Matagorda Bay Ecosystem Assessment Overview and Synopsis

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Purpose and Need for this Overview and Synopsis Report:

This ecosystem assessment for Matagorda Bay has been a major undertaking in terms of magnitude and scope. The work of the Principal Investigators and their associated teams of scientists has resulted in a major body of work containing compelling data and findings detailed in a comprehensive technical report of over 400 pages. While this level of detail is certainly necessary to adequately convey the findings in a thorough manner, the depth and technical components makes summarizing and sharing these key findings and takeaways in a concise and readable manner exceptionally challenging. Thus, the purpose and need for this overview and synopsis was to synthesize the overall findings in a relatively short comprehensive framework that delineates key findings, their significance, and make management recommendations. Should readers be compelled to further explore the detailed scientific background, methods, results, and findings, those are available in the comprehensive technical report.

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Project Background and Introduction

Spanning over 400 square miles of the Central Texas coast, Matagorda Bay serves as a rich resource for numerous industries including commercial and recreational fishing, farming and agriculture, and tourism. Just as impressive as the fishing grounds in Matagorda Bay, the system also boasts impressive avian biodiversity and productivity. Unlike the industrial bays and ports to the north and south, Matagorda Bay is surrounded by a relatively small human population. Thus, extensive and relatively undeveloped, Matagorda Bay is frequently dubbed 'pristine' by those who live and work around the water's edge. In fact, Matagorda Bay does not have the same sources of environmental degradation that compromise the natural resources of bays to the north and south. However, given the complexity of factors that influence the bay, from economic development to hurricanes, the 'pristine' status of Matagorda Bay is not certain. With the aid of stakeholder engagement, this study sought to develop science-based solutions that balance economic activity and the sustainable use of environmental resources in Matagorda Bay.

The bay supports a wide diversity of fish, endangered and threatened sea turtles, and a diversity of waterfowl. The last wild migrating flock of endangered whooping cranes is expanding east from the neighboring San Antonio Bay, and it is thought that Matagorda Bay could potentially become part of their habitat range. Several species of imperiled shorebirds, including the black skimmer and American oystercatcher, may be seen foraging and resting among intact oyster reefs and shallow waters. Despite the ecological and economic value of the area, little research has been conducted on the distribution and health of the many important habitats in the bay and their value to the overall ecosystem health. Thus, The Texas Comptroller of Public Accounts (CPA) partnered with the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University – Corpus Christi in 2019 to conduct research to:

(1) inform the development of effective conservation strategies for endangered sea turtles; and

(2) explore opportunities for avian conservation relative to potential impacts from flooding and sea rise by implementing a multi-disciplinary ecosystem assessment of Matagorda Bay.

This assessment of West Matagorda Bay was unique in that it was the first study to integrate a broad ecosystem-based management approach to a major estuarine system. Traditional studies in this region and others have generally focused on the role single species play in ecosystem food webs, habitat, and water quality. While managing species on an individual basis can provide valuable biological information, to fully understand ecosystems, it is important to gain an in-depth understanding of the fundamental underlying ecological processes and stressors (e.g., flooding and sea level rise) that interact to support a resilient ecosystem. This could not be more relevant than when managing endangered species - knowing their biology is important, but understanding the ecosystem that supports these fragile populations is paramount. Sea turtles and endangered bird populations in Texas' estuaries are a perfect example of where robust science on the estuarine ecosystem that supports these endangered species can greatly enhance recovery and long-term sustainability of their populations. Data generated from an ecosystem-based approach such as this study will be crucial to developing effective restoration and conservation strategies, and they can be used to identify and prioritize areas for long-term protection of sea turtles and many other species. Moreover, this study generated key baseline information that will be essential to gauge progress and make predictions about future change.

This study was multifaceted and complex and comprehensive in scope. However, the underpinning focus was to apply robust science on the estuarine ecosystem to better understand how this bay supports endangered species, promotes/enhances recovery, and develop long-term scientific recommendations for sustaining and enhancing their populations. Thus, a major focus was on iconic sea turtle populations that occur in the area. Matagorda Bay hosts several species of endangered and threatened sea turtles that forage on crabs and seagrasses sheltered in its shallow waters. Researchers captured, tagged, and tracked sea turtle movement to determine how they utilize available resources. Tissue samples were used to incorporate sea turtles into the context of a larger food web analysis. By collecting sea turtle, fish, and plant tissues, researchers evaluated energy flow pathways within the bay ecosystem. Finally, researchers collected data necessary to establish baseline conditions of marsh productivity. Marshes play a fundamental role in the bay's health. The productivity of these habitats influences the abundance and diversity of the marine and avian life that enrich the bay ecosystem. Researchers also compiled, collected, and analyzed abiotic and biotic data to provide comprehensive results to Matagorda Bay stakeholders. Benthic mapping along segments of open water delineated key estuarine habitats, including oyster reefs and seagrass beds, and established a baseline habitat condition for fishes and other estuarine species. The mapping was also closely linked with water quality and biological sampling to gather insight on the ecological processes occurring in the ecosystem.

Along with their respective research teams, this team of expert scientists addressed the most pressing issues in endangered species conservation for sea turtles and other endangered or threatened species (e.g., coastal birds) that rely upon these ecosystems. This Overview and Synopsis along with the comprehensive technical report will help to better understand the suite of imperiled, threatened, and endangered sea turtle and bird species, as well as the potential impacts of evolving environmental factors.

Project Goals:

- Inform the development of effective restoration and conservation strategies for endangered sea turtles;
- Explore opportunities for mitigation and restoration activities to inform priority areas for conservation relative to potential impacts from flooding and sea rise with regard to bird species of interest by implementing a multi-disciplinary ecosystem assessment for West Matagorda Bay;

- Inform the viability of future habitat restoration efforts in the Colorado River Delta particularly for critical nursery habitat.

Research Objectives:

- Develop detailed habitat maps forming the basis for the study. As the primary function of an estuary stems from foundational habitats, this mapping will allow assessments and visualization of biological and physical characteristics of the estuary on a spatial and temporal (seasonal) basis.
- Establish an extensive animal tracking component for key species of interest. This will allow an understanding of distribution, migration, and movement patterns.
- Perform detailed ecological assessments of specific habitat communities that will allow us to assess macrofaunal density, bird abundance, richness, community composition, food base, and habitat trends on a seasonal basis to make predictions about temporal changes and ecological hotspots of productivity.
- Perform strategic water quality monitoring to establish baselines and better understand changing environmental conditions on nutrients, plankton and other food base factors as a measure of productivity.
- Conduct detailed food web evaluations using isotopic and amino acid analyses to determine key ecological interactions among species of interest and their habitats.
- Evaluate the influence of habitat arrangement and dynamic changes in water quality and quantity on a monthly basis to understand changes to habitat suitability for species of interest.
- Engage the Matagorda Bay scientific, management, and policy communities and other stakeholders in the process to gather feedback and give updates as to the status of this project.
- Perform a detailed benthic habitat characterization of the Colorado River Delta study area to provide an updated habitat baseline.
- Conduct a comprehensive ecological assessment linking the distribution of species and their habitats spatially within the Colorado River Delta study area.
- Complete a hydrological assessment to better understand water availability, flow paths, and topography in the Colorado River Delta.

These research goals and objectives were met and overarching findings are captured in the summaries of the study components below. Full comprehensive analyses and discussion are delineated in the technical report.

Habitat Mapping for Evaluation of Habitat Change

Integral components of the overall Matagorda Bay Ecological Assessment included: the development of a comprehensive benthic habitat map of the West Matagorda Bay project area; an assessment of the abundance, community composition, distribution, seasonality, and habitat trends of shorebird and colonial waterbirds with emphasis on designated species of interest; the seasonal sampling of marsh vegetation to establish baseline conditions related to community structure and avian habitat utilization. The objective of each individual effort was to support the TAMU-CC scientific team's over-arching goal of identifying priority areas for restoration and management activities relative to potential impacts from flooding and sea rise.

As part of this comprehensive effort, side-scan sonar (SSS) was conducted throughout Matagorda Bay and bathymetric surveying of approximately 56,000 acres was completed to map benthic habitats (substrate, open bay bottom, oyster reefs, and seagrasses) and water depths (Figure 1 andFigure **2**). During and after completion of the remote sensing phase of the survey, the side scan sonar was processed and a high-resolution mosaic created to guide field verification sampling. A map of potential oyster habitat was compiled through geospatial imagery classification of the SSS imagery using training samples of known oyster reefs, as well as heads-up digitization of known reef areas, resulting in approximately 4,000 acres of potential oyster reef habitat. Live oysters or spat (juvenile oysters) were found at 21 sampling sites during field verification, primarily in the northeast corner of Matagorda Bay. An additional 12 locations contained dead oysters, broken shells, shell hash, or other indicators of possible reef habitat. These sites are more uniformly dispersed across Matagorda Bay, from the northeastern corner down to the southwestern end of the bay. Figure 2 (top) displays the results of oyster reef mapping following the classification approach and ground truthing conducted in 2020.

Potential seagrass beds in the project area were delineated from benthic habitat imagery coupled with the most recent (at the time) accessible high-resolution imagery with sufficient water clarity and minimal cloud cover (Google Earth Pro 7.3.3.7786, 12/1/2018, Matagorda Bay, Eye alt 16,920 feet, accessed 7/6/2020). A map of potential seagrass beds was generated through geospatial imagery classification of the true color imagery using training samples of visible seagrass beds in Matagorda Bay and was then cleaned to remove terrestrial vegetation with similar pixel values, yielding approximately 2,130 acres classified as seagrass. Physical investigations specific to seagrass habitat were conducted to verify SSS results and existing high-resolution imagery and collect limited biological resource information. Shoal grass (*Halodule beaudettei*) was the dominant species across the entire area, followed by sea star grass (*Halophilla engelmannii*) and widgeon grass (*Ruppia maritima*). As of mid-August 2020, seagrass beds across the Matagorda Bay study area were estimated to cover approximately 1,908 acres (Figure 2, bottom).

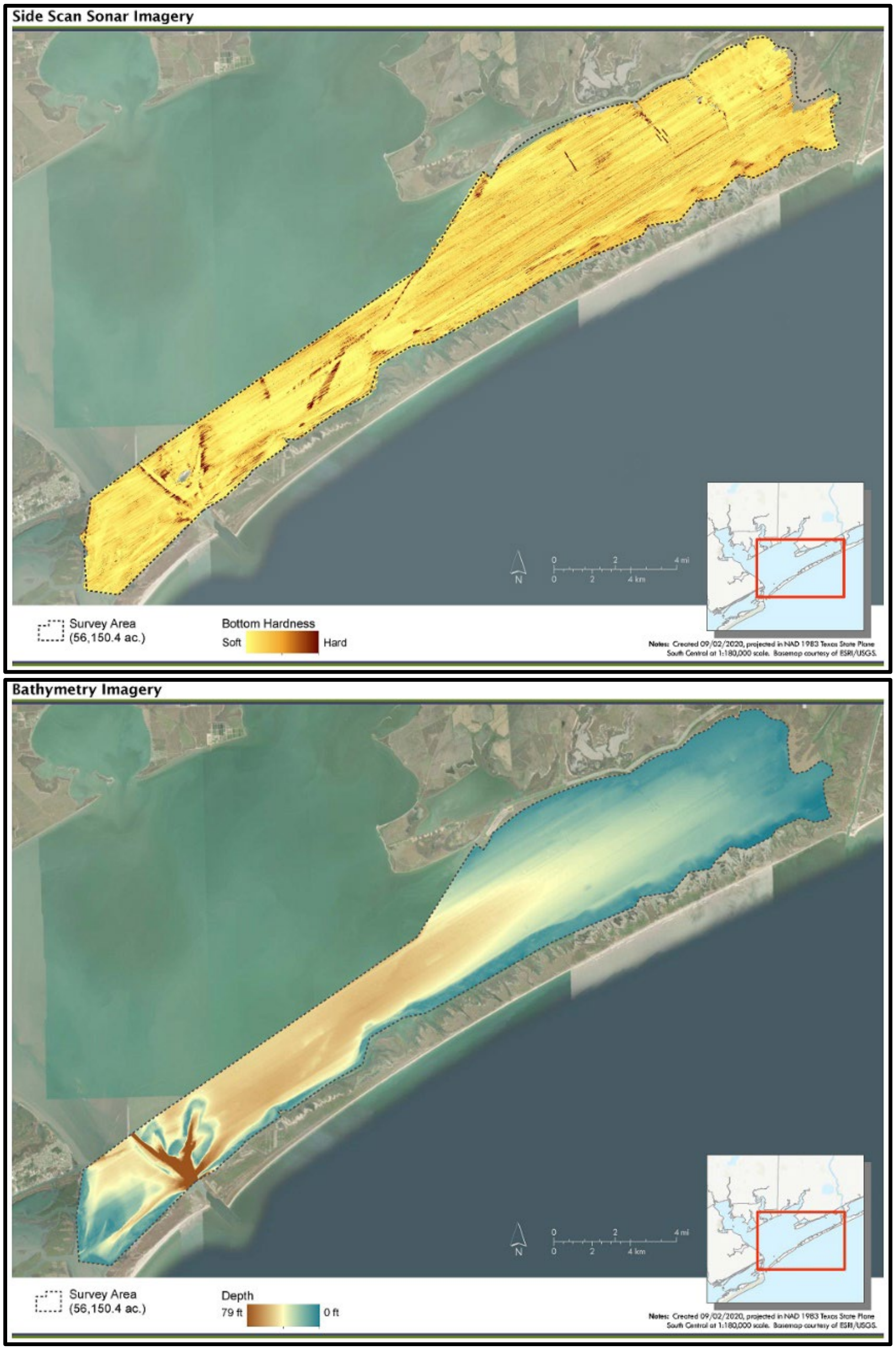

Figure 1. ***Side scan sonar imagery (top) and bathymetry imagery (bottom).***

Figure 2. ***Oyster reef and viable habitat coverage (top) and seagrass coverage (bottom) within the surveyed project area.***

In addition, land cover dynamics were assessed over numerous time scales (past, present, and future) to gain a better understanding of West Matagorda Bay. The margins of West Matagorda Bay were mapped (< 2 km landward from the shoreline) and separated the study area into five sections for analyses (Figure 3). At the conclusion of this study, a high-resolution habitat map was created, habitat changes since the mid-1800's were assessed, modeling of local coastal habitat changes were predicted under two sea-level rise (SLR) scenarios, and vulnerable habitat locations were determined.

Land cover metrics were analyzed for the coastal region of the study area (Colorado River Delta through Matagorda Island) over fourteen imagery dates (1850's, 1930's, 1943, 1953, 1972, 1981, 1995, 2001, 2004, 2009, 2012, 2015, 2018, 2020) spanning 170 years. Numerous imagery sources were manually digitized with varying spatial and spectral resolutions to map water, sand, and vegetation. Within the Colorado River Delta, estuarine marsh vegetation grew 21.22 km^2 from 1850 to 2020 with the greatest growth rate occurring from 1933–1943. While the Colorado River Delta continually grew through time, the other three sections (Matagorda Peninsula, Pass Cavallo to Matagorda Ship Channel, and the eastern portion of Matagorda Island) underwent periods of growth and loss. Overall, from 1850–2020, there was a net vegetation loss along Matagorda Peninsula (6.83 km^2) and Pass Cavallo to Matagorda ship Channel (0.75 km^2), and a net sand loss for Matagorda Peninsula (7.91 km^2) and Matagorda Island (1.36 km^2).

Field sampling included generating transects every 20 m perpendicular to the coast to assess coastal migration over time. Overall, from 1850–2020, the total land width decreased 201 m along Matagorda Peninsula, 355 m from Pass Cavallo to Matagorda Ship Channel, and 448 m along Matagorda Island. Further, long term positional changes of the Gulf shoreline, Gulf vegetation Line, and Bay shoreline averaged over the 170-years indicated 1) a landward movement of Gulf shoreline and Gulf vegetation line extending 28 km along Matagorda Peninsula from the Colorado River, 2) a seaward migration of Gulf shoreline and Gulf vegetation line for the rest of Matagorda Peninsula, and 3) a seaward migration of the Bay shoreline for the entire study area (Figure 4). Ultimately, vegetation width decreased due to 1) erosion on the bay side converting vegetation to water ultimately reducing critical marsh habitat, and 2) a conversion of upland vegetation to sand on the Gulf side.

Additionally, satellite imagery was fused with lidar to obtain a 2 m high-resolution, up to date habitat map (mapping water, bare ground, upland forest and grass, marsh, algal flats, culverts, bridge decks, buildings, and agriculture lands) for the entire study area. A novel stacked classification approach was developed to take advantage of high-resolution satellite imagery and airborne LiDAR point clouds by stacking a rule-based classifier on a group of machine learning classifiers for multispectral images and a filter classifier for LiDAR point clouds. This study then modeled potential land cover changes under two projected sea-level rise (SLR) scenarios (intermediate-low of 0.5 m and intermediate-high of 1.5 m) of global mean sea-level rise (GMSLR) by 2100 using the Sea Level Affecting Marshes Model (SLAMM).

Mapping results indicated that currently the Colorado River Delta and Matagorda Island are dominated by wetlands, Matagorda Peninsula and Pass Cavallo to Matagorda Ship Channel are dominated by upland grass, and Inland Matagorda is dominated by upland grass, forests, and agricultural crops. However, under the 0.5 and 1.5 m SLR scenarios, wetland and upland vegetation extent is predicted to diminish drastically while beach and flat extent varies by location and SLR scenario. Currently, the Colorado River Delta is dominated by wetlands, however, SLR modeling predicts wetlands will convert to beaches & flats under the 0.5 m scenario and open water under the 1.5 m scenario. Currently, upland grass dominates within Matagorda Peninsula and Pass Cavallo to Matagorda Ship Channel, however, under the modeled SLR scenarios, changes from land to water occur on both the Gulf and Bay sides, overall reducing the width of the land extent. Due to these changes, currently stable upland habitat is considered "Critical Habitat" and "Habitat Prone to Surge Flooding" under 0.5 and 1.5 m SLR scenarios.

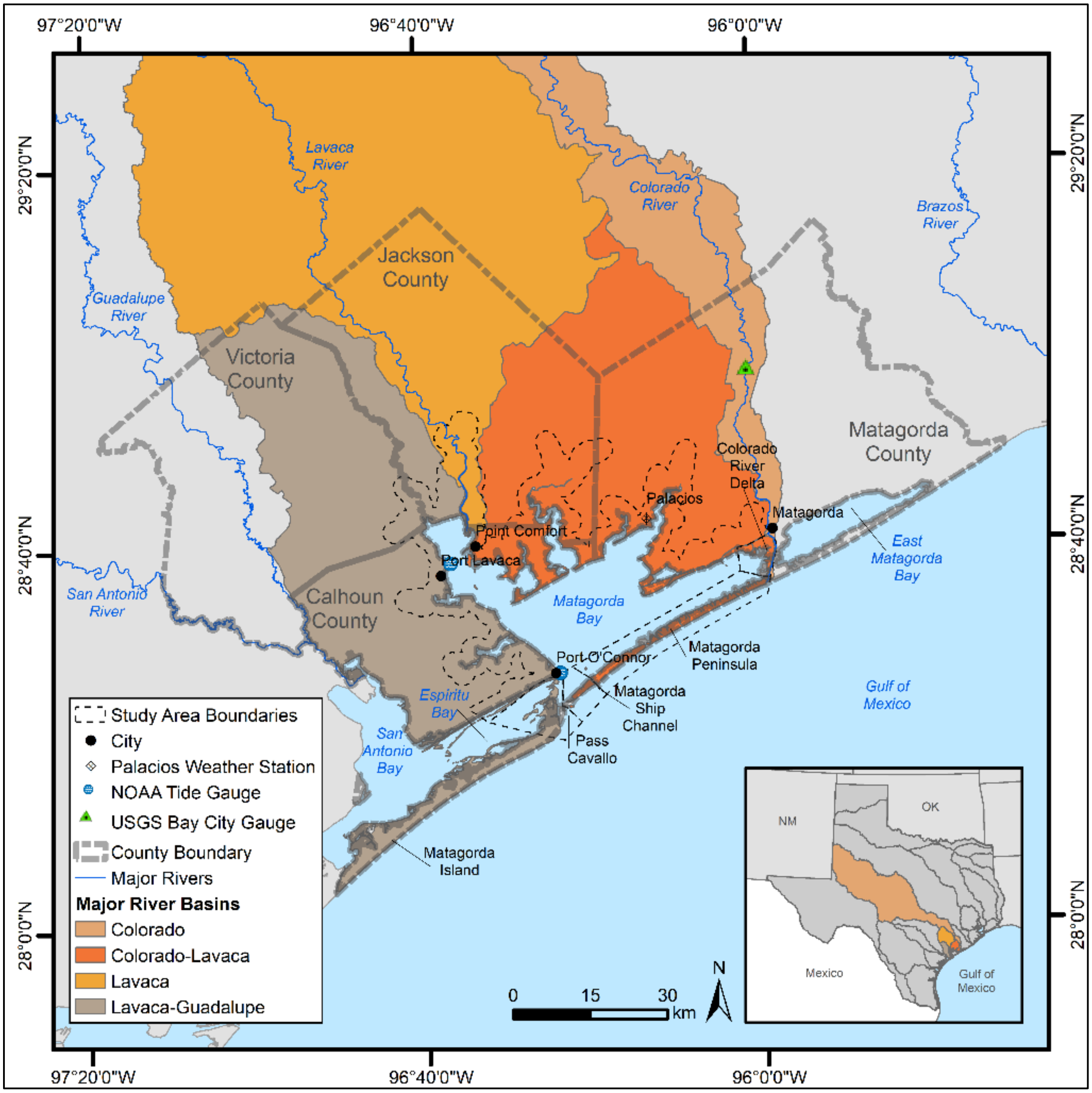

Figure 3. Map depicting the study area sections and the Matagorda Bay surrounding area.

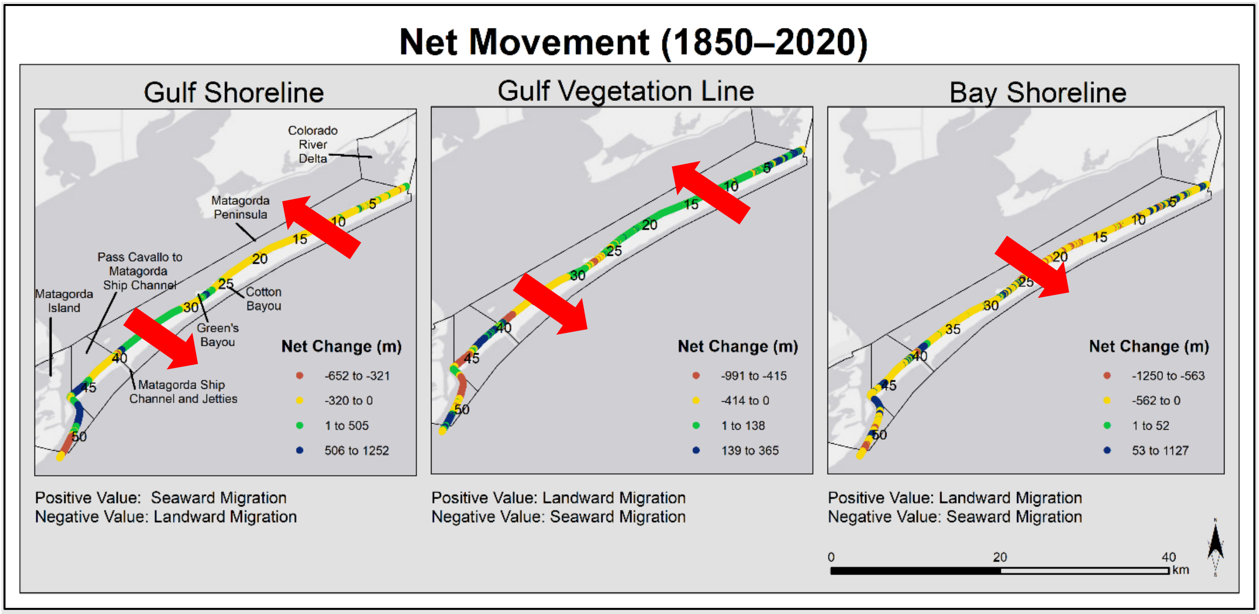

Figure 4. Net Movement of the 1) Gulf Shoreline, 2) Gulf Vegetation Line, and 3) Bay Shoreline over time. Numbers 5–50 represent distance (km) from the Colorado River Delta, red arrows represent the direction of movement.

Sea Turtle Movement and Ecosystem Connectivity

Matagorda Bay was once the epicenter of a commercial sea turtle fishery that began in the mid-1800s and removed millions of pounds of sea turtles from Texas bays and estuaries, the Gulf of Mexico, and the wider Caribbean within a few decades. It has been more than 120 years since this commercial fishery crashed and eventually ceased to exist in Texas. Since then, multiple management and conservation measures have been implemented to save sea turtles from extinction. Most notable among these measures was the U.S. Endangered Species Act of 1973, which provided sea turtles with protection on land and at sea, and the 1990 federal requirement for U.S. fishing vessels to use turtle excluder devices (TEDs) in their nets to reduce the incidental capture and mortality of sea turtles.

Long-term research conducted by the Texas Parks and Wildlife Department (TPWD), as part of their in-water systematic gill net survey since 1980, has demonstrated increasing numbers of sea turtles in the west Matagorda Bay complex beginning in 1993 (the complex includes Lavaca Bay, Cox Bay, Keller Bay, Carancahua Bay, and Tres Palacios Bay). Prior sea turtle studies conducted in west Matagorda Bay in the 1990s and 2000s also demonstrated increasing numbers of sea turtles in the region. These studies identified the different sea turtle species living in the bay, some of the areas occupied by sea turtles, and their movements within and outside the bay. These foundational studies were small in scope, focused on sea turtles only, and provided critical biological information about the sea turtles in Matagorda Bay. Beginning in 2009, sea turtles were captured annually by the TPWD survey, the number of captures increased significantly, and the species captured were primarily green turtles (*Chelonia mydas*) and Kemp's ridleys (*Lepidochelys kempii*). Loggerhead sea turtles (*Caretta caretta*) and hawksbill sea turtles (*Eretmochelys imbricata*) were also captured in TPWD surveys, though in lower numbers. Collectively, these studies have demonstrated the importance of Matagorda Bay to threatened and endangered sea turtles.

The aim of the current study was to use an ecosystem-based approach to study the west Matagorda Bay ecosystem. While single-species studies provide key inputs on population demographic parameters and other valuable biological information, management without an in-depth understanding of the fundamental underlying ecological processes and stressors that interact to structure a resilient ecosystem may be ineffective. This first-of-its-kind study was designed to provide an in-depth understanding of the ecosystem that supports threatened and endangered sea turtles. Robust science on the estuarine ecosystem that supports sea turtles can enhance recovery and long-term sustainability of their populations. Data generated from an ecosystem-based approach are crucial to developing effective management and conservation strategies and can be used to identify and prioritize areas to protect sea turtles within the estuarine complex.

Our overarching goal was to determine the spatiotemporal distribution of sea turtles in west Matagorda Bay, to identify critical habitat within the bay, to determine if these habitats are used year-round or seasonally, to document sea turtle migration to other bay systems and the Gulf of Mexico, and to understand the environmental drivers of these migrations. We also sought to understand the ecological roles of the sea turtles in this estuarine complex, the health of the sea turtles, and the ecosystem processes that impact them and their survival outlook.

From 2019-2021 we captured 33 sea turtles (32 green turtles and 1 Kemp's ridley) in west Matagorda Bay between Magnolia Beach and Green fields using entanglement nets set in shallow water and deep-water areas in multiple locations. Sea turtles were recorded in this area in previous studies, and during the current study by citizen scientists using the iSeaTurtle app that we developed to engage the local communities' assistance in identifying areas used by sea turtles in Matagorda Bay. We attached 2 different types of transmitters to 23 green turtles, including 20 satellite transmitters and 12 acoustic transmitters: 3 turtles had only acoustic transmitters, 11 turtles had only satellite transmitters, and 9 turtles had both transmitters. The satellite transmitters sent GPS locations of turtles to a satellite system and these data were made available to us for analysis of sea turtle movements and migrations. Signals from the acoustic transmitters were recorded when a sea turtle swam near one of the 21 acoustic monitoring receivers deployed in Matagorda Bay or near acoustic receivers located elsewhere as part of the Texas Acoustic Array Network. During the unexpected and severe winter storm Uri in February 2021, we obtained additional data from 62 deceased green turtle carcasses (size, length, gender, species, location) found in Matagorda Bay to contribute to the current study.

All the green turtles we captured in water were juveniles and sub-adults, ranging in size from 29.8 cm - 47.2 cm (curved shell length). The Kemp's ridley we captured was a juvenile 27.5 cm in length. All the turtles we captured in water were visually healthy animals that exhibited their best body condition during the warmer months of the year. During the colder months, turtles often had mud and microalgae films on their shells, indicating that they had spent time on or in the mud substrate of the bay. Several turtles had scars on their flippers and shells indicating previous interactions with boat propellers and other items. Fibropapillomatosis, a common disease found in green turtles, was recorded in 31% of the turtles we captured.

The green turtles that stranded during winter storm Uri provided evidence that smaller and larger green turtles reside in Matagorda Bay. We found small individuals less than 30 cm in shell length, and larger individuals greater than 50 cm in shell length. These smaller turtles are consistent with the size of green turtles that are described as “post-pelagic stage” turtles that are recent recruits from deep water habitats. These larger turtles are consistent with the size of green turtles that are known to be “sub-adult stage” individuals.

Results from in-water captures and stranding data combined provide evidence of year-round presence of green turtles in Matagorda Bay, with seasonal fluctuations in the abundance of turtles. Virtually all turtles that remained inside Matagorda Bay during the deep freeze died due to extended exposure to the cold. In April 2021 after the freeze, we consistently captured sea turtles, their numbers increased into the summer months, and we believe this seasonal influx was driven by sea turtles migrating from southern Caribbean regions.

The majority of the green turtles we tracked with satellite and acoustic transmitters remained resident in Matagorda Bay, however we also found connectivity with other Texas bays as well as the Gulf of Mexico and Mexican waters. One green turtle migrated to Espiritu Santo Bay and then Aransas Bay. Three green turtles migrated into the Gulf of Mexico through the Matagorda Ship Channel or Pass Cavallo and swam south towards Mexico. One of these green turtles swam into Mexican waters and then returned to U.S. waters and remained resident in the lower Laguna Madre. Another green turtle swam south towards the U.S.-Mexico border and then turned north and swam to an area offshore Corpus Christi Bay before it stopped transmitting. All these migrations occurred in advance of or during approaching cold fronts and are consistent with previous studies that found migration initiated in response to cold fronts that reduce ambient and water temperatures below 15°C.

The green turtles that were resident in Matagorda Bay (i.e., did not migrate into the Gulf of Mexico) remained close to their original areas of capture. Their home ranges measured on average 3.0 ± 1.7 km^2 (range 0.4 – 6.1 km^2), and their core areas measured on average 0.5 ± 0.4 km^2 (range 0.1 – 1.4 km^2). We identified two primary high use areas based on satellite and acoustic tracking data: 1) the seagrass beds behind Matagorda Island, near Decros Point and the eastern side of the Island, and 2) the J-hook area between the entrance to Mule Slough and Saluria Bayou. Most green turtle locations overlapped with shallow water seagrass beds, in particular areas where the seagrass species diversity was highest and composed of *Halodule beaudettei*, *Halophila engelmannii*, and *Ruppia maritima*. Green turtle locations also overlapped with deeper water soft bottom habitats (i.e. mud). The shallow water seagrass beds serve as feeding areas for green turtles, while the deeper water soft bottom habitats are used primarily as resting areas. We found variation among individual green turtles in their habitat use. Some green turtles spent most of the daytime in the shallow waters near seagrass, while their nighttime was spent in deeper waters. Other green turtles spent equal time in both habitats. We found these movements were correlated with water temperature, with sea turtles spending more time in deeper waters in the colder months.

Citizen science data collected with the iSeaTurtle app revealed similar sea turtle high use areas when compared to the satellite tracking data. One additional high use area identified by citizen scientists is the Matagorda Ship Channel. The rock jetties in this channel provide important substrate for macroalgae forage for sea turtles to eat as they recruit from their oceanic life stage into their neritic life stage in bays and estuaries. Jetties are a well-documented and important sea turtle high use area along the Texas coast.

Green turtles are the most abundant species in west Matagorda Bay. Loggerhead sea turtles and Kemp's ridleys were also recorded during the study but were not tracked. Green turtles have increased significantly in Texas in recent years, and their recovery outlook is promising due to long-term conservation programs at nesting beaches across the southern Gulf of Mexico and Caribbean, the use of turtle excluder devices in Texas coastal waters, and the healthy coastal ecosystems in Texas' bays and estuaries.

Future Management Recommendations:

Texas bays and estuaries provide one of the most important developmental habitats for green turtles in the northwestern Gulf of Mexico. Our study confirms that Matagorda Bay provides important developmental feeding and resting areas for green turtles and extends the range of critical habitat for the species further north than previously documented. The high use areas we identified in this study, including the seagrass beds and the jetties in west Matagorda Bay, require special management consideration or protections for immature and juvenile green turtles that use these areas daily to feed, rest, develop and grow. We recommend prioritizing areas of high seagrass diversity for protection of green turtle foraging habitat. We also recommend managing the seagrass beds present to maintain their abundance and diversity of seagrass species critical to green turtles in Matagorda Bay. Interventions to reduce or manage commercial and recreational boat activity as well as other human activities in these high use areas is also important. Examples include reducing boat speed in these areas, increasing education and outreach to recreational boaters about the presence of sea turtles and what to do if they capture/injure a turtle, and preventing removal or destruction of seagrass.

We also recommend special consideration of the jetties in the Matagorda Ship Channel due to the high number of sea turtles sighted and the multi-species observed there. Recent dredging of Aransas Pass had immediate impacts on the jetty habitat, sea turtles were disturbed by these activities, and they left the area (Personal Observation). Fewer sea turtles were sighted there for as long as a year following the dredging (Personal Observation). Activities that alter these habitats, even temporarily, can adversely impact immature sea turtles that depend on these areas as they transition from oceanic waters to bay and estuarine developmental habitats. In addition to providing areas for sea turtles to feed and rest, the Matagorda Ship Channel is used by green turtles for transit from Matagorda Bay to the Gulf of Mexico during extreme weather events. Restricting this access could threaten a greater number of sea turtles during future winter freezes.

Winter storm Uri confirmed that the high density of sea turtles in Matagorda Bay and surrounding bays from Aransas Bay to east Matagorda Bay require targeted search and rescue efforts during extreme cold weather events. These efforts should begin when the water temperature declines to 10°C. Current efforts for sea turtle search and rescue are concentrated near South Padre Island, North Padre Island, Mustang Island, Corpus Christi, and in the Galveston Bay region. If recovered quickly, cold-stunned turtles can be released offshore into warmer water or held temporarily in rehabilitation facilities if necessary. Deceased turtles can and should be used for future investigations, including the long-term health status of sea turtles in Texas. Lastly, fibropapillomatosis was detected in a third of the green turtles we studied. Further investigation of the prevalence of this disease in Texas turtles and the factors contributing to its spread are critically needed.

Biological Sampling Across Habitats

Post-Settlement Nekton Assessment

Recruitment to and use of seagrass and saltmarsh habitats by post-settlement nekton has been linked to biological and physicochemical properties of the estuary during settlement and early life periods. The purpose of this portion of the study was to assess variation in abundance (density) and diversity of post-settlement nekton using these habitats in Matagorda Bay, a subtropical estuary on the Gulf Coast of Texas, and then determine environmental conditions that correspond to increased density and diversity. To do this, post-settlement nekton were sampled seasonally from each habitat in 2020 and 2021 using an epibenthic sled. Seagrass consistently had higher abundances of post-settlement nekton than saltmarsh, and the density of nekton in both habitats differed by season and year. Diverse assemblages were present in both seagrass and saltmarsh habitat and both diversity measures evaluated at the family level (taxonomic richness [T_F] and Shannon diversity [H’]) differed significantly between seasons and years. Community structure also differed significantly between seagrass and saltmarsh habitat, and dissimilarity was influenced principally by shifts in the families of fishes that use these nursery habitats seasonally (Sciaenidae [drums and croakers], Paralichthyidae [sand flounders], Gerreidae [mojarras], Syngnathidae [pipefishes and seahorses]) and highly abundant resident taxa that occur throughout the year (Gobiidae [gobies], Sparidae [porgies], and Fundulidae [killifishes]). Density, T_F, and H’ were all significantly related to habitat type, dissolved oxygen, and distance to tidal pass. Density and H’ were related to salinity, year, and time of day, while density and T_F were related to water temperature and turbidity. Lastly, both diversity indices were significantly related to tide height. Further study of species in the family Sciaenidae revealed species-specific differences in nursery habitat use that help explain observed shifts in density and diversity at the family level. This study identified conditions and areas of the estuary that support abundant and diverse assemblages of post-settlement nekton, and findings from this study will serve as a foundation for monitoring the health and stability of seagrass and saltmarsh nurseries in Matagorda Bay.

Avian Assessment

Over the three-year study period the observed bird community was typical of a Texas Gulf Coast estuarine ecosystem, with multiple species of rail inhabiting the lower marsh habitats, an abundance of tern, heron, and wading bird species utilizing the marsh fringe, and large flocks of shorebirds foraging and roosting on the tidal flats. Across all study sites (Figure 5), taxa richness showed little variation between winter and spring sampling, with a notable decrease in overall richness in the fall. Across sampling years, taxa richness was consistently more variable in the winter than in other seasons. This is most likely attributable to differences in the rate and timing of large flocks arriving to over-winter in the bay in addition to the larger fluctuations in within-season bird activity due to the more severe weather patterns typical of the Texas gulf coast winter. The barrier island study sites generally displayed higher diversity than sites located along the Gulf Intracoastal waterway (GIWW). Most notably, BI-1 exhibited considerably higher avian diversity than all other study sites. Taxa evenness was much lower during the winter for the Oyster Lake study site, as large numbers of migratory single-species flocks of Sandhill Crane (*Antigone canadensis*) and waterfowl were commonly observed utilizing the smaller more wind-protected lake for roosting. Analysis of assemblage structure supported that there is a meaningful difference in the observed avian communities in the bay, differing by both study site and season.

Relative to species of interest, the barrier island study sites hosted the most species, including American Oystercatcher (winter), Black Skimmer (spring and winter), Eastern Black Rail (fall), and Piping Plover (winter). However, Whooping Cranes were only observed at the GIWW-associated study sites (Mad Island Marsh and Oyster Lake) during fall and winter sampling. Red Knots were not observed during this study. This is most likely a function of study site location wherein sampling efforts were restricted to interior bay areas and did not include the beach habitat commonly used by this species. In general, the seasonality and habitat associations observed for species of interest in the bay were consistent with the available literature for these species. Passive sampling using acoustic recording devices did not produce any observations of the target species, demonstrating the difficulty of studying species with narrow and seasonal distribution (Whooping Crane) or highly cryptic behavior (Eastern Black Rail).

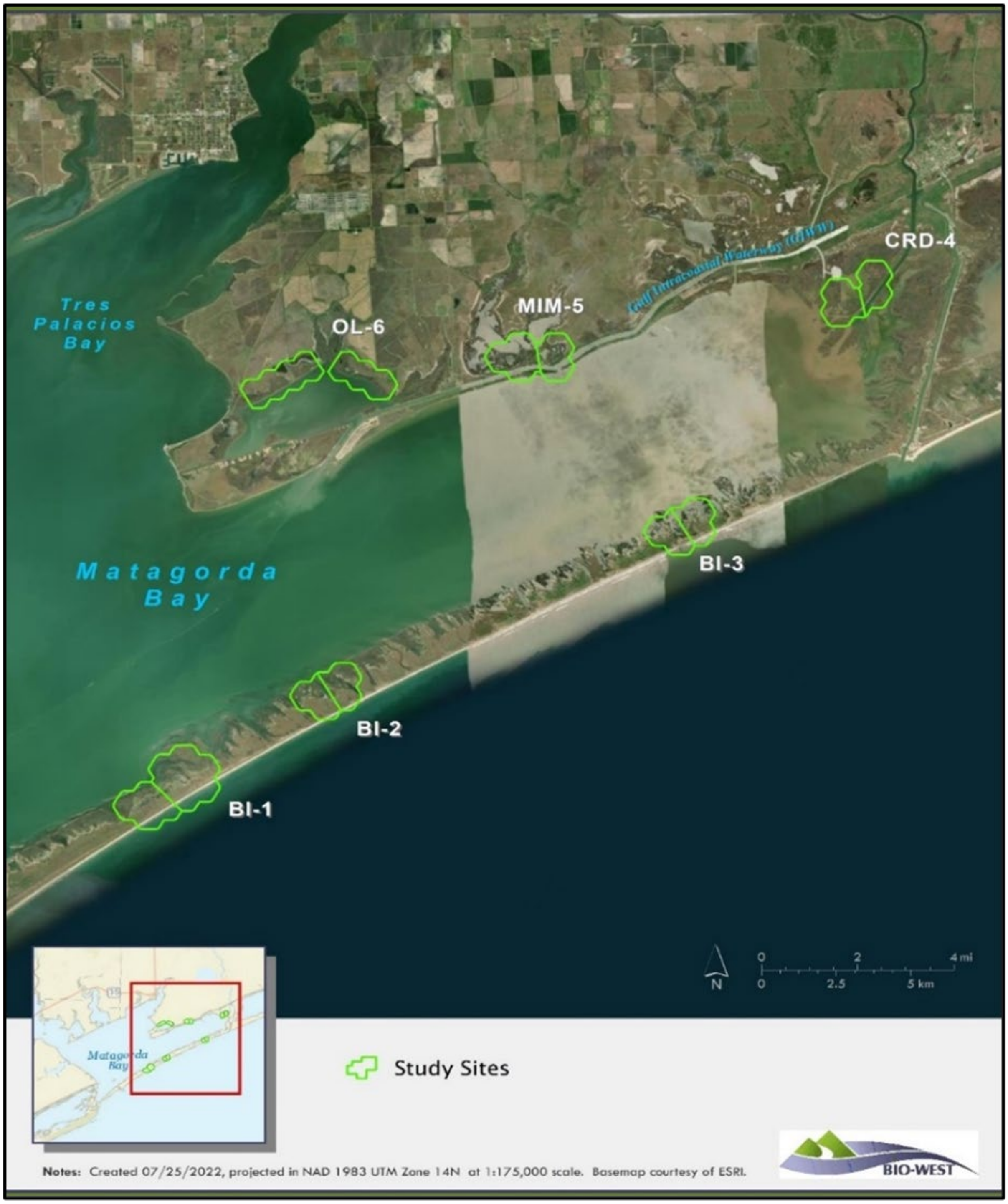

Figure 5. Matagorda Bay study sites utilized for avian community and marsh vegetation assessments.

Two years of seasonal marsh vegetation sampling within the bay demonstrated the high degree of temporal and spatial variation in estuarine saltmarsh communities, differing both across and within study sites. At a broader scale, study sites were generally dominated by one to a few species. Of the barrier island study sites, BI-1 exhibited the lowest plant diversity. Conversely, this study site produced the most species of interest and highest levels of avian diversity observed across the study. This provides evidence to suggest that coastal bird diversity in the bay may be driven largely by the amount of open water habitat interspersed throughout the saltmarsh rather than the availability of higher numbers of landcover types or levels of plant diversity. Relative to vegetation, analyses indicated that the GIWW-associated study sites were generally more closely associated with lower marsh habitats and higher levels of plant species diversity. The expansive lower marshes prevalent throughout Mad Island Marsh and Oyster Lake represented habitat commonly utilized by migratory waterfowl and cranes. These areas also maintained higher levels of Carolina Wolfberry, an important forage species for Whooping Crane. While the barrier island study sites presented higher levels of overall bird diversity and hosted more avian species of interest, the GIWW-associated study sites, represent demonstrably suitable habitat for Whooping Crane.

As common with estuaries, the ecological diversity of organisms varies both spatially and temporally and is largely driven by the interactive affects of a myriad of environmental factors, as evidenced in the overall Matagorda Bay Ecological Assessment. This ecological interconnectivity speaks to the productivity of the bay but complicates recommendations for potential ecological enhancements over time with respect to flooding and sea level rise. A variety of restoration strategies have been designed and implemented within similar systems, with varying degrees of practicality and affect. In addition, the allocation of resources to one strategy over another depends on overall project goals (i.e., managing for diversity vs. managing for a single species). To a certain extent, both of these goals can potentially be met, as managing strategically for specific umbrella species may enhance habitat conditions for a litany of other species. For instance, the results from our study suggest that estuarine marsh habitats support the highest species diversities. Moreover, among species observed, Eastern Black Rail are more closely associated with these habitats, suggesting that managing for Black Rail habitat could have more affect on overall diversity than managing for other SOI. Additionally, as future meteorological conditions change, increases in oyster bed foraging habitat would be beneficial for the American oystercatcher and other shorebirds by creating habitat, forage, and shoreline protection, if appropriately located. The creation of temporary rookery islands could benefit colonial waterbirds and provide refuge for migrants. The expansion of coastal wetlands and estuarine plant species inland with potential sea level rise, supplemented with freshwater sources, could enhance existing marsh, waterfowl and crane species.

Based on this ecosystem assessment, the project team recommends three main zones suitable for preparatory enhancement and restoration activities (Figure 6). Here, the term “preparatory” is used to suggest that benefits from these types of activities may not be fully recognized until a future date and will be dependent on actual meteorological and sea level conditions (rather than model predictions). The main areas identified include Zone A) the barrier island at approximately BI-2 and in Bay habitats towards Pass Cavallo as this area supports higher quality and quantity of seagrass, interspersed oyster hash/shell, existing rookery islands, migratory bird habitat, and sea turtles; Zone B) the coastal marshes on the inland side of the GIWW as they support resident marsh birds, waterfowl, and Whooping Cranes; and Zone C) the expanding reaches of the Colorado River Delta as it supports a growing delta, expanding oyster reefs, and complex estuarine nursery habitats. Restoration efforts in Zone A are recommended to focus on shoreline protection, rookery island development, and seagrass protection in support of birds, habitat, and sea turtles as highlighted in the overall assessment. Restoration efforts in Zone B along the GIWW or Zone C in the Delta are recommended to focus on freshwater inflow enhancement to support long-term habitat as well as short-term refuges. As documented in the overall Matagorda Bay Ecological Assessment, these areas support key components of the food web and nursery habitats to support the productivity of the Bay in times of flood, sea level rise, and extreme drought.

Figure 6. ***Potential Restoration Zones for Consideration within the Matagorda Bay Ecosystem Assessment Project Area.***

Trophic Ecology and Food Web Analysis

The Matagorda Bay food web is robust and supports a wide diversity of consumers through different sources of primary production. Particulate organic matter (POM) has the largest source contribution, indicating the open water habitat of the bay is likely important for fostering plankton communities and sustaining planktivore feeders. Many planktivorous consumers are important prey to the larger bodied, piscivorous predators of the system, enhancing the importance of POM as a key contributor to the Matagorda Bay food web (Figure 7). Benthic production is also an important contributor to omnivores and detritivores but varies over space and time. While seagrasses and marsh habitat sources are reflected among the consumers, it is likely that they are not large diet source contributors themselves and instead support productive and necessary diet sources for the food web. For management recommendations, the flow from the Colorado river is important in establishing the prominent estuarine gradient within Matagorda Bay, allowing for a more diverse and stable food web. Preserving valuable habitat (seagrasses and marsh habitat) and the flow dynamics that exist within the Matagorda Bay system is critical to having a resilient food web in the face of continued anthropogenic and environmental changes.

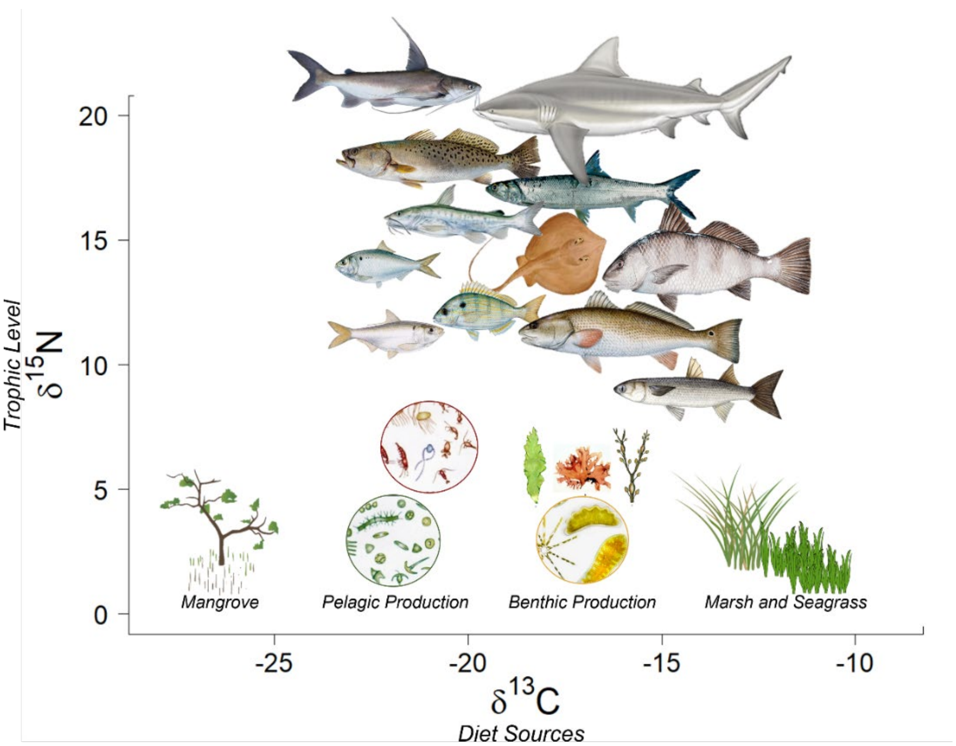

Figure 7. Visual representation of the primary producers and the trophic level of the various consumers found within the Matagorda Bay ecosystem.

Habitat and Resource Use Across the Matagorda Bay Ecosystem

Estuaries are highly dynamic and rapidly changing ecosystems due to their location at the land-sea interface and unique combination of terrestrial and marine influences. Large nutrient inputs from the watershed and organic matter contributions (i.e. primary producers, detrital matter) support many key ecosystem functions, including nutrient cycling, biological production, and maintenance of biodiversity. These functions are maintained by a variety of habitats including seagrass beds, oyster reefs, wind-tidal flats, saltmarshes, and soft-sediment communities. Although differences in function between habitat types have been well characterized, environmental setting and condition can have a distinct impact on function as well. Proximity to adjacent habitats, seasonal changes in water level, and distribution across a landscape can all play a role in how each habitat functions. Here we address how habitat setting and changing environmental conditions can influence community structure and resource use within oyster reefs and wind-tidal flats of Matagorda Bay. We also show how setting can impact resource quality and use across the entire bay ecosystem.

Just as a boreal forest is different from a tropical one, oyster reefs too can vary by location and habitat setting. This has been previously showcased through studies of intertidal and subtidal oyster reefs, where inundation and exposure play a large role in differentiating reef communities. However, these differences in habitat setting can be further nuanced by proximity to other habitats. For instance, subtidal oyster reefs may be found in isolated bars in open-bay settings as well as fringing along the coast directly adjacent to saltmarsh. While both reefs are submerged year-round, their proximity to adjacent habitat, or lack thereof, can have a significant impact on the oyster population and resident reef community. Our findings indicate isolated open-bay reefs have greater overall oyster abundance than marsh-fringing reefs. However, oysters on open-bay reefs have a patchier distribution across a shell-hash bottom, perhaps due to relatively higher rates of physical disturbance from boating traffic and adjacent oyster harvest. These influences on reef structure in turn shape the faunal community, which is dominated by crab species at open-bay reefs. In contrast, marsh-fringing reefs have fewer oysters that are more evenly distributed across a soft-sediment bottom. Human influences here are reduced due proximity to the shore, making them less navigable by boat and protected from harvest under Texas Parks and Wildlife Department regulations. Fauna at marsh-fringing reefs are characterized by higher abundance of infaunal organisms, likely due in part to the proximity to adjacent habitats and reduced impact from human activities. Taken together, these findings indicate that habitat setting plays a significant role in oyster reef structure and functioning.

In addition to a habitat's placement within the larger landscape, changing environmental conditions can also have a large impact on communities and resource quality. As humans we see how daily weather conditions and long-term climate patterns play a role in both plant growth (grass growing after a big rain) and patterns of animal abundances (more squirrels in the spring). The same is true for habitats within estuaries. Wind-tidal flats are a unique habitat in which we can observe this phenomenon. Wind-tidal flats are soft-sediment habitats, often adjacent to saltmarsh, where irregular inundation and exposure favor the dominance of cyanobacterial mats.

These blue-green algae are important for binding sediments, cycling nutrients, recruiting fauna, and supporting wind-tidal flat importance as feeding grounds for wintering and migrating birds. However, long-term changes in inundation frequency place tidal flats at risk worldwide. This work characterized how seasonal inundation and spatial changes across the marsh-tidal flat complex affect community composition and resource quality. Focusing on spring (more inundation) and summer (less inundation) 2021, our findings show increased flooding of wind-tidal flats during the spring was accompanied by greater coverage by cyanobacterial mats. Summer was characterized by less flooding and higher abundance of fauna. Organic matter quality increased moving from the center of the tidal flat and towards the marsh. Seasonal differences in resource quality and community structure likely impact ecological functioning of tidal flats, where changes in infaunal recruitment may have important consequences for foraging organisms, such as shorebirds.

As has been demonstrated, both habitat setting and environmental condition can play a role in how estuarine habitats function. If we zoom out to the scale of an ecosystem, we can see how these differences may contribute to larger patterns of resource availability and quality. We evaluated how the distribution of primary producers from different subtidal habitats (open water, soft-sediment, seagrass bed, oyster reef) contribute to food web functioning across the Matagorda Bay ecosystem. Oyster diets were analyzed to determine how resources may be incorporated into the Matagorda Bay food web based on their distribution and proximity to other habitats within the bay. Our findings indicate that the quality of organic matter in both water and sediment is high across the bay, with the greatest contributions coming from areas with dense seagrass. Analysis of oyster diets demonstrated that the greatest organic matter contributions come from organic matter on oyster shells, benthic algae, and macroalgae, with little variation regardless of position within the bay. Differences in organic matter quantity between sediment and water may help to tease apart differences in resource use when organic matter quality from both sources is high.

Water Quality and Plankton Monitoring using Historical and Ongoing Datasets

Matagorda Bay and its tributaries support highly productive aquatic habitats for birds, fish, and shellfish. However, changing watershed land use, increasing populations and development, and climate variability/change can negatively affect water quality, which is a major determinant of the overall health of estuaries such as Matagorda Bay. Thus, regular assessment of water quality status and trends are important for supporting management and decision making around estuarine ecosystem health. An assessment of water quality in Matagorda Bay using data obtained from the Texas Commission on Environmental Quality's Surface Water Quality Monitoring Program was completed. Analysis of nutrient indicators show that, in general, the Matagorda Bay ecosystem is not currently displaying widespread symptoms of excess nutrients. Based on screening levels set forth by TCEQ, Lavaca Bay and Tres Palacios Bay are exceptions to this statement, as both frequently (>20% of samples collected) exceeded chlorophyll *a* screening levels. Furthermore, Lavaca Bay had one or more stations displaying long-term increases in chlorophyll *a*, TKN or TP, or long-term decreases in dissolved oxygen, all of which point to an ecosystem that is under pressure from watershed nutrient sources. Additional attention clearly needs to be paid to nutrient conditions in Lavaca Bay and its feeder rivers/creeks before harm occurs to the ecosystem. Aside from nutrient-related issues, there are concerns about long-term alterations to freshwater inflow and salinity levels in estuaries of the central Texas coast. Only one station, located near the mouth of the Lavaca River in Lavaca Bay, showed a long-term salinity increase. However, numerous stakeholder concerns have been raised about salinity in the eastern arm of West Matagorda Bay where, unfortunately, no TCEQ monitoring stations are currently active. Additional monitoring is recommended in this data poor region of Matagorda Bay to allow for a more holistic assessment of conditions in the bay.

Phytoplankton are important primary producers in estuaries and represent a link between freshwater inflow and higher order consumers (fish, shellfish). They are also sensitive indicators of environmental variability and change. Estuaries of the Texas coast, such as Matagorda Bay, are vulnerable to long-term decreases in freshwater inflow due to increasing upstream human freshwater needs as well as climate change. Thus, it is critical to understand how phytoplankton communities respond to freshwater inflow variability in order to project how future inflow changes may affect estuarine ecosystem functioning and health. One of the goals of this study was to quantify the influence of variability in Colorado River discharge on nutrients and phytoplankton Matagorda Bay. Over a 24-month period, a suite of environmental variables along with phytoplankton community composition and biovolume was measured. The distribution of nutrients, chlorophyll and phytoplankton were influenced by riverine inflow, with each of these variables being generally in highest concentration near the river and decreasing moving away from the river mouth. There were no obvious signs of excessive nutrient loading coming from the river, highlighting the essential role of the Colorado River in fertilizing the productivity of Matagorda Bay. Phytoplankton functional groups had distinct responses to environmental variability, but diatoms were consistently the largest contributor to overall phytoplankton community biovolume, likely due to high wind speeds in the area. Overall, these findings highlight the essential role that the Colorado River plays in the Matagorda Bay ecosystem.

Project Findings Summary

There is wide consensus in the scientific community that to conserve natural resources, managers must take an ecosystem-based management approach. This assessment of West Matagorda Bay was unique in that it was the first study to integrate a broad ecosystem-based management approach to fully gain an in-depth understanding of the fundamental underlying ecological processes and stressors that interact to support a resilient ecosystem. The data presented here help identify and prioritize areas for protecting and sustaining marine populations within this estuarine complex.

To address those needs, we assembled an expert team consisting of world-class sea turtle biologists and marine ecologists to meet the needs of this research effort. The overall goal of this project was to inform the development of effective restoration and conservation strategies for endangered sea turtles by implementing a multi-disciplinary ecosystem assessment for West Matagorda Bay. To accomplish this goal, the team addressed a set of key research objectives to address the overall goal of informing the development of effective restoration and conservation strategies for endangered sea turtles and birds by implementing a multi-disciplinary ecosystem assessment of West Matagorda Bay.

Key Deliverables and Takeaways:

The key deliverables and takeaways are summarized below. For specific details on these findings, see the full technical report.

Habitat Mapping – We develop detailed habitat maps forming the basis of the study. As the primary function of an estuary relies on an understanding of these foundational habitats, this mapping allows assessments and visualization of biological and physical characteristics of the estuary on a spatial and temporal basis. These delineations showed how key areas support the species of interest situated within the habitat mosaic but also how they will be affected by flooding events and any potential sea rise in the future.

- Having these comprehensive baseline maps allowed for a detailed evaluation of the West Matagorda Bay project area that included an assessment of the abundance, community composition, distribution, seasonality, and habitat trends.
- Land cover dynamics were assessed over numerous time scales (past, present, and future) to gain a better understanding of West Matagorda Bay. These allowed for documentation of habitat changes since the mid-1800's along with modeling of local coastal habitat changes predicted under two sea-level rise (SLR) scenarios and further characterized vulnerable habitat locations as future management priority areas.
- The intertidal and bordering uplands of the Matagorda Bay system were mapped using state-of-the-art high-resolution multispectral satellite imagery. The imagery was

combined with topographic lidar data with similar spatial resolution plus earlier land classification data with a 30-m pixel scale in a novel processing routine that classifies intertidal and marginal upland environments.

- Georeferencing of historical maps and vertical aerial photographs plus information from prior studies of coastal change reveal the morphodynamics of the Colorado River Delta, Matagorda Peninsula, and the eastern portion of Matagorda Island during the last 170 years. Matagorda Peninsula and Island are barrier features, which protect Matagorda Bay from high-energy conditions as well as host habitats themselves. From 1850 to 2020, the combined intertidal and upland areas experienced a net decrease in area from 97 to 78 km^2, a 20% reduction in size. The Colorado River Delta, on the other hand, increased in size from about 2 km^2 to 23 km^2, adding valuable marsh habitat to the bay.
- Matagorda Bay is experiencing Sea Level Rise (SLR) making bay margin environments susceptible to changes in habitat types. Results from the Sea Level Affecting Marshes Model (SLAMM) were compiled and assessed for the intertidal and bordering uplands of the Colorado Delta, Matagorda Peninsula, and the eastern portion Matagorda Island. All areas are projected to increase in open water in both 0.5- and 1.5-m SLR scenarios by the year 2100. Most notably, the majority of the Colorado River Delta marsh is projected to convert to tidal flats under the 0.5-m scenario and to open water in the 1.5-m scenario. Matagorda Peninsula and Island are expected to experience a decrease in estuarine mash in both scenarios.
- SLR land cover change modeling results, storm surge vulnerability maps, and a detailed topographic model developed from lidar data were combined in a habitat vulnerability map for the entire intertidal and bordering upland margin of the Matagorda Bay system. The map shows areas of present and future critical habitats that provide valuable ecosystem functions. For the 0.5 m SLR scenario, 239 km^2 of current marsh, beaches, dunes, and tidal flats are expected to remain as critical habitat, 166 km^2 of non-critical habitat are expected to become critical habitat, and 72 km^2 are expected to become open water under the 0.5 m GMSLR scenario. However, under the 1.5 m SLR scenario, only 112 km^2 of current marsh, beaches, dunes, flats are expected to remain as critical habitat, 226 km^2 are expected to become critical habitat, and 212 km^2 are expected to become open water. Under the 1.5 m scenario, basically all present-day marsh and flat areas are converted to open water while presently stable upland habitat is converted to critical habitat. This emphasizes the importance of preserving upland environments susceptible to transitioning to critical habitats as sea level rises and storms persist.

Sea Turtle Movement – We established an extensive animal tracking component for key species of interest, allowing an understanding of distribution, migration, and movement patterns for these animals of interest. We showed how the bay supports endangered species, promotes/enhances recovery, and developed long-term scientific recommendations for sustaining and enhancing their populations. This first-of-its-kind study provides an in-depth understanding of the ecosystem that supports threatened and endangered sea turtles. In this ecosystem-based approach, we developed effective management and conservation strategies that can be used to identify and prioritize areas to protect for sea turtles within the estuarine complex by describing their distribution, seasonal habitat use, and migration patterns along the Gulf of Mexico including drivers for these movement patterns. Finally, we provided data on the ecological roles of sea turtles in this estuarine complex, the health of the sea turtles, and the ecosystem processes that impact these marine reptiles.

- Texas bays and estuaries provide one of the most important developmental habitats for green turtles in the northwestern Gulf of Mexico. Our study confirms that Matagorda Bay provides important developmental feeding and resting areas for green turtles, with populations increasing since the 1990's, and extends the range of critical habitat for the species further north than previously documented.
- Most of the green turtles we tracked with satellite and acoustic transmitters remained resident in Matagorda Bay; however, we also found connectivity with other Texas bays and the Gulf of Mexico and Mexican waters.
- The high use areas we identified in this study, including the seagrass beds and the jetties in west Matagorda Bay, require special management consideration or protections for immature and juvenile green turtles that use these areas daily to feed, rest, develop, and grow. We recommend prioritizing areas of high seagrass diversity for the protection of green turtle foraging habitat.
- We also recommend managing the seagrass beds present to maintain their abundance and diversity of seagrass species critical to green turtles in Matagorda Bay.
- We also recommend special consideration of the jetties in the Matagorda Ship Channel due to the high number of sea turtles sighted and the multiple species observed there.
- Changing ambient and water temperatures, particularly below 15°C, are drivers of green turtle movements within and outside Matagorda Bay. Targeted search and rescue efforts for cold-stunned turtles should begin when water temperatures decline below 10°C.

Biological Sampling – Benthic habitats (including seagrasses, oyster reefs, and open bay bottom) throughout the project area support thriving and diverse ecological communities. This study demonstrated that recruitment to and use of seagrass and saltmarsh habitats by post-settlement nekton in Matagorda Bay was linked to biological and physicochemical properties of the estuary during settlement and early life periods. For the avian component, we observed a bird community typical of a Texas Gulf Coast estuarine ecosystem. Seasonal marsh vegetation sampling within the bay demonstrated the high degree of temporal and spatial variation in estuarine saltmarsh communities, differing both across and within study sites.

- This study provides insights for management of this important Texas estuary by identifying conditions related to high abundance and diversity of post-settlement fishes, which are known to influence population and ecosystem resilience.
- Seagrass and saltmarshes are major components of estuarine habitats in Matagorda Bay, and these structured habitats serve as nurseries for a wide range of fishes.

- Seagrass consistently had higher abundances of post-settlement fishes than saltmarsh, and the density of fishes in both habitats differed by season and year.
- Diverse assemblages were present in both seagrass and saltmarsh habitat and both diversity measures evaluated at the family level (taxonomic richness and Shannon diversity) differed significantly between seasons and years.
- Community structure differed significantly between seagrass and saltmarsh habitat driven primarily by families of fishes that use these nursery habitats seasonally (drum and croaker, flounder, mojarra, and pipefishes) and highly abundant resident taxa that occur throughout the year (gobies, porgies, and killifishes).
- Density, richness, and diversity of juvenile fishes in Matagorda Bay were related primarily to three factors: habitat type (seagrass vs. saltmarsh), dissolved oxygen, and distance to tidal pass.
- Species in the family Sciaenidae revealed species-specific differences in habitat use, with staggered entry into Matagorda Bay nurseries to presumably limit temporal overlap and potential competition.
- The study confirmed and documented the unique ecological nuances with respect to diversity and abundance of marsh vegetative communities and coastal bird assemblages between the barrier island sites and the more inland marsh locations.
- We observed multiple species of rail inhabiting the lower marsh habitats, an abundance of tern, heron, and wading bird species utilizing the marsh fringe, and large flocks of shorebirds foraging and roosting on the tidal flats.
- Overall, the ecological diversity of organisms varies both spatially and temporally and is largely driven by the interactive effects of a myriad of environmental factors.

Trophic Ecology and Food Web Analyses – We showed that the Matagorda Bay food web is robust and supports a wide diversity of consumers through different sources of primary production.

- Particulate organic matter (POM) has the largest source contribution, indicating the open water habitat of the bay is likely important for fostering plankton communities and sustaining planktivore feeders. While seagrasses and marsh habitat sources are reflected among the consumers, it is likely that they are not large diet source contributors themselves and instead support productive and necessary nursery habitat for the food web.
- Due to the heterogeneity of the Matagorda Bay system, the food web is best understood by analyzing across different spatial scales and regions throughout the bay.
- Many planktivorous consumers are important prey to the larger bodied, piscivorous predators of the system, enhancing the importance of POM as a key contributor to the Matagorda Bay food web.

- Benthic production is also an important contributor to omnivores and detritivores but varies over space and time.
- Preserving valuable habitat (seagrasses and marsh habitat) and the flow dynamics that exist within the Matagorda Bay system is critical to having a resilient food web in the face of continued anthropogenic and environmental changes.

Habitat and Resource Use across the Matagorda Bay Ecosystem – We showed that Matagorda Bay is a highly dynamic and rapidly changing ecosystem due to its location at the land-sea interface and unique combination of terrestrial and marine influences.

- Large nutrient inputs from the watershed and organic matter contributions support many key ecosystem functions.
- These functions are maintained by a variety of habitats including seagrass beds, oyster reefs, wind-tidal flats, saltmarshes, and soft-sediment communities.
- These results also demonstrate that habitat setting can impact resource quality and use across the entire bay ecosystem. For example, isolated open-bay reefs have greater overall oyster abundance than marsh-fringing reefs. Taken together, these findings indicate that habitat setting plays a significant role in oyster reef structure and functioning.
- The wind-tidal flats of this system are important for binding sediments, cycling nutrients, recruiting fauna, and serving as feeding grounds for wintering and migrating birds.

Water Quality and Plankton Monitoring – Water quality is a key determinant of ecosystem health. Other components of the study showed that Matagorda Bay and its tributaries generally support highly productive aquatic habitats for birds, fish, and shellfish, which can be attributed in part to good water quality. However, changing watershed land use, increasing populations and development, and climate variability/change can negatively affect water quality, and there are indications that water quality in the ecosystem is not as healthy as it was in previous years.

- Regular assessment of water quality status and trends are important for supporting management and decision making around estuarine ecosystem health.
- Additional attention is recommended to studying nutrient conditions in Lavaca Bay and its feeder rivers/creeks before harm occurs to the ecosystem.
- This study also underscores the impact of long-term alterations to freshwater inflow and salinity levels in estuaries of the central Texas coast.
- Additionally, our plankton community studies highlight the essential role that the Colorado River plays in the Matagorda Bay ecosystem.

Recommendations for Future Management:

Together this work focused on two key overall deliverables to be met. Specifically, these were:

(1) Recommendations for mitigation and restoration activities that will address impacts of flooding and sea rise for Species of Interest; and

(2) Identification of priority areas in need of protection, where the implementation of mitigation and restoration activities would be feasible and beneficial.

First, our baseline mapping allowed for determination of the status of habitat types and coverages within the estuary, and we have provided detailed habitat maps. Our intense fine-scale mapping studies allowed us to assess habitat changes from the mid-1800's to present. This coupled with modeling of local coastal habitat changes allowed for creating predictable land-use changes under two sea-level rise (SLR) scenarios. This enables further characterization of vulnerable habitat locations as prioritization of future area in need of protection, management, or restoration.

As is common with estuaries, the ecological diversity of organisms varies both spatially and temporally and is largely driven by the interactive effects of a myriad of environmental and ecological factors. This underscores the need for more ecosystem-level studies such as this. These dynamics are captured in the overall Matagorda Bay Ecological Assessment Report. The ecological interconnectivity in estuaries such as Matagorda Bay speak to the productivity of the Bay, but also presents challenges on how to address potential ecological change over time with respect to flooding and sea level rise. Briefly:

- A variety of restoration strategies have been designed and implemented within similar systems, with varying degrees of practicality and effect. In addition, the allocation of resources to one strategy over another depends on overall project goals (i.e., managing for diversity vs. managing for a single species). This report specifically addresses these needs and prioritizes areas in most need of protection.
- The flow from the Colorado River is important in establishing the prominent estuarine gradient within Matagorda Bay, preserving valuable habitat (seagrasses and marsh habitat), is critical to having a stable diverse food web and is a major driver for the estuarine complex.
- This study provides insights for management of this important Texas estuary by identifying conditions related to high abundance and diversity of post-settlement nekton, which are known to influence population and ecosystem resilience. These parameters were driven by the availability of key habitats, and particular attention to those habitat types is clearly warranted for future conservation.
- Results from our study suggest that estuarine vegetation habitats such as seagrasses and salt marshes support the highest abundance and species diversities for birds. Moreover, among avian species observed, Eastern Black Rail are more closely associated with marsh habitats.

- Increases in oyster bed foraging habitat would be beneficial for the American oystercatcher and other shorebirds by creating habitat, forage, and shoreline protection.
- The creation of temporary rookery islands could benefit colonial waterbirds and provide refuge for migrants. The expansion of coastal wetlands and estuarine plant species inland with potential sea level rise, supplemented with freshwater sources, could enhance existing marsh, waterfowl and crane species.
- Restoration and mitigation opportunities are numerous within the project area, and it is imperative that this expansive database and maps be thoroughly examined and considered a priori, and the desired ecological goals be clearly articulated to maximize success in future development and implementation.
- The wind-tidal flats of this system are important for binding sediments, cycling nutrients, recruiting fauna, and supporting wind-tidal flat importance as feeding grounds for wintering and migrating birds. However, long-term changes in inundation frequency place tidal flats at risk worldwide. This work characterized how seasonal inundation and spatial changes across the marsh-tidal flat complex affect community composition and resource quality. Seasonal differences in resource quality and community structure likely impact ecological functioning of tidal flats, where changes in infauna recruitment may have important consequences for foraging organisms, such as shorebirds.
- Additional attention to nutrient conditions is recommended in Lavaca Bay and its feeder rivers/creeks to monitor any potential impacts to the ecosystem.
- Only one water quality station, located near the mouth of the Lavaca River in Lavaca Bay, showed a long-term salinity increase. However, numerous stakeholder concerns have been raised about salinity in the eastern arm of West Matagorda Bay where, unfortunately, no TCEQ monitoring stations are currently active. Additional monitoring is recommended in this data poor region of Matagorda Bay to allow for a more holistic assessment of conditions in the bay.
- Phytoplankton are important primary producers in estuaries and represent a link between freshwater inflow and higher order consumers (fish, shellfish). They are also sensitive indicators of environmental variability and change. Estuaries of the Texas coast, such as Matagorda Bay, are vulnerable to long-term decreases in freshwater inflow due to increasing upstream human freshwater needs as well as climate change. Thus, it is critical to understand how phytoplankton communities respond to freshwater inflow variability in order to project how future inflow changes may affect estuarine ecosystem functioning and health.

In summary, data generated from an ecosystem-based approach such as this study will be crucial to developing effective restoration and conservation strategies, and it can be used to identify and prioritize areas for long-term protection of endangered species such as turtles, coastal birds, and many other species. While this work is extensive, it also sets the stage for future research and other studies that will further contribute toward understanding how the Matagorda Bay Ecosystem functions. Moreover, this study generated key baseline information that will be essential to gauge progress and make predictions about and assess future changes in the Matagorda Bay System.