke, RD Richard, P	Utilization of estuarine organic matter during growth and migration by juvenile brown shrimp *Penaeus aztecus* in a South Texas estuary	2000	1995-1996	Shrimp species, length, 13C and 15N for shrimp, zooplankton, POM, SOM, and vegetation, trophic level	Investigated trophic dynamics of migratory juvenile brown shrimp
Journal Article	Albert, BM	Vegetation History and Estuarine Ecology of the Texas Gulf Coastal Plain in Relation to Climate and Sea-Level Changes According to Three Pollen Cores	2023		Sediment grain size and color, pollen deposits, radio dating, pollen of modern plants	
Report	Ockerman, DJ	Water Budget for the Nueces Estuary, Texas, May–October 1998	2001	1998	Discharge, rainfall, inflow, runoff, stage, tidal flow, return flows, evaporation, water budget	
Journal Article	Knowles, TR	Water for Texas: An Overview of Future Needs	1998		Ground water use, runoff, water demand and supply	

Appendix E. Top 60 most identified authors within the Nueces Delta body of literature. All remaining authors had only one publication. Ten most published authors in bold.

Author	Count	Author	Count
Montagna	25	Lu	3
Dunton	14	Yoskowitz	3
Tunnell	8	Adams	2
Palmer	7	Buzan	2
Hill	7	Simms	2
Hodges	5	Breier	2
Ward	5	Forbes	2
DelRosario	5	Gordon	2
Roelke	5	Stachelek	2
Kalke	5	Murgulet	2
Heinsch	4	Rony	2
Buyukates	4	Steffan	2
Heilman	4	Rizzo	2
Lloyd	4	Smith	2
McInnes	4	Santschi	2
Calnan	4	Ritter	2
Nicolau	3	Hutchison	2
Li	3	Tremblay	2
White	3	Wiles	2
Schoenbaechler	3	Hoeinghaus	2
Guthrie	3	Matsumoto	2
Liu	3	Williams	2
Baxter	3	King	2
Rasser	3	Arsuffi	2
Alexander	3	Withers	2
Morton	3	Cobos	2
Tolan	3	Stewart	2
Zimba	3	Tennant	2
Nelson	2	Turner	2
Gibeaut	3	Pollack	1

REFERENCES

Alexander, H. D., & Dunton, K. H. (2002). Freshwater inundation effects on emergent vegetation of a hypersaline salt marsh. *Estuaries*, *25*(6), 1426–1435. https://doi.org/10.1007/bf02692236

Alexander, H. D., & Dunton, K. H. (2006). Treated Wastewater Effluent as an Alternative Freshwater Source in a Hypersaline Salt Marsh: Impacts on Salinity, Inorganic Nitrogen, and Emergent Vegetation. *Journal of Coastal Research*, *22*(2), 377–392. http://www.jstor.org/stable/4300295

Chang, W., Cheng, J., Allaire, J. J., Sievert, C., Schloerke, B., Xie, Y., Allen, J., McPherson, J., Dipert, A., & Borges, B. (2024). *shiny: Web Application Framework for R*. https://shiny.posit.co/

Corporation for Digital Scholarship. (2024). *Zotero* (6.0.35) [Software]. https://www.zotero.org/ (Original work published 2006)

Dunton, K. H., Hardegree, B., & Whitledge, T. E. (2001). Response of Estuarine Marsh Vegetation to Interannual Variations in Precipitation. In *Estuarine Research Federation Estuaries* (Vol. 24, Issue 6A, pp. 851–861).

Dunton, K. H., Ward, G. H., Montagna, P. A., & Whitledge, T. E. (2000). *Rincon Bayou Demonstration Project* (p. 307) [Concluding Report]. U.S. Bureau of Reclamation. https://doi.org/10.5962/bhl.title.24130

Dunton, K. H., Whiteaker, T., & Rasser, M. K. (2019). *Patterns of Emergent Vegetation in the Rincon Bayou Delta, 2005-2016* (Final Report to Texas Water Development Board 1600011971; p. 50). University of Texas at Austin. https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1600011971.pdf

Fagherazzi, S., Mariotti, G., Leonardi, N., Canestrelli, A., Nardin, W., & Kearney, W. S. (2020). Salt Marsh Dynamics in a Period of Accelerated Sea Level Rise. *Journal of Geophysical Research: Earth Surface*, *125*(8), e2019JF005200. https://doi.org/10.1029/2019JF005200

Forbes, M. G., & Dunton, K. H. (2006). Response of a subtropical estuarine marsh to local climatic change in the southwestern gulf of Mexico. *Estuaries and Coasts*, *29*(6), 1242–1254. https://doi.org/10.1007/BF02781824

Henley, D. E., Rauschuber, D. G., Land, Program (U.S.), W. R. D., Team (U.S.), N. C. E., Fish, U. S., & Region 2, W. S. (1981). *Freshwater Needs of Fish and Wildlife Resources in the Nueces-Corpus Christi Bay Area, Texas: A Literature Synthesis*. Biological Services Program, U.S. Fish and Wildlife Service. https://books.google.com/books?id=S94QEQK9aZYC

Hill, E. M., Nicolau, B. A., & Zimba, P. V. (2011). History of Water and Habitat Improvement in the Nueces Estuary, Texas, USA. *Texas Water Journal*, *2*(1), Article 1. https://doi.org/10.21423/twj.v2i1.2104

Jones, W. R., Spence, M. J., Bowman, A. W., Evers, L., & Molinari, D. A. (2014). A software tool for the spatiotemporal analysis and reporting of groundwater monitoring data.

Environmental Modelling & Software, *55*, 242–249. https://doi.org/10.1016/j.envsoft.2014.01.020
Lawrence, M. G. (2005). The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air: A Simple Conversion and Applications. *Bulletin of the American Meteorological Society*, *86*(2), 225–234. https://doi.org/10.1175/BAMS-86-2-225
Montagna, P. A., Palmer, T., Gil, M., Hill, E., Nicolau, B., & Dunton, K. (2009). *Response of the Nueces Estuarine Marsh System to Freshwater Inflow: An Integrative Data Synthesis of Baseline Conditions for Faunal Communities* (Final Report to the Coastal Bend Bays and Estuaries Program 0821; p. 33).
Montagna, P. A., Sadovski, A. L., King, S. A., Nelson, K. K., Palmer, T. A., & Dunton, K. H. (2017). Modeling the effect of water level on the Nueces Delta marsh community. *Wetlands Ecology and Management*, *25*(6), 731–742. https://doi.org/10.1007/s11273-017-9547-x
National Hurricane Center. (2024). *Remnants of Alberto Public Advisory*. National Weather Service. https://www.nhc.noaa.gov/text/refresh/MIATCPAT1+shtml/202042.shtml?
NOS CO-OPS. (2013). *Coastal meteorological and water temperature data from National Water Level Observation Network (NWLON) and Physical Oceanographic Real-Time System (PORTS) stations of the NOAA Center for Operational Oceanographic Products and Services (CO-OPS)* [dataset]. NOAA National Centers for Environmental Information. https://www.ncei.noaa.gov/archive/accession/CO-OPS-NWLON-PORTS
Oregon State University. (2014). *PRISM Climate Group* [dataset]. https://prism.oregonstate.edu
Osland, M. J., Chivoiu, B., Enwright, N. M., Thorne, K. M., Guntenspergen, G. R., Grace, J. B., Dale, L. L., Brooks, W., Herold, N., Day, J. W., Sklar, F. H., & Swarzenzki, C. M. (2022). Migration and transformation of coastal wetlands in response to rising seas. *Science Advances*, *8*(26), eabo5174. https://doi.org/10.1126/sciadv.abo5174
Osland, M. J., Gabler, C. A., Grace, J. B., Day, R. H., McCoy, M. L., McLeod, J. L., From, A. S., Enwright, N. M., Feher, L. C., Stagg, C. L., & Hartley, S. B. (2018). Climate and plant controls on soil organic matter in coastal wetlands. *Global Change Biology*, *24*(11), 5361–5379. https://doi.org/10.1111/gcb.14376
Osland, M. J., Grace, J. B., Guntenspergen, G. R., Thorne, K. M., Carr, J. A., & Feher, L. C. (2019). Climatic Controls on the Distribution of Foundation Plant Species in Coastal Wetlands of the Conterminous United States: Knowledge Gaps and Emerging Research Needs. *Estuaries and Coasts*, *42*(8), 1991–2003. https://doi.org/10.1007/s12237-019-00640-z
R Core Team. (2023). *R: A language and environment for statistical computing* (4.3.2) [Software]. R Foundation for Statistical Computing, Vienna, Austria.
Saintilan, N., Kovalenko, K. E., Guntenspergen, G., Rogers, K., Lynch, J. C., Cahoon, D. R., Lovelock, C. E., Friess, D. A., Ashe, E., Krauss, K. W., Cormier, N., Spencer, T., Adams, J., Raw, J., Ibanez, C., Scarton, F., Temmerman, S., Meire, P., Maris, T., … Khan, N.

(2022). Constraints on the adjustment of tidal marshes to accelerating sea level rise. *Science*, *377*(6605), 523–527. https://doi.org/10.1126/science.abo7872

Spivak, A. C., Sanderman, J., Bowen, J. L., Canuel, E. A., & Hopkinson, C. S. (2019). Global-change controls on soil-carbon accumulation and loss in coastal vegetated ecosystems. *Nature Geoscience*, *12*(9), 685–692. https://doi.org/10.1038/s41561-019-0435-2

Stachelek, J., & Dunton, K. H. (2013). Freshwater inflow requirements for the Nueces Delta, Texas: Spartina alterniflora as an indicator of ecosystem condition. *Texas Water Journal*, *4*(2), 62–73. https://twj-ojs-tdl.tdl.org/twj/article/view/6354/6484

Sweet, W. V., Hamlington, B. D., Kopp, R. E., Weaver, C. P., Barnard, P. L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J. P., Larour, E., Marcy, D., Marra, J. J., Obeysekera, J., Osler, M., Pendleton, M., … Zuzak, C. (2022). *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines* (Technical Report NOS 01; p. 111). National Oceanographic and Atmospheric Administration, National Ocean Service. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Wickham, H. (2024). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org