Final Report

Colorado River Delta Ecosystem Assessment: Gathering key baseline data to guide future habitat restoration in Matagorda Bay

MBMT Contract No. 0015

Reporting Period: 01 March 2021 – 31 July 2023

Submitted by:

Gregory W. Stunz, Ph.D.
Matthew K. Streich, Ph.D.
Harte Research Institute for Gulf of Mexico Studies
Texas A&M University-Corpus Christi
6300 Ocean Drive, Unit 5869
Corpus Christi, TX 78412
Telephone: 361-825-3254
Email: greg.stunz@tamucc.edu

and

BIO-WEST, Inc.
1812 Central Commerce Court
Round Rock, TX 78664

Submitted to:

Steven J. Raabe, P.E., Trustee
Matagorda Bay Mitigation Trust
P.O. Box 1269
Poth, TX 78147
Via Email to: Trustee@mbmtrust.com

October 2023

Table of Contents

List of Tables

List of Figures

Acknowledgements

The Matagorda Bay Mitigation Trust provided financial support for this project through contract number 0015.

We thank the Harte Research Institute for Gulf of Mexico Studies for their administrative and logistical support. Numerous staff and students from the Center for Sportfish Science and Conservation provided valuable assistance with nekton and water quality sampling in the field and spent significant time in the lab processing nekton samples including Jason Williams, Jeff Kaiser, Quentin Hall, Jensen Smith, and Anastasia Canu.

In addition, we would like to thank the many dedicated BIO-WEST ecologists who contributed to this endeavor. The benthic habitat mapping and coastal bird survey components of this project were labor intensive and involved many hours in the field and post-processing. In addition, BIO-WEST ecologists conducted the hydrological assessment aimed at determining future options for freshwater inflow mitigation strategies during extended periods of drought.

Executive Summary

The presently expanding Colorado River Delta supports some of the most critical nursery habitats in the Matagorda Bay ecosystem and arguably along the Texas Gulf Coast. This assessment of the Colorado River Delta took an ecosystem-based approach and comprised habitat mapping, seasonal monitoring of estuarine nekton and coastal bird communities, and a hydrological assessment to evaluate potential viability of future sites for freshwater mitigation projects. Overall, shorebird and migratory bird species composition and abundance maintained a relatively high overlap between all sites. However, the site north of the Gulf Intracoastal Waterway (GIWW) was characterized by an increased prevalence of passerines due to the presence of nearby woodland and grassland areas. This site also exhibited the most avian species and greatest diversity. Nekton communities were composed of both resident and estuarine-dependent species. Nekton samples in this study were dominated by grass shrimp and penaeid shrimp, important prey resources for a variety of organisms including coastal birds and sportfish such as spotted seatrout and red drum. Taken with the frequent finding of seasonal effects on nekton species, this study suggests that all areas where nekton were sampled served as important nursery habitat and contributed to the overall productivity of the Colorado River Delta.

Potential freshwater inflow projects aimed at maintaining nekton abundance and overall ecosystem functioning during extreme droughts should consider sites that may more frequently depart from brackish conditions or more frequently reach salinity extremes. The northern two sites investigated in this study meet these criteria and also appear to be the most feasible from a water quantity perspective. Staying north of the GIWW has the advantage of reducing the amount of freshwater that might be needed as a result of no loss to the waterway. A second site adjacent to an existing cut that also supports live oysters, quality nekton habitat, and diverse coastal bird assemblages is another location worthy of future study. It is recommended that a water distribution pilot project be conducted to test the concept that additional freshwater input could indeed be detected in this area and offer a benefit to the existing ecological community.

Although the results from this study provide the initial steps to understanding how differences in environmental conditions influence the biotic communities of the Colorado River Delta at varying spatiotemporal scales, additional long-term monitoring is required to relate ecological variability to specific environmental variables such as freshwater inflows. Additional seasonal monitoring of these upper two sites and one or two control sites further out in the delta is recommended with respect to site-specific salinity, nekton use, marsh vegetation composition and biomass, and oyster reef health. This additional study would help to better quantify typical environment-related shifts in habitat utilization by estuarine-dependent species in this area.

This Colorado River Delta ecosystem assessment was successful in developing an updated comprehensive ecological baseline for benthic habitats, nekton assemblages, and coastal birds. A hydrological assessment was performed to examine potential water sources, water quality, and distribution options that may be available to support the Colorado River Delta's existing ecological functions during extended periods of drought. This report describes the study area, experimental design, methodologies implemented, and study results over the course of the two-year project. Finally, this report outlines some conceptual ideas for Colorado River Delta conservation aimed at ecological sustainability during extended drought.

Introduction

The Colorado River Delta supports some of the most critical nursery habitats in the Matagorda Bay ecosystem and is one of only a handful of deltas along the entire Texas Gulf Coast that is presently expanding. This thriving delta supports a full spectrum of the estuarine food web – from plankton, shrimp, crabs, forage fish, speckled trout and redfish, to endangered species such as whooping cranes and Kemp's ridley sea turtles – while also supporting numerous industries including commercial and recreational fishing, farming and agriculture, and tourism (Stunz et al. 2023). Despite its current level of productivity, the Colorado River Delta is under many of the same stresses that other estuaries face including habitat degradation, climate change, changes to freshwater inflows, and increasing frequency of ecological extremes such as drought.

The quality, quantity, and timing of freshwater inflow alters the condition of estuaries, which in turn drives the structure, function, and sustainability of estuarine habitats (Alber 2002). Freshwater inflows are heavily influenced by large-scale climatic cycles, which are becoming more variable over time (Tolan 2007; Pollack et al. 2011). In Texas, water demand and evaporation are expected to increase in the future, while water supply is expected to decrease (Nielsen-Gammon 2011), resulting in increased stresses on estuarine ecosystems. Considering freshwater inflows drive water quality and subsequently productivity through changes to nutrient and chlorophyll concentrations (Montagna et al. 2018), it is imperative to gather and understand baseline data on biological communities at the riverine-marine interface.

Despite its ecological and economic importance, relatively little research has been recently been conducted on the distribution, abundance, and health of the many important habitats and biological communities in the Colorado River Delta and its value to the overall health of the Matagorda Bay Ecosystem. The Matagorda Bay Ecosystem Assessment (MBEA), a recent multimillion dollar study, provided a comprehensive assessment of habitat availability and distribution, water quality, coastal bird and sea turtle ecology, food web evaluation, and biological communities inhabiting key habitats such as seagrass meadows, saltmarsh, and oyster reef in the lower portion of Matagorda Bay (Stunz et al. 2023). Notably, due to project directives, habitats and biological communities were not fully evaluated in the Colorado River Delta. Other previous work supported by the Lower Colorado River Authority (LCRA) and San Antonio Water System (SAWS) included the development of a dynamic salinity and bay habitat model for the Colorado River Delta and Matagorda Bay (MBHE 2007, MBHE 2008). This project provided extremely valuable information to build upon but lacked enough up to date components to complete the delta restoration picture during extended drought.

The overarching goal of this study was to provide an updated ecological baseline that can inform the design and implementation of future habitat restoration efforts focused maximizing the distribution of available freshwater inflow to support key habitats and water quality in the Colorado River Delta. Three primary tasks and corresponding specific objectives guided this effort and included:

Task 1: Perform a detailed benthic habitat characterization of the Colorado River Delta study area to provide an updated habitat baseline.

1) Develop a comprehensive benthic habitat map for the entire project area using a combination of aerial imagery interpretation and an acoustic remote sensing survey.

Task 2: Conduct a comprehensive ecological assessment linking the distribution of species and their habitats spatially within the Colorado River Delta study area.

1) Complete two years of seasonal ecological data collection for juvenile finfish and shellfish, marsh vegetation, and coastal birds.

2) Capture a full range of inflow conditions to characterize ecological conditions over time and under different seasonal stresses, in particular drought.

Task 3: Complete a hydrological assessment to better understand water availability, flow paths, and topography in the Colorado River Delta.

1) Complete a comprehensive literature review, desktop investigation, and on-site evaluation of potential freshwater inflow enhancement opportunities.

2) Use ecological and hydrological data collected in this study to establish and promote future water quality monitoring zones.

3) Use seasonal long-term ecological data and hydrological data coupled with existing information to best select, design, and assess future habitat restoration and freshwater inflow enhancement projects in the Colorado River Delta aimed at ecosystem sustainability during drought.

Methods

Task 1 – Benthic Habitat Characterization

Benthic habitat characterization was completed using both side-scan sonar and air and spaceborne optical imagery. The side scan sonar was helpful in identifying oyster reefs and hard substrate in areas too deep to use optical imagery. Conversely, optical imagery was more appropriate to document oyster reef and submerged aquatic vegetation in areas too shallow to traverse in a research vessel. Together, these techniques were applied to the Colorado River Delta which comprises approximately 5,500 acres. During times of the year, the Colorado River Delta includes a salinity gradient moving away from the mouth of the Colorado River towards the open bay. Five main habitat types of interest were identified because of their direct or indirect support of estuarine fauna: salt marsh, oyster reef, submerged aquatic vegetation, non-vegetated bottom, and algal flat. The benthic marine habitat survey followed protocols accepted by the Texas Parks and Wildlife Department (TPWD), U.S. Army Corps of Engineers (USACE), and National Marine Fisheries Service (NMFS). The benthic habitat map was compiled in three basic phases including optical imagery interpretation; remote sensing survey; and limited ground-truthing through physical investigation.

Optical Imagery Interpretation

Due to the limited depth of the Colorado River Delta, benthic mapping of the project area using side-scan sonar was supplemented with high-resolution satellite imagery. Recently captured high-resolution multispectral satellite imagery from 2020 through 2022 was sourced from three private companies across a range of dates and tidal conditions. Esri ArcMap supervised classification was utilized to split landcover types of oyster reef/shell hash beds from open water, vegetated earth, and bare earth, and the imagery-delineated oyster reef was exported and compared between imagery sources to cross-check imagery classification results. An example of the Landcover classification of high-resolution satellite imagery collected over multiple periods in the last three years analyzed to identify oyster beds is shown in **Figure 1**. These identified areas were also compared to hard shell surfaces located during sonar mapping of the area (next section).

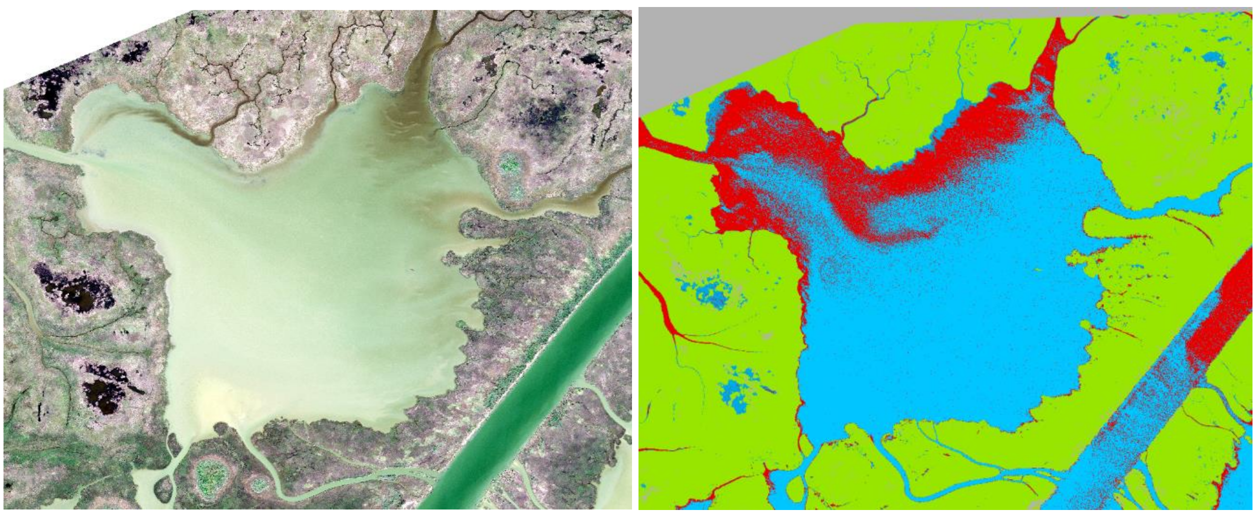

Figure 1. High resolution satellite imagery from November 2022 and groundcover classification to extract oyster bed areas for comparison against sonar imaging.

Sonar Remote Sensing Survey

For areas too deep to capture with satellite imagery, remote sensing equipment was utilized and included a differentially-corrected global positioning system (DGPS), fathometer, and side-scan sonar towed from a survey vessel. Navigation and positional information for the survey vessel and each instrument sensor was collected along with depth soundings at a rate of one reading per second along all survey transects traveled. Vessel speed during the survey was approximately five knots, providing in-line depth spacing of approximately 6.8 feet. A minimum water depth of 2.5 feet is required to provide adequate depth for the sonar and draft for vessel navigation. The resulting marine resources data includes: depth contours, side-scan sonar imagery and ground verification locations. Identified features were geo-rectified and made available for electronic dissemination in ArcGIS or Google Earth format, and the sonar-mapped benthic surface was cross-checked against oyster reef identified by landcover classification of high-resolution satellite imagery. **Figure 2** highlights the areas surveyed using remote sensing equipment.

Figure 2. Side-scan Sonar imaging within the study site area of the Colorado River Delta.

Physical Investigation

Upon completion, interpretation and compilation of satellite and remote sensing imagery, project team ecologists visited an array of sites in May 2023. For this limited ground-truthing effort, processed electronic data was loaded onto a DGPS with sub-meter accuracy, which uses real time data to show current position in relation to the mapped substrate anomalies. Traveling in a shallow-draft, survey vessel the team traversed across the project area to assess randomly selected sites within both oyster reef/shell hash and non-reef open water. This field effort was conducted to verify the accuracy of the delineated oyster reef from both remote sensing methods.

Task 2 – Ecological Assessment

Nekton Abundance and Community Structure

Juvenile nekton (e.g., fish, shrimp, crabs, etc.) were sampled from marsh-edge habitat at five sites within the Colorado River Delta using an epibenthic sled (**Figure 3**). The epibenthic sled consists of a metal frame (0.75 m high × 0.6 m wide) with a 1-mm mesh conical plankton net, and it has been well established as an efficient sampling gear for small nekton in Texas estuaries (Stunz et al. 2002; Neahr et al. 2010; Nevins et al. 2014). At each site, the sled was towed by hand for 17 m, covering 10 m^2 of bottom along flooded marsh edge. Samples from each tow were rough sorted in the field before preservation in 10% buffered formalin. Two sampling events were conducted each season (spring: May-June, summer: August-September, fall: October-November, winter: February) from spring 2021 through fall 2022. Three independent epibenthic sled tows were conducted at each of the five sites during each sampling event, resulting in 30 samples/season or six samples/site/season. Concurrent water quality samples were also collected at each sampling site and included water temperature (°C), dissolved oxygen (mg/L), and salinity (ppt).

In the laboratory, fishes and crustaceans in each sample were sorted, counted, identified to the lowest possible taxon, measured. If more than 22 individuals of each species or group were counted, the largest, smallest, and 20 randomly selected individuals were measured (Reese et al. 2008). Fishes were measured using standard length (SL), shrimps were measured using total length (TL) between the tip of rostrum and the telson, and crab species were measured using carapace width (CW). After each sample had been processed, all nekton were preserved in 70% ethanol for long-term storage.

Mean density (no./m^2), relative abundance (RA %), frequency of occurrence (FO %), and mean size (mm) were calculated for each species or taxonomic group during each season. Mean density was calculated from all samples collected each season, and mean size was calculated from the total number of individuals of a species measured during that season. Relative abundance was calculated as the percent of individuals of a species in the total number of fishes or crustaceans in a particular season (Reese et al. 2008). Frequency of occurrence was the number of tows that an individual species occurred out of the total number of tows in a particular season. Because we were also interested in potential site differences that might inform future restoration or water modification projects, mean density, mean size, and relative abundance were also calculated for each site.

Density data were analyzed using a three-way ANOVA with year, season, and site as main factors. This model was used for key species groups (total organisms, total fish, total crustaceans, grass shrimp, and penaeid shrimp) or species of interest (Atlantic croaker, red drum, spotted seatrout). When significant interactions among the main factors were detected, post-hoc ANOVAs and/or Tukey's Honestly Significant Difference (Tukey's HSD) was used to determine which levels of each factor differed from each other. The distribution of residuals was evaluated, and density and size data were log(x+1) transformed to ensure homogeneity of variance and normality of residuals. A multivariate analysis was also conducted to evaluate differences in nekton communities among seasons and sites using PRIMER v7. Mean densities for each species or taxonomic group were calculated by sampling event (date) for each site.

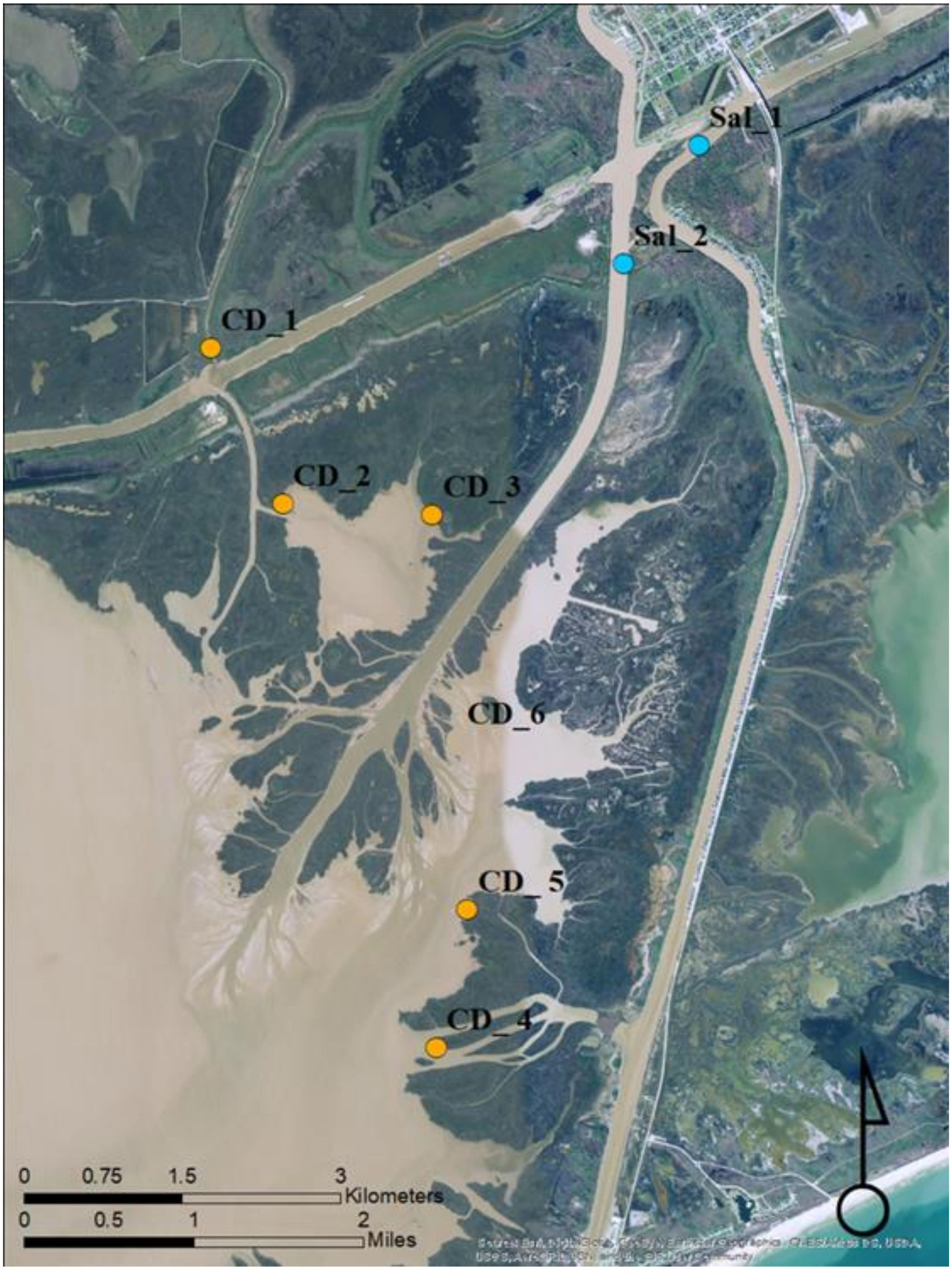

Figure 3. Map of the study area showing locations of nekton (CD_1 to CD_5) sampling and additional salinity sampling sites in the Colorado River Delta. CD_6 was too shallow to effectively sample for nekton but did involve avian monitoring.

Data were fourth root transformed prior to analysis to down weight the contribution of dominant species (e.g., grass shrimp) and allow for changes in uncommon species to be statistically discernable in subsequent analyses (Clark and Green 1988). These data were then converted into a resemblance matrix using Bray-Curtis similarities. Nonmetric multidimensional scaling (nMDS) was run on the resemblance matrix to visually assess group structure among our samples. Nekton community differences were assessed using a two-way analysis of similarities (ANOSIM; Clark and Green 1988) with season and site as factors. To evaluate annual variability, season-year combinations were used for season (e.g., spring '21, spring '22, summer '21, summer '22, etc.). Pairwise comparisons were conducted for significant factors to determine which sites or seasons were different. This analysis was followed with hierarchical agglomerative clustering (via CLUSTER) and similarity profile (SIMPROF) testing to determine whether it was appropriate to interpret the resulting nMDS groupings. Species specific contributions to the observed similarity or dissimilarity among seasons or sites were assessed using a similarity percentage (SIMPER) analysis (Clark et al. 1993). Finally, a BEST analysis (i.e., BIO-ENV) was performed to determine which combination of water quality variables (water temperature, salinity, dissolved oxygen) best explained the variation in observed nekton communities (i.e., highest Spearman's rank correlation coefficient ρ; Clarke 1993; Clarke and Ainsworth 1993). Vector plots of key species (based on SIMPER) and water quality variables from BEST were overlaid onto the nMDS plot to help visualize nekton community differences among our samples. All tests of significance were conducted using an α value of 0.05.

Coastal Bird Surveys

To establish a baseline of avian communities across study sites and habitat types, timed point counts were conducted at six overall study sites adjacent to or nearby the nekton sites during all seasons between Spring 2021 to Winter 2023. Six timed point counts were conducted per site during each sampling event, including three counts located in proximity to emergent vegetated marsh edge (ME) and three located in non-emergent vegetated bay bottom (SB). The selection of timed point count locations occurred in the field at the time of each sampling event and was influenced by the seasonal variation in accessibility and availability of habitat types. Timed point counts were conducted for a 10-minute period. During timed point counts, all avian species observed (identified either aurally or visually), number of individuals, habitat associations at the time of observation, and relevant climate parameters were recorded (Verner 1985; USDA 1997). Additionally, acoustic recorders were deployed and set to record continuously at each of the six sample sites. Recorders were set prior to the onset of avian point counts and retrieved at the conclusion of each survey effort. Acoustic analysis for all sampling focused on reviewing recordings for evidence of calling Eastern Black Rail (*Laterallus jamaicensis)* and Whooping Crane (*Grus americana*).

<u>Task 3 – Hydrological Assessment</u>

To better understand these flow paths and topography of the Colorado River Delta project area, a desktop investigation focusing on landforms, topography, existing flow paths, habitat connectivity and water quality was conducted. The investigation used the aforementioned historical (MBHE) and more recent (MBEA) data sets, high-resolution satellite imagery and May 2023 field assessment to examine and explore potential water sources and distribution options that may be available to support Colorado River Delta ecological functions during extended periods of drought.

Results

Task 1 – Benthic Habitat Characterization

Multispectral satellite imagery was utilized in color infrared band combination to visually separate vegetation from water and bare earth. Training samples were created for visibly recognizable areas of open water, inland water, vegetation/earth, and oyster reef and applied across the entire raster dataset for supervised classification of the landcover (**Figure 4**). The resulting raster yielded likely oyster reef regions, and was converted to vector data and smoothed. Subsequent ground-truthing of 48 randomly selected sample points within delineated areas of oyster reef from the imagery confirmed live oyster presence at 89.2% of sites where oysters were expected (33 of 37 sites) and at 26.7% of adjacent near-shore areas where reef was not delineated from imagery (4 of 15 sites). Although imagery classification showed many areas of inland water and channels to be possible oyster reef, this was assumed to be errors from similar pixel values which was confirmed during ground-truthing. Thus, these areas were cleaned and removed from final oyster reef mapping (**Figure 5**).

Due to the extreme low tide during ground-truthing, oyster reefs were observed in several areas not previously mapped as reef sites, such as along the banks of Old River (Site 1) (**Figure 6**) and along the sides of the cut extending from the GIWW towards Site 2. These areas were outside of the original benthic habitat boundary, so no multispectral satellite imagery was obtained or processed for these areas. These hard substrate areas were documented during sonar survey efforts and it was confirmed that these reefs supported live oysters during the May 2023 field verification effort.

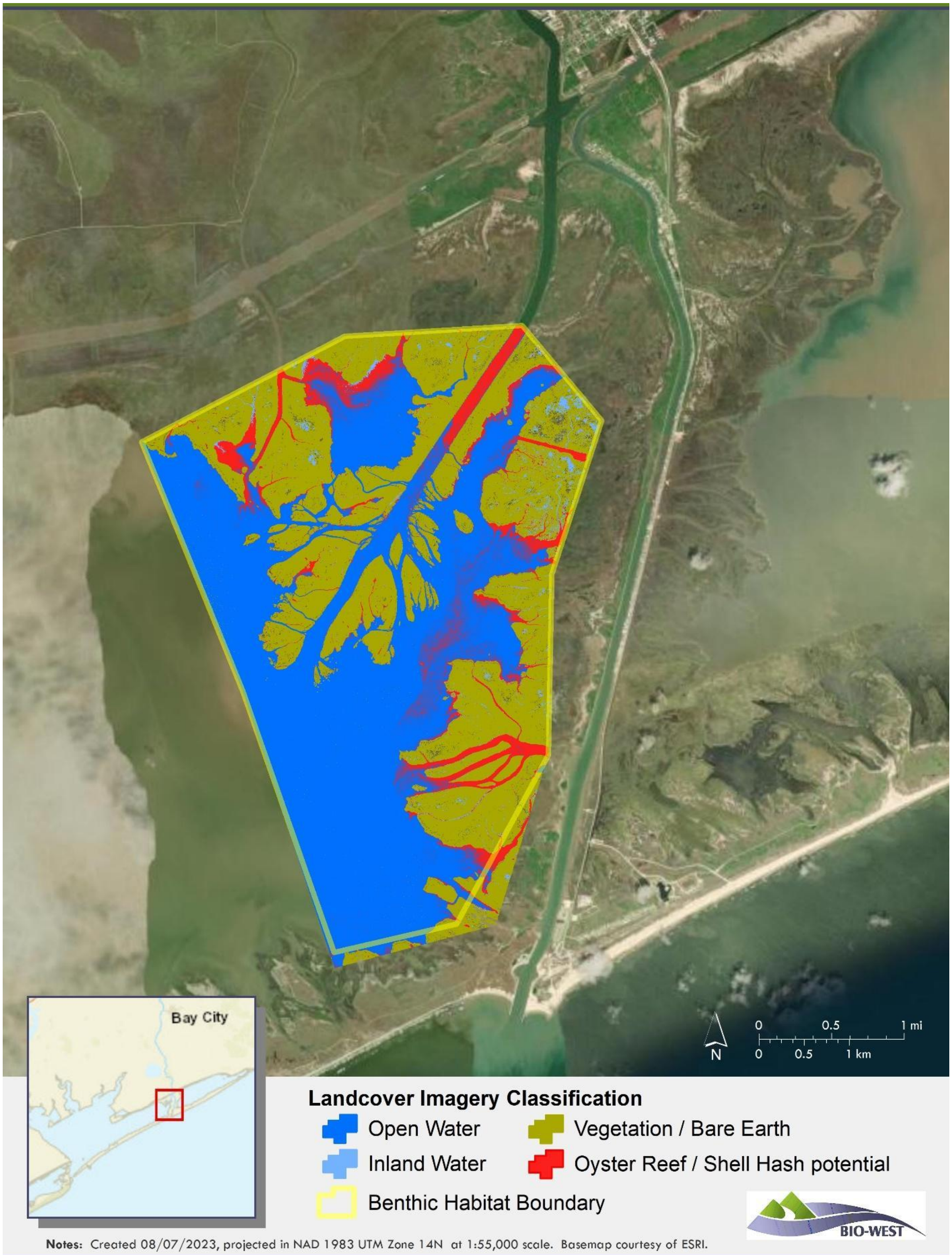

Figure 4. Multispectral satellite imagery of the Colorado River Delta original benthic habitat boundary.

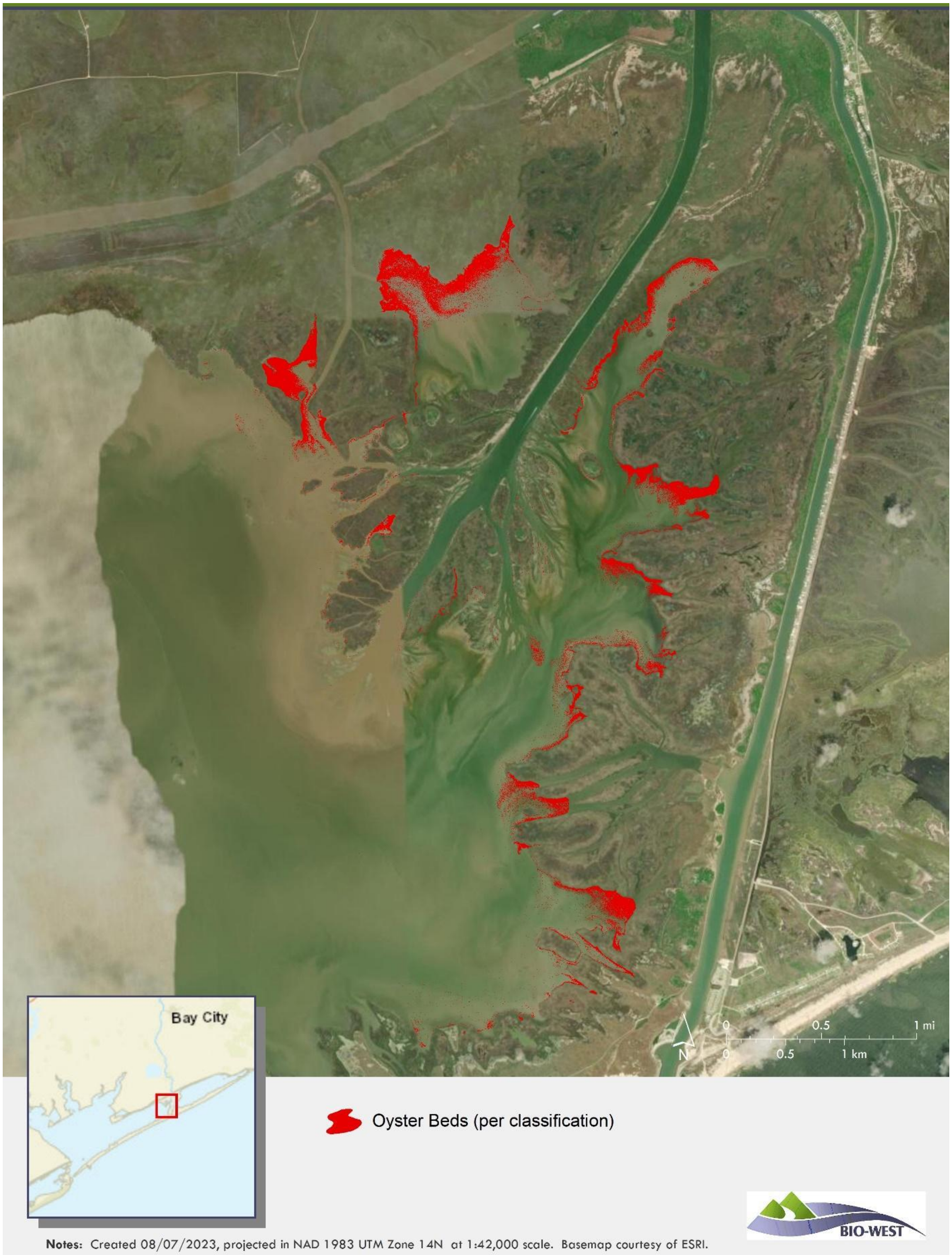

Figure 5. Oyster Reef map from multispectral imagery classification of the Colorado River Delta original benthic habitat boundary.

Figure 6. Oyster Reef map images near Site 1 of the Colorado River Delta.

Task 2 – Ecological Assessment

Nekton Abundance and Community Structure

A total of 106,263 organisms were collected during this study. Of these, 4,266 fishes were identified from 26 fish species or species groups, and 101,997 crustaceans representing 5 species groups were identified. Of the crustaceans, the top three species in abundance were grass shrimp (77.8%; *Palaemonetes spp.*), penaeid shrimp (19.6%; Penaeidae spp.), and blue crab (2.4%; *Callinectes sapidus*). For fish, the highest relative abundance was observed for gobies (33.9% of the catch; Gobiidae spp.), pinfish (17.9%; *Lagodon rhomboides*), and gulf menhaden (16.4%; *Brevoortia patronus*). Each year, grass shrimp and penaeid shrimp dominated the samples, which combined represented 94.5% of the catch in 2021 and 92.3% of the catch in 2022. In 2021, the top five fish by relative abundance were gobies (46.8%), gulf menhaden (9.8%), pinfish (9.2%), gulf killifish (8.5%; *Fundulus grandis*), and red drum (5.9%; *Sciaenops ocellatus*). In 2022, gobies (25.9%), pinfish (23.3%), gulf menhaden (20.4%), bay anchovy (7.7%; *Anchoa mitchilli*), and gulf killifish (7.0%) were most abundant. Certain species groups (e.g., Sciaenids) were observed more frequently and in higher abundance during their peak recruitment seasons (**Supplementary Table 1**). Water levels were lowest in winter, prohibiting one winter 2022 sampling event, and no sampling events were possible in winter 2023.

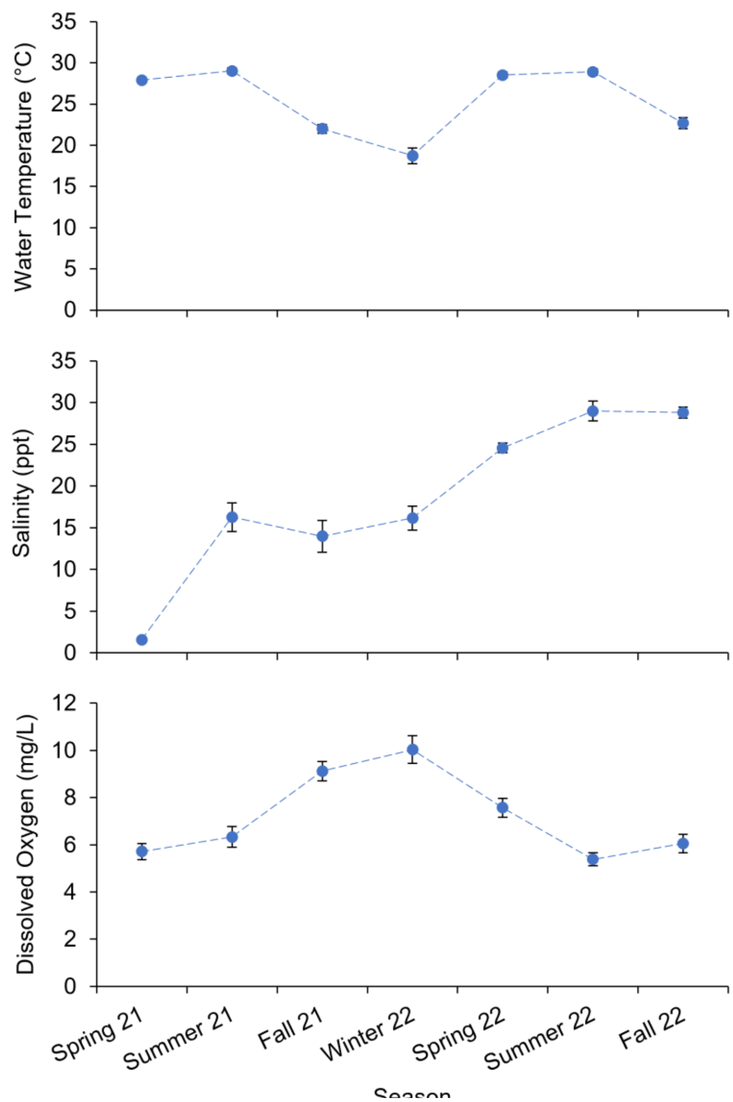

Figure 7. Mean water temperature (°C; top), salinity (ppt; middle), and dissolved oxygen (mg/L) by season during the study period. Error bars represent ± 1 SE.

Water quality parameters in the Colorado River Delta varied seasonally during the study period (**Figure 7**). Mean water temperatures ranged from 18.7°C (SE = 2.7) in winter 2022 to 29.0°C (SE = 1.2) in summer 2021. Dissolved oxygen was inversely related to water temperature with the lowest values observed in summer 2022 (mean = 5.4 mg/L;

SE = 1.0) and highest values in winter 2022 (mean = 10.0 mg/L; SE = 2.0; Figure 7). Salinity showed a generally increasing trend over the study period and was lowest in spring 2021 (mean = 1.6 ppt; SE = 1.0) and highest in summer 2022 (mean = 29.0 ppt; SE = 1.2). Colorado River gauge data (USGS 08162501; near Wadsworth, TX) indicated that mean annual discharge was approximately 2.6 times greater in 2021 (2,086 cfs) than in 2022 (796 cfs). These higher inflows contributed to a general trend of lower salinities in 2021, especially in spring.

The three-way ANOVA for total organisms detected seasonal shifts in density during the study. The year x season interaction was significant ($F_{2,6072} = 5.49$, $P = 0.004$), indicating that density varied by season but not in a similar fashion between years (**Figure 8**). In 2021, total organism

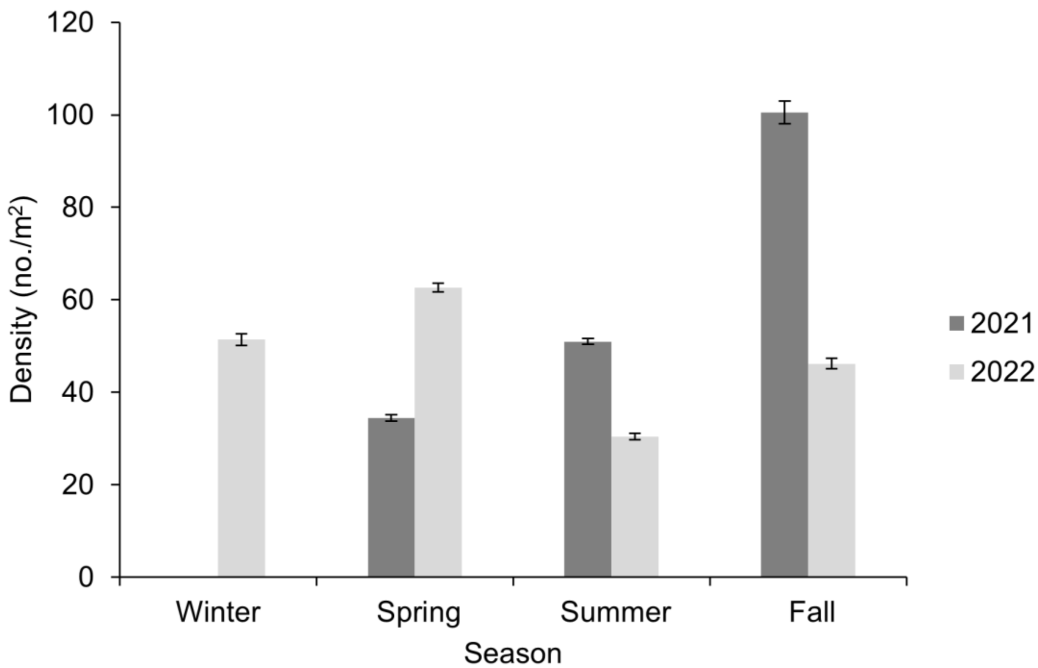

Figure 8. Total organism density (no./m2) by season and year in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

density was lower in spring (mean = 34.47 ind./m^2; SE = 0.71) and greater in the summer (mean = 50.96 ind./m^2; SE = 0.66) and fall (mean = 100.50 ind./m^2; SE = 2.44) seasons (Tukey HSD; $P < 0.05$). In contrast, total organism density was more consistent among seasons in 2022, averaging 47.64 ind./m^2. Total fish density also varied as a function of season and year and also by site (**Figure 9**). Both year x season ($F_{2,5087} = 3.34$, $P = 0.035$) and season x site ($F_{12,5087} = 2.44$, $P = 0.004$) interactions were significant, indicating that seasonal trends were not consistent by year or among sites. In 2021, total fish density were lowest in spring (mean = 0.83 ind./m^2; SE = 0.04) and increased to 2.6 ind./m^2 (SE = 0.07) by fall. In 2022, winter fish density (mean = 4.61 ind./m^2) were greater than spring, summer, and fall seasons, which averaged 2.05 ind./m^2. Post hoc ANOVAs by season indicated fish density were similar among sites during the spring, fall, and winter ($P > 0.05$), but different in the summer ($F_{4,1555} = 6.96$, $P < 0.001$) when mean fish density was higher at

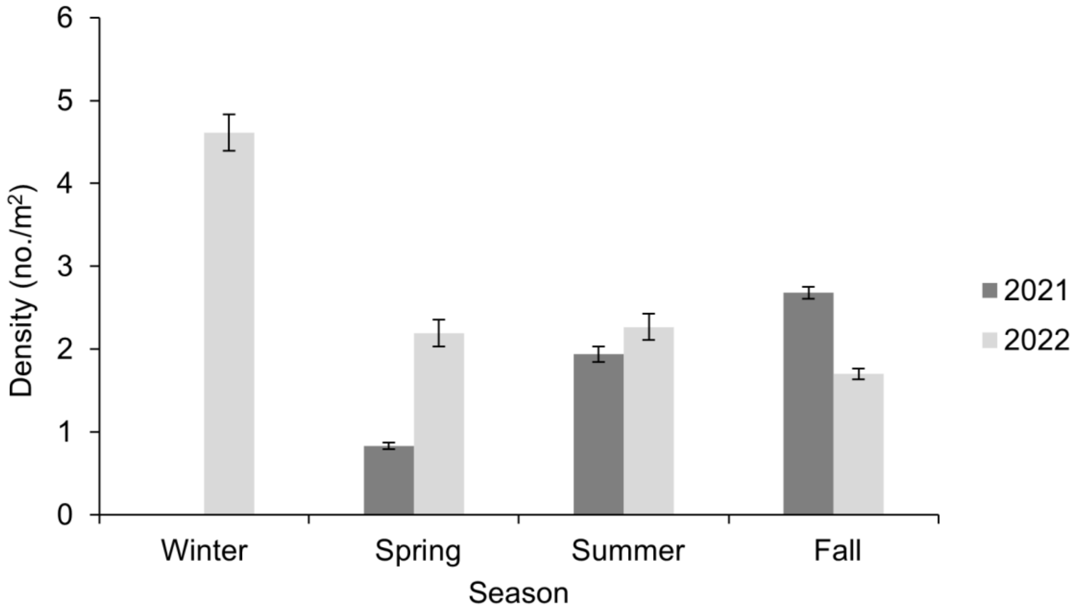

Figure 9. Total fish density (no./m2) by season and year in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE

both sites closer to the open bay (Site 4 and Site 5) than sites closer to the Gulf Intracoastal Waterway (GIWW; Site 1, Site 2, Site 3; Tukey HSD P<0.05). Total crustacean density varied by season, but differently in 2021 versus 2022 (**Figure 10**). The year x season interaction was significant ($F_{2,950}$ = 677, P = 0.001), as total crustacean density, like total organisms and total fish, increased in 2021 from a low of 33.64 ind./m^2 (SE = 4.38) in spring to 97.82 ind./m^2 (SE = 15.12) in the fall. In 2022, total crustacean density was more stable, averaging 44.94 ind./m^2. Post hoc ANOVAs by season indicated that total crustacean density was different between years in spring ($F_{1,298}$ = 5.62, P = 0.018; greater in 2022) and summer ($F_{1,298}$ = 7.69, P = 0.006; greater in 2021).

Species specific trends in density were influenced by site, season, and year. The three-way ANOVA for grass shrimp density detected a significant year x season x site interaction ($F_{8,162}$ = 3.03, P = 0.003), indicating that density differences among seasons were not the same between years or among sites. In 2021, grass shrimp density was significantly greater in fall (mean = 83.43 ind./m^2; SE = 13.68) than in spring (mean = 30.75 ind./m^2; SE = 3.96) or summer (mean = 31.27 ind./m^2; SE = 3.01; Tukey HSD P < 0.05). In 2022, spring grass shrimp density (mean = 46.05 ind./m^2; SE = 4.75) was greater than in the summer (mean = 22.36 ind./m^2; SE = 3.58) or fall (mean = 26.02 ind./m^2; SE = 5.80) seasons (Tukey HSD P < 0.05). There were no clear trends in grass shrimp density by site; however, higher catches were observed at Site 3 (mean = 194.55 ind./m^2; SE = 27.18) relative to the other sites in fall 2021 **(Figure 11**). Similar to grass shrimp, penaeid shrimp density varied by season and site but in different ways each year. The year x season x site interaction was significant ($F_{8,162}$ = 5.96, P < 0.001). In 2021, penaeid shrimp density was significantly lower in spring (mean = 2.60 ind./m^2; SE = 0.55) than in summer (mean = 15.86 ind./m^2; SE = 2.17) or fall (mean = 11.72 ind./m^2; SE = 1.78; Tukey HSD P < 0.05). In 2022, penaeid density in winter (mean = 0.03 ind./m^2; SE = 0.02) was significantly lower than every other season (Tukey HSD P < 0.05).

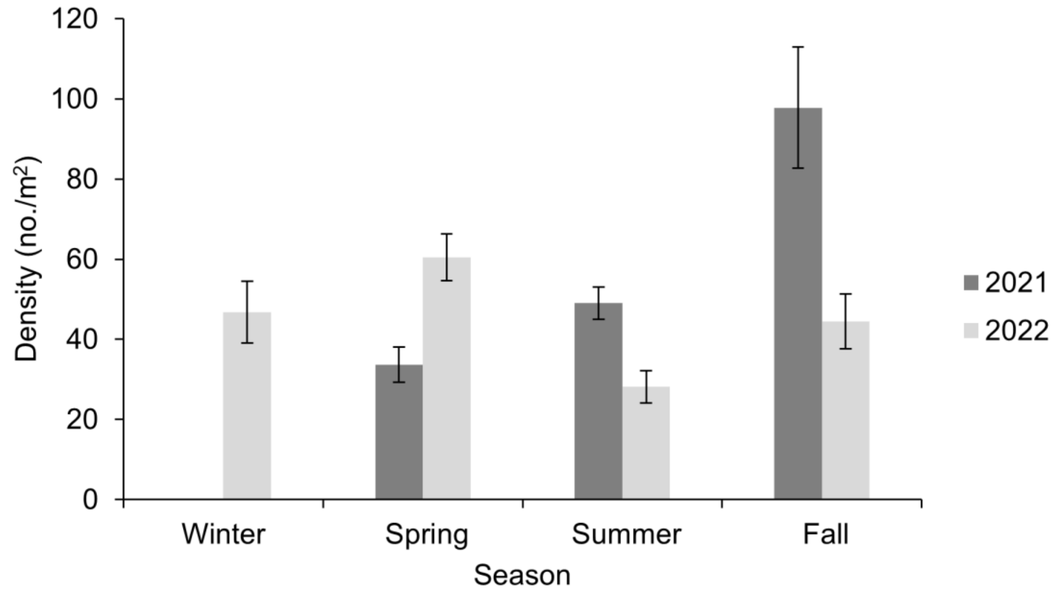

Figure 10. Total crustacean density (no./m^2) by season and year in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

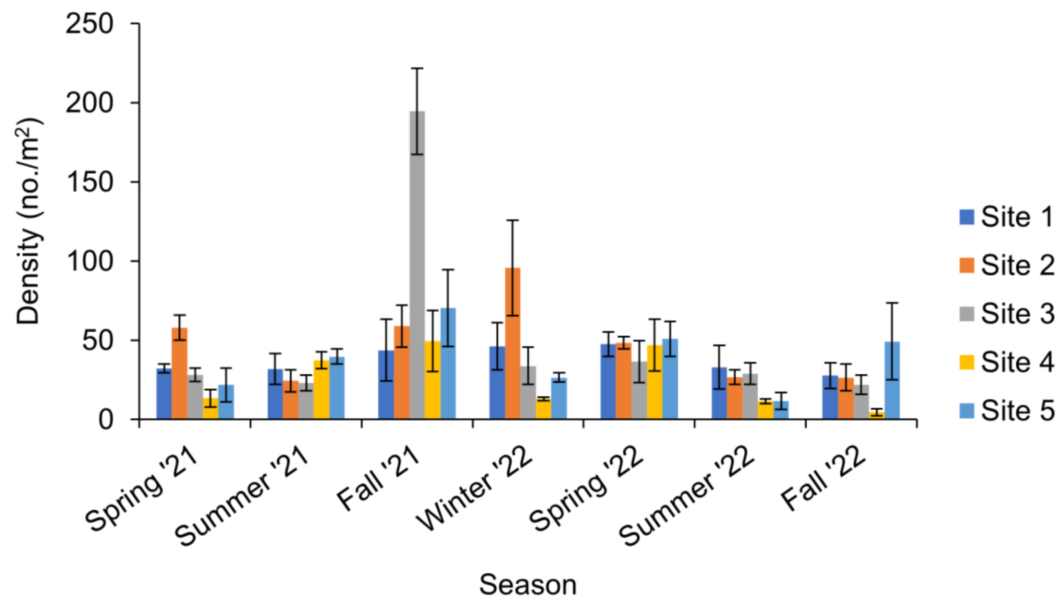

Figure 11. Grass shrimp density (no./m2) by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

There was high variability in penaeid density by site with generally few site differences within a season-year combination, though there was a tendency for Site 1 to be lower in the fall than Site 2, Site 4, and Site 5, which were closer to the open bay (**Figure 12**). Blue crab density also varied by season and sites but differently between years ($F_{8,162} = 4.57$, $P < 0.001$). In 2021, there was a

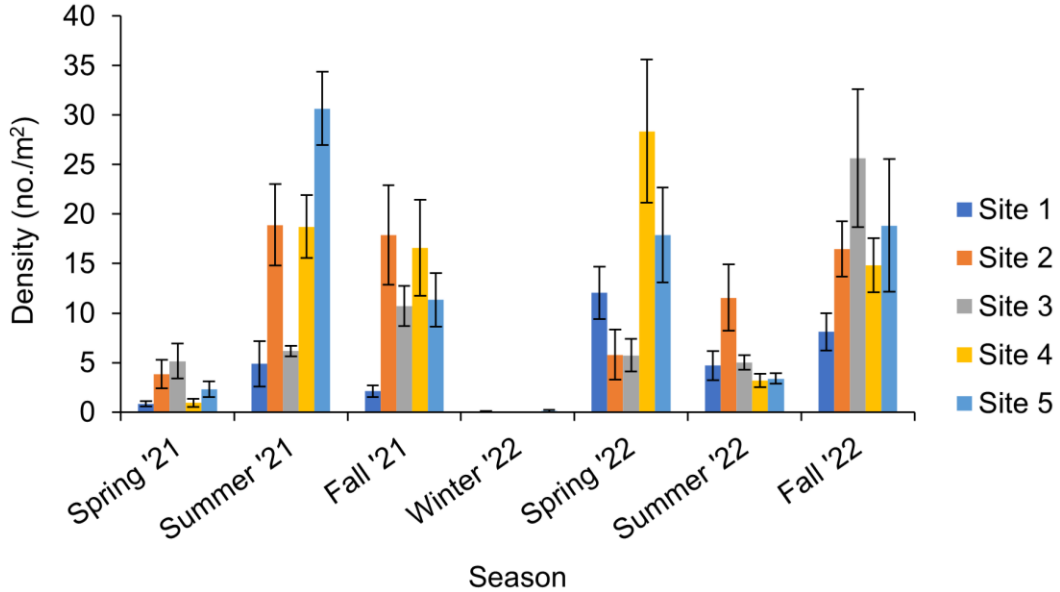

Figure 12. Penaeid shrimp density (no./m^2) by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

similar trend of increasing abundance from spring to fall, with a tendency for sites 2, 3, and 4 to have higher abundance than Site 1, which was on the upriver side of the GIWW (Tukey HSD $P < 0.05$). The highest blue crab density was observed in winter 2022 at Site 2 (mean = 14.60 ind./m^2; SE = 5.20) and was higher than every other site in that season (Tukey HSD $P < 0.05$; **Figure 13**). Atlantic croaker (*Micropogonias undulatus*) occurred in all seasons but not the same seasons each year (**Figure 14a**).

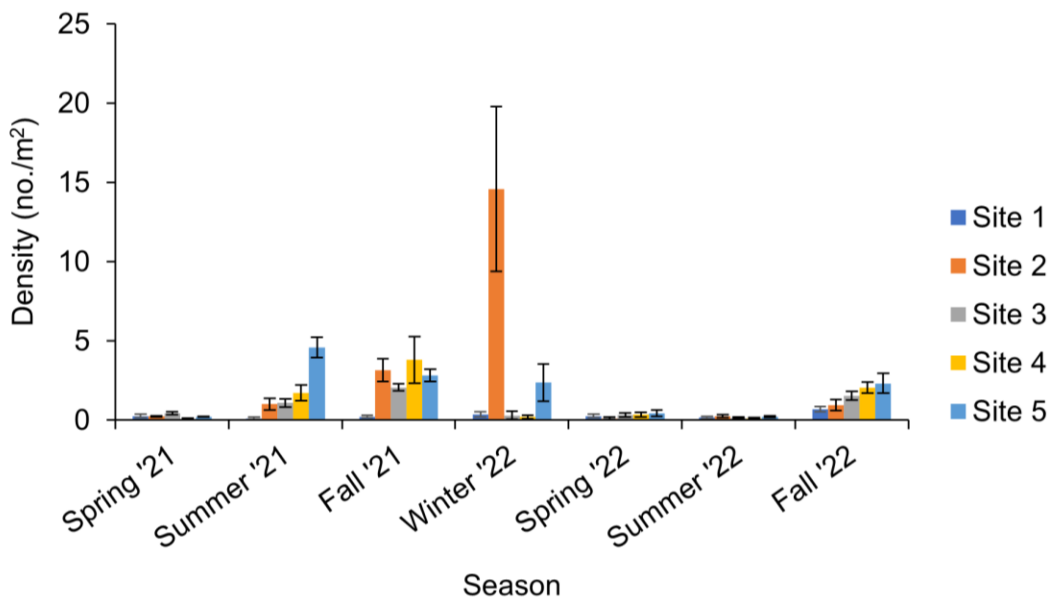

Figure 13. Blue crab density (no./m^2) by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

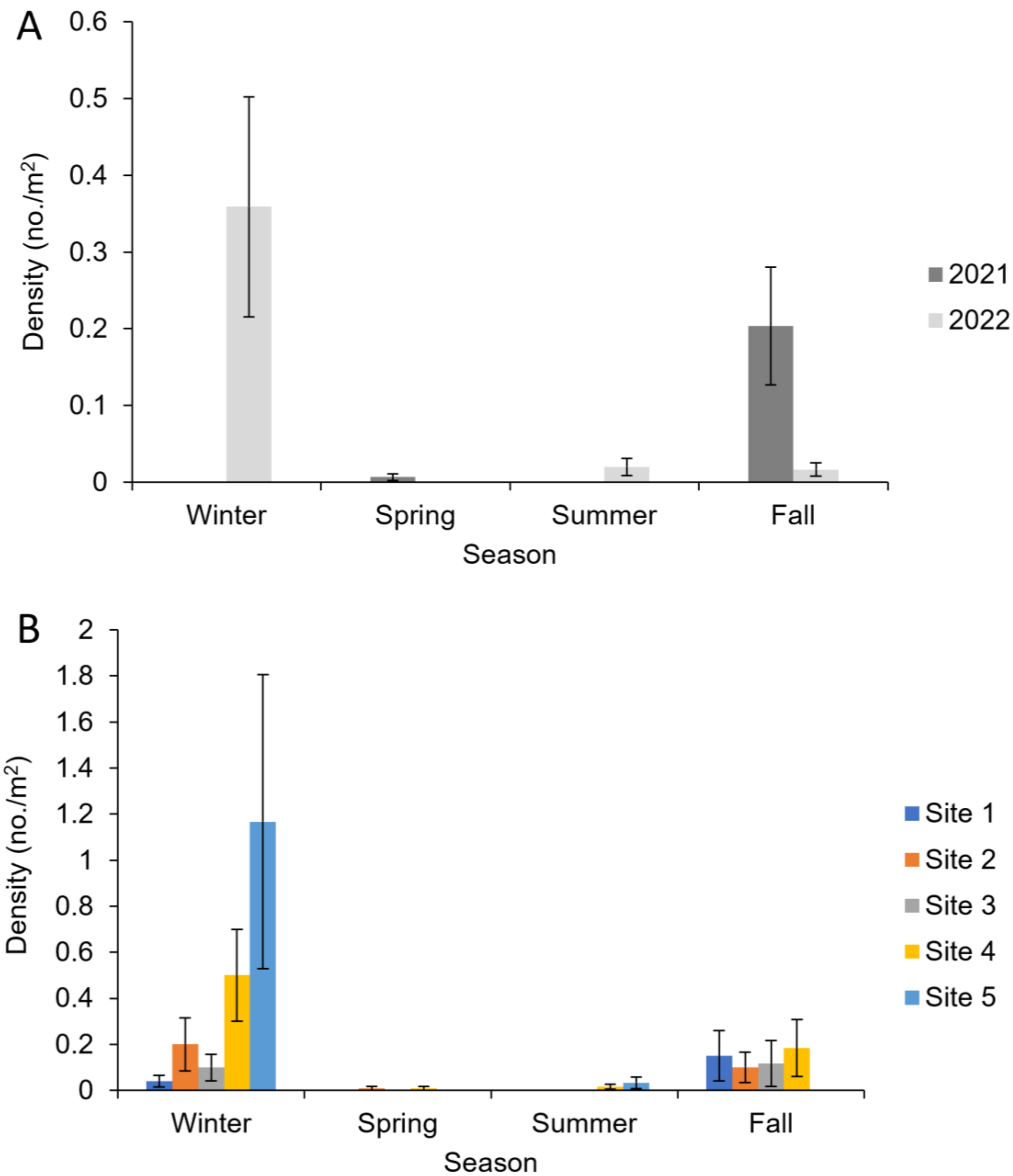

Figure 14. Atlantic croaker density (no./m2) by season and year (A) and by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

The year x season interaction was significant ($F_{2,162} = 4.88$, $P = 0.009$), indicating that seasonal trends in density were not consistent each year. Post hoc ANOVAs indicated that density varied by season in each year of the study ($P < 0.001$). In 2021, fall density (mean = 0.20 ind./m^2; SE = 0.08) was significantly greater than in spring (mean = 0.01 ind./m^2; SE = 0.01) or summer (mean = 0.00 ind./m^2; SE = 0.00). In 2022, Atlantic croaker density was higher in winter (mean = 0.35 ind./m^2; SE = 0.14) than in spring, summer, or fall seasons. The season x site interaction was also significant ($F_{12,162} = 3.53$, $P < 0.001$), and there was a trend of higher density at more sites in fall and winter (**Figure 14b**), post hoc testing did not reveal site differences with seasons ($P > 0.05$). Red drum density varied by site and season but not consistently between the two study years (**Figure 15**).

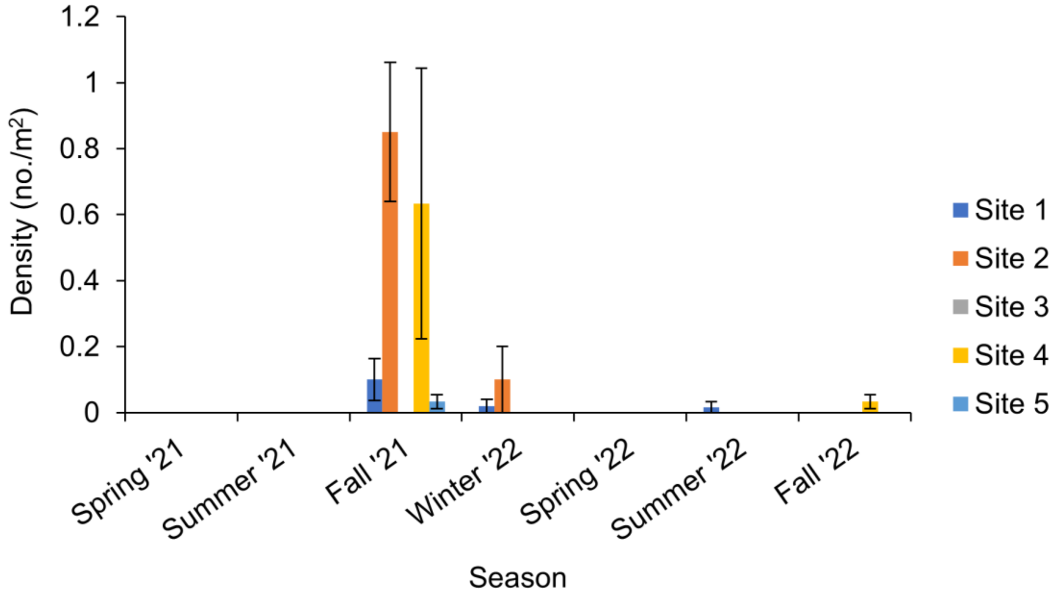

Figure 15. Red drum density (no./m2) by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

The year x season x site interaction was significant ($F_{8,162}$ = 4.76; P < 0.001). Post hoc ANOVAs revealed significant season-site interactions in 2021 (P <0.001) and 2022 (P = 0.028). These differences in density were driven by high variability in fall recruitment between years and the relative patchiness of limited red drum among sites during the peak fall recruitment season. For example, red drum density was highest in fall 2021 (mean = 0.32 ind./m^2; SE = 0.11) with red drum occurring at 4 of the 5 sites that season. In contrast, red drum were only observed at Site 4 in fall 2022 and occurred at much lower density (mean = 0.01 ind./m^2; SE = 0.01). No red drum were encountered during the spring and few were encountered in winter or summer (none in summer 2021). Spotted seatrout (*Cynoscion nebulosus*) were encountered in every season except the winter with a peak recruitment observed during the summer season (**Figure 16**). The season x site interaction was significant ($F_{12,162}$ = 3.34, P < 0.001), indicating that seatrout density varied by sites but not in a consistent way among seasons. In the spring, density was higher at Site 4 (mean = 0.04 ind./m^2; SE = 0.02) than Site 1 or Site 2, where spotted seatrout were not encountered. In summer, higher densities were observed at Site 4 (mean = 0.24 ind./m^2; SE = 0.09) and Site 5 (mean = 0.21 ind./m^2; SE = 0.07) that at Site 1 (mean = 0 ind./m^2; SE = 0.00) or Site 3 (mean = 0.03 ind./m^2; SE = 0.01). Spotted seatrout densities in the fall were lower and similar among sites (P > 0.05). The season x site interaction was significant ($F_{12,162}$ = 3.34, P < 0.001), indicating that seatrout density varied by sites but not in a consistent way among seasons. In the spring, density was higher at Site 4 (mean = 0.04 ind./m^2; SE = 0.02) than Site 1 or Site 2, where spotted seatrout were not encountered. In summer, higher densities were observed at Site 4 (mean = 0.24 ind./m^2; SE = 0.09) and Site 5 (mean = 0.21 ind./m^2; SE = 0.07) that at Site 1 (mean = 0 ind./m^2; SE = 0.00) or Site 3 (mean = 0.03 ind./m^2; SE = 0.01). Spotted seatrout densities in the fall were lower and similar among sites (P > 0.05).

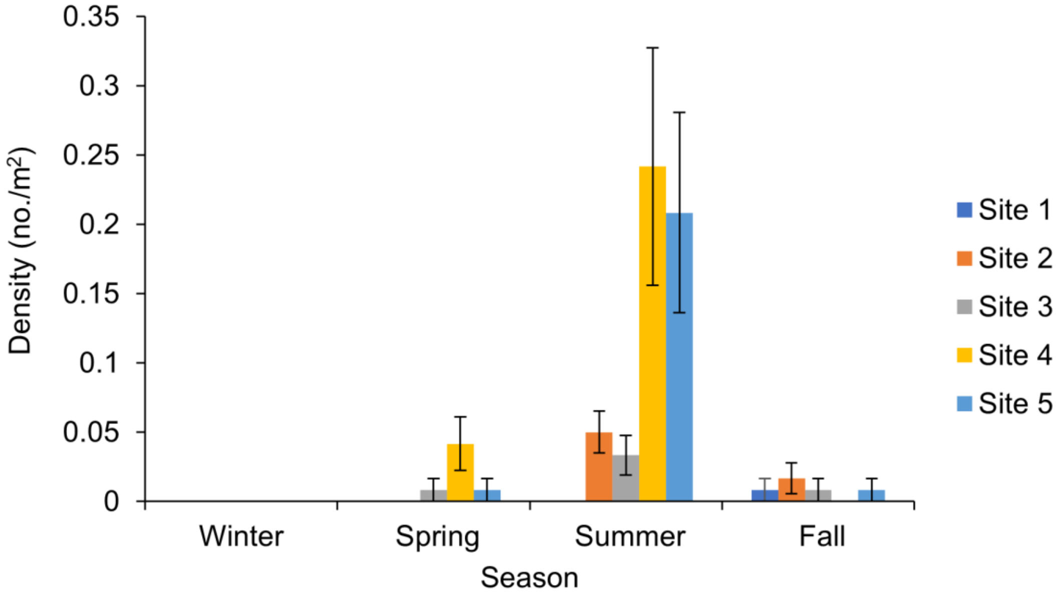

Figure 16. Spotted seatrout density (no./m2) by season and site in the Colorado River Delta, 2021-2022. Error bars represent ± 1 SE.

Ordination of samples using nMDS revealed several groupings of nekton communities by season (season-year; **Figure 17**). When tested using ANOSIM with site and season as factors, site was not significant ($R = 0.105$, $P = 0.124$), but there was a significant effect of season ($R = 0.508$, $P < 0.001$). The subsequent cluster analysis with SIMPROF testing identified six groups with distinct community structure. These groups included a group with mostly all spring 2021 samples, a winter group, one group with only Site 4 samples, a group with summer samples from Site 4 and Site 5, and a large group with over half of the samples from multiple sites and seasons. Investigation of these groups with SIMPER revealed that differences in nekton community structure spring 2021 and summer 2021 were driven by higher contributions of penaeid shrimp, blue crabs, and gobies in summer samples. Fall 2021 was differentiated from other seasons based on higher contributions of grass shrimp, gulf killifish, and red drum. Winter samples were differentiated from spring, summer, and fall samples based on lower contributions of penaeid shrimp and higher contributions of pinfish and Atlantic croaker. Among the three water quality parameters tested (water temperature, salinity, dissolved oxygen), the BEST analysis (BIO-ENV) suggested that water temperature and salinity best matched the observed patterns in nekton communities in the Colorado River Delta ($\rho = 0.258$, $P = 0.001$). Spearman's ρ for individual variables was higher for water temperature ($\rho = 0.207$) than for salinity ($\rho = 0.143$).

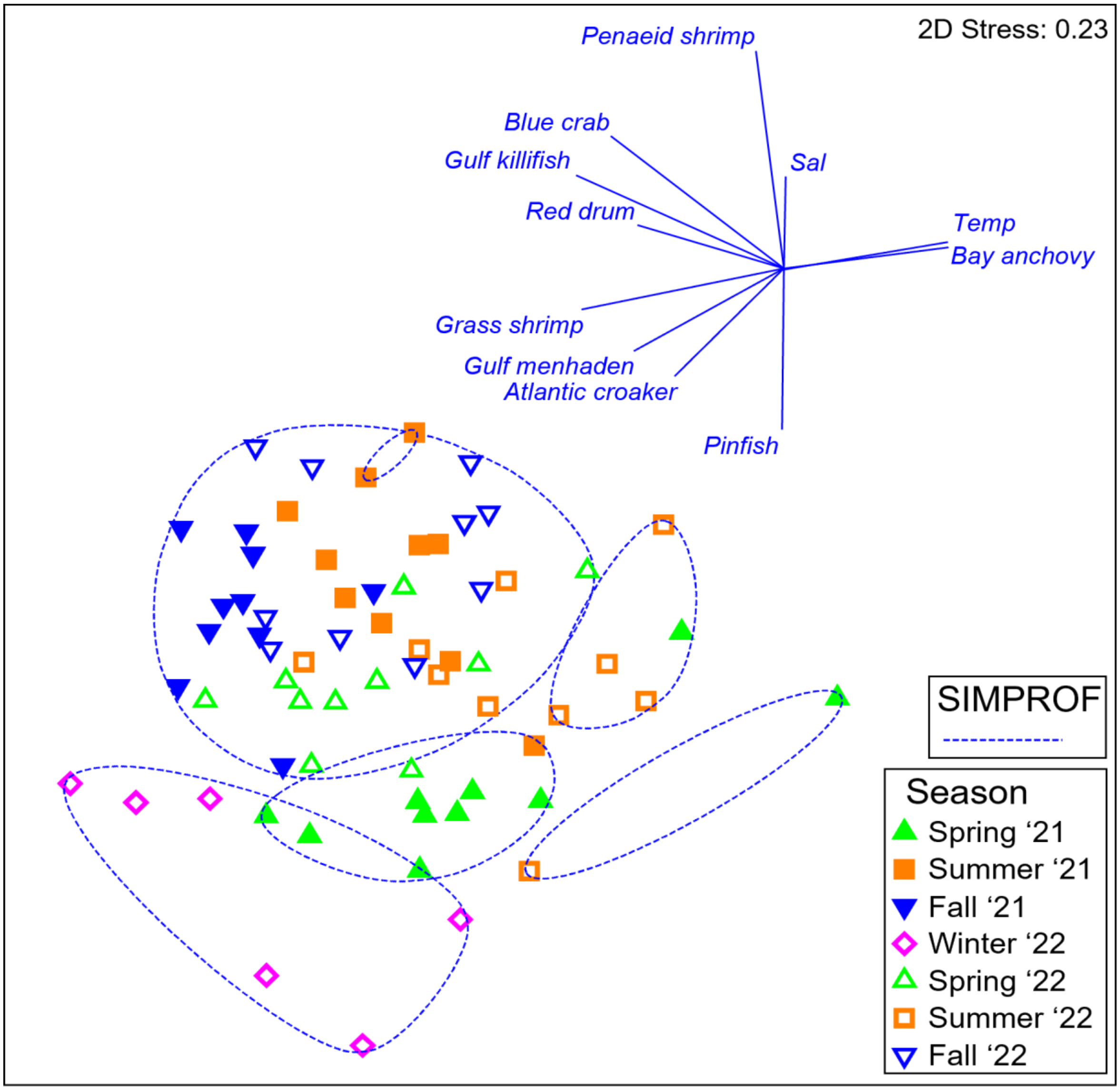

Figure 17. Nonmetric multidimensional scaling ordination using fourth-root transformed densities and Bray-Curtis similarities from Colorado River Delta nekton sampling, 2021-2022. Significant groupings from SIMPROF testing are denoted by dashed ellipses. The vector plot shows the relationships with biotic (species) and abiotic variables (water temperature and salinity) influencing nekton community groups.

Coastal Bird Surveys

Over the course of the project, six seasonal coastal bird surveys were conducted representing two each from each spring, fall and winter. Summer was not included since this season typically represents the period with the most limited species richness and bird diversity along the mid-Texas coast. Point counts were conducted within both emergent vegetated marsh or non-emergent vegetated bay bottom in the Avian Monitoring Areas (**Figure 18**). However, given the radius of avian detectability (approximately 160-meters) and habitat heterogeneity present in the Colorado River Delta, species were observed across seven different habitat types. Therefore, species observations were reported by study site and associated habitat type. Dominant habitat was the habitat in use at time of observation, dominate habitat included: emergent marsh, open water, shoreline, mud flat, woody debris, scrubland, and exposed oyster reef (**Table 1**).

Figure 18. Avian Monitoring Areas and Audio Recording Unit deployment points within the study area.

Table 1. Seasonal occurrence, site occurrence, count (#), relative abundance (above 1%) and dominant habitat type of the avian communities observed during seasonal sampling.

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
American Avocet	x		x	x	x		x		x	172	2.11%	x	x	x	x		x	
American White Pelican	x	x	x	x	x	x	x		x	483	5.93%	x	x	x	x	x	x	
Blue-winged Teal	x		x	x	x	x	x	x	x	595	7.31%		x					
Boat-tailed Grackle	x	x	x	x	x	x	x	x	x	334	4.10%	x	x			x	x	x
Brown Pelican	x	x	x	x	x	x	x	x	x	175	2.15%	x	x	x		x	x	
Canvasback			x				x			100	1.23%		x					
Caspian Tern	x	x	x	x	x	x	x	x	x	114	1.40%	x	x		x		x	
Clapper Rail	x	x	x	x	x	x	x	x	x	126	1.55%	x						
Crested Caracara			x	x						4	0.05%		x			x		
Dowitcher sp.	x		x		x	x	x		x	249	3.06%	x			x			
Double-crested Cormorant	x		x	x	x	x	x	x	x	115	1.41%	x	x		x	x	x	
Forster's Tern	x	x	x	x	x	x	x	x	x	464	5.70%	x	x	x	x	x	x	
Great Egret	x	x	x	x	x	x	x	x	x	105	1.29%	x	x	x	x	x	x	
Green-winged Teal		x	x			x	x		x	466	5.72%	x	x					
Laughing Gull	x	x	x	x	x	x	x	x	x	405	4.97%	x	x	x		x	x	
Least Sandpiper	x	x	x		x	x	x		x	177	2.17%	x	x	x	x			
Neotropic Cormorant	x	x	x	x	x	x	x	x	x	98	1.20%	x	x	x		x	x	
Northern Shoveler	x			x	x					106	1.30%	x	x					
Pintail			x				x	x		155	1.90%		x					
Red-winged Blackbird	x	x	x	x	x	x	x	x	x	501	6.15%	x	x	x	x	x	x	
Sanderling	x		x	x		x	x	x	x	398	4.89%		x	x	x			
Seaside Sparrow	x	x	x	x	x	x	x	x	x	99	1.22%	x						
Snowy Egret	x	x	x	x	x	x	x	x	x	144	1.77%	x	x	x	x	x	x	
Tricolored Heron	x	x	x	x	x	x	x	x	x	132	1.62%	x	x	x		x	x	
Turkey Vulture	x	x	x	x	x	x	x	x	x	92	1.13%	x	x	x		x	x	

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
Western Sandpiper			x		x	x	x	x	x	232	2.85%	x	x		x			
White Ibis		x	x	x	x	x	x	x	x	142	1.74%	x	x	x		x	x	
Willet	x	x	x	x	x	x	x	x	x	248	3.05%	x	x	x	x		x	

In total, 8,141 individuals represented by 113 species were observed during all seasonal sampling events (**Supplementary Table 2**). The avian community was typical of an ecosystem presenting an assortment of both saltwater influenced marsh edge, shoreline, and mudflat habitat (Foster et al. 2009). All sites were characterized by an abundance of shorebird and/or migratory bird species, with relatively high species overlap between sites. The most common species observed was Blue-winged Teal (7.31%; *Spatula discors*), followed by Red-winged Blackbird (6.15%; *Agelaius phoeniceus*), and American White Pelican (5.93%; *Pelecanus erythrorhynchos)*. Blue-winged Teal and Red-winged Blackbird were present across all six sites, while American White Pelican was present in only five of the six survey sites. Together, these three species accounted for 19% of all species observations. Site 1 was characterized by an increased prevalence of passerines due to the presence of nearby woodland and grassland areas. Site 1 also exhibited both the highest taxa richness (81) and Shannon diversity (1.75) (**Table 2**). The highest individual count (2,374) and second highest taxa richness (60) was observed at Site 4. Marsh-associated species were generally observed across all six sites, generally utilizing most of the dominate habitat type.

Table 2. Avian count (#), taxa richness (#), relative abundance (%), and Shannon diversity by site (Figure 18).

Site	Count	Taxa Richness	Relative Abundance (%)	Shannon Diversity
1	1,111	81	13.65	1.73
2	1,145	60	14.1	1.45
3	1,472	54	18.1	1.18
4	2,374	60	29.2	0.87
5	800	46	9.8	0.51
6	1,239	50	15.2	0.28

In addition to point counts, BIO-WEST conducted passive acoustic surveys. This involves the strategic deployment of automated recording units (ARUs), a technique commonly used in the assessment of avian populations (e.g., Digby et al. 2013; Sanders & Mennill 2014; Towsey et al. 2014). One method used to process the large quantity of acoustic data generated from ARUs is to employ automated sound recognition algorithms which facilitate the search for vocalizations of interest by using a species-specific model (Acevedo et al. 2009; Brandes 2008; Browning et al. 2017). This method allows for the batch processing of hundreds of field recordings, significantly reducing the time required for extracting information from the recordings (Waddle et al. 2009; Willacy et al. 2015).

The project team completed passive acoustic sampling events within six predetermined study sites within the Colorado River Delta (**Figure 18**). At each study site, one Song Meter SM4 Bioacoustic recorder (Wildlife Acoustics, Inc., Maynard, MA, USA 2018) was deployed and left for the duration of the sampling period. The recorders for sites 3, 4, and 5 were not place in the same location each sample period. This manipulation was due to incoming or outgoing tide, which logistically enabled the crew to place the device in the same location. The recorders produce digital recordings in "stereo.wav" format from two built-in omnidirectional microphones and save data to a removable memory card. Recorders were secured to t-posts at each site approximately 0.75 to 1.25 m off the ground or water (**Figure 19**). All recorders were programmed to record continuously from time of deployment to time of collection.

Figure 19. Typical view of a deployed Song Meter SM4 Bioacoustic Recorder.

Two species of interest, the Eastern Black Rail (*Laterallus jamaicensis*) and the Whooping Crane (*Grus americana*) were examined using this technique. The Eastern Black Rail is a secretive marsh bird, well-suited for assessment via passive acoustic surveys as it is notoriously cryptic with lower probabilities of detection as compared to other species when conducting traditional avian surveys given its life history and habitat requirements (Eddleman et al. 1988; Conway et al. 2010). The Whooping Crane is federally listed as an endangered species by the USFWS and has been observed in adjacent Matagorda Bay inland marshes.

The software package Kaleidoscope Pro© (version 5.1.9; Wildlife Acoustics, Inc., Maynard, MA, USA 2018*b*) was used to analyze recorded audio data at each study site. An Eastern Black Rail classifier was built using approximately 92 recordings of calling Eastern Black Rails (comprising 1,060 distinct vocalizations used in model development) obtained from the Macaulay Library at the Cornell Lab of Ornithology (Cornell Lab of Ornithology 2018) and from the Xeno-canto Archive (http://www.xeno-canto.org/). After initially training the classifier model to detect Black Rail calls, the project team further refined the model using binary classifiers to improve its ability to discriminate between Black Rail calls and non-target species (Sokolova et al. 2006). Once a well-performing model was produced, the project team tested classifier efficacy by running it against a set of control data. A similar process was completed for the Whooping Crane classifier.

After creating an Eastern Black Rail and Whooping Crane classifier, the project team ran the algorithm against our entire data set of field recordings by each study site, and then qualified observers manually reviewed every putative Eastern Black Rail and Whooping Crane detection identified by the classifier both aurally and visually (i.e., listening to the detection and inspecting the spectrogram, respectively). The six automated acoustic recorders deployed within the Colorado River Delta during the Winter, Spring, and Fall seasons of 2021-2023 produced 688.2 hours of recorded audio files. Data processing (**Table 3**) resulted in 582,690 detections, of which the classifier automatically identified 7,817 putative detections (1.34% of total detections) across all six study sites and seasons. Manual review of putative detections by project team biologists found all detections were false-positive detections and not true Eastern Black Rail or Whooping Crane calls. Unfortunately, over the course of the study, due to inclement weather and technical issues, not all sites returned audio during each recording season.

Table 3. Summary of automated acoustic analysis of Eastern Black Rail and Whooping Crane field recordings from six study sites in Colorado River Delta.

Site	Season	Logging Period	Hours Logged	Output Detections	Putative Detections (Percent of Output)	BR/WC True Detections
Old River	Spring	May	45	91,108	269 (0.30%)	**0**
Old River	Fall	Oct	41	126,468	115 (0.09%)	**0**
Old River	Winter	Feb	47	13,444	1,191 (8.86%)	**0**
Old River	Fall	Nov	34	15,196	406 (2.67%)	**0**
West Lake	Fall	Oct	40	29,069	444 (1.53%)	**0**
West Lake	Winter	Feb	45	10,847	583 (5.37)	**0**
West Lake	Fall	Nov	36	9,133	494 (5.41)	**0**
East Lake	Fall	Oct	40	26,525	659 (2.48%)	**0**
East Lake	Fall	Nov	32	8,256	329 (3.98%)	**0**
Diversion	Fall	Oct	39	49,659	194 (0.39%)	**0**
Diversion	Winter	Feb	45	10,915	1405 (12.87%)	**0**
Tiger's Island	Spring	May	45	53,124	270 (0.51%)	**0**
Tiger's Island	Fall	Oct	38	14,153	174 (1.23%)	**0**
Tiger's Island	Winter	Feb	44	3,898	284 (7.29%)	**0**
Tiger's Island	Fall	Nov	34	6,418	258 (4.02%)	**0**
Gull Island	Spring	May	45	81961	68 (0.08%)	**0**
Gull Island	Fall	Oct	38.2	23607	381 (1.61%)	**0**
Gull Island	Fall	Nov	38	8909	293 (3.29%)	**0**
Total			**688.2**	**582,690**	**7,817 (1.34%)**	**0**

Task 3 – Hydrological Assessment

With increasing of inland waters, the Colorado River Delta vegetative communities have expanded over the past century (**Figures 20 and 21**). Supporting and sustaining the Colorado River Delta into the future during times of extreme drought will require maximizing the distribution of available freshwater inflow to sustain ecological integrity. As previously discussed, the focus of this assessment was to explore ways to sustain ecological diversity during periods of extreme drought. During these extremely low inflow conditions, the Colorado River Delta can experience high salinity conditions with limited nutrient input. Throughout the historical record, the reduction of inflow levels has never extirpated any of the key species addressed in the Texas Parks and Wildlife Department's coastal fisheries database for Matagorda Bay. The ecological objectives during these extreme periods are to sustain live oysters, maintain estuarine benthic character, and provide refuge habitat for shellfish and forage fish to the extent possible. At present, the Colorado River Delta has a direct relationship to Colorado River inflow during these extreme drought conditions. To the degree practicable during extreme droughts, a minimum inflow of 15,000 ac-ft per month was recommended in MBHE (2008) to maintain salinity conditions below 30 ppt in the immediate area of the Colorado River Delta. During these extremes, it will be important to provide refuge areas for marsh vegetation, oysters, shellfish and forage fish outside of the main river channel. Therefore, it is highly anticipated that extended drought conditions will require additional measures to protect oyster health and provide refuge for key species within specific Colorado River Delta locales.

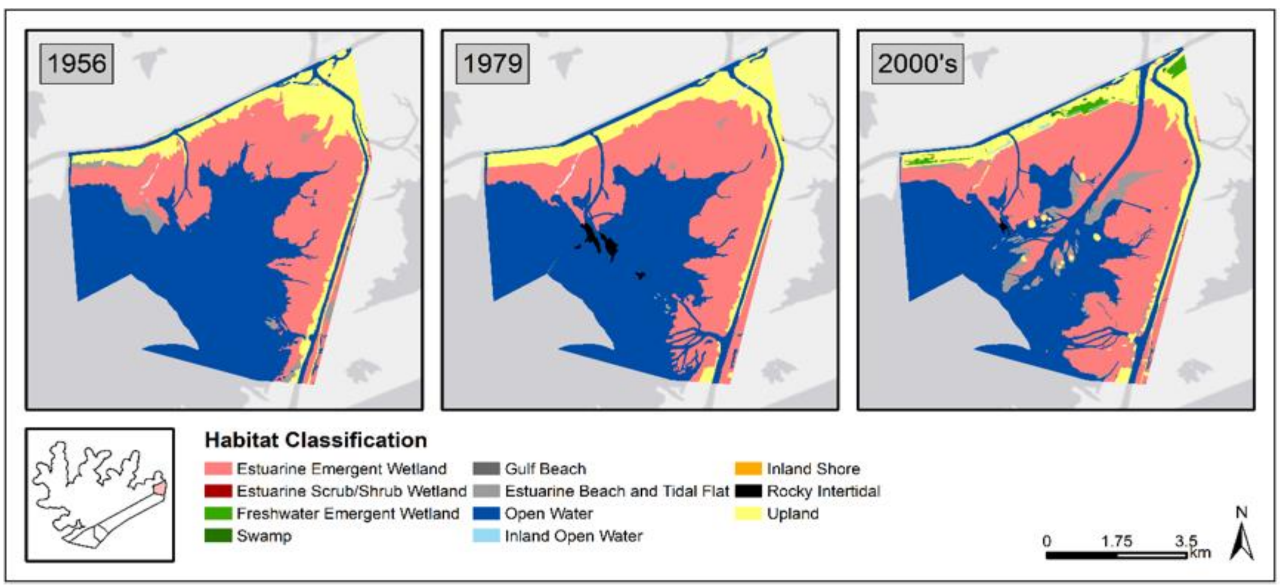

Figure 20. Colorado River Delta wetland classification over time (Source: Stunz et al. 2023).

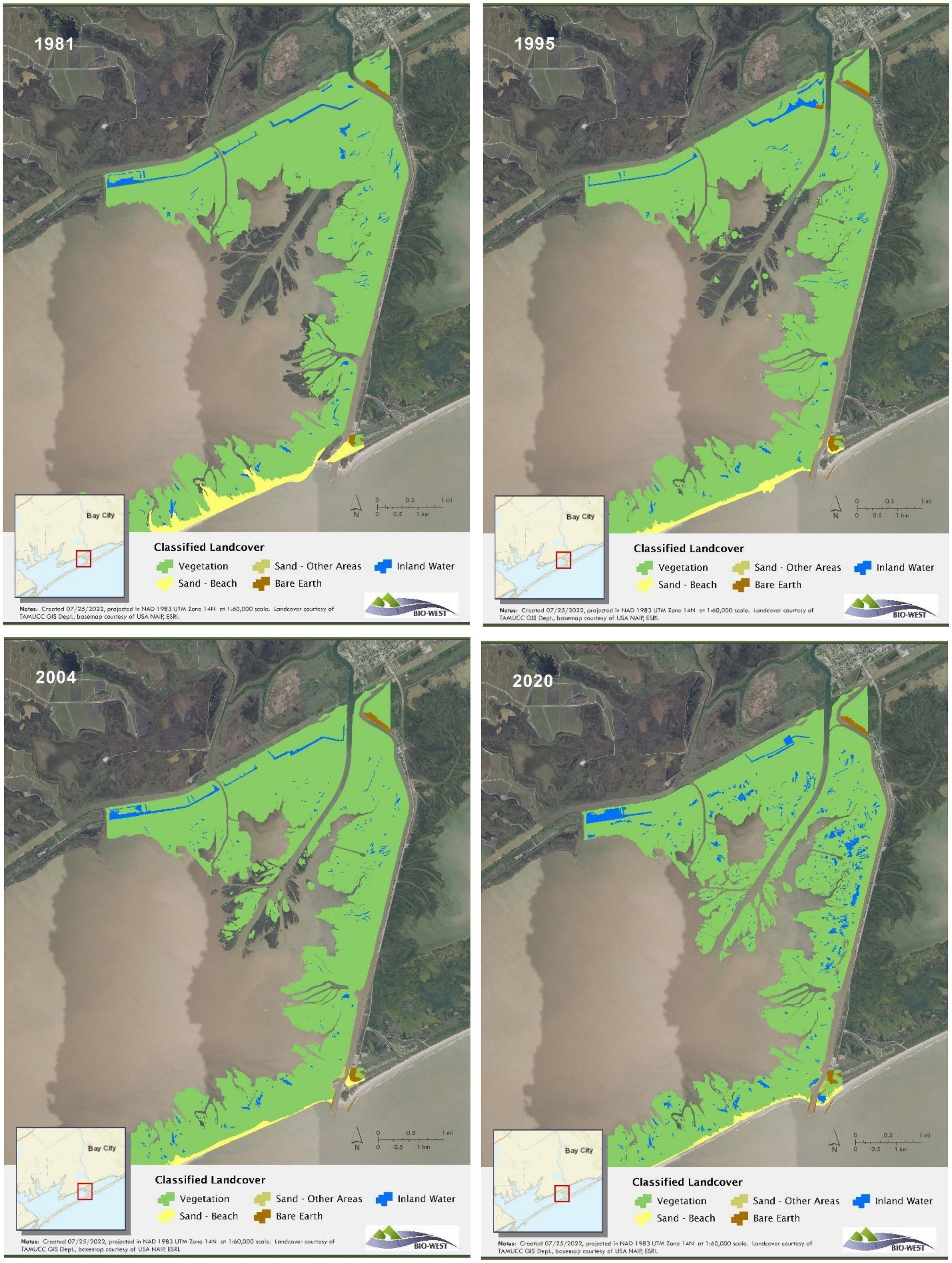

Figure 21. Colorado River Delta landcover changes over time (1981 to 2020) (Source: Stunz et al. 2023).

From this assessment, sites 1 (Old River) and 2 (Lake West) (**Figure 22**) are considered the best candidates to receive possible freshwater inflow from existing or future water sources and infrastructure. These sources could include a strategic use of the Lower Colorado River Authority (LCRA) Gulf Coast District irrigation canals, groundwater wells, alternative water control features, and/or redistribution of Colorado River water.

Figure 22. Colorado River Delta potential refuge areas (blue circles) recommended for further study. The orange rectangle represents another area considered but eliminated.

Discussion and Implications

The Colorado River Delta serves as important nursery habitat for a variety of ecologically and economically important estuarine species and resident or transitory home for a plethora of coastal birds. In general, shorebird and migratory birds maintained a relatively high species overlap between all sites. However, Site 1 (north of the GIWW) was characterized by an increased prevalence of passerines due to the presence of nearby woodland and grassland areas. Site 1 also exhibited both the highest taxa richness and diversity of birds. Nekton communities were composed of both resident species that spend their entire lives in estuaries (e.g., grass shrimp, pinfish, gobies) and estuarine-dependent species which may rely heavily on estuarine nursery habitats especially during their early life as post-settlement juveniles (e.g., redfish, penaeid shrimp). Nekton samples in this study were dominated by grass shrimp and penaeid shrimp, important prey resources for a variety of organisms including coastal birds and sportfish such as spotted seatrout and red drum. Community structure differed seasonally for many nekton species, and these differences were influenced by variation in the timing of spawning and subsequent recruitment of early juveniles to nursery habitats which is common for estuarine dependent species (Kneib 1993; Minello 1999). Site-to-site differences were far less pronounced, and few trends were evident suggesting that all areas where nekton sampling occurred serve as important marsh edge nursery habitat.

The recruitment of nekton into estuaries is highly variable, and this was obvious through the observed seasonal effects and inter-annual differences in the occurrence and density of key species. Perhaps the largest interannual difference in nekton communities was related to higher inflows in spring 2021 when salinities at all sites were nearly completely fresh (mean = 1.6 ppt). While many species of nekton observed are adapted to tolerate variable salinities in estuaries, extremely low salinities in spring 2021 may have reduced habitat quality for juvenile nekton or displaced nekton from the area. There were also clear pulses of estuarine-dependent recruits during their peak recruitment seasons. For example, red drum density was highest in the fall, the reported spawning period and peak recruitment season for the species (Holt et al. 1983; Murphy and Taylor 1990; Stunz et al. 2002), but density was approximately 46× greater in fall 2021 compared to fall 2022. This difference could be attributed to lower survival rates resulting from a combination of increased predation or increased competition for food resources. Atlantic croaker also exhibited variable interannual recruitment with nearly 12× greater recruitment observed in fall 2021 than fall 2022. Though winter is the peak recruitment season for Atlantic croaker (Rooker et al. 1998; Searcy et al. 2007), we were unable to compare interannual recruitment for Atlantic croaker between years as no samples were collected in winter 2023 due to low water levels.

In contrast to red drum and Atlantic Croaker, spotted seatrout have a broader recruitment window from spring through the fall with a peak in summer (Neahr et al. 2010). Spotted seatrout density observed in this study (mean = 0.04 ind./m^2) were similar to densities reported by Neahr et al. (2010) in Matagorda Bay and San Antonio Bay. Texas Parks and Wildlife Department 2023 spring gillnet data indicated Matagorda Bay catch per unit effort was 32% below the 10-year mean (TPWD unpublished). Considering the spotted seatrout population is still recovering from the February 2021 freeze event, consistent or increased recruitment is important to help rebuild the population. The lack of a year x season interaction for spotted seatrout density indicates that recruitment was consistent between years during the study period. Importantly, the densities we observed in 2021 and 2022 are higher than density reported by Stunz et al. (2023) in marsh edge habitat of Matagorda Bay in 2021 (mean = 0.01 ind./m^2), which may indicate increasing recruitment and highlights the importance of the Colorado River Delta in supporting robust recreational fisheries.

Nekton communities in the Colorado River Delta were primarily driven by seasonal effects, although some site-to-site differences were observed. For example, a pattern of greater density of total fish, penaeid shrimp, Atlantic croaker, and spotted seatrout at sites CD_4 and _CD_5 (Figure 3) relative to the other sites were observed. There are several possible reasons, which may all contribute at some level, to the observed pattern including 1) increased connectivity to the east arm of Matagorda Bay (closer proximity to a large portion of the adult spawning population), 2) increased connectivity to the Gulf of Mexico (source of estuarine-dependent recruits) through the old Colorado River channel, Bragg's Cut, and the current Diversion Channel, and 3) more consistent brackish conditions with distance from freshwater source. Connectivity and proximity are important factors influencing high levels of nekton recruitment (Bushon 2006; Reese et al. 2008; Hall et al. 2016). For example, Bushon (2006) demonstrated that red drum densities decreased with increasing distance from the nearest tidal inlet. This phenomenon could explain lower densities of fish and penaeid shrimp in areas with lower connectivity (e.g., Site 1). For most other species, site differences were not detected or were inconsistent over time. Taken with the frequent finding of seasonal effects on nekton species, this study suggests that all areas where nekton were sampled served as important nursery habitat and contributed to the overall productivity of the Colorado River Delta.

Potential freshwater inflow projects aimed at maintaining nekton abundance and overall ecosystem functioning during extreme droughts should therefore consider sites that may more frequently depart from brackish conditions or more frequently reach salinity extremes. Sites 1 and 2 meet these criteria and also appear to be the most feasible from a water quantity perspective. The ability to tap into existing or future water resources and infrastructure during times of extreme drought and high salinity could be essential in keeping this critical nursery viable as well as retain and support existing subtidal and intertidal oyster reef habitats. The focus during these times is to provide refuge habitat for shellfish and forage fish to the extent possible. It has been documented that even at salinities near or above 30 ppt, oysters can survive dermo infection for some period of time (MBHE 2007). That said, it is also acknowledged that the level of dermo infection during extreme temperatures often accompanying these periods of extended low inflow may still cause extensive mortality. Similar to nature, there are no guarantees during these extremes, but freshwater inflow is a key driver that might provide valuable assistance with these ecological sustainability objectives.

Staying north of the GIWW (Site 1) has several advantages by reducing the amount of freshwater that might be needed as a result of no loss to the waterway. This site did maintain the highest bird diversity and supported live oyster reefs and comparable nekton habitat. Although Site 2 would require water coming across the GIWW (if the water source was in the north), this area is adjacent to the existing cut and also supports live oysters, quality nekton habitat, and diverse coastal bird assemblages. Finally, the Northeast corner of the Colorado River Delta (near Site 3, **Figure 22**) looks to present the path of least resistance, with the least amount of land to manipulate and a shorter diversion path should water from the main stem Colorado River be diverted. Although no engineering study was conducted, we caution that opening a cut in this northeast corner would likely contribute extensive sediment and organic matter into Site 3, eliminating the harder substrate presently there that supports thriving oyster reefs. It is imperative to consider the existing ecological structure of each site and what it took for it to be created and sustained to date. Seasonal delivery would also need to be considered to establish which season would provide the best result for the upcoming year's habitat, and result in the least amount of die off. The critical low-flow summer time period seems the most logical; however, should the amount of water provided not be sufficient to prevent oyster mortality or vegetation die-off, then selective freshets provided in the spring or fall to support the marsh vegetation communities might be the most beneficial use of water when considering the following year's nekton stock.

From this study, it is recommended that a pilot project be conducted at Site 1 or Site 2 to test the concept that additional freshwater input could indeed be detected in this area and offer a benefit to the existing ecological community. It is recommended that this project focus on locally available water sources (i.e. LCRA irrigation canals) as a proof of concept. Should the results be favorable, other options for drought mitigation such as off-channel reservoirs, near-surface groundwater wells, or further enhancement of irrigation canals with additional hydrological analyses could be further explored. Any habitat modification would need to consider the potential effects of sea level rise and climate change.

Although the results from this study provide the initial steps to understanding how differences in environmental conditions influence the biotic communities of the Colorado River Delta at varying spatiotemporal scales, additional long-term monitoring is required to relate ecological variability to specific environmental variables such as freshwater inflows. Additional seasonal monitoring of Sites 1, 2 and CD_5 (as a control) with respect to site-specific salinity, nekton use, marsh vegetation composition and biomass, and oyster reef health would help to better quantify typical environment-related shifts in habitat utilization by estuarine-dependent species in this area.

References

Acevedo, M.A., & L.J. Villanueva-Rivera. 2006. Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. Wildlife Society Bulletin 34:211-214.

Alber, M. 2002. A conceptual model of estuarine freshwater inflow management. Estuaries 25:1246-1261.

Brandes, T.S. 2008. Automated sound recording and analysis techniques for bird surveys and conservation. Bird Conservation International. 18 (S1).

Browning, E., R. Gibb, P. Glover-Kapfer, & K.E. Jones. 2017. Passive acoustic monitoring in ecology and conservation. Conservation technology. Technical Report

Bushon, A. M. 2006. Recruitment, spatial distribution, and fine-scale movement patterns of estuarine-dependent species through major and shallow passes in Texas. M.S. Thesis, Texas A&M University-Corpus Christi, Corpus Christi, Texas.

Clarke, K. R., and R. H. Green. 1988. Statistical design and analysis for a 'biological effects' study. Marine Ecology Progress Series 46:213-226.

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

Clarke, K. R., and M. Ainsworth. 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92:205–219.

Conway, C.J., C. Sulzman, & B.E. Raulston. 2010. Factors affecting detection probability of California Black Rails. Journal of Wildlife Management. 68(2): 360-370.

Digby, A., M. Towsey, B.D. Bell, & P.D. Teal. 2013. A practical comparison of manual and autonomous methods for acoustic monitoring. Methods in Ecology and Evolution. 4: 675-683.

Eddleman, W.R., F.L. Knopf, B. Meanley, F.A. Reid, & R. Zembal. 1988. Conservation of North American rallids. Wilson Bulletin 100:458-475.

Forster, C.R., A.F Amos, and L.A. Fuiman. 2009. Trends in Abundance of Coastal Birds and Human Activity on a Texas Barrier Island Over Three Decades. Estuaries and Coasts (2009) 32:1079-1089.

Hall, Q. A., M. M. Reese Robillard, J. A. Williams, M. J. Ajemian, and G. W. Stunz. 2016. Reopening of a remote tidal inlet increases recruitment of estuarine-dependent nekton. Estuaries and Coasts 39:1769-1784.

Holt, S. A.,C.L. Kitting, and C. R. Arnold.1983. Distribution of young red drums among different seagrass meadows. Transactions of the American Fisheries Society 112:267–271.

Kneib, R. T. 1993. Growth and mortality in successive cohorts offish larvae within an estuarine nursery. Marine Ecology Progress Series 94: 115-127.

MBHE. 2007. Matagorda Bay Health Evaluation, Final Habitat Assessment Report. Prepared for the Lower Colorado River Authority and San Antonio Water System. June 2007.

MBHE. 2008. Matagorda Bay Health Evaluation, Matagorda Bay Inflow Criteria (Colorado River). Prepared for the Lower Colorado River Authority and San Antonio Water System. October 2008.

Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. American Fisheries Society Symposium

Montagna, P. A., X. Hu, T. A. Palmer, and M. Wetz. 2018. Effect of hydrological variability on the biogeochemistry of estuaries across a regional climatic gradient. Limnology and Oceanography 63:2465-2478.

Murphy, M. D., and R. G. Taylor. 1990. Reproduction, growth, and mortality of red drum *Sciaenops ocellatus* in Florida waters. Fishery Bulletin 88:531–542.

Neahr, T. A., G. W. Stunz, and T. J. Minello. 2010. Habitat use patterns of newly settled spotted seatrout in estuaries of the north-western Gulf of Mexico. Fisheries Management and Ecology 17:404–413.

Nevins, J. A., J. B. Pollack, and G. W. Stunz. 2014. Characterizing nekton use of the largest unfished oyster reef in the United States compared with adjacent estuarine habitats. Journal of Shellfish Research 33:227–238.

Pollack, J. B., T. A. Palmer, and P. A. Montagna. 2011. Long-term trends in the response of benthic macrofauna to climate variability in the Lavaca-Colorado Estuary, Texas. Marine Ecology Progress Series 436:67-80.

Reese, M. M., G. W. Stunz, and A. M. Bushon. 2008. Recruitment of Estuarine-Dependent Nekton Through a New Tidal Inlet: The Opening of Packery Channel in Corpus Christi, TX, USA. Estuaries and Coasts 31:1143-1157.

Rozas, L. P., T. J. Minello, I. Munuera-Fernández, B. Fry, and B. Wissel. 2005. Macrofaunal distributions and habitat change following winter–spring releases of freshwater into the Breton Sound estuary, Louisiana (USA). Estuarine, Coastal and Shelf Science 65:319-336.

Rooker, J. R., S. A. Holt, M. A. Soto, and G. J. Holt. 1998. Post-settlement patterns of habitat use by sciaenid fishes in subtropical seagrass meadows. Estuaries 21:318–327.

Sanders, C.E. & D.J. Mennill. 2014. Acoustic monitoring of nocturnally migrating birds accurately assesses the timing and magnitude of migration through the Great Lakes. Condor. 116: 371-383

Searcy, S. P., D. B. Eggleston, and J. A. Hare. 2007. Environmental influences on the relationship between juvenile and larval growth of Atlantic Croaker (*Micropogonias undulatus*). Marine Ecology Progress Series 349:81–88.

Sokolova, M., N. Japkowicz, & S. Szpakowicz. 2006. Beyond accuracy, F-score and ROC: a family of discriminant measures for performance evaluation. Advances in Artificial Intelligence. 4304: 1015-1021.

Stunz, G. W., T. J. Minello, and P. S. Levin. 2002. A comparison of early juvenile red drum densities among various habitat types in Galveston Bay, Texas. Estuaries 25:76–85.

Stunz, G. W., J. C. Gibeaut, E. L. Oborny, P. T. Plotkin, J. B. Pollack, J. R. Rooker, R. J. D. Wells, and M. S. Wetz. 2023. Matagorda Bay Ecosystem Assessment Technical Report. Texas Comptroller of Public Accounts CMD 19-6799CS. 423 pp.

Tolan, J. M. 2007. El Niño-Southern Oscillation impacts translated to the watershed scale: Estuarine salinity patterns along the Texas Gulf Coast, 1982 to 2004. Estuarine, Coastal and Shelf Science 72:247–260.

Towsey, M., J. Wimmer, I. Williamson, & P. Roe. 2014. The use of acoustic indices to determine avian species richness in audio-recordings of the environment. Ecological Informatics. 21: 110-119.

United States Department of Agriculture (USDA), Forest Service. 1997. Monitoring bird populations by point counts. General technical Report. PSW-GTR-149.

Verner, Jared. 1985. Assessment of counting techniques. Current Ornithology. 2: 247-302.

Waddle, J.H., T.F. Thigpen, & B.M. Glorios. 2009. Efficacy of automatic vocalization recognition software for anuran monitoring. Herpetological Conservation and Biology. 4(3): 384-388.

Willacy, R., M. Mahony, & D. Newell. 2015. If a frog calls in the forest: bioacoustics monitoring reveals the breeding phenology of the endangered Richmond Range mountain frog (*Philoria* richmondensis). Austral Ecology. 40(6).

Zimmerman, R. J., T. J. Minello, M. C. Castiglione, and D. L. Smith. 1990a. Utilization of marsh and associated habitats along a salinity gradient in Galveston Bay. NOAA Technical Memorandum, NMFS-SEFC-250.

Zimmerman, R. J., T. J. Minello, M. C. Castiglione, and D. L. Smith. 1990b. The use of Juncus and Spartina marshes by fisheries species in Lavaca Bay, Texas, with reference to effects of floods. NOAA Technical Memorandum, NMFS-SEFC-251.

Supplementary Table 1. Seasonal total catch, relative abundance (RA by group [fish, crustaceans] and overall), frequency of occurrence (FO), mean density (no./m^2), and mean size (mm) of nekton sampled in the Colorado River Delta, 2021-2022.

		Total Catch	Group RA (%)	Overall RA (%)	FO	FO (%)	Mean Density (no./m^2)	SE	Mean Size (mm)	SE
Spring '21										
Total Organisms		10341					34.470	(0.708)		
Total Fish		249		2.4			0.830	(0.038)		
Atlantic Croaker	*Micropogonias undulatus*	2	0.8	0.0	2	6.7	0.007	(0.005)	10.9	(0.819)
Bay Anchovy	*Anchoa mitchilli*	9	3.6	0.1	3	10.0	0.030	(0.024)	21.9	(1.992)
Bay Whiff	*Citharichthys spilopterus*	4	1.6	0.0	2	6.7	0.013	(0.010)	25.1	(6.034)
Diamond Killifish	*Adinia xenica*	7	2.8	0.1	2	6.7	0.023	(0.020)	27.5	(2.190)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	89	35.7	0.9	12	40.0	0.297	(0.154)	11.9	(0.953)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	2	0.8	0.0	1	3.3	0.007	(0.007)	36.8	(4.500)
Gulf Menhaden	*Brevoortia patronus*	36	14.5	0.3	7	23.3	0.120	(0.069)	27.5	(1.021)
Inland Silverside	*Menidia beryllina*	37	14.9	0.4	11	36.7	0.123	(0.043)	25.5	(0.873)
Longnose Killifish	*Fundulus similis*	3	1.2	0.0	1	3.3	0.010	(0.010)	23.7	(3.982)
Pinfish	*Lagodon rhomboides*	26	10.4	0.3	13	43.3	0.087	(0.022)	40.3	(1.499)
Pipefish	*Syngnathus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Rainwater Killifish	*Lucania parva*	2	0.8	0.0	1	3.3	0.007	(0.007)	29.3	(1.550)
Red Drum	*Sciaenops ocellatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	2	0.8	0.0	1	3.3	0.007	(0.007)	15.0	(0.000)
Shrimp Eel	*Ophichthus gomesii*	1	0.4	0.0	1	3.3	0.003	(0.003)	60.1	(0.000)
Silver Perch	*Bairdiella chrysoura*	1	0.4	0.0	1	3.3	0.003	(0.003)	14.5	(3.950)
Skilletfish	*Gobiesox strumosus*	9	3.6	0.1	6	20.0	0.030	(0.013)	22.0	(1.174)
Southern Flounder	*Paralichthys lethostigma*	1	0.4	0.0	1	3.3	0.003	(0.003)	69.0	(0.000)
Spot	*Leiostomus xanthurus*	14	5.6	0.1	7	23.3	0.047	(0.017)	41.0	(2.180)
Spotfin Mojarra	*Eucinostomus argenteus*	4	1.6	0.0	2	6.7	0.013	(0.010)	13.9	(1.617)
Spotted Seatrout	*Cynoscion nebulosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Striped Mullet	*Mugil cephalus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		10092		97.6			33.640	(4.382)		
Arrow Shrimp	*Tozeuma carolinense*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Blue Crab	*Callinectus sapidus*	74	0.7	0.7	25	83.3	0.247	(0.037)	19.4	(1.135)
Grass Shrimp	*Palaemonetes spp.*	9224	91.4	89.2	29	96.7	30.747	(3.962)	27.1	(0.218)
Mud Crab	*Xanthidae spp.*	13	0.1	0.1	7	23.3	0.043	(0.017)	7.9	(0.701)
Penaeid Shrimp	*Penaeidae spp.*	781	7.7	7.6	28	93.3	2.603	(0.554)	30.8	(0.657)
Summer '21										
Total Organisms		15287					50.957	(0.662)		
Total Fish		581		3.8			1.937	(0.093)		
Atlantic Croaker	*Micropogonias undulatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Bay Anchovy	*Anchoa mitchilli*	17	2.9	0.1	6	20.0	0.057	(0.031)	13.6	(0.582)

Bay Whiff	*Citharichthys spilopterus*	22	3.8	0.1	7	23.3	0.073	(0.035)	18.4	(0.929)
Diamond Killifish	*Adinia xenica*	3	0.5	0.0	3	10.0	0.010	(0.006)	24.8	(4.990)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	320	55.1	2.1	26	86.7	1.067	(0.182)	12.3	(0.362)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	18	3.1	0.1	9	30.0	0.060	(0.025)	24.7	(2.548)
Gulf Menhaden	*Brevoortia patronus*	3	0.5	0.0	2	6.7	0.010	(0.007)	16.2	(8.915)
Inland Silverside	*Menidia beryllina*	12	2.1	0.1	3	10.0	0.040	(0.024)	18.2	(4.438)
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Pinfish	*Lagodon rhomboides*	124	21.3	0.8	4	13.3	0.413	(0.396)	7.2	(0.363)
Pipefish	*Syngnathus spp.*	1	0.2	0.0	1	3.3	0.003	(0.003)	99.9	(0.000)
Rainwater Killifish	*Lucania parva*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Red Drum	*Sciaenops ocellatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Seahorse	*Hippocampus spp.*	1	0.2	0.0	1	3.3	0.003	(0.003)	81.7	(0.000)
Sheepshead Minnow	*Cyprinodon variegatus*	3	0.5	0.0	2	6.7	0.010	(0.007)	16.2	(0.498)
Shrimp Eel	*Ophichthus gomesii*	1	0.2	0.0	1	3.3	0.003	(0.003)	63.2	(0.000)
Silver Perch	*Bairdiella chrysoura*	10	1.7	0.1	4	13.3	0.033	(0.019)	14.1	(1.694)
Skilletfish	*Gobiesox strumosus*	1	0.2	0.0	1	3.3	0.003	(0.003)	31.9	(0.000)
Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotfin Mojarra	*Eucinostomus argenteus*	12	2.1	0.1	6	20.0	0.040	(0.020)	14.4	(1.782)
Spotted Seatrout	*Cynoscion nebulosus*	29	5.0	0.2	13	43.3	0.097	(0.031)	18.4	(1.070)
Striped Mullet	*Mugil cephalus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Tonguefish	*Symphurus spp.*	4	0.7	0.0	2	6.7	0.013	(0.010)	16.2	(0.904)
Total Crustaceans		14706		96.2			49.020	(4.079)		
Arrow Shrimp	*Tozeuma carolinense*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Blue Crab	*Callinectus sapidus*	511	3.5	3.3	27	90.0	1.703	(0.332)	9.2	(0.219)
Grass Shrimp	*Palaemonetes spp.*	9380	63.8	61.4	30	100.0	31.267	(3.006)	23.9	(0.212)
Mud Crab	*Xanthidae spp.*	57	0.4	0.4	18	60.0	0.190	(0.057)	5.0	(0.311)
Penaeid Shrimp	*Penaeidae spp.*	4758	32.4	31.1	30	100.0	15.860	(2.171)	26.8	(0.535)
Fall '21										
Total Organisms		30149					100.497	(2.439)		
Total Fish		804		2.7			2.680	(0.074)		
Atlantic Croaker	*Micropogonias undulatus*	61	7.6	0.2	10	33.3	0.203	(0.077)	9.0	(0.225)
Bay Anchovy	*Anchoa mitchilli*	13	1.6	0.0	4	13.3	0.043	(0.026)	19.0	(2.336)
Bay Whiff	*Citharichthys spilopterus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Diamond Killifish	*Adinia xenica*	17	2.1	0.1	11	36.7	0.057	(0.019)	30.7	(1.750)
Fat Sleeper	*Dormitator maculatus*	3	0.4	0.0	3	10.0	0.010	(0.006)	63.1	(2.007)
Goby	*Gobiidae spp.*	356	44.3	1.2	28	93.3	1.187	(0.236)	17.1	(0.308)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	119	14.8	0.4	24	80.0	0.397	(0.101)	22.8	(0.776)
Gulf Menhaden	*Brevoortia patronus*	121	15.0	0.4	11	36.7	0.403	(0.192)	15.9	(0.255)
Inland Silverside	*Menidia beryllina*	10	1.2	0.0	4	13.3	0.033	(0.024)	14.7	(0.445)
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		

Pinfish	*Lagodon rhomboides*	1	0.1	0.0	1	3.3	0.003	(0.003)	11.8	(0.000)
Pipefish	*Syngnathus spp.*	1	0.1	0.0	1	3.3	0.003	(0.003)	26.1	(0.000)
Rainwater Killifish	*Lucania parva*	1	0.1	0.0	1	3.3	0.003	(0.003)	84.0	(0.000)
Red Drum	*Sciaenops ocellatus*	97	12.1	0.3	13	43.3	0.323	(0.108)	11.3	(0.245)
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Shrimp Eel	*Ophichthus gomesii*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Silver Perch	*Bairdiella chrysoura*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Skilletfish	*Gobiesox strumosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotfin Mojarra	*Eucinostomus argenteus*	1	0.1	0.0	1	3.3	0.003	(0.003)	12.4	(0.000)
Spotted Seatrout	*Cynoscion nebulosus*	3	0.4	0.0	3	10.0	0.010	(0.006)	16.1	(8.553)
Striped Mullet	*Mugil cephalus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		29345		97.3			97.817	(15.116)		
Arrow Shrimp	*Tozeuma carolinense*	0		0.0	0	0.0	0.000	(0.000)		
Blue Crab	*Callinectus sapidus*	723		2.4	28	93.3	2.410	(0.389)	9.4	(0.301)
Grass Shrimp	*Palaemonetes spp.*	25029		83.0	29	96.7	83.430	(13.678)	19.6	(0.250)
Mud Crab	*Xanthidae spp.*	76		0.3	26	86.7	0.253	(0.043)	5.1	(0.322)
Penaeid Shrimp	*Penaeidae spp.*	3517		11.7	29	96.7	11.723	(1.780)	22.8	(0.518)
Winter '22										
Total Organisms		8732					51.365	(1.252)		
Total Fish		784		9.0			4.612	(0.219)		
Atlantic Croaker	*Micropogonias undulatus*	61	7.8	0.7	11	64.7	0.359	(0.144)	13.7	(0.362)
Bay Anchovy	*Anchoa mitchilli*	1	0.1	0.0	1	5.9	0.006	(0.006)	16.1	(0.000)
Bay Whiff	*Citharichthys spilopterus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Diamond Killifish	*Adinia xenica*	22	2.8	0.3	6	35.3	0.129	(0.073)	28.8	(1.167)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	29	3.7	0.3	13	76.5	0.171	(0.048)	21.4	(1.740)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	24	3.1	0.3	9	52.9	0.141	(0.059)	32.4	(2.529)
Gulf Menhaden	*Brevoortia patronus*	71	9.1	0.8	7	41.2	0.418	(0.233)	23.2	(0.699)
Inland Silverside	*Menidia beryllina*	6	0.8	0.1	4	23.5	0.035	(0.017)	33.4	(7.797)
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Pinfish	*Lagodon rhomboides*	562	71.7	6.4	17	100.0	3.306	(1.350)	14.3	(0.137)
Pipefish	*Syngnathus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Rainwater Killifish	*Lucania parva*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Red Drum	*Sciaenops ocellatus*	4	0.5	0.0	2	11.8	0.024	(0.018)	12.3	(0.630)
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Shrimp Eel	*Ophichthus gomesii*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Silver Perch	*Bairdiella chrysoura*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Skilletfish	*Gobiesox strumosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		

Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotfin Mojarra	*Eucinostomus argenteus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotted Seatrout	*Cynoscion nebulosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Striped Mullet	*Mugil cephalus*	4	0.5	0.0	3	17.6	0.024	(0.014)	45.8	(20.001)
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		7948		91.0			46.753	(7.676)		
Arrow Shrimp	*Tozeuma carolinense*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Blue Crab	*Callinectus sapidus*	542	6.8	6.2	16	94.1	3.188	(1.553)	12.8	(0.432)
Grass Shrimp	*Palaemonetes spp.*	7368	92.7	84.4	17	100.0	43.341	(9.178)	25.0	(0.282)
Mud Crab	*Xanthidae spp.*	33	0.4	0.4	5	29.4	0.194	(0.124)	7.8	(0.641)
Penaeid Shrimp	*Penaeidae spp.*	5	0.1	0.1	2	11.8	0.029	(0.021)	12.1	(0.973)
Spring '22										
Total Organisms		18781					62.603	(0.948)		
Total Fish		658		3.5			2.193	(0.162)		
Atlantic Croaker	*Micropogonias undulatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Bay Anchovy	*Anchoa mitchilli*	5	0.8	0.0	3	10.0	0.017	(0.010)	24.2	(6.171)
Bay Whiff	*Citharichthys spilopterus*	1	0.2	0.0	1	3.3	0.003	(0.003)	43.1	(0.000)
Diamond Killifish	*Adinia xenica*	3	0.5	0.0	3	10.0	0.010	(0.006)	24.6	(3.659)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	45	6.8	0.2	18	60.0	0.150	(0.032)	19.1	(1.520)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	42	6.4	0.2	23	76.7	0.140	(0.023)	24.4	(0.925)
Gulf Menhaden	*Brevoortia patronus*	421	64.0	2.2	11	36.7	1.403	(0.741)	28.5	(0.682)
Inland Silverside	*Menidia beryllina*	12	1.8	0.1	5	16.7	0.040	(0.019)	15.9	(1.335)
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Pinfish	*Lagodon rhomboides*	23	3.5	0.1	12	40.0	0.077	(0.022)	26.2	(2.833)
Pipefish	*Syngnathus spp.*	10	1.5	0.1	7	23.3	0.033	(0.013)	96.1	(8.842)
Rainwater Killifish	*Lucania parva*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Red Drum	*Sciaenops ocellatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Shrimp Eel	*Ophichthus gomesii*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Silver Perch	*Bairdiella chrysoura*	7	1.1	0.0	6	20.0	0.023	(0.009)	15.8	(2.610)
Skilletfish	*Gobiesox strumosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	7	1.1	0.0	3	10.0	0.023	(0.015)	44.1	(1.142)
Spotfin Mojarra	*Eucinostomus argenteus*	2	0.3	0.0	1	3.3	0.007	(0.007)	18.3	(6.100)
Spotted Seatrout	*Cynoscion nebulosus*	7	1.1	0.0	6	20.0	0.023	(0.009)	9.9	(0.735)
Striped Mullet	*Mugil cephalus*	73	11.1	0.4	6	20.0	0.243	(0.206)	26.6	(0.618)
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		18123		96.5			60.410	(5.817)		
Arrow Shrimp	*Tozeuma carolinense*	2	0.0	0.0	1	3.3	0.007	(0.007)	6.3	(0.150)
Blue Crab	*Callinectus sapidus*	90	0.5	0.5	20	66.7	0.300	(0.062)	20.6	(1.250)

Grass Shrimp	*Palaemonetes spp.*	13816	76.2	73.6	30	100.0	46.053	(4.749)	26.0	(0.224)
Mud Crab	*Xanthidae spp.*	27	0.1	0.1	5	16.7	0.090	(0.067)	7.2	(0.476)
Penaeid Shrimp	*Penaeidae spp.*	4188	23.1	22.3	30	100.0	13.960	(2.374)	29.5	(0.599)
Summer '22										
Total Organisms		9121					30.403	(0.666)		
Total Fish		680		7.5			2.267	(0.158)		
Atlantic Croaker	*Micropogonias undulatus*	6	0.9	0.1	4	13.3	0.020	(0.011)	21.2	(2.827)
Bay Anchovy	*Anchoa mitchilli*	193	28.4	2.1	16	53.3	0.643	(0.234)	19.3	(0.307)
Bay Whiff	*Citharichthys spilopterus*	2	0.3	0.0	2	6.7	0.007	(0.005)	21.4	(0.950)
Diamond Killifish	*Adinia xenica*	3	0.4	0.0	3	10.0	0.010	(0.006)	33.0	(6.121)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	378	55.6	4.1	23	76.7	1.260	(0.708)	9.3	(0.413)
Gray Snapper	*Lutjanus griseus*	1	0.1	0.0	1	3.3	0.003	(0.003)	15.3	(0.000)
Gulf Killifish	*Fundulus grandis*	3	0.4	0.0	3	10.0	0.010	(0.006)	47.5	(12.695)
Gulf Menhaden	*Brevoortia patronus*	18	2.6	0.2	4	13.3	0.060	(0.039)	13.6	(0.592)
Inland Silverside	*Menidia beryllina*	26	3.8	0.3	5	16.7	0.087	(0.044)	21.8	(1.341)
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Pinfish	*Lagodon rhomboides*	11	1.6	0.1	8	26.7	0.037	(0.012)	9.6	(0.961)
Pipefish	*Syngnathus spp.*	2	0.3	0.0	2	6.7	0.007	(0.005)	125.6	(17.750)
Rainwater Killifish	*Lucania parva*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Red Drum	*Sciaenops ocellatus*	1	0.1	0.0	1	3.3	0.003	(0.003)	9.9	(0.000)
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Shrimp Eel	*Ophichthus gomesii*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Silver Perch	*Bairdiella chrysoura*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Skilletfish	*Gobiesox strumosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotfin Mojarra	*Eucinostomus argenteus*	1	0.1	0.0	1	3.3	0.003	(0.003)	16.1	(0.000)
Spotted Seatrout	*Cynoscion nebulosus*	35	5.1	0.4	13	43.3	0.117	(0.041)	20.7	(1.006)
Striped Mullet	*Mugil cephalus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		8441		92.5			28.137	(4.045)		
Arrow Shrimp	*Tozeuma carolinense*	4	0.0	0.0	3	10.0	0.013	(0.008)	11.6	(2.554)
Blue Crab	*Callinectus sapidus*	53	0.6	0.6	22	73.3	0.177	(0.027)	9.3	(0.643)
Grass Shrimp	*Palaemonetes spp.*	6708	79.5	73.5	29	96.7	22.360	(3.578)	23.9	(0.197)
Mud Crab	*Xanthidae spp.*	7	0.1	0.1	4	13.3	0.023	(0.014)	8.5	(1.539)
Penaeid Shrimp	*Penaeidae spp.*	1669	19.8	18.3	29	96.7	5.563	(0.912)	19.5	(0.531)
Fall '22										
Total Organisms		13852					46.173	(1.099)		
Total Fish		510		3.7			1.700	(0.066)		
Atlantic Croaker	*Micropogonias undulatus*	5	1.0	0.0	4	13.3	0.017	(0.008)	8.7	(0.514)
Bay Anchovy	*Anchoa mitchilli*	4	0.8	0.0	3	10.0	0.013	(0.008)	10.4	(1.996)
Bay Whiff	*Citharichthys spilopterus*	0	0.0	0.0	0	0.0	0.000	(0.000)		

Diamond Killifish	*Adinia xenica*	23	4.5	0.2	8	26.7	0.077	(0.029)	18.5	(1.459)
Fat Sleeper	*Dormitator maculatus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Goby	*Gobiidae spp.*	231	45.3	1.7	19	63.3	0.770	(0.260)	17.8	(0.389)
Gray Snapper	*Lutjanus griseus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Gulf Killifish	*Fundulus grandis*	114	22.4	0.8	18	60.0	0.380	(0.101)	21.3	(0.656)
Gulf Menhaden	*Brevoortia patronus*	28	5.5	0.2	8	26.7	0.093	(0.037)	15.2	(0.453)
Inland Silverside	*Menidia beryllina*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Longnose Killifish	*Fundulus similis*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Pinfish	*Lagodon rhomboides*	17	3.3	0.1	9	30.0	0.057	(0.020)	10.6	(0.263)
Pipefish	*Syngnathus spp.*	4	0.8	0.0	4	13.3	0.013	(0.006)	89.5	(11.794)
Rainwater Killifish	*Lucania parva*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Red Drum	*Sciaenops ocellatus*	2	0.4	0.0	2	6.7	0.007	(0.005)	11.6	(1.500)
Seahorse	*Hippocampus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Sheepshead Minnow	*Cyprinodon variegatus*	80	15.7	0.6	8	26.7	0.267	(0.127)	22.1	(0.535)
Shrimp Eel	*Ophichthus gomesii*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Silver Perch	*Bairdiella chrysoura*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Skilletfish	*Gobiesox strumosus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Southern Flounder	*Paralichthys lethostigma*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spot	*Leiostomus xanthurus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotfin Mojarra	*Eucinostomus argenteus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Spotted Seatrout	*Cynoscion nebulosus*	2	0.4	0.0	2	6.7	0.007	(0.005)	19.8	(14.150)
Striped Mullet	*Mugil cephalus*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Tonguefish	*Symphurus spp.*	0	0.0	0.0	0	0.0	0.000	(0.000)		
Total Crustaceans		13342		96.3			44.473	(6.807)		
Arrow Shrimp	*Tozeuma carolinense*	42	0.3	0.3	8	26.7	0.140	(0.058)	12.4	(0.835)
Blue Crab	*Callinectus sapidus*	452	3.4	3.3	30	100.0	1.507	(0.196)	8.6	(0.252)
Grass Shrimp	*Palaemonetes spp.*	7806	58.5	56.4	30	100.0	26.020	(5.796)	18.0	(0.222)
Mud Crab	*Xanthidae spp.*	9	0.1	0.1	6	20.0	0.030	(0.015)	5.5	(0.767)
Penaeid Shrimp	*Penaeidae spp.*	5033	37.7	36.3	30	100.0	16.777	(2.232)	16.5	(0.369)

Supplementary Table 2. Seasonal occurrence, site occurrence, count (#), relative abundance (%) and dominant habitat type of the avian communities observed during seasonal sampling. Habitat types included emergent marsh (EM), open water (OW), shoreline (SL), mud flat (MF), woody debris (WD), scrubland (ScL), and exposed oyster beds (EO).

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
American Avocet	x		x	x	x		x		x	172	2.11%	x	x	x	x		x	
American Bittern	x				x					1	0.01%	x						
American Crow			x	x						4	0.05%						x	
American Kestrel			x	x						1	0.01%						x	
American Pipit			x	x						6	0.07%						x	
American White Ibis	x	x	x	x	x	x	x	x		77	0.95%	x	x	x	x			
American White Pelican	x	x	x	x	x	x	x		x	483	5.93%	x	x	x	x	x	x	
Barn Swallow	x			x	x	x		x	x	25	0.31%	x	x				x	
Belted Kingfisher		x	x	x			x	x	x	22	0.27%	x	x	x		x	x	
Black Skimmer	x		x		x		x		x	72	0.88%		x		x			
Black-bellied Plover	x		x			x	x		x	54	0.66%	x	x	x	x			
Black-bellied Whistling Duck		x			x					1	0.01%							
Black Tern	x			x	x	x	x	x	x	24	0.29%	x	x			x	x	
Black-crowned Night Heron	x						x	x		4	0.05%	x					x	
Black-necked Stilt	x	x	x	x	x			x	x	21	0.26%	x	x	x			x	
Blue-gray Gnatcatcher			x	x						8	0.10%						x	
Blue-winged Teal	x		x	x	x	x	x	x	x	595	7.31%		x					
Boat-tailed Grackle	x	x	x	x	x	x	x	x	x	334	4.10%	x	x			x	x	x

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
Brown Pelican	x	x	x	x	x	x	x	x	x	175	2.15%	x	x	x		x	x	
Brown-headed Cowbird	x		x	x	x				x	13	0.16%	x	x			x	x	
Canvasback			x				x			100	1.23%		x					
Carolina Chickadee	x		x	x						12	0.15%			x		x	x	
Carolina Wren		x	x	x						12	0.15%					x	x	
Caspian Tern	x	x	x	x	x	x	x	x	x	114	1.40%	x	x		x		x	
Cattle Egret	x	x		x	x			x	x	14	0.17%	x		x			x	
Clapper Rail	x	x	x	x	x	x	x	x	x	126	1.55%	x						
Cave Swallow	x				x	x				2	0.02%		x					
Chipping Swallow	x			x						1	0.01%						x	
Cliff Swallow	x			x		x		x		43	0.53%	x	x					
Common Gallinule			x	x		x				2	0.02%	x						
Common Grackle		x		x		x			x	9	0.11%		x					
Common Tern	x			x	x	x	x	x		164	2.01%	x	x	x		x		
Common Yellowthroat		x	x	x	x					29	0.36%					x	x	
Crested Caracara			x	x						4	0.05%		x			x		
Dowitcher sp.	x		x		x	x	x		x	249	3.06%	x			x			
Double-crested Cormorant	x		x	x	x	x	x	x	x	115	1.41%	x	x		x	x	x	
Eastern Meadowlark	x	x	x	x	x		x			19	0.23%	x				x	x	
Eastern Phoebe			x	x						4	0.05%			x			x	
Forster's Tern	x	x	x	x	x	x	x	x	x	464	5.70%	x	x	x	x	x	x	
Glossy Ibis			x	x						1	0.01%						x	

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
Great Blue Heron	x	x	x	x	x	x	x	x	x	78	0.96%	x	x	x		x	x	
Great Egret	x	x	x	x	x	x	x	x	x	105	1.29%	x	x	x	x	x	x	
Greater Scaup	x				x	x				6	0.07%	x						
Greater Yellowlegs	x		x	x	x	x				17	0.21%	x	x	x	x			
Great-tailed Grackle	x	x		x			x			18	0.22%		x				x	
Green Heron	x			x						7	0.09%	x	x				x	
Green-winged Teal		x	x			x	x		x	466	5.72%	x	x					
Gull billed Tern	x		x			x	x			3	0.04%		x					
Herring Gull			x			x	x			24	0.29%	x			x			
House Wren			x	x	x	x				8	0.10%	x					x	
Killdeer		x	x	x	x	x				1	0.01%	x	x	x	x			
Laughing Gull	x	x	x	x	x	x	x	x	x	405	4.97%	x	x	x		x	x	
Least Bittern	x			x	x	x	x	x	x	32	0.39%	x						
Least Sandpiper	x	x	x		x	x	x		x	177	2.17%	x	x	x	x			
Least Tern	x							x	x	10	0.12%	x	x					
Lesser Black Backed Gull			x			x				1	0.01%		x					
Lesser Scaup			x						x	25	0.31%		x					
Lesser Yellowlegs			x	x						2	0.02%						x	
Lincoln's Sparrow			x	x						1	0.01%						x	
Little Blue Heron	x	x	x	x	x	x	x		x	19	0.23%	x	x	x		x	x	x
Long-Billed Curlew			x				x		x	7	0.09%			x	x			
Magnificent Frigatebird	x		x		x		x			14	0.17%	x	x					

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
Mallard			x					x		2	0.02%		x					
Marbled Godwit		x			x				x	11	0.14%		x	x				
Marsh Wren		x	x	x	x	x	x	x	x	40	0.49%	x		x		x	x	
Mourning Dove	x		x	x	x		x			9	0.11%	x		x			x	
Neotropic Cormorant	x	x	x	x	x	x	x	x	x	98	1.20%	x	x	x		x	x	
Northern Cardinal	x	x	x	x	x	x		x		51	0.63%	x				x	x	
Northern Harrier		x	x	x	x	x	x	x	x	33	0.41%	x	x				x	
Northern Mockingbird	x	x	x	x		x		x		12	0.15%						x	
Northern Shoveler	x			x	x					106	1.30%	x	x					
Osprey	x	x	x		x	x	x	x		35	0.43%	x	x	x		x	x	
Palm Warbler			x	x						1	0.01%						x	
Painted Bunting	x			x	x					5	0.06%					x	x	
Pectoral Sandpiper	x								x	4	0.05%			x				
Peregrine Falcon			x			x				1	0.01%	x						
Pintail			x				x	x		155	1.90%		x					
Purple Martin	x					x				3	0.04%	x						
Redhead			x		x					75	0.92%		x					
Red shouldered Hawk		x	x	x						2	0.02%						x	
Red-tailed Hawk			x	x						1	0.01%		x					
Reddish Egret	x	x	x		x	x	x		x	10	0.12%		x	x	x	x		
Red-winged Blackbird	x	x	x	x	x	x	x	x	x	501	6.15%	x	x	x	x	x	x	

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
Ring-billed Gull		x	x	x	x		x	x		79	0.97%		x		x	x	x	
Roseate Spoonbill		x	x	x		x	x	x	x	28	0.34%	x	x				x	
Royal Tern	x	x	x	x	x	x	x	x	x	69	0.85%	x	x		x	x		
Ruby-crowned Kinglet			x	x						7	0.09%						x	
Ruddy Turnstone						x	x	x	x	23	0.28%	x	x					
Sanderling	x		x	x		x	x	x	x	398	4.89%		x	x	x			
Savannah Sparrow			x	x						1	0.01%						x	
Seaside Sparrow	x	x	x	x	x	x	x	x	x	99	1.22%	x						
Sedge Wren		x	x	x	x	x	x	x	x	29	0.36%	x	x				x	
Semipalmated Plover	x		x						x	10	0.12%		x	x				
Short-billed Dowitcher			x				x			28	0.34%		x			x		
Snow Goose			x					x		50	0.61%	x						
Snowy Egret	x	x	x	x	x	x	x	x	x	144	1.77%	x	x	x	x	x	x	
Spotted Sandpiper	x		x	x			x			4	0.05%			x		x		
Swamp Sparrow		x	x	x				x		39	0.48%	x				x	x	
Tree Swallow		x	x	x	x					17	0.21%	x	x				x	
Tricolored Heron	x	x	x	x	x	x	x	x	x	132	1.62%	x	x	x		x	x	
Turkey Vulture	x	x	x	x	x	x	x	x	x	92	1.13%	x	x	x		x	x	
Weight			x				x			1	0.01%		x					
Western Sandpiper			x		x	x	x	x	x	232	2.85%	x	x		x			
Whimbrel			x	x						1	0.01%	x						
White eyed Vireo	x	x		x						4	0.05%						x	

Taxa	Season			Site						Count	Relative Abundance (%)	Dominant Habitat Type						
	S	F	W	1	2	3	4	5	6			EM	OW	SL	MF	WD	ScL	EO
White Ibis		x	x	x	x	x	x	x	x	142	1.74%	x	x	x		x	x	
White-faced Ibis			x	x						69	0.85%		x				x	
White-tailed Hawk		x		x						1	0.01%						x	
Willet	x	x	x	x	x	x	x	x	x	248	3.05%	x	x	x	x		x	
Wilson’s Plover			x				x			25	0.31%				x			
Yellow-billed Cuckoo			x	x						1	0.01%						x	
Yellow-rumped Warbler			x	x						11	0.14%						x	