TEXAS A&M UNIVERSITY
CORPUS CHRISTI

DEPARTMENT OF LIFE SCIENCES, COLLEGE OF SCIENCE AND ENGINEERING
WEBSITE: HTTP://LSCI.TAMUCC.EDU/INDEX.HTML
6300 Ocean Drive, Unit 5806
Corpus Christi, Texas
P 361.825.2754 ● F 361.825.2770

23 April 2021

To: Leigh Perry, Project Manager, Coastal Bend Bays and Estuary Program

Dear Leigh:

Please find attached the electronic version of the final report for Contract No. 2010 “An Assessment of Tidal Flat Functionality as Habitat for Shorebirds: Bond Oso, Oso Bay, Texas.”

The digital files for the mapping component will be sent via US mail under a separate cover.

Thank you for your support of this project.

Sincerely,

Kim Withers

Kim Withers, Ph.D.

An Assessment of Tidal Flat Functionality as Habitat for Shorebirds: Blind Oso, Oso Bay, Texas

Final Report

Publication CBBEP – XXX
Project Number – 2010
April, 2021

Prepared by:

Kim Withers, Ph.D., Associate Professor and Hua Zhang, Associate Professor
Texas A&M University-Corpus Christi
Department of Life Sciences, Department of Engineering, and Center for Coastal Studies
6300 Ocean Drive, Corpus Christi, Texas
kim.withers@tamucc.edu
Phone: (361) 825-5907

Submitted to:
Coastal Bend Bays & Estuaries Program
615 N. Upper Broadway, Suite 1200
Corpus Christi, TX 78401

An Assessment of Tidal Flat Functionality as Habitat for Shorebirds: Blind Oso, Oso Bay, Texas

Principal Investigators:

Kim Withers, Ph.D.
Hua Zhang, Ph.D

Texas A&M University-Corpus Christi
Department of Life Sciences, Department of Engineering, and Center for Coastal Studies

April 2021

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

A number of people contributed to this study and report and we thank them. Dr. Paul Zimba analyzed the chlorophyll *a* samples. Andrew Windham helped with the bird surveys and benthic sample analysis. Erin Hill entered data and ran quality assurance checks; she also produced preliminary graphs and analyses of the data for review. Teresa Barrera-Carrillo provided editorial review and helped compile the historical perspective.

EXECUTIVE SUMMARY

Introduction

Wind-tidal flats in the Texas Coastal Bend are preferred shorebird foraging habitat and provide critical food resources during a stressful part of annual cycle, migration, and overwintering. The wind-tidal flats in Oso Bay around Ward Island are part of the designated critical habitat of endangered/threatened Piping Plover. Large numbers of shorebirds have used tidal flats in the Oso Bay system although their numbers have been decreasing. More than 50% of the historical extent of wind-tidal flats in the Coastal Bend have already been lost, largely due to relative sea-level rise which converts flats to either permanently submerged habitat, or vegetated habitat. The focus of this study is the area within the Oso Bay system known as the "Blind Oso."

From the standpoint of tidal flat functionality as shorebird foraging habitat, increasing vegetation on tidal flats throughout the Blind Oso is one of the most damaging effects of the alterations to hydrology that have occurred over the last 40+ years. These alterations include relative sea- level rise, increased wastewater and stormwater discharge, increased exchange with Corpus Christi Bay via the raised bridge on Ocean Drive the cooling water pumped from the Laguna Madre through the Barney Davis powerplant and then into upper Oso Bay. The additions of water from all sources have altered sediment salinity and/or have caused inundation/exposure to occur more regularly promoting increased coverage of vascular plants. As plant cover increases, suitability of the tidal flats as shorebird habitat decreases. The project objective was to collect data for an updated assessment of functionality of the tidal flats in The Blind Oso ("new" baseline). The objectives of this study were: 1) to compile and review the recent literature on biotic and abiotic process and dynamics related to wind-tidal flats in the Blind Oso; 2) to update and quantify the amount of marsh vegetation that has developed over the last decade in the Blind Oso tidal flat, and 3) to evaluate the functionality of Blind Oso tidal flat.

Methods

Objective 1: Literature Review

The review of the available literature focused on the Oso Bay tidal flat system. The review included peer-reviewed sources and secondary sources such as technical reports etc. and includes the last two decades of work.

Objective 2: Mapping

A detailed map of the current extent and composition of vegetation in the Blind Oso and along the shorelines of Ward Island and Oso Bay was produced at <3m resolution using multispectral images for vegetation mapping. Aerial images of the National Agriculture Imagery Program were obtained using Google Earth Engine. The images have four bands (RGB and NIR) with 1-m resolution. All of the NAIP images available for the study area were acquired for this project. A ground survey was conducted to collect reference data following the scheme of stratified random sampling. Using ArcGIS, the study area was divided into several uniform grids and three random points were randomly generated within each grid as potential sampling location. At each of these locations, species compositions were delineated and fractional vegetation cover was estimated via visual inspection. Actual coordinates of all sampling locations were measured using a Trimble GNSS receiver.

Objective 3: Evaluate Blind Oso Tidal Flat Productivity

The "Strategy for Evaluating Tidal Flat Productivity" a method that was proposed and used by Withers and Tunnell (1998), was used evaluate the productivity of the Blind Oso tidal flats, with the data collected during that study serving as a baseline for this study. Sediment chlorophyll *a* (acetone extraction, HPLC analysis), and sediment water content were measured as were macrobenthic invertebrate density and biomass; bird surveys were conducted. Habitat functionality was evaluated using the data generated in this study and were evaluated using the Withers and Tunnell (1998) strategy as appropriate.

Results

Objective 1: Literature Review and Historical Perspective

Oso Bay, Texas, also known as Cayo del Oso, is an enclosed, secondary bay located along the southern shoreline of Corpus Christi Bay. The shorelines of the Oso Bay/Oso Creek system, have been described as "human-altered." Tidal flats in South Texas and Oso Bay are found at elevations between mean sea level (MSL) and 1 m above MSL. In its natural state, Oso Creek would be an ephemeral creek dominated by runoff from infrequent rain events. However, hydrodynamics of the Oso Bay system are dominated by discharges of both fresh and saline water, which total as much as 565 mgd. In addition, Meteorological events (e.g., large-scale rain events caused by tropical storms), seasonal changes in water levels, and relative sea-level rise (+0.15 m since 1982) also influence the hydrodynamics.

Since the late 1800s, sedimentation, hydrological alterations, and human modifications have contributed to changes in and around Oso Bay. After 1934, bridge and road construction in a variety of locations altered hydrology and sedimentation patterns. After World War II, bridge and road building continued, in addition to construction of homes and hardening of shorelines as urban development expanded. This trend continues to the present.

The benthic invertebrate community found in the Blind Oso has varied little across studies and time. Regardless of the study, polychaetes dominate the benthic community. The most abundant polychaetes are members of the families Spionidae and Capitellidae which is what would be expected due to the moderate organic enrichment associated with the wastewater treatment plant.

About 30 shorebird species have been recorded on tidal flats in the Blind Oso; abundance varies greatly from study to study and over time. Birds were most abundant during spring migration (February-April) and winter (November-January) and were less abundant during mid-late summer and fall migratory periods. Sandpipers (=peeps; *Calidris* spp.) were the most common and abundant species.

Objective 2: Mapping

The first analysis of vegetation change in the Blind Oso covered 1934-1991 and clearly showed the development of the "Oso Delta" and the correlation between the increasing wastewater discharge from the Oso Wastewater Treatment Plant and marsh development over time. Wastewater discharge increased from <2 mgd in the 1940s to around 15 mgd and vegetation cover increased from 0% to a high of 19%.

In 2020, the marsh vegetation had expanded over much of the Blind Oso and was not confined to the Oso Delta. The vegetation mostly consisted of black mangrove (*Avicennia germinans*) Too little smooth cordgrass (*Spartina alterniflora*) was encountered it to be mapped separately. Marsh vegetation represented 28.2% of the area (not including mapped deep water), with algal mat coverage comprising ~68%.

Objective 3: Functionality for Shorebirds

Primary productivity, terms of chlorophyll *a*, was measured very differently in 1998 vs the present study. In this study, sediment chlorophyll *a* concentrations ranged from a mean of 10.6 mg/m^2 to 23 mg/m^2 and fell within the range of those measured on other tidal flats around the world. Water content averaged about 35% and varied little among microhabitats. Estimated functional value was on the low end of the value matrix – between 1 and 2, however this is an artifact of the overestimation of chlorophyll *a* values in the 1998 study. Primary productivity by cyanobacterial mats is likely adequate.

Macrobenthic communities were dominated by polychaetes. Mean polychaete density was ~14,000/m^2 and mean polychaete biomass was ~12 g dry weight/m^2. These values were similar to those recorded in previous studies of the Blind Oso. The value matrix for secondary productivity exceeds 3, so provision of organisms for foraging appears to be good.

Shorebirds were not abundant with only 601 total shorebirds counted in the five censuses. There were two days that made up the majority of the total birds observed. Most shorebirds observed were foraging. The value matrices for consumers could not be used because neither density nor exposed area for the census days could be determined. However, the very sparse use of the area by birds outside of the two days small flocks were observed suggests that the current extent of vegetation, even if it is sparse, inhibits shorebirds from using the habitat.

Conclusions and Recommendations

Arguably, tidal flats are among the most endangered habitats, due to the difficulties in mapping them, their lack of "charisma," and the creeping changes that happen as hydrodynamics are altered by sea-level rise, development, or other factors. The tidal flats of the Blind Oso have been altered dramatically over the last 40 years from a non-vegetated sandflat with a saltmarsh at the "Oso Delta" to a mostly vegetated flat, without large exposed areas except along the edges where current inundation is fairly limited. At this point, the trajectory from a bare tidal flat to a marsh probably cannot be changed unless water exchange with Corpus Christi Bay is reduced dramatically, and ways to reduce freshwater inflow and increase salinity are found.

INTRODUCTION

Wind-tidal flats in the Texas Coastal Bend are preferred shorebird foraging habitat and provide critical food resources during a stressful part of annual cycle, migration, and overwintering. The wind-tidal flats in Oso Bay around Ward Island are part of the designated critical habitat of endangered/threatened Piping Plover; about half of the continental population of the species winters in Texas, with significant numbers found on Oso Bay tidal flats between Ward Island and the Naval Air Station (Withers 2014) but few are found elsewhere in the system. Large numbers of shorebirds have used tidal flats in the Oso Bay system (e.g., Withers and Chapman 1993, Withers 1994, Withers and Tunnell 1998, Barrera-Carrillo 2000, Harding 2004) although their numbers have been decreasing for at least the last decade. More than 50% of the historical extent of wind-tidal flats in the Coastal Bend have already been lost, largely due to relative sea-level rise which converts flats to either permanently submerged habitat, or vegetated habitat (Withers and Tunnell 1998). Oso Bay and its associated flats are embedded within an urban landscape that is largely where hydrodynamic alterations in the bay have originated.

The focus of this study is the area within the Oso Bay system known as the “Blind Oso” (Figure 1) and more specifically an area that Tunnell (1991) referred to as the “Restricted Blind Oso” (RBO). From the standpoint of tidal flat functionality as shorebird foraging habitat, increasing vegetation on tidal flats throughout the Blind Oso is one of the most damaging effects of the alterations to hydrology that have occurred over the last 40+ years. These alterations include relative sea- level rise, increased wastewater and stormwater discharge, and increased exchange with Corpus Christi Bay following elevation of the bridge on Ocean Drive between the mainland and Ward Island. A major factor in the changing hydrodynamics of the bay has been the Barney Davis powerplant, built during the 1970s. It began generating electricity at its full capacity (~650 MW) in 1978 (Hildebrand and King 1978) and pumped of high salinity water from the Laguna Madre through the plant for cooling. The additions of water from all sources have altered salinity in RBO sediments and/or have caused inundation/exposure to occur more regularly. By reducing both irregularity in the inundation/exposure regime and porewater/substrate salinity, marsh vegetation has expanded. Vegetated habitats, especially those with water depths that exceed a centimeter or two, are not suitable foraging habitat for most shorebirds, but they are particularly problematic for sight foragers such as Piping Plovers.

Wastewater outflow from the Oso Wastewater Treatment, plant in concert with other, associated processes such as reduced salinity and altered hydrology, has caused expansion of marsh and mangrove vegetation on tidal flats in the Blind Oso; this change is particularly apparent on in the RBO. Increased coverage of vascular plants decreases suitability of the tidal flats around Ward Island as shorebird habitat and especially in the Blind Oso. The objectives of this study were: 1) to compile and review the recent literature on biotic and abiotic process and dynamics related to wind-tidal flats in the Restricted Blind Oso; 2) to update and quantify the amount of marsh vegetation that has developed over the last decade in the Blind Oso, and 3) to evaluate the functionality of the RBO tidal flat.

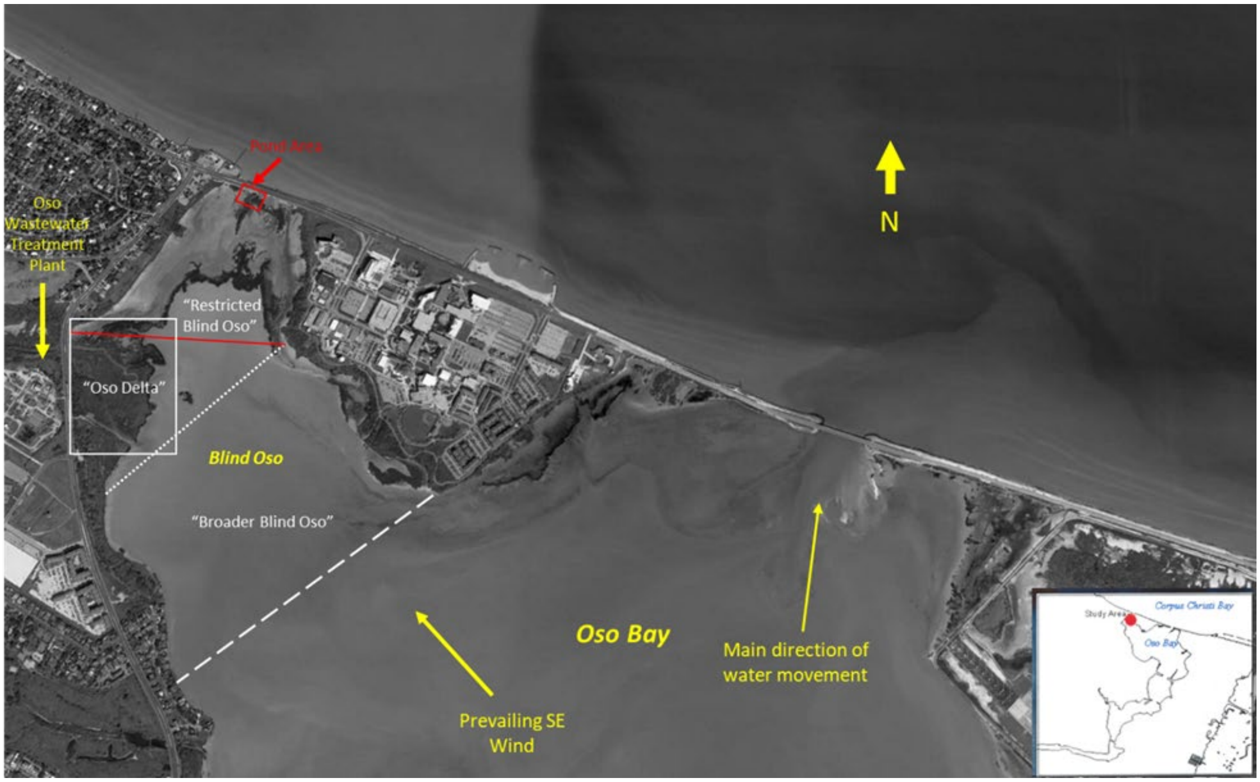

Figure 1. Aerial view of Oso Bay – 31 January 2020 (Google Earth). The study area was located behind the solid red line, which extends from the northern side of the Ennis Joslin bridge to Ward Island, within the area Tunnell (1991) delineated as the "Restricted Blind Oso" (ROB). This photo shows the location of areas that are important and/or mentioned multiple times in the text, including the "Broader Blind Oso" (BBO), the "Oso Delta," and the Pond Area. In addition, the direction of the prevailing winds and the main direction of water movement are indicated.

The project objective was to collect data for an updated assessment of functionality of the tidal flats in The Blind Oso ("new" baseline). The specific area of interest is the RBO (see Figure 1) on the northwestern side of Ward Island which separates Oso Bay from Corpus Christi Bay. The RBO is an important shorebird migratory staging and wintering area. The amount of suitable shorebird habitat has been changing over the last 40 years due to natural and anthropogenic factors; inundation/submersion depth and frequency have increased with concomitant increase in the extent of marsh vegetation coverage and density. This study will provide updated data on the current functionality of the Blind Oso to support management decisions for the area.

METHODS

Objective 1: Literature Review

The review of the available literature included peer-reviewed sources and secondary sources such as technical reports etc. The current review expands upon the review in Withers and Tunnell (1998) but is focused on the Oso Bay tidal flat system and includes the last two decades of work. Published and unpublished literature, as well as other sources of information (e.g., legal documents) were reviewed by the Principal Investigator to provide a comprehensive summary of the ecology, geology, and hydrology of the Blind Oso and impacts/disturbances that are ongoing. Published data resources included peer-reviewed scientific journal articles and agency documents. Unpublished data resources included agency reports and permit reviews, dissertations, and theses. Quality of results and conclusions found in each document were assessed using the following criteria: 1) QA/QC measures imposed on data collection; 2) information of specific and consistent methodological procedures; 3) evaluation of concurrent research objectives, methods, and results of independent data sets for comparative purposes; and, 4) best professional judgement.

Objective 2: Mapping

Barrera et al. (1992) produced the first detailed maps showing development of vegetation in the Blind Oso during the 1990s after the wastewater treatment plant began discharging treated wastewater. A detailed map of the current extent and composition of vegetation in the Blind Oso and along the shorelines of Ward Island and Oso Bay was produced at <3m resolution using multispectral images for vegetation mapping.

Aerial images of the National Agriculture Imagery Program were obtained using Google Earth Engine. The images have four bands (RGB and NIR) with 1-m resolution. All of the NAIP images available for the study area were acquired for this project. Multispectral high-resolution satellite images were acquired using Planet Explorer. These images have RGB, NIR, and Panchromatic bands with resolution varying from 0.72 m to 3.7 m depending on the type of sensors. All of the Planet images available for the study area were acquired for this project.

A ground survey was conducted to collect reference data following the scheme of stratified random sampling (Figure 2). Using ArcGIS, the study area was divided into several uniform grids and three random points were randomly generated within each grid as potential sampling location. At each of these locations, species compositions were delineated and fractional vegetation cover was estimated via visual inspection. Actual coordinates of all sampling locations were measured using a Trimble GNSS receiver.

The analyses of aerial and satellite images consisted of several steps: (i) image resampling to ensure a consistent resolution (< 3 m) for images from difference sources; (ii) calculation of multispectral vegetation and water indexes to enhance spectral signatures of different water, tidal flat, and vegetation features; (iii) development of a binary mask to exclude areas above shorelines; (iv) inclusion of auxiliary factors to enhance classification; (v) supervised classification using a combination of data driven and spectral unmixing approaches; (vi) accuracy assessment based on reference data derived from this project and other existing sources; (vii) calculation of the area fractions of different landscape classes and other geospatial measures as needed; and (viii) generation of vegetation maps.

All geospatial data was assessed for quality, completeness, and relevance using standards identified from literature review. The assessment emphasized geometric accuracy, consistence of spatial resolution, and user accessibility. Data may have been limited by1) cloud cover during the project period and its impact on image collection; 2) quality of reference data from existing

Figure 2. Map of water depths overlain with the points that were ground-truthed during June 2020 to produce the vegetation map. Data collected from these points included ~water depth, and sediment type, and vegetation type.

sources; 3) loss of information during the fusion of images from different sources; and 4) differences between new maps and historical maps due to phenological variations and tidal conditions.

Objective 3: Evaluate Blind Oso Tidal Flat Productivity

The "Strategy for Evaluating Tidal Flat Productivity" a method that was proposed and used by Withers and Tunnell (1998) was used evaluate the productivity of the Blind Oso tidal flats, with the data collected during that study serving as a baseline for this study. This method uses exposed area, benthic invertebrate abundance/biomass, bird abundance, sediment water content, sediment chlorophyll *a*, and sediment total organic carbon. For details of the method, see Withers and Tunnell (1998) Chapter 7 (http://cbbep.org/publications/virtuallibrary/cc26.pdf). The flat was divided into two zones (Figure 3). The area was divided because it was postulated that they represent somewhat different conditions for all measured parameters. The figure shows that Zone 1 appears to have more vegetation than Zone 2.

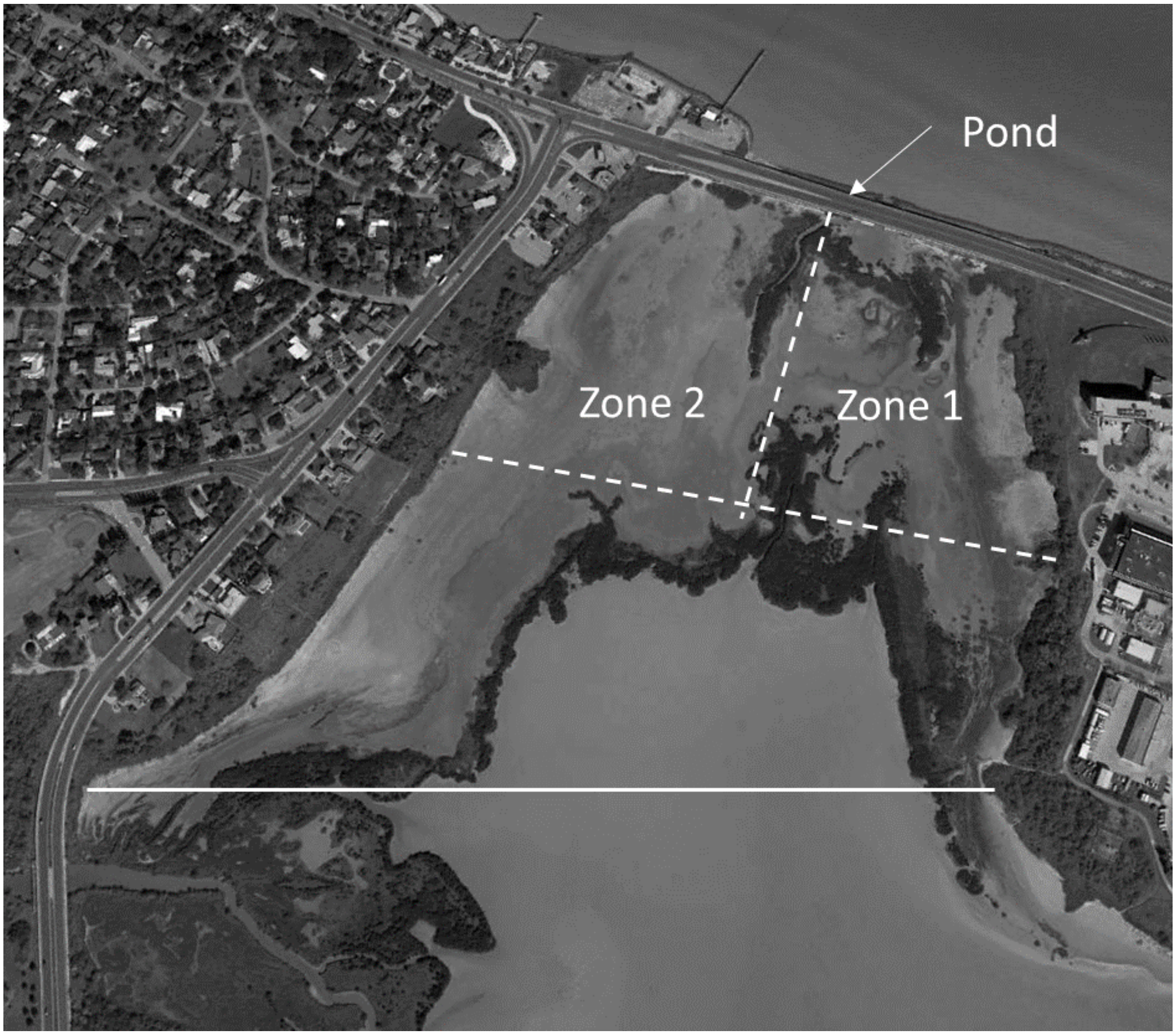

Figure 3. Close-up view of the study area showing the zones defined for collection of benthic invertebrate data and bird data. The solid white line shows the maximum extent of the study area as defined for mapping. The horizontal dashed line shows the extent of the study area with regard to biotic data collections. Zone 2 represents an area where there is less vegetation and potentially more coverage by cyanobacteria; more vascular vegetation coverage is evident in Zone 1.

Sediment Chlorophyll *a*—Sediment cores (1.01 cm diameter, >1 cm deep) were collected in the field at each benthic invertebrate sampling site. Cores were transferred to the lab within an hour of their collection and frozen. Prior to analysis, cores were trimmed to exactly 1 cm depth then placed in a 15 mL centrifuge tube and extracted with 2 mL acetone following EPA Method 447. Extraction was done in the dark at 4 °C for 4-24 hrs. After centrifugation, core samples were ampulated and analyzed using the methods of Zimba et al. (1999). This methodology was developed prior to the EPA publication of method 447.0 but is similar in approach. Differences include the column and solvent gradients. These methods were shown to be comparable in a round-robin conducted by Laurie van Heukelem working with NASA (Zimba pers. comm.). A pigment library, established using standards from VKI Denmark, was used for identification and quantitation of peaks.

Sediment Total Organic Carbon and Sediment Water Content—Total organic carbon (TOC) and water content in sediment will be determined using loss of weight and loss on ignition (LOI) respectively (see SOP in Appendix 1 for details). A sediment core (PVC cylindrical push corer; 10. 16 cm diameter, pushed to a depth of 10 cm) for TOC/water content will be collected at the same time/place cores for benthic invertebrate organisms are collected. Each TOC/water content sediment core will be extruded into a plastic bag and placed on ice prior to transport back to the lab. In the lab, the core will be removed from the bag and homogenized. Two subsamples from each homogenized core will be removed placed into preweighed crucibles and weighed. The difference between the weight of the empty preweighed crucible and the crucible containing the sample is the *wet weight.* First, weight loss associated with water loss will be measured by heating the subsamples overnight at 100 °C, followed by cooling in a desiccator, and reweighing. The differences between the weight after drying and the weight after ~12 hrs at 100 °C divided by the initial wet weight (*100) is the *percentage water content in the sediment*. This calculation also gives the *dry weight of the sediment sample* which will be used to calculate the TOC. Crucibles will then be placed in a muffle furnace and heated to 550 °C for 4 hours to remove *organic material*; crucibles must be allowed to cool in an unvented desiccator and are weighed once they have cooled to determine organic material loss. Crucibles are then placed into the muffle furnace at 1000 °C for two hours to burn off any *carbonate and other materials* (e.g., water stored in the lattice of the clay minerals, and/or diatom silica). These are cooled and weighed to get the final weight. Percent TOC is the difference between *organic material* loss (500 °C) and *carbonate material* loss (1000 °C) divided by dry weight of the sample and then multiplied by 100.

Secondary productivity methods: benthic infauna (polychaete density etc.)—Biological sampling methods are similar to procedures in the TCEQ SWQM Procedures Manual 2003. A PVC cylindrical push corer, 5.08 cm diameter, will be used to sample benthic infauna to a depth of 10 cm. Two replicate samples (81.1 cm^2 each) were taken from each microhabitat that was present in each zone. Each sample was pre-cleaned upon collection. Sediment is placed in a 0.5 mm mesh biobag and field washed by gently homogenizing the samples by hand. Following this procedure, sediment samples were transported to CCS facilities and preserved in a 10% formalin and seawater solution for ~ 7 days. Laboratory procedures are based on currently accepted practices in benthic ecology (Holmes and McIntyre 1984). The techniques have been in use since 1984 and have been subjected to peer-review techniques (Kalke and Montagna 1991; Montagna and Kalke 1992).

Consumers—Shorebird and wading bird abundance was determined by censusing birds within the Blind Oso north of the red line (Figure 1). A census implies that all birds within the area will be found and counted. Birds were identified to species except those taxa that are difficult to identify in the field: Long- and Short-billed Dowitchers (=dowitcher), Lesser and Greater Yellowlegs (=yellowlegs), Semipalmated, Western, Least sandpipers and Sanderlings (=peeps). Birds were identified and counted in the first 3-4 hours after dawn from 3 elevated fixed points on the Oso Bridge using a spotting scope and/or binoculars. Four bird censuses were accomplished between February and April 2020. Count days were chosen so environmental conditions were favorable for birds to be present, i.e., winds less than 24 kph (15 mph) for the 6 hours prior to and at the time of a scheduled count, no frontal passage within 24 hours, rain or fog, etc. (Withers 2014).

RESULTS

Objective 1: Literature Review and Historical Perspective

The Blind Oso is part of an urban wetland complex and the tidal flats associated with the mouth of Oso Bay, including the Blind Oso, have been subjected to human influences for a very long time. In fact, the Cayo del Oso archaeological site encompasses the Blind Oso (https://texasbeyondhistory.net/coast/images/ap2.html). The indigenous people of the area camped within the watershed, buried more than 5000 of their dead there, and left trash deposits and other artifacts attesting to their presence. The theme of human influence and alteration continues to the present day.

Physical Environment—Oso Bay, Texas, also known as Cayo del Oso, is an enclosed, secondary bay located along the southern shoreline of Corpus Christi Bay (Nicolau 2001). Formed during Pleistocene glacial advances and retreats (Morton and Paine 1984), Oso Bay is the estuary for Oso Creek (Hildebrand and King, 1978), exchanging marine water with Corpus Christi Bay and receiving freshwater from the creek. The hydrodynamics of the Oso Creek/Oso Bay system is currently dominated by effluents that are permitted to be discharged into the system (Nicolau 2002). In 1984, roughly half the shorelines of the Oso Bay/Oso Creek system, as well as the surrounding bays were described as “human-altered” (Morton and Paine 1984); it is very likely that that amount is much higher today.

Watershed Characteristics—The Oso watershed is approximately 600 km^2 (Bowman and Jennings 1992) draining the center of Nueces County. Oso Creek flows from Robstown and the western edge of Corpus Christi over flat terrain for 45 km before emptying into Oso Bay. Economic activities within the watershed include oil and gas refining and production, agriculture, manufacturing, ranching and tourism. Most of the watershed soils are characterized as heavy blackland clay (USDA 1992). Along the creek, farming and ranching are and have been chief land uses. In 2011, the NLCD land use/land cover for Oso Creek indicated that the dominate land use was cultivated crops (63%) with urban/suburban development comprising 20% (Figure 4; TCEQ 2019). Note however that this summary does not include the area in the lower reaches of the Oso system. In the early 2000s, land use/land cover for the entire system showed urban areas comprising about 30% of the watershed and croplands/shrub and forested areas comprised ~41%. Also of interest is that the fact that the map produced from the NLCD data shows no forest or shrublands along the creek; the table provided in the report includes these categories but together they comprise less than 6% of the area. Although the area of forested lands and/or shrublands cannot be directly compared quantitatively it does appear that this category of land cover has declined in the watershed since the late 1990s or early 2000s. The continued conversion of shrublands to cropland will contribute to sedimentation in the bay. Conversion of upland thorn brush to cropland at the elbow of Oso Creek between 1899-1902 began rapid and substantial human-caused sedimentation in the bay (Price and Gunter 1943).

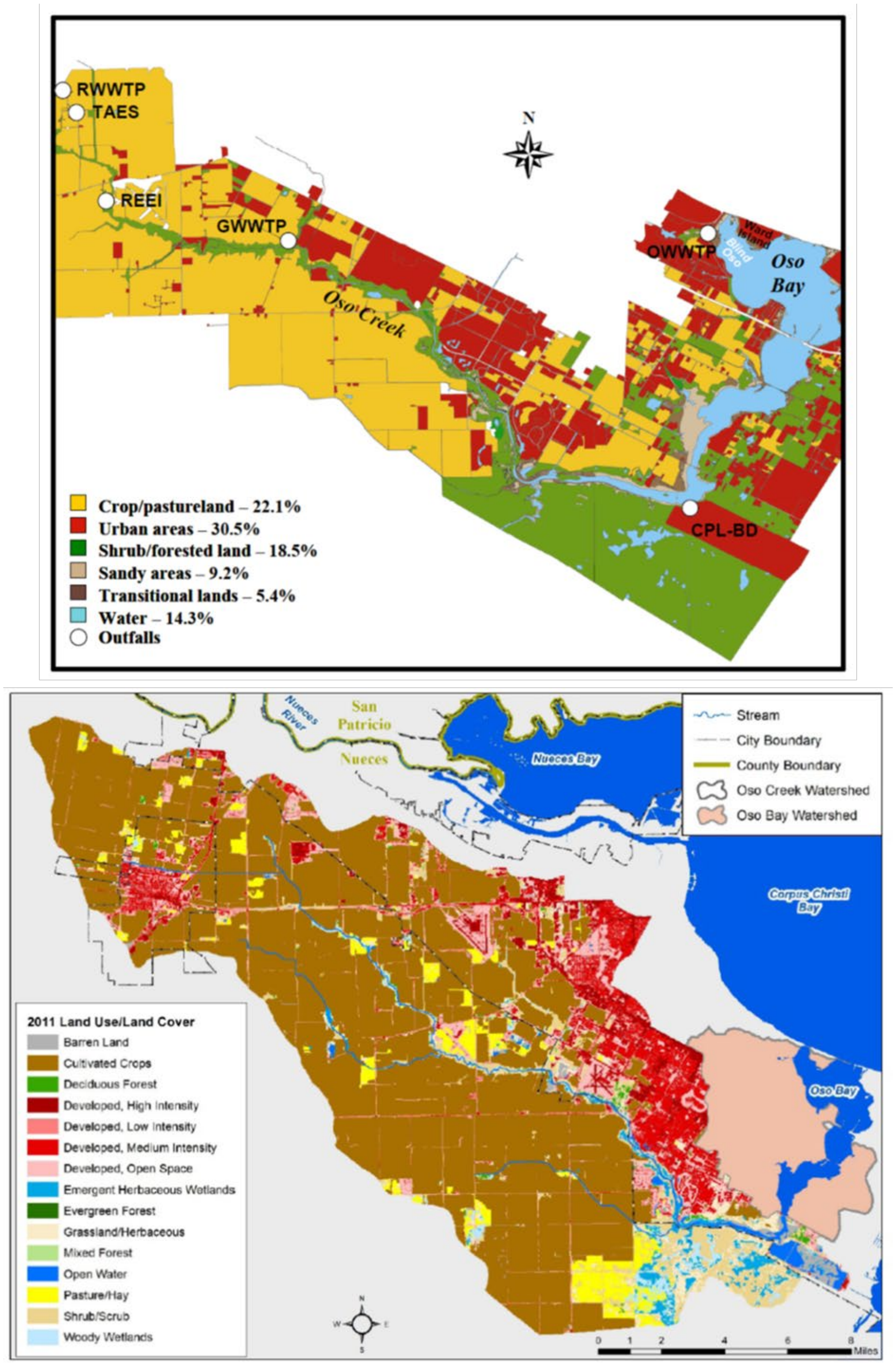

Figure 4. Land use/land cover of the entire Oso Watershed (top,~2000; from Nicolau 2001) and Oso Creek (bottom, 2011, from TCEQ 2019).

Geomorphology of Oso Bay tidal flats—In estuarine deltaic environments, tidal flats develop upon crevasse splays, abandoned levees, relict meanderbelt sands, and slopewash-alluvial fans along valley walls. Wind-tidal flats in lower reaches of streams such as Oso and Petronila creeks, develop on fluvial fan-delta sand deposits where gradients decrease and the erosional character of the stream diminishes. Tidal flats that occur on the mainland bay margin develop where southeasterly winds deflated older eolian deposits, Pleistocene barrier-strandplain deposits, and deltaic deposits. Unlike barrier island flats which are composed primarily of sand, mainland flats are primarily composed of clays (Brown et al., 1976; McGowen et al., 1976; Brown et al. 1977).

Regardless of formation or location, tidal flats in South Texas and Oso Bay are found at elevations between mean sea level (MSL) and 1 m above MSL. They slope gently lagoonward (≈ 10 cm/km) (Herber, 1981). In deltaic environments, tidal flats replace salt and brackish water marsh vegetation locally. In lower reaches of ephemeral streams and along bay margins, wind-tidal flats may be backed by clay dunes such as along Oso Bay and Baffin Bay lower tributary drainages.

Hydrology and Hydrodynamics of Oso Creek and Oso Bay—In the absence of the permitted effluent discharges, Oso Creek would be an ephemeral creek dominated by runoff from infrequent rain events and there would be relatively little water flowing into the system. However, the creek and bay system have proven to be a convenient receiving area for various discharges. For example, production of crude oil in the Saxet Field, west of Oso Bay (Goebel 1977), generated >100,000 barrels of brine waste per day, which then flowed via ditches into Oso Bay (Hildebrand and King 1974). The brine discharge was finally discontinued in 1973 when the Texas Railroad Commission put a halt to the practice after 40+ years. One of the lasting effects, however, was the breakdown of soil structure, resulting in accelerated erosion and sedimentation (Hildebrand and King 1974).

The hydrodynamics of the system continue to be dominated by discharges, which total as much as 565 mgd. The Barney Davis Powerplant (permitted at 540 mgd) contributes more than 90% of the volume of inflows when the plant is running at full capacity. Hypersaline water is pumped from the Laguna Madre into cooling ponds and after cooling, the water is discharged into Oso Creek. When the plant is operating at full capacity, as it did in through from the late 1970s through the 1990's, it was pumping ~530 mgd into Oso Bay. Volumes of cooling water through the plant varied through the 2000s when the plant was rarely operating at full capacity. Today the plant operates at full capacity only about 10% of the time; 70% of the time cooling water volumes are ~233 mgd or less (Shephard et al. 2016). Freshwater inflows include 25.2 mgd wastewater from five permitted wastewater treatment plants with the Oso Wastewater Treatment Plant, which discharges water directly into the study area, permitted for 16.2 mgd (64% of metered freshwater inflows). In addition, freshwater comes into the system from urban and agricultural runoff, stormwater, and three golf courses. The Blind Oso, and particularly the RBO, currently receives significant volumes of water from Corpus Christi Bay through the bridge that was built in 1995-1996.

Meteorological events (e.g., large-scale rain events caused by tropical storms), seasonal changes in water levels, and relative sea-level rise also influence the hydrodynamics of the Blind Oso. Seasonal high and low water levels in the bays occur twice yearly: highs during April/May and

September/October and lows during January/February and July/August. Strong winds from either the northeast or southeast can rapidly flood the area and/or blow the water out of the system depending on the specific conditions—especially with regard to associated rainfall and/or interaction with seasonal high/low tides. Relative sea-level rise is also altering the historical patterns of exposure and submersion by contributing to higher water levels in all seasons. Since 1983, relatively sea-level in the Corpus Christi area has risen 0.15 m (~6 in; Figure 5).

Human Modifications—Sedimentation, hydrological alterations, and human modifications have contributed to a variety of changes in and around Oso Bay since the late 1800's. For example, brush removal in the watershed led to rapid sedimentation resulting in changes in water depths in the bay (Price and Gunter 1943). Before the brush was cleared, water along the south shore of Ward Island near the mouth of Oso Bay was deep enough to permit boats of a "fair size" to come and go from the docks of a hide and tallow factory that operated from 1870-1880. By 1933, however, sedimentation had caused so much shallowing that even rowboats could not use the former dock site. In addition, harvestable oysters were reported in the northeastern part of Oso Bay from 1890-1900, but by 1929 the area was too shallow to sustain oysters. The RBO, aka the "False Oso" was a broad, silted, and abandoned channel between Ward Island and the mainland by 1900.

Few human modifications affected Oso Bay prior to 1934 (Morton and Paine 1984). After that time however, bridge and road construction in a variety of locations altered hydrology and sedimentation patterns. Prior to World War II, a road was constructed across the mouth of Oso Bay to Ward Island, a bridge was constructed across the upper reaches of the bay, and a water impoundment was built in western Oso Bay. As war loomed on the horizon, Ward Island was developed as Naval Radar Training Center (Givens 2018). Fill material was placed on the east side of Oso Bay to link Ward Island to the mainland (Price and Gunter 1943). Construction of improved roads, fences, and facilities on the island and the Encinal Peninsula began in June 1940 and when completed included a 400-foot trestle bridge and a1200-foot concrete bridge across Oso Bay, water lines, a twenty-mile-long railroad track, runways, and much more (Leatherwood, nd).

Bridge and road building, in addition to construction of homes and hardening of shorelines, continue to the present. Two examples of road/bridge construction include widening of Ennis Joslin Road and the elevated 4-lane bridge over the RBO connecting the mainland to Ward Island. There has been no quantification of shoreline hardening around the RBO, however, there are very clear examples of hardening along the shoreline associated with residential development south of Suter Park (personal obs.)

The Biota—The benthic invertebrate community found in the Blind Oso has varied little across studies and time. Regardless of the study, annelids dominate the benthic community; the most abundant annelid families are Spionidae and Capitellidae (Texas Water Commission, unpublished data 1988-1989; Barrera-Carrillo 2000; Withers and Tunnell 1998, Harding 2004, de Santiago et al. 2020, and others). When species are listed, the assemblage of polychaetes is dominated by opportunistic species such as *Capitella capitata* and *Streblospio benedicti*, consistent with what would be expected due to the moderate organic enrichment associated with

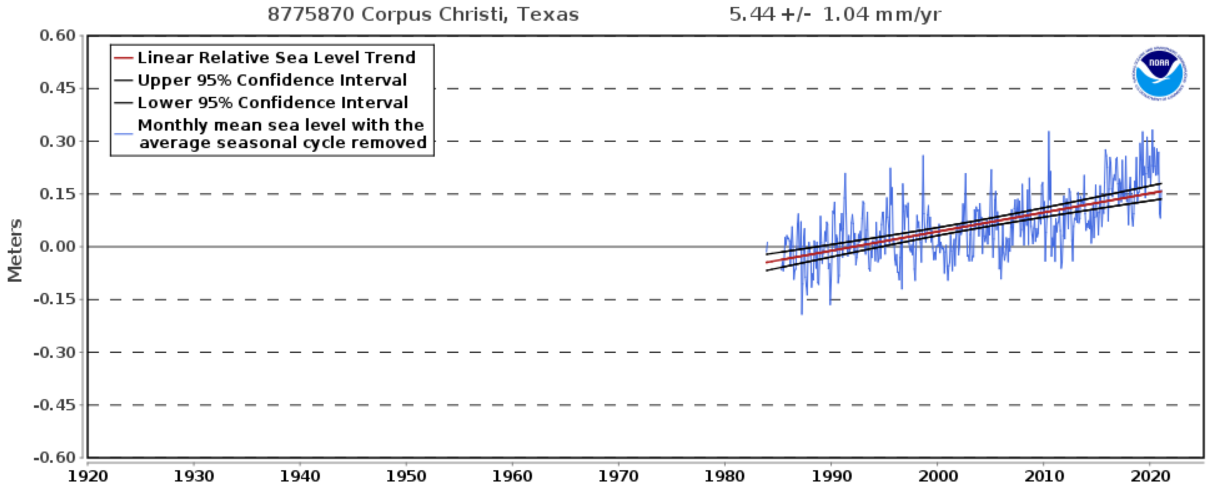

Figure 5. Record of relative sea-level rise at Corpus Christi, Texas 1983-2020. From https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8775870

the wastewater treatment plant. Other common organisms include arthropods such as amphipods and dipteran larvae.

During winter and migratory periods, tens of thousands of shorebirds may be found on tidal flat habitats in the Corpus Christi Bay-Laguna Madre estuarine complex which includes the flats in Oso Bay (Senner & Howe 1984, Withers and Chapman 1993). Tidal flats are one of the most significant feeding areas for migrating and wintering birds on the Texas Gulf Coast, and the wetlands and barrier islands in the region are the first large expanses of suitable habitat between northern breeding grounds and more distant wintering grounds in South America (Withers 2002). While the vast majority of tidal flat acreage on the Texas Coast is found in the Laguna Madre, significant expanses are found around Galveston Bay (e.g., Bolivar Flats) and Oso Bay. Oso Bay ranked 7th in the maximum number of Western Sandpipers during July-December between 1975-1985 (Skagen et al. 1999) and has been a significant location for migrating and wintering shorebirds for decades.

Presence of tidal flats in the mosaic of the coastal environment is particularly important for shorebirds and wading birds. The flats provide an abundant source of food and are near upland and transitional habitats for roosting and nesting. Alternate feeding sites on the beach are also nearby for wading birds when flats are exposed or for shorebirds when flats are completely flooded. Health of the bay ecosystem is one of the most critical aspects in survival of the tidal flat system because the bay supplies most of the water which nourishes the flats. The next most

flat system because the bay supplies most of the water which nourishes the flats. The next most

critical component in long-term maintenance of tidal flats is runoff from adjacent upland areas (Longley et al., 1989). The primary threat to tidal flat systems is public perception they are barren wastelands. Tidal flats are often targeted for coastal development and frequently overlay oil and gas deposits. In the past, tidal flats were often chosen as sites for dredge material disposal and mitigation projects in which they were scraped down in order to attempt creation of coastal marsh or seagrass systems. Tidal flats act as flood basins which buffer or dampen wind-driven bay and lagoon waters, protecting adjacent vegetated habitats (White and Brogden, 1977). Use of tidal flats as dredge material disposal areas leads to compartmentalization and alterations of natural water circulation patterns.

Shorebirds (Charadriiformes) are the most conspicuous vertebrate consumers on flats. They feed on benthic invertebrate infauna and epifauna. Wading birds such as Great Blue Heron (*Ardea herodias*) and Reddish Egret (*Egretta rufescens*) are common in shallow waters adjacent to flats. Bay ducks such as scaup (*Aythya* spp.) and Redheads (*Aythya americana*) often feed in deeper water near flats. Gulls and terns (Laridae) are often abundant and use flats as "loafing" areas. Other birds such as Horned Lark (*Eremophila alpestris*), Barn Swallow (*Hirundo rustica*), Boat-tailed Grackle (*Quiscalus major*), Sandhill Crane (*Grus canadensis*), American White Pelican (*Pelecanus erythrorhynchos*), Black Skimmer (*Rhynchops niger*), and Canada Goose (*Branta canadensis*) turn up occasionally on flats or in shallow adjacent waters.

About 30 shorebird species have been recorded on tidal flats around Ward Island (primarily the Blind Oso and areas directly to the west of Ward Island). Studies that encompassed a year of weekly or biweekly censuses on the tidal flat and associated intertidal areas yielded 7250 individuals (Barrera-Carrillo 2000), 16,942 individuals (Harding 2004), and 34,822 individuals (Withers and Chapman 1993). Peeps (Western Sandpiper and Semipalmated Sandpiper; some studies include Least Sandpiper and Sanderling in this category) were the most common and abundant species (Table 1). Birds were most abundant during spring migration (February-April) and winter (November-January) and were less abundant during mid-late summer and fall migratory periods.

Dowitchers (*Limnodromous* spp.) and dunlin (*Calidris alpina*) were abundant in the shallow water areas around flats These longer-billed (if not longer-legged) species are tactile foragers, whereas plovers, (visual foragers) feed on organisms on or just below the surface of the substrate. Sandpipers are also largely visual foragers but many, such as the Western Sandpiper, include a tactile element in their foraging strategy (Pienkowski 1981) allowing them to use a variety of habitats. Most shorebirds exhibit preferences for certain microhabitats resulting in partitioning of the tidal flat. Because species exhibit preferences, the shorebird community within each microhabitat or zone is dominated by different species groups. Shallow water areas tend to be dominated by longer-legged and/or longer-billed shorebirds such as dowitchers, American Avocets (*Recurvirostra americana*) and Willets (*Cataptrophorus semipalmatus*). Sandpipers tend to be found on wet substrate or along the water's edge whereas plovers dominate in the drier areas of the flat.

Wading birds are found in deeper areas adjacent to flats but also use flats when they are flooded. Six species have been observed in the Blind Oso (Barrera-Carrillo 2000, others). Great Egret (*Casmerodius albus*) and Roseate Spoonbill (*Ajaia ajaja*) were most common in the Blind Oso, particularly after flooding. The wading bird community using the Blind Oso has received little study.

Table 1. Shorebird species observed on mudflats in Oso Bay ranked by total abundance during the study. Blank = none observed. Studies used I = Withers and Chapman (1993), II =Withers (2004), III = Barrera-Carrillo (2000), IV = Harding (2004), V = McDaniel (2011), VI = Rossi (2014).

Species	**I**	**II**	**III**	**IV**	**V**	**VI**
Peeps (*Calidris mauri, C. semipalmatus*)	1	1	1	1	1	1
Dowitchers (*Limnodromous* spp.)	2	2	2	2	3	2
Dunlin (*Calidris alpina*)	3	3	5	5	2	
American Avocet (*Recurvirostra americana*)	4	5	22	12	6	5
Black-bellied Plover (*Pluvialis squatorola*)	5	4	3	3	7	6
Marbled Godwit (*Limosa fedoa*)	6	7	7	4	9	3
Willet (*Cataptrophorus semipalmatus*)	7	8	9	11*	10	4
Black-necked Stilt (*Himantopus mexicanus*)	8		13	6	5	9
Sanderling (*Calidris alba*)	9	9*	6	15		
Least Sandpiper (*Calidris minutilla*)		9*	12			
Wilson's Plover (*Charadrus wilsonia*)	10		11	10		
Semipalmated Plover (*Charadrius semipalmatus*)	11	6	4	9		7
Long-billed Curlew (*Numenius americanus*)	12		19	11*	8	8
Stilt Sandpiper (*Calidris himantopus*)	13		21	19		
Lesser Yellowlegs (*Tringa flavipes*)	14		23	13	11	
Snowy Plover (*Charadrius alexandrinus*)	15		16	16		
Killdeer (*Charadrius vociferus*)	16		17	7	4	
Ruddy Turnstone (*Arenaria interpres*)	17	11	14	20		
Wilson's Phalarope (*Phalaropus tricolor*)	18		20			
Greater Yellowlegs (*Tringa melanoleucus*)	19		18		13	
Whimbrel (*Numenius phaeopus*)	20		15	18	12	
Piping Plover (*Charadrius melodus*)	21	10	10	22		
Baird's Sandpiper (*Calidris bairdii*)	22			14		
Spotted Sandpiper (*Actitis macularia*)	23					
Pectoral Sandpiper (*Calidris melanotus*)	24			23		
Red Knot (*Calidris canutus*)			8	17		
American Oystercatcher (*Haematopus palliatus*)						10
White-rumped Sandpiper (*Calidris fuscicollis*)				8		
Solitary Sandpiper (*Tringa solitaria*)				21		

Objective 2: Mapping Results

Barrera et al. (1992) used historic aerial photos and early GIS software to conduct the first analysis of vegetation change in the Blind Oso between 1934-1991 (Figure 6). This record clearly shows the development of the "Oso Delta" and the correlation between the increasing wastewater discharge from the Oso Wastewater Treatment Plant and marsh development over time. Wastewater discharge increased from <2 mgd in the 1940s to around 15 mgd and vegetation cover increased from 0% to a high of 19%. Declines in cover in the Oso Delta were seen between 1948 and 1958 during one of the severest droughts on record and between 1982 and 1991, a decade that saw two of the most severe freezes in the history of the area (1983, 1989) in addition to a severe drought.

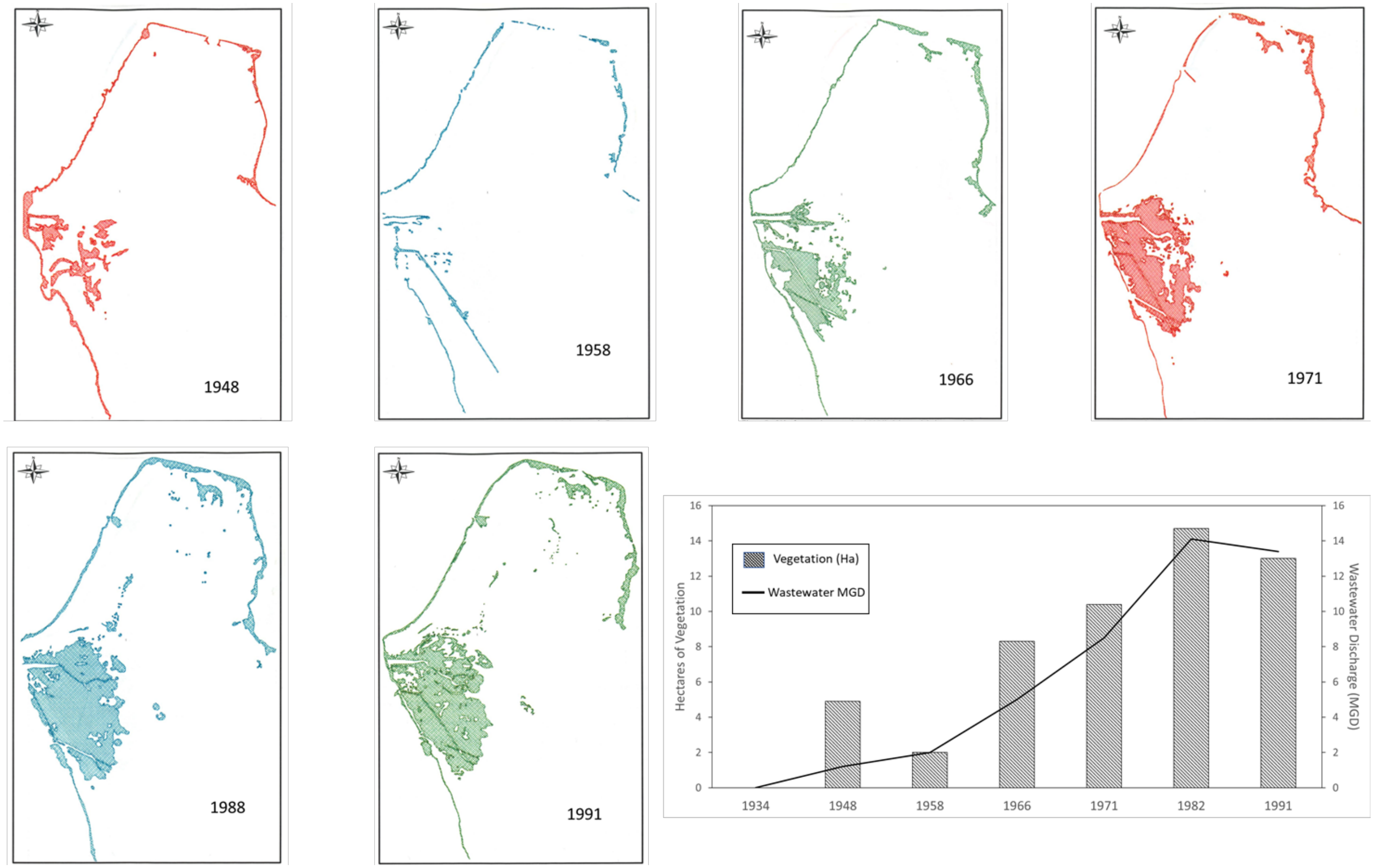

Figure 6. Expansion of vegetation in the Blind Oso 1934-1991. No map is supplied for 1934 which was prior to the construction of the Oso Wastewater Treatment Plant (aka Oso Water Reclamation Plant) in ca. 1938. From Barrera-Carillo (2000).

The mapping undertaken for this project was more detailed than that of Barrera et al. and did not encompass the Oso Delta. The vegetated area of the delta is ~13 ha (estimated using the polygon area tool in Google Earth) which is the same as was reported by Barrera et al. (1992) for the entire Blind Oso in 1991; however, the amount of vegetation outside of the delta was found in fringes along the edges of the area and in the pond area in1991 and probably represented less than 10% of total cover. In addition, the majority of vegetation mapped in the Oso Delta by Barrera. (1991) and Barrera (2000) was *Spartina alterniflora* with the vegetation mapped in the fringes around the edges of the bay and the pond are consisting largely of high marsh halophytes such as *Distichlis spicata*, *Monanthochloe littoralis*, and *Borrichia frutescens,* while the area around the pond had a mix of both low marsh and high marsh species. The goal of this mapping was to look at the suitability of the area for shorebirds which prefer unvegetated habitats and to provide a baseline against which future vegetation change in the RBO could be measured.

Vegetation Cover—In 2020, the marsh vegetation largely consisted of *Avicennia germinans* with an understory of *Salicornia*, *Batis maritima* (mapped as "mangroves"; Figure 7, Table 2), but very little *Spartina* which exists largely as a fringe on the western edge of the mangrove. Too little *Spartina* was encountered in the RBO during our ground-truthing for it to be mapped separately. High/marsh and upland essentially correspond to Barerra-Carrillo (2000) "fringe" description. Areas that are most likely to convert to marsh or mangrove in the future are those mapped as "Algal mat in deep water." These areas are where elevations are between mean sea level and 0.1 m below mean sea level (Figure 8). Cyanobacterial mats generally form around mean sea level but they require an irregular inundation and exposure regime. If they remain inundated for too long, or if the inundation/exposure is too regular, vascular plants can take hold. Although mats of cyanobacteria were evident when we were ground truthing the area extended inundation can essentially drown the mat forming organisms. Algal mat in shallow water is more likely to maintain the irregular inundation and exposure required for maintenance. However, many of these areas had significant amounts of *Salicornia* which grows in "flushes" when conditions are right.

While the greatest change recorded by Barrera et al. (1992) was the expansion of vegetation in the Oso Delta in response to increasing wastewater discharge, the maps that were produced also show that change was occurring in the pond area and across the middle of the flat coincident with tidal creeks that began to develop between the pond area and the delta area coincident with restoration of exchange with Corpus Christi Bay when the culverts were reopened in the late 1980's and the long-term alterations in hydrology caused by the Barney Davis powerplant. Specifically, the 500+ mgd of water pumped out of the Laguna Madre and into Oso Creek resulted in higher water levels in the Oso Bay system and more regular inundation of the Blind Oso. Together, these factors began the fundamental reductions of soil salinities that resulted in conditions more suitable for vegetation growth. The opening of the bridge in 1996 sealed the trajectory of change by allowing greater volumes of lower salinity water into the pond area and moving out across the flat. In addition, he sediment and detritus trapped by live or dead *Salicornia* which grows at least intermittently on most areas of the flats that are not in deep water helps increase microelevations, which can ultimately lead to additional expansion of vegetation into the mostly bare areas preferred by shorebirds.

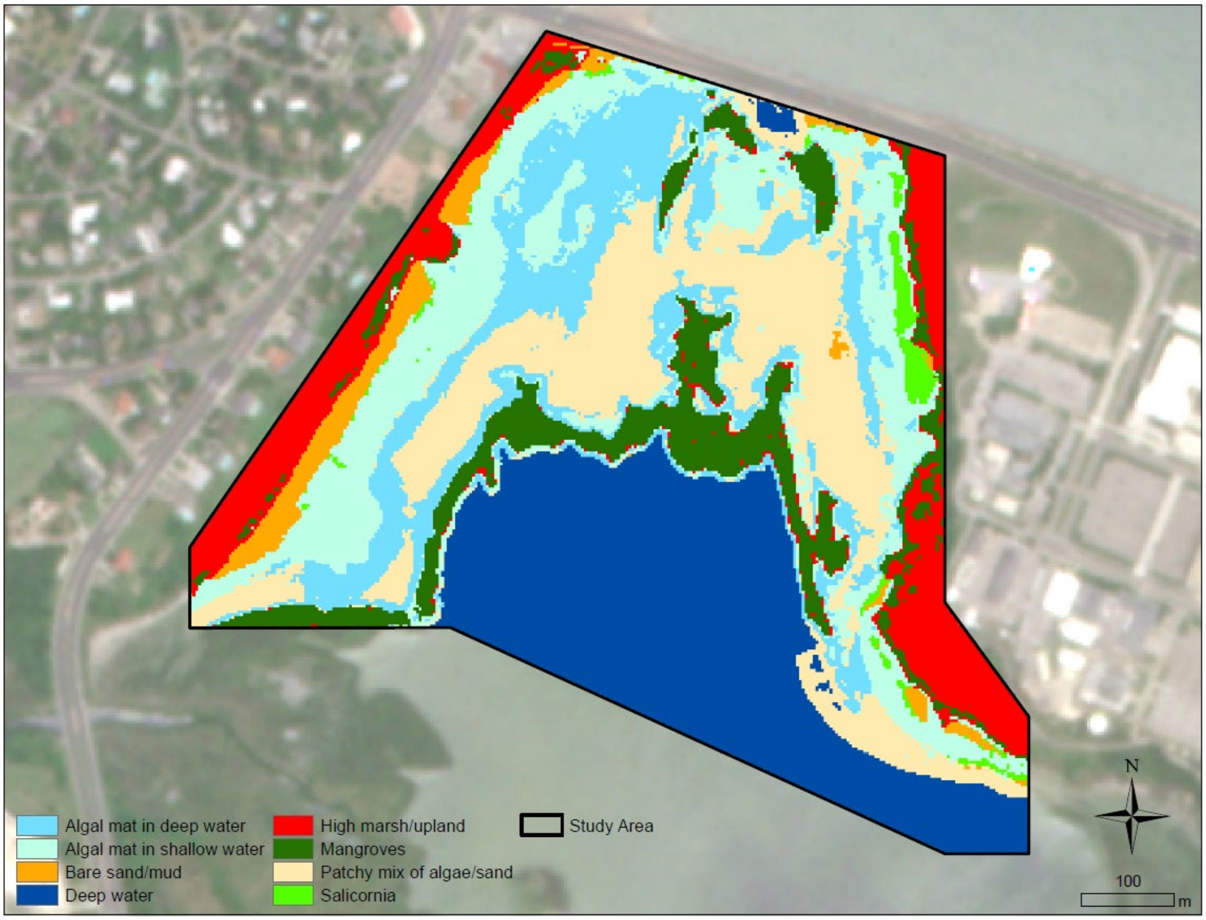

Figure 7. Map of vegetation, water depth, and/or sediment type (June 2020) based on observations at more than 200 randomly chosen points.

Table 2. Estimated area (ha) and percent cover of categories of vegetation, water depth, and/or sediment type (June 2020) based on observations at more than 200 randomly chosen points.

Category	Area (ha)	Percent Cover
Deep water (>0.25 m)	11.7	25.0
Mangroves	4.4	9.5
High marsh/upland	4.9	10.5
Bare sand/mud	1.5	3.2
Algal mat in deep water (>0.15 m)	7.0	14.9
Salicornia	0.6	1.3
Patchy mix of algae/sand (emergent)	8.8	18.7
Algal mat in shallow water <0.15 m)	7.9	16.9
Total	46.8	100.0
Total Vascular Vegetation (ha)	9.9	28.2[1]
Total Algal Cover	23.7	67.5[1]
Total Bare	1.5	4.3[1]

[1] These percentages were based on the total areas (35.1 ha) of all categories except “Deep Water.”

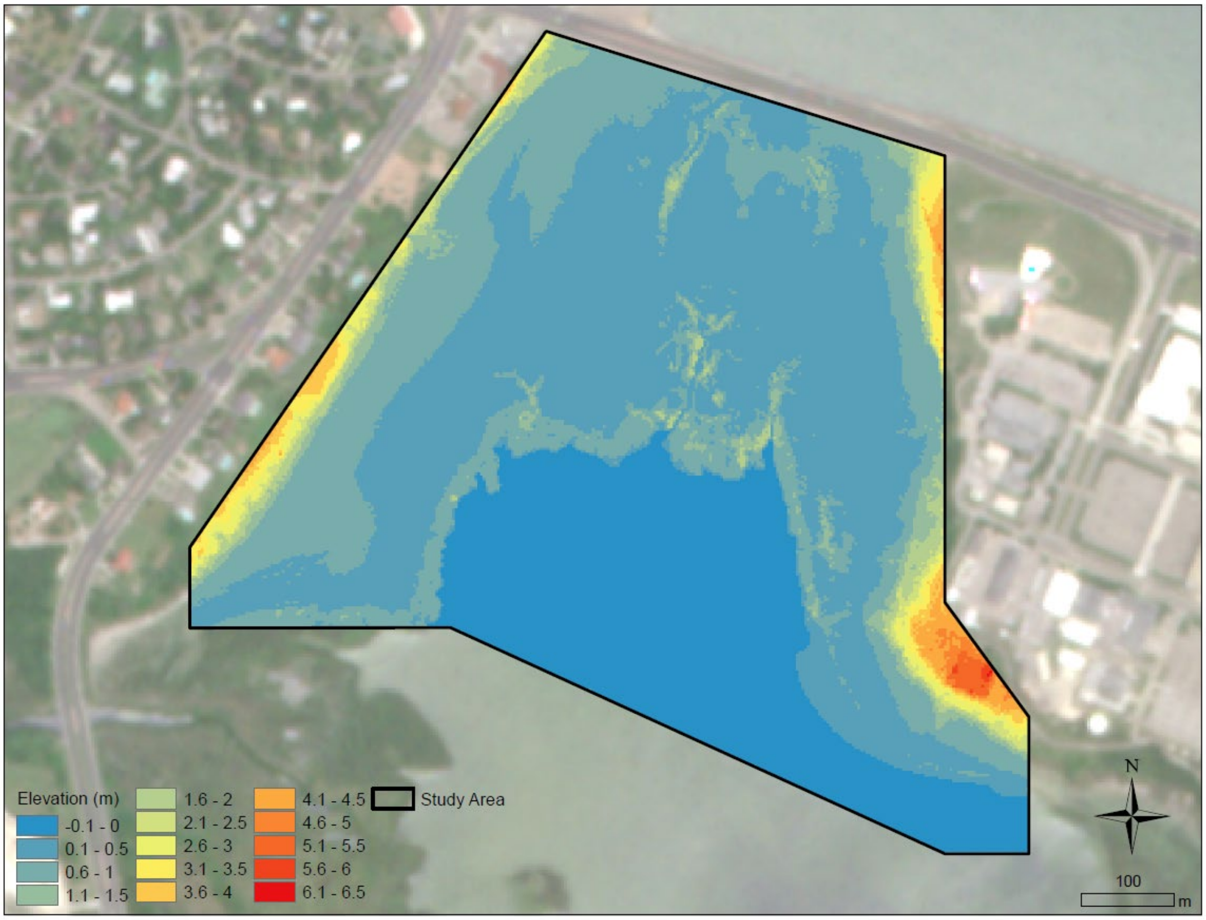

Figure 8. Elevations in the study area estimated using satellite data.

Objective 3: Tidal Flat Functionality for Shorebirds

The impetus for this research was to provide an updated baseline of the extent of vegetation and the quality of habitat for wintering and migrating shorebirds in the Blind Oso. In 1998 I came up with a strategy for evaluating local tidal flat habitats (Withers and Tunnell 1998) using more than just the presence of birds which was based on a published evaluation strategy for tidal flats on the East Coast that relied heavily on the presence of birds (Diaz 1982, Diaz et al. 1982a, b). In addition, the evaluation strategy of Diaz and others did not take into consideration the pervasiveness and potential role/importance of cyanobacterial mats My thinking was that because birds are mobile, relying on the presence of birds to define functionality meant that potentially good habitats might not be recognized and that even when birds were present, they did not necessarily indicate that the habitat was of high quality for foraging because data on their behavior were not included. In addition, because the cyanobacterial mats are so widespread in this area, their role in supporting benthic invertebrate communities and ultimately foraging shorebirds meant that the published strategy could not just be taken off the shelf and used without modification.

The Blind Oso has been recognized as a good, even critical, habitat for shorebirds but there is anecdotal evidence that shorebird numbers and use as foraging habitat have declined since the first study of seasonal abundance and habitat use in 1985-1986 (Withers and Chapman 1993). In this section, I summarize the data that were collected in the present study, and apply the strategy proposed in 1998 as appropriate. As the first (that I am aware of) attempt to actually use the strategy, weaknesses are evident, especially because, due to a variety of factors, data collection was limited to the "cursory examination" with a time frame of "during at least 2 months between November and March" (Withers and Tunnell 1998). In addition, due to equipment malfunction, I was not able to analyze the total organic carbon samples.

Data Summary and Comparison to Withers and Tunnell (1998)—Sediment chlorophyll *a* in the Blind Oso, putatively dominated by cyanobacteria (the algal/cyanobacterial species composition of mats was not determined) varied between zones 1 and 2 (Figure 9), with larger amounts in Zone 1 regardless of microhabitat. The overall mean in Zone 1 was 23 mg chlorophyll a/m^2 with significant variability (SD = 35.5 mg/m^2). In Zone 2, the overall mean was less than half that of Zone 1 (10.7 mg chlorophyll a/m^2) and there was less variability (SD = 10.6 mg/m^2). The mean chlorophyll *a* in Oso Bay reported by Withers and Tunnell (1998) was 183.1 mg/m^2 with a range of zero to over 1000 mg/m^2! Caution must be used in comparing to and making inferences based on the differences between then and now because a different, and much less accurate method (spectrophotometry), was used for chlorophyll determinations because that is the method that was available. In the present study the very accurate HPLC method was used. Water content varied little among the microhabitats (Table 3) thus it has little value in assessing the functionality of the microhabitats.

While anecdotally the algal mat has been diminished in the system, there are no data with which to evaluate that claim. The value matrices produced for primary productivity by Withers and Tunnell (1998) cannot be used here because they rely on chlorophyll *a* values that are very likely overestimated by the method used, and overestimates tend to be greater in the presence of chlorophyll *a* degradation products (Dos Santos et al. 2003). Because sediments were tested, and even though samples were treated to remove phaeophytin (a chlorophyll *a* degradation product), the effectiveness of the treatment is unknown, and degradation products may have been very abundant. An additional source of error in Withers and Tunnell (1998) was that while the core diameter remained the same, the actual amount of sediment used for the analysis likely varied, potentially exacerbating the overestimates when the amount of sediment was larger. The sediment chlorophyll *a* concentrations measured in the present study fall within the range measured on tidal flats in Kwangyang Bay Korea (Sin et al. 2009) and on the Fingringhoe tidal flat in the Colne estuary on the east coast of Essex, UK (Redzuan 2017) as well as those measured by Odum et al. (1958) from a variety of tidal flats in the Coastal Bend.

Polychaetes dominated the assemblage in both zones and in all microhabitats (Figure 10). While the pattern of increasing macrobenthic density from the dry microhabitat to the submerged was the same in the two zones (Figure 11A, Table 4), densities were substantially lower in Zone 1 in all microhabitats except dry; there was also a great deal of variability in densities especially in the edge and submerged microhabitats. Mean macrobenthic densities in Zone 1 (15,238/m^2 ± 23,493) and Zone 2 (20,870/m ± 21,199) were similar to the highest overall average densities for

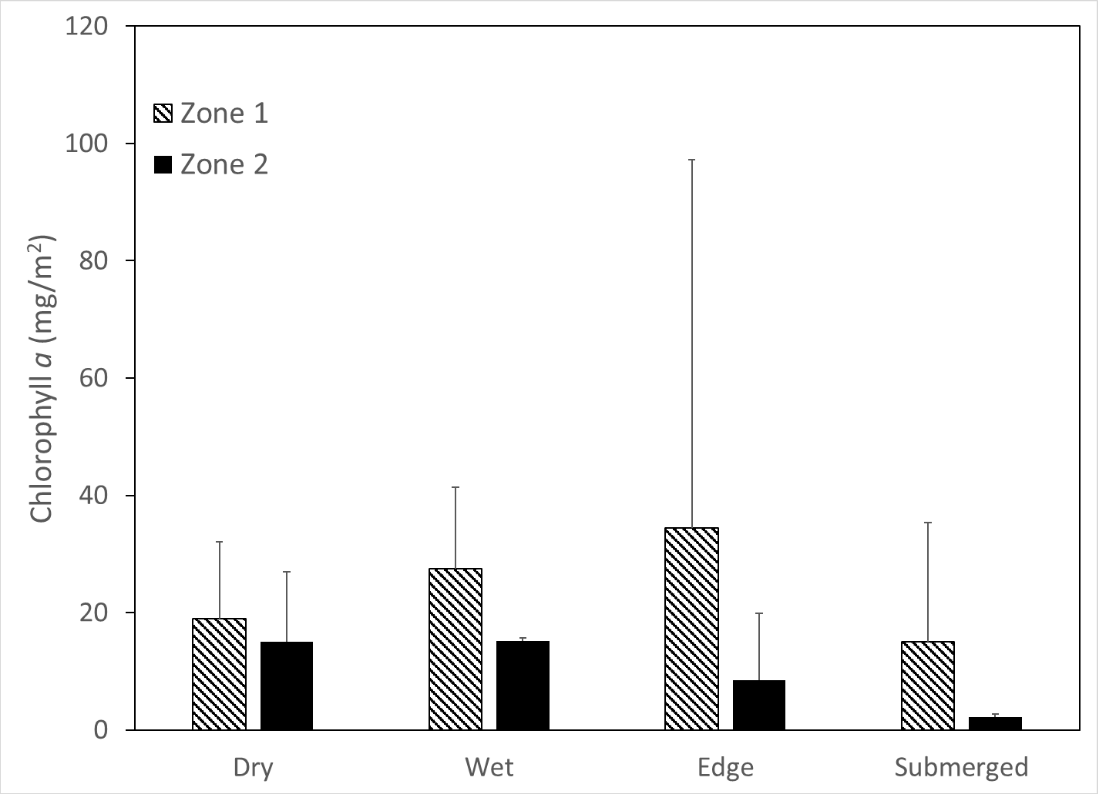

Figure 9. Chlorophyll *a* (mg/m^2) by zone and microhabitat.

Table 3. Mean water content (%) in sediments in the Blind Oso in the present study.

Zone	Microhabitat			
	Dry	Wet	Edge	Submerged
1	35	36	39	38
2	36	36	39	40
Overall	35	36	39	38

the Blind Oso in Withers and Tunnell (1998). Barrera-Carrillo (2000) recorded a mean of 11,288/m^2 in her tidal flat sampling plot.

Biomass in Zone 2 was similar to Zone 1 in the submerged microhabitat, but biomasses in the other microhabitats were substantially higher in Zone 2 (Figure 11B, Table 5). Densities of microbenthic organisms were greater in Zone 2, but it may also be that the animals are larger. Very specifically the difference between the biomasses in the dry microhabitats which have similar densities suggests that there are larger animals in Zone 2 although there is also a great deal of variability in biomasses recorded in most microhabitats.

During this study, the numbers of shorebirds were small most days (Figure 12). I censused shorebirds from the same location and using essentially the same method that my graduate student, Maren Harding, used during her thesis research in 2002-2003 (Harding 2004). In the

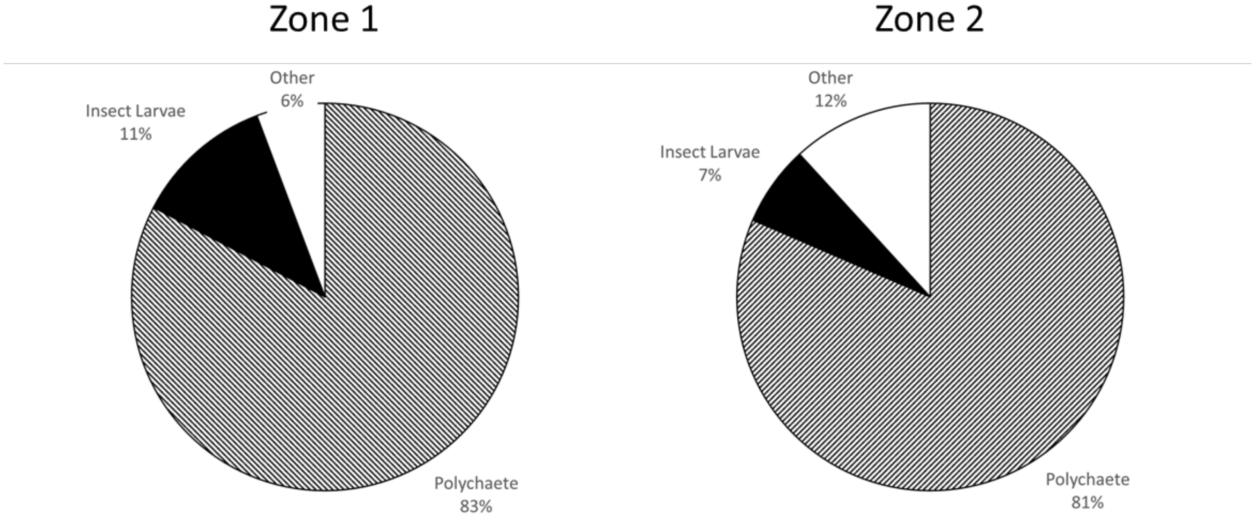

Figure 10. Macrobenthic community composition in Zones 1 and Zone 2.

present study, 11 shorebird species were recorded in the five censuses accomplished in February and March 2020: Long-billed Curlew, Willet, "peep" (*Calidris* spp., potentially including Western, Semipalmated, and Least Sandpipers, as well as Sanderlings), yellowlegs (difficult to distinguish between Greater and Lesser Yellowlegs), American Avocet, American Oystercatcher, Dunlin, Marbled Godwit, Black-bellied Plover, Stilt Sandpiper, and Black-necked Stilt. Of those 11 species, only peeps, Willet, and Black-bellied Plover were encountered in 3 or 4 censuses. Similarly, Harding (2004) recorded 5 species in February and 13 species in March, with "peeps," Black-bellied Plovers, Killdeer, Willets, and Long-billed Curlews encountered in both months.

The total number of birds recorded by Harding (2004) during February 2003 (939) and March 2003 (835) is about 50% higher than the number recorded in this study (601 individuals). The vast majority of birds were foraging. Overall, fewer birds were recorded in Zone 1 and the dry microhabitat was used very infrequently. The large average number of birds foraging in the submerged habitat in Zone 2 was due to a large flock (~200 individuals) of Dunlin that was present on a single day; likewise the larger average number of birds foraging at the edge and in the submerged habitat in Zone 1 was due to a large number of peeps (~170 individuals) present on a single day.

Functional Evaluation–Value Index Matrices—As noted in the opening paragraph of this section (Objective 3), difficulties were encountered in trying to apply the evaluation strategy using the data collected for this study. One general difficulty is that although data were collected from the Blind Oso, because they were judged to have been affected by organic enrichment from the wastewater treatment plant and the flat was not considered an algal flat, the matrices were constructed to be used on "pristine" algal flats such as those found in Laguna Madre (Withers

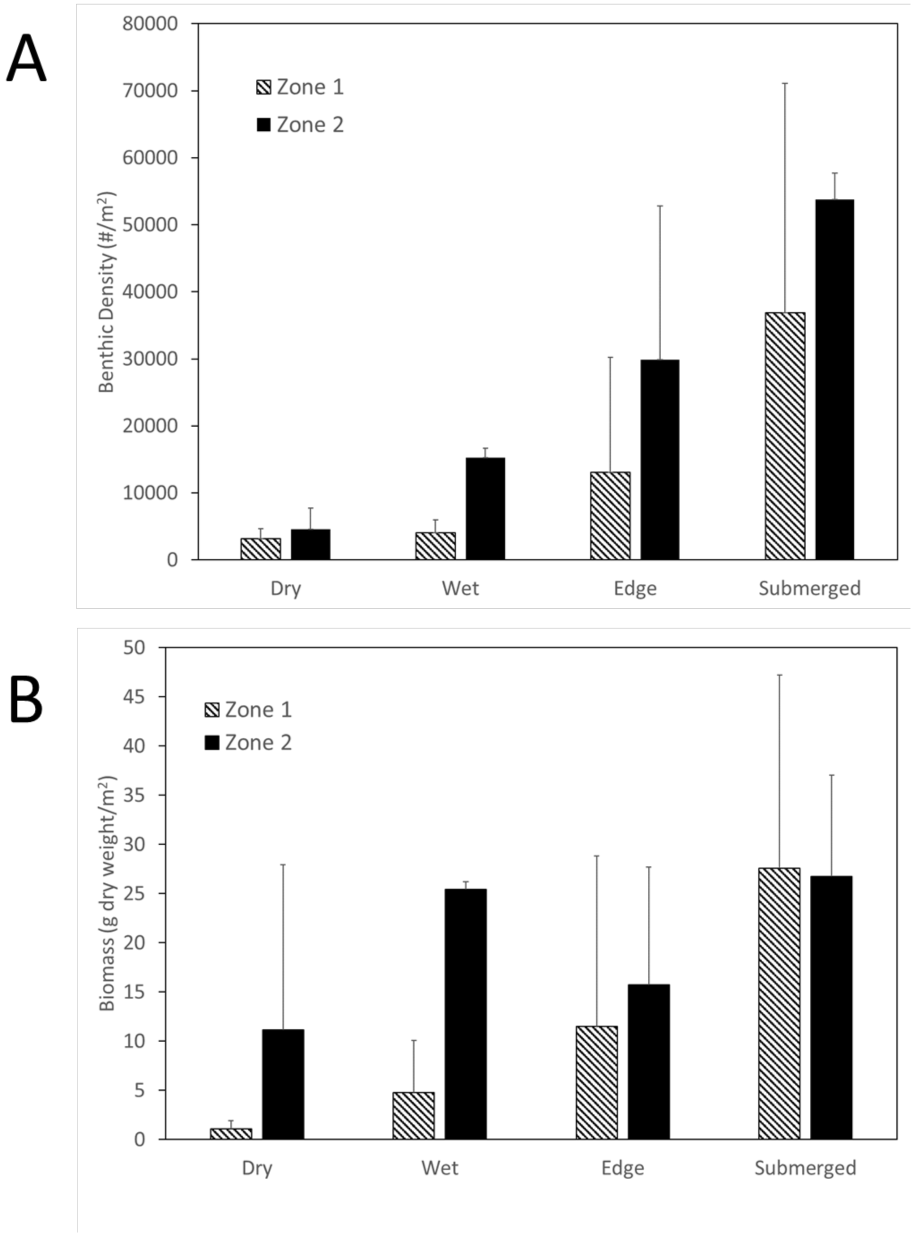

Figure 11. Density (A; #/m^2) and biomass (B; g dry weight/m^2) of the macrobenthos in Zones 1 and 2.

Table 4. Mean density (# /m^2) ± SD of macrobenthic organisms by taxonomic category and zone in sediments in the Blind Oso in the present study.

Zone	Organism		
	Polychaete	Insect Larvae	Other
1	12,594 ± 22,603	1770 ± 1375	874 ± 1747
2	17,008 ± 18,365	1394 ± 888	2465 ± 4889
Overall	14,152 ±21,027	1638 ±1224	1435 ± 3241

Table 5. Mean biomass (g dry weight/m^2) ± SD of macrobenthic organisms by taxonomic category and zone in sediments in the Blind Oso in the present study.

Zone		Organism	
	Polychaete	Insect Larvae	Other
1	10.1 ±16.8	0.9±1.1	0.8 ±2.7
2	14.6 ±13.1	1.2 ± 1.4	0.5 ± 0.9
Overall	11.7 ± 15.6	1.0 ± 1.2	0.7 ± 2.2

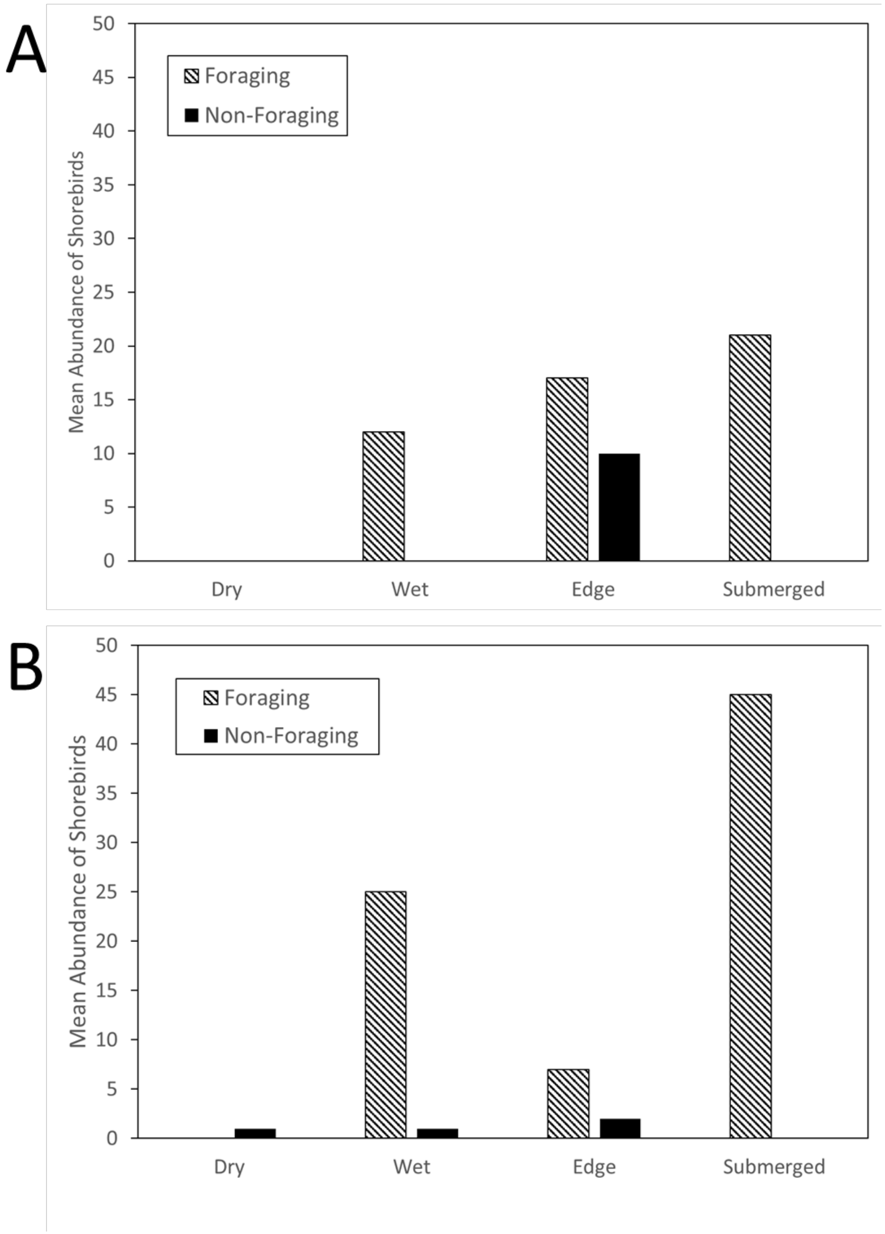

Figure 12. Mean abundance of foraging and non-foraging shorebirds by microhabitat in Zone 1 (A) and Zone 2 (B).

and Tunnell 1998). The value matrices are semiquantitative, relative indices that range from 1 = lower functionality to 3 = higher functionality

With regard to primary productivity, as noted previously, the method used for chlorophyll *a* determinations was unreliable and prone to overestimation. Thus, the value matrix constructed for the combination of chlorophyll and water content results in an estimated functional value of between 1 and 2 because the values of chlorophyll determined in this study were very low compared to the values on the value matrices. The percent water content falls within the mid-value for functionality.

Secondary productivity, measured as macrobenthic invertebrate biomass and density, is greater in the Blind Oso than within the algal mats of the Laguna Madre. This may be at least partially due to organic enrichment from the wastewater plant. Thus, the value matrices for secondary productivity exceed 3 for all three measures: polychaete density vs polychaeta biomass; insect larval density vs insect larval biomass, and macrobenthic density vs macrobenthic biomass. Function with regard to provision of organisms for shorebird foraging appears to be good. However, since shorebirds prefer habitats with the shallowest water or exposed a more fine-grained evaluation was attempted. Value matrices indicate that function is good in the wet, edge, and submerged habitats indicating that shorebirds who prefer those habitats should find the habitat suitable; the dry habitat less so, and this is the habitat that tends to be preferred by sight foragers like Piping Plover.

The problem with the value index matrix for consumers centers around the difficulties of determining shorebird density on these irregular and changing habitats. With the exception of the longer-legged (e.g., Willet) and/or longer-billed shorebirds (e.g., dowitcher, Dunlin) the majority of shorebirds require habitats that have either very shallow water or that are exposed. Neither of the matrices are usable, since they rely on having a measure of shorebird density (#/ha) or exposed area (ha). The majority of birds that were not associated with those two instances when large flocks were present were found along the edges of deeper water and in many cases that was a relatively small area during any given census. The extent of vegetation, even if it is sparse, inhibits shorebirds from using the habitat. The majority of exposed area (both unvegetated and emergent) exists in Zone 2 along the flanks of the bluff; this area was used little by shorebirds during this study (personal observations) or during Harding's study in 2002-2003.

CONCLUSIONS AND RECOMMENDATIONS

Worldwide, extent of tidal flats declined by at least 16% between 1984 and 2016 (Murray et al. 2019). Arguably, tidal flats are among the most endangered habitats, due to the difficulties in mapping them, their lack of "charisma," and the creeping changes that happen as hydrodynamics are altered by sea-level rise, development, or other factors.

The tidal flats of the Blind Oso have been altered dramatically over the last 40 years. The area has been transformed from a non-vegetated sandflat with a saltmarsh at the "Oso Delta" that began developing in the 1940s when a wastewater treatment plant was established on the southwestern shore to a mostly vegetated flat, without large exposed areas except along the edges where current inundation is fairly limited. These changes have resulted from the accumulation of human alterations: wastewater outflows, both directly onto the flat as well as via the discharges into Oso Creek; development and associated runoff on Ward Island and the banks of Oso Bay; the expansion and raising of the bridge on Ocean Drive between the city and Ward Island, and water pumped out of the Laguna Madre, through the Barney Davis powerplant, and into Oso Creek. In addition, the 0.15 m of relative sea-level rise has also reduced the frequency and unpredictability of exposure, which is needed to keep vascular plant communities in check. While prey for shorebirds is not in short supply, the expansion of vegetation on the flats precludes their use by shorebirds except in those areas that remain free of all vegetation. And those areas are small and getting smaller every day. Deeper water and vegetation are fine with wading birds, waterfowl, and secretive marsh birds, but habitats that are suitable for those birds are not suitable for shorebirds.

Wes Tunnell (1991) proposed a habitat enhancement program for the Blind Oso to the City of Corpus Christi as mitigation for some damage done to seagrass beds while repairing Dimmit Pier. He was prescient in his vision for one of the projects, a wind-tidal flats protection zone, with design elements including “maintain the tidal flats as they are presently,” in other words, unvegetated and available for shorebirds. He also proposed design elements that would prevent access to the flats by motor vehicles. What he didn’t know at that time was that the bridge between the mainland and Ward Island would be raised and that the culverts would be replaced by a free-flowing opening connecting the RBO with Corpus Christi Bay. At the time, the USFWS asked me my opinion on the project. My answer was that unless they put a water control structure on that opening, the flat would become vegetated.

Recommendations

At this point, the trajectory from a bare tidal flat to a marsh probably cannot be changed unless water exchange with Corpus Christi Bay is reduced dramatically, and ways to reduce freshwater inflow and increase salinity are found.

The inflow of hypersaline water from the Laguna Madre probably helped porewater salinity to remain hypersaline, which reducing the suitability of the area for vascular marsh plant growth. Since the Barney Davis powerplant rarely runs at full capacity and since the raised bridge over the RBO, the mixing of freshwater and saltier waters likely means that salinities in the bay are at best mesohaline. Reduction in wastewater outflow in the Blind Oso could also help increase salinities. A study of porewater salinity, sediment salinity, and salinity of overlying waters with a water depth study could provide information that would help slow expansion of vegetation. In addition, reducing the exchange between the RBO and Corpus Christi Bay might also help increase salinity. It would be interesting to explore using water control structure on the opening.

LITERATURE CITED

Barrera, T. A., D. Waechter, G. Jeffress, and J. W. Tunnell. 1992. A temporal salt marsh study: implementation of a GIS. 1992 URISA Proceedings, Washington, D.C., pages 251-260.

Barrera-Carrillo, T. A. 2000. Historic vegetation changes in the Blind Oso (Oso Bay), Texas: avian abundance and habitat use of the resulting wetland mosaic. MS Thesis, Texas A&M University-Corpus Christi, Corpus Christi, Texas.

Bowman, J. W. and P. Jennings. 1992. Oso Bay, an assessment of a South Texas bay system. Texas Water Commission, LP-92.

Brown, L. F., Jr., J. L. Brewton, J. H. McGowen, T. J. Evans, W. L. Fisher, and C. G. Groat. 1976. Environmental geologic atlas of the Texas coastal zone: Corpus Christi area. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 123 pages., 9 maps

Brown, L. F., Jr., J. H. McGowen, T. J. Evans, C. G. Groat, and W. L. Fisher. 1977. Environmental geologic atlas of the Texas coastal zone: Kingsville area. Bur. Econ. Geol., Univ. Texas. Austin, Texas. 131 pages., 9 maps.

de Santiago, K., T. A. Palmer, M. S. Wetz, and J. B. Pollack. 2020. Response of microbenthic communities to changes in water quality in a subtropical, microtidal estuary. Experimental Results 1(e34): 1-9. DOI: 10.1017/exp.2020.44

Diaz, R. J. 1982. Examination of tidal flats: vol. 3, evaluation methodology. US Dept. Transportation, FHWA/RD-80/183. Washington, D. C. 48 pages.

Diaz, R. J., G. Markwith, R. J. Orth, W. Rizzo, and R. Wetzel. 1982. Examination of tidal flats: vol. 1, research report. US Dept. Transportation, FHWA/RD-80/181. Washington, D.C. 82 pages.

Diaz, R. J., R. J. Orth, G. Markwith, W. Rizzo, R. Wetzel, and K. Storey. 1982. Examination of tidal flats: vol. 2, a review of identified values. US Dept. Transportation, FHWA/RD-80/182. Washington, D. C. 47 pages.

Dos Santos, A. C. A., Calijuri, M. C., Moraes, E. M., Adorno, M. A. T., Falco, Pl. B., Carvalho, D. P., Deberdt, G. L. B. and Benassi, S. F. 2003. Comparison of three methods for chlorphyll determination: spectrophtometry and fluorimetry in samples containing pigment mixtures and spectrophotmetry in samples with separate pigments through high performance liquid chromatography. Acta Limnologica Brasiensia 15 (3): 7-18.

Givens, M. 2018. What was the Big Secret on John Ward's Island? Corpus Christi Caller Times, 14 August 2018 https://www.caller.com/story/news/columnists/murphy-givens/2018/08/14/ward-island-between-corpus-christi-and-oso-bays/981812002/

Goebel, L. 1977. Water birds of Oso Bay, Corpus Christi, Texas. Unpublished report to Corpus Christi Museum of Science and History.

Harding, M. N. 2004. Effects of hydrology and prey density on shorebird distribution in the Blind Oso, Oso Bay, Corpus Christi, Texas. MS Thesis, Texas A&M University-Corpus Christi, Corpus Christi, Texas.

Herber, J. P. 1981. Holocene sediments under Laguna Madre, Cameron County, Texas. M.A. Thesis, Univ. of Texas. Austin, Texas.

Hildebrand, H. and D. King. 1974. A biological study of the Cayo del Oso and Pita Island area of the Laguna Madre. Annual Rept. to Central Power and Light Company (CPL). Corpus Christi, Texas.

Hildebrand, H. and D. King. 1978. A biological study of the Cayo del Oso and Pita Island area of the Laguna Madre. Final Rept. to Central Power and Light Company (CPL), Vol. 1. Corpus Christi, Texas.

Holmes, N. A. and A. D. McIntyre (eds.). 1984. Methods for the study of marine benthos. IBP Handbook 16, 2nd edition. Oxford: Blackwell Scientific Publications.

Kalke, R. D. and P. A. Montagna. 1991. The effect of fresh-water inflow on macrobenthos in the Lavaca River delta and upper Lavaca Bay. Contributions in Marine Science 32: 49-72.

Leatherwood, A. "Naval Air Station, Corpus Christi," Handbook of Texas Online, accessed April 11, 2021, https://www.tshaonline.org/handbook/entries/naval-air-station-corpus-christi.

Longley, W. L., W. B. Brogden, and S. N. James. 1989. Texas barrier island region characterization: conceptual models. USFWS NWRC Open File Rept. 89-05. 418 pages.

McDaniel, F. L. 2011. Hydrological effects on wintering abundance and behavior of aquatic birds on a wind tidal flat, Blind Oso, Oso Bay, Corpus Christi, Texas. MS Professional Paper, Texas A&M University-Corpus Christi, Corpus Christi, Texas.

McGowen, J. H., C. V. Proctor, Jr., L. F. Brown, Jr., T. J. Evans, W. L. Fisher, and C. G. Groat. 1976. Environmental geologic atlas of the Texas coastal zone: Port Lavaca area. Bur. Econ. Geol., Univ. Texas. Austin, Texas 107 pages., 9 maps.

Montagna, P. A. and R. D. Kalke. 1992. The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces estuaries, Texas. Estuaries 15: 307-326.

Morton, R. A. and J. G. Paine. 1984. Historical shoreline changes in Corpus Christi, Oso, and Nueces bays, Texas Gulf Coast. Bureau of Economic Geology Geological Circular 84-6. University of Texas, Austin, TX

Murray, N. J., S. R. Phinn, M. DeWitt, et al. 2019. The global distribution and trajectory of tidal flats. Nature 565:222–265.

Nicolau, B. A. 2001. Water Quality and biological characterization of Oso Creek and Oso Bay, Corpus Christi, Texas. Center for Coastal Studies Technical Report TAMUCC-0102-CCS. Texas A&M University-Corpus Christi, Corpus Christi, TX. https://www.tceq.texas.gov/assets/public/waterquality/tmdl/67osobaybacteria/67-oso-tnrccandtglo-finalrev1.pdf

Price, W. A. and G. Gunter. 1943. Certain recent geological and biological changes in South Texas, with consideration of probably causes. Proceedings and Transactions of the Texas Academy of Science 26: 138-150.

Redzuan, N. S. 2017. Microphytobenthos (MPB) biomass variability and sediment-water column exchanges on an intertidal flat: influence of weather-related abiotic factors across neap-spring-neap tidal cycles. Dissertation, School of Biological Sciences, University of Essex, UK.

Rossi, R. 2014. A comparison of shorebird studies on south Ward Island, Oso Bay, Corpus Christi, Texas. MS Professional Paper, Texas A&M University-Corpus Christi.

Senner, S. E. and M. A. Howe. 1984. Conservation of nearctic shorebirds. Pages 370-415 in Burger, J. and B. L. Olla (eds.), Shorebirds: breeding behaviour and population. Plenum Press. New York, New York.

Shepherd, M. A., A. Labay, P. J. Shea, R. Rautiainen, and C. Achutan. 2016. Operational, water quality and temporal factors affecting impingement of fish and shellfish at a Texas coastal power plant. Global Ecology and Conservation 5: 48-57.

Sin, Y. S. O. Ryu, and E. Song. 2009. Characteristics of benchi chlorophyll *a* and sediment properties in the tidal flats of Kwangyang Bay, Korea. Algae 24(3): 149-161.

Skagen, S. K., P. B. Sharpe, R. G. Waltermire, and M. B. Dillon. 1999. Biogeographical profiles of shorebird migration in midcontinental North America. USGS Biological Science Report 2000-0003. Fort Collins, CO: US Department of Interior. 46 pp.

TCEQ. 2019. One Total Maximum Daily Load for indicator bacteria in Oso Creek. Water Quality Planning Division, Office of Water. Austin, TX. https://www.tceq.texas.gov/assets/public/waterquality/tmdl/67osocreekbacteria/67-osocreek-bacteria-tmdl-adopted-approved.pdf

Tunnell, J. W., Jr. 1991. Final report, Blind Oso habitat enhancement program. Center for Coastal Studies Technical Report CCSU-9102-CCS. Corpus Christi State University.

USDA. 1992. Soil survey, Nueces County, Texas. US Department of Agriculture Soil Conservation Report.

White, W. A. and W. B. Brogden. 1977. Descriptions of land and water resources. Appendix A in Kier, R. S. and E. G. Fruh (eds.) Environmental and economic impacts of recreational community development, Mustang Island and north Padre Island, vol. 1. Univ. Texas. Austin, Texas

Withers, K. 1994. The relationship of macrobenthic prey availability to shorebird use of blue-green algal flats in the Upper Laguna Madre. Ph.D. dissertation, Texas A&M University, College Station.

Withers, K. 2002. Shorebird use of coastal wetland and barrier island habitat in the Gulf of Mexico. The Scientific World Journal 2: 514-536

Withers, K. 2014. Spatial and temporal abundance of non-breeding piping plovers within designated critical habitat associated with Naval Air Station-Corpus Christi (Texas Units 11 and 12). Texas A&M University – Corpus Christi, Center for Coastal Studies Tech. Rept. TAMUCC-1403-CCS.

Withers, K. and B. R. Chapman. 1993. Seasonal abundance and habitat use of shorebirds on an Oso Bay mudflat, Corpus Christi, Texas. Journal of Field Ornithology 64:382-392.

Withers, K. and J. W. Tunnell, Jr. 1998. Identification of tidal flat alterations and determination of effects on biological productivity of these habitats within the Coastal Bend. Corpus Christi Bay National Estuary Program CCBNEP-26. Corpus Christi, Texas.