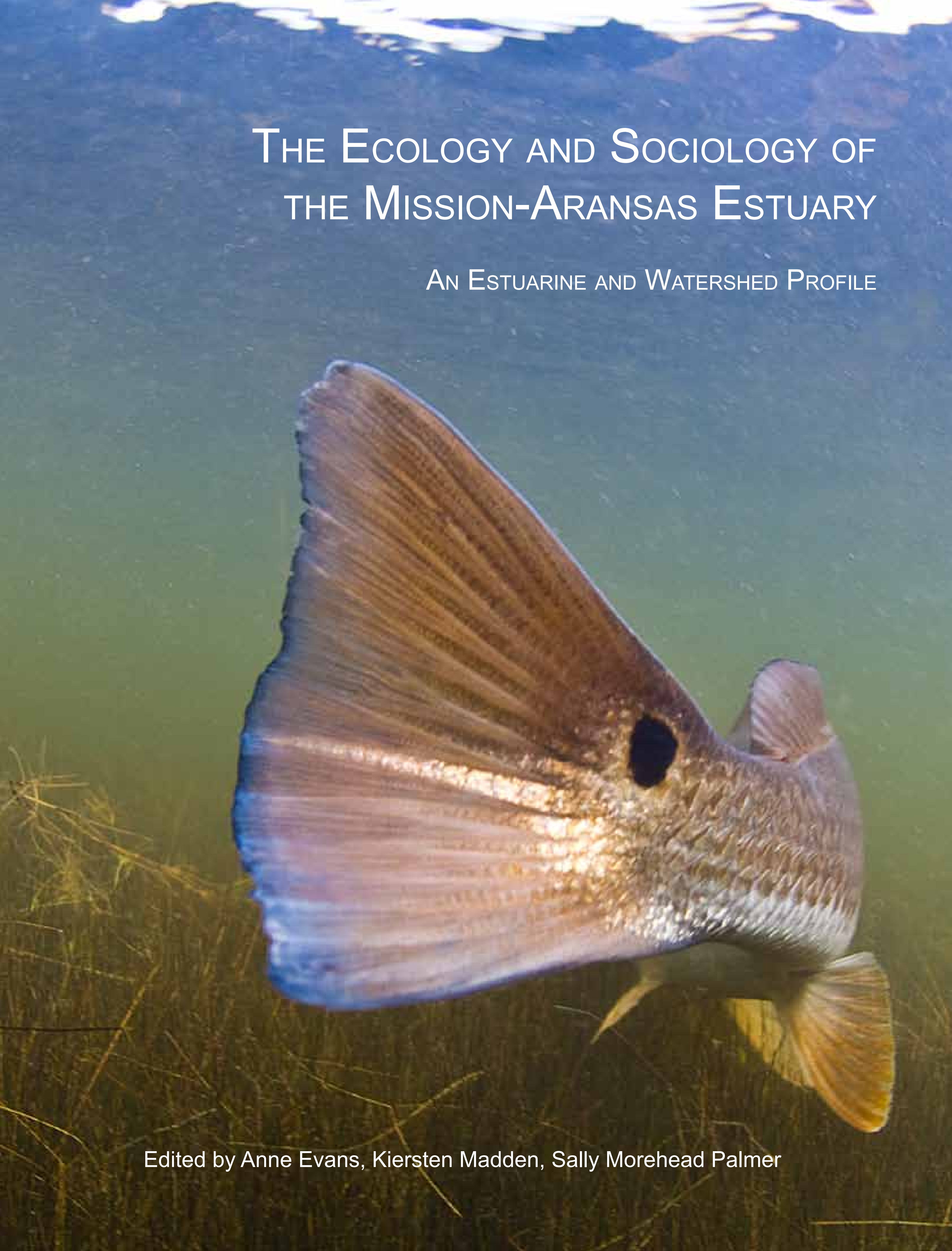

The Ecology and Sociology of the Mission-Aransas Estuary

An Estuarine and Watershed Profile

Edited by Anne Evans, Kiersten Madden, Sally Morehead Palmer

THE ECOLOGY AND SOCIOLOGY OF THE MISSION-ARANSAS ESTUARY

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MISSION ★ ARANSAS
NATIONAL ESTUARINE RESEARCH RESERVE

On the cover: Photo courtesy of Tosh Brown, www.toshbrown.com

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Kiersten Madden serves as the Mission-Aransas NERR Stewardship Coordinator. She received a BA in biology from Augustana College in 2002 and completed a PhD in marine science from The University of Texas at Austin in 2007. Her thesis examined the foraging behaviors of Weddell seals in the Antarctic fast-ice environment. Kiersten also has work experience in GK-12 education, biological surveys, environmental education, and restoration. As Stewardship Coordinator for the NERR, Kiersten's primary duties include: monitoring land management practices among reserve partners, supporting clean-up and recycling programs, characterizing the reserve through habitat mapping, initiating restoration and mitigation projects with appropriate partners, and identifying potential areas for land acquisition.

Sally Morehead Palmer is the Mission-Aransas NERR Manager. She is responsible for over-seeing the Reserve staff and handles many of the day-to-day operations of the NERR. Sally received a BA in biology from the University of Rhode Island in 1999 and completed her MS in marine science at The University of Texas at Austin in 2002. For her thesis she examined anthropogenic impacts on marine communities in McMurdo Sound, Antarctica. In 2002, Sally returned to The University of Texas and worked on securing the designation of the Mission-Aransas NERR.

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EXECUTIVE SUMMARY

The Mission-Aransas National Estuarine Research Reserve (NERR) is one of 28 national estuarine reserves created to promote the responsible use and management of the nation's estuaries through a program combining scientific research, education, and stewardship. The purpose of this document is to provide researchers and resource managers with an adequate basis of knowledge to further development of scientific studies and applied management investigations. This document describes the different physical ecosystem components, ecological processes, habitats, and watersheds of the Reserve.

The Mission-Aransas NERR is a complex of wetland, terrestrial, and marine environments. The land is primarily coastal prairie with unique oak motte habitats. The wetlands include riparian habitat, and freshwater and salt water marshes. Within the water areas, the bays are large, open, and include extensive wind tidal flats, seagrass meadows, mangroves, and oyster reefs. This site profile describes each habitat by their location, type, distribution, abundance, current status and trends, issues of concerns, and future research plans.

Research within the Mission-Aransas NERR seeks to improve the understanding of the Texas coastal zone ecosystems structure and function. Current research includes: nutrient loading and transformation, estimates of community metabolism, water quality monitoring, freshwater inflow, climate change and fishery habitat. Harmful algal blooms, zooplankton, coliform bacteria, submerged aquatic vegetation, and marsh grass are monitored through the System-Wide Monitoring Program (SWMP). This document also describes the climate, hydrography and oceanography, geology, water quality, and endangered species within the Mission-Aransas NERR.

Map of 28 National Estuarine Research Reserves

Chapter 1 INTRODUCTION

Sally Morehead Palmer

The Mission-Aransas National Estuarine Research Reserve (NERR) is approximately 185,708 acres of diverse habitats, ranging from riparian woodlands to large expanses of seagrass meadows. The site profile was organized based on the National Estuarine Research Reserve System (NERRS) classification scheme. The classification scheme was developed to standardize the way land cover data are classified within the NERR system. All cover types are organized by categories adopted from the National Wetland Classification Standard and designed to be analogous in both structure and content. The classification scheme is a useful tool for comprehensive, high-resolution mapping and inventory of coastal habitat and landscape features.

Mission River

Descriptions of the physical ecosystem components, ecological processes, habitats, and watershed are provided in subsequent chapters to further scientific understanding and inquiry. Habitats within the NERR are characterized by their locations, types and distributions, abundance, current status and trends, issues of concerns, and future research initiatives within the NERR. The watershed is characterized by both the human and ecological interfaces. A conceptual ecosystem model is also provided to highlight the important linkages between humans and habitat responses.

This site profile is created as a requirement by the NERRS. The NERRS was created by the Coastal Zone Management Act (CZMA) of 1972, as amended, 16 USC Section 1461, to augment the Federal Coastal Zone Management (CZM) Program. The CZM Program is dedicated to comprehensive, sustainable management of the nation's coasts. The NERRS is a network of protected areas established to promote informed management of the Nation's estuaries and coastal habitats. Currently, the NERRS consists of 28 Reserves in 21 states and US territories, protecting over one million acres of estuarine lands and waters.

As stated in the NERRS regulations, 15 CFR Part 921.1(a), the NERRS mission is *the establishment and management, through Federal-state cooperation, of a national system of Estuarine Research Reserves representative of the various regions and estuarine types in the United States. Estuarine Research Reserves are established to provide opportunities for long-term research, education, and interpretation.*

Federal regulations, 15 CFR Part 921.1(b), provide five specific goals for the NERRS:

(1) Ensure a stable environment for research through long-term protection of NERR resources;

(2) Address coastal management issues identified as significant through coordinated estuarine research within the NERRS;

(3) Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;

(4) Promote Federal, state, public and private use of one or more Reserves within the NERRS when such entities conduct estuarine research; and

(5) Conduct and coordinate estuarine research within the NERRS, gathering and making available information necessary for improved understanding and management of estuarine areas.

Reserve Mission, Vision, and Goals

The National Oceanic and Atmospheric Administration (NOAA) has identified eleven distinct biogeographic regions and 29 subregions in the US, each of which contains several types of estuarine ecosystems (15 CFR Part 921, Appendix I and II). The Mission-Aransas NERR is a representative of the western Gulf of Mexico bioregion and provides valuable input of the hydrologic and biological characteristics common in this biogeographic region. It is the third largest reserve in the National System due to the fact that Texas bay systems are quite large. The Texas coast is proudly one of the most pristine coasts in the entire US due to low population density, making it an ideal area for a reserve. The Mission-Aransas NERR is located 30 miles northeast of Corpus Christi, Texas in the Aransas Bay complex and the University of Texas Marine Science Institute is the lead State Agency for the Reserve.

The University of Texas Marine Science Institute (UTMSI) and Mission-Aransas NERR provide excellent opportunities for researchers. The Reserve is within easy driving distance of all coastal towns in South Texas and the cities of Corpus Christi, Rockport, Refugio, Victoria, Houston, San Antonio, Austin, and its surrounding municipalities. The Mission-Aransas NERR is an important area for commercial and recreational fishing, and hydrocarbon production. The Reserve is also used by various environmental interest groups, civic organizations, and private and professional societies for field trips and educational seminars. The majority of users include non-profit institutions, and other users, such as, students of all ages, teachers, local residents and visitors. Other major users are fellows from the Graduate Research Fellowship program sponsored by NOAA.

The Estuarine Reserves Division of the Office of Ocean and Coastal Resource Management of NOAA administers the reserve system. The Division currently provides support for three system-wide programs: the System-Wide Monitoring Program, the Graduate Research Fellowship Program, and the Coastal Training Program. They also provide support for reserve initiatives on restoration science, invasive species, K-12 education, and reserve specific research, monitoring, education, and resource stewardship initiatives and programs.

The NERRS Graduate Research Fellowship Program is one of the largest graduate programs supported by NOAA. Fellows conduct their research within a Reserve and gain hands-on experience by engaging with reserve staff and participating in their host reserve's research, education, stewardship, and training programs. Fellows use reserves as living laboratories to address NERRS natural and social science priority issues based on the reserves' local coastal management needs. Current fellows in the Mission-Aransas NERR are studying the influence of abiotic and biotic factors on southern flounder nursery habitat and the role of planktonic grazers in harmful algal bloom dynamics.

The Reserve operates several research and monitoring programs to understand the structure and function of the Mission-Aransas Estuary. The System-Wide Monitoring Program (SWMP) is a core component of every reserve. The goal of the Mission-Aransas Reserve SWMP is to develop quantitative measurements of short-term variability and long-term changes in water quality, biotic diversity, and land-use/land-cover characteristics of estuaries and estuarine ecosystems for the purposes of contributing to effective coastal zone management. The SWMP provides valuable long-term data on water quality and weather at 15 minute time intervals. As part of a nationally standardized network, the long-term data collection efforts will facilitate a better understanding of basic estuarine conditions and will allow the Reserve to serve as a sentinel for detecting change.

The NERRS Science Collaborative puts Reserve-based science to work for coastal communities coping with the impacts of land use change, pollutions, and habitat degradation in the context of a changing climate. The program brings the intended users of science into the research process so their perspective can inform problem definition, project implementation, and ultimately, the practical application of a project's results to a particular problem.

The primary research objective for the NERRS is to determine the causes and effects of natural and anthropogenically-induced change in the ecology of estuarine and estuarine-like ecosystems.

The mission of the Mission-Aransas NERR is *to develop and facilitate partnerships that enhance coastal decision-making through an integrated program of research, education, and stewardship.*

The vision of the Mission-Aransas NERR is *to develop a center of excellence to create and disseminate knowledge necessary to maintain a healthy Texas coastal zone.*

There are three goals used to support the Reserve mission:

Goal 1: To improve understanding of Texas coastal zone ecosystems structure and function. Understanding of ecosystems is based on the creation of new knowledge that is primarily derived through basic and applied research. New knowledge is often an essential component needed to improve coastal decision making.

Goal 2: To increase understanding of coastal ecosystems by diverse audiences. Education and outreach are the primary delivery mechanisms to explain what coastal ecosystems are and how they work. It is essential that information is disseminated broadly within our society.

Goal 3: To promote public appreciation and support for stewardship of coastal resources. In many ways, stewardship is an outcome resulting from the integration of research and education. Research creates information that is communicated through education. This information forms the basis for an appreciation of the values of an environment, and that, in turn, promotes a public sense of ownership of natural resources.

Dagger Point at Aransas National Wildlife Refuge

Chapter 2 BIOGEOGRAPHIC REGION

Sally Morehead Palmer

The National Estuarine Research Reserve System (NERRS) is a network of protected areas that serve as reference sites for research, education and stewardship. Reserves are located throughout the different biogeographic regions of the United States. A biogeographic region is a geographic area with similar plants, animals, and prevailing climate. There are currently 28 NERR sites scattered among 18 of a total 29 recognized biogeographic subregions of the country (Figure 2.1). The Mission-Aransas National Estuarine Research Reserve (NERR) represents the Western Gulf Biogeographic Subregion.

The Reserve has similar habitats to other Reserves in the Gulf of Mexico: Grand Bay and Weeks Bay (tidal marshes), Apalachicola (oyster fishery and small communities based on tourism and fishing), and Rookery and Jobos Bay (mangrove habitats). Shared issues among the Reserves of the Gulf of Mexico include freshwater inflow, land use change, habitat loss, invasive species, and relative sea level rise.

Figure 2.1. Map of the 28 NERR sites located in the United States.

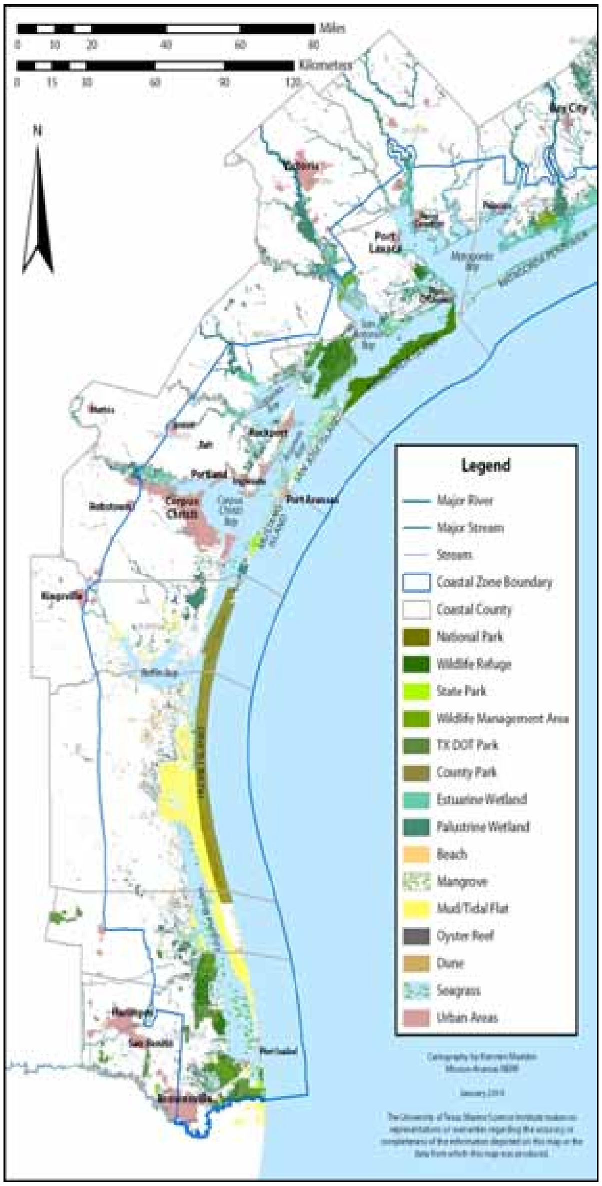

Figure 2.2. Map of the major estuaries of the Western Gulf Biogeographic Subregion.

The Western Gulf Subregion lies wholly in Texas, comprises most of the Texas coast, and is bounded by the border with Mexico to the southwest and the border of Galveston Bay to the northeast. This Subregion includes six major bay-estuarine systems and two river systems (Figure 2.2 and Figure 2.3). The major bay-estuarine systems are Lavaca-Colorado, Guadalupe, Mission-Aransas, Nueces, and Laguna Madre. Laguna Madre is comprised of two different systems: Upper Laguna Madre/Baffin Bay and Lower Laguna Madre. The two river systems are the Brazos and Rio Grande rivers.

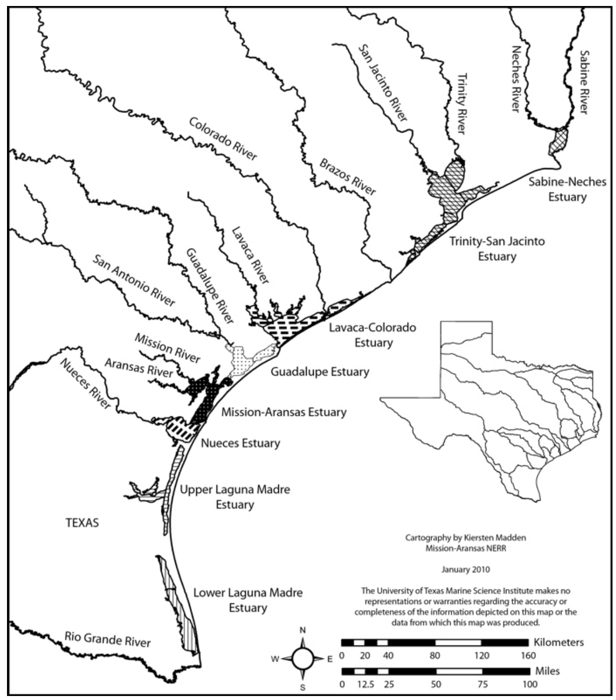

Figure 2.3. Major rivers and estuaries along the Texas coast.

Chapter 3 PHYSICAL ASPECTS

Sally Morehead Palmer

The Mission-Aransas Estuary is a typical Western Gulf of Mexico estuary (Diener, 1975). The estuarine system is composed of tertiary, secondary, and primary bays. Mesquite, Aransas, and Redfish bays are primary bays, i.e., they are adjacent to oceanic outlets. Copano, Port, and St. Charles bays are examples of secondary bays, while Mission Bay is a tertiary bay. These bays vary in size and geologic origin. Aransas Bay is the largest bay within the estuary, followed by Copano and Mesquite bay (Figure 3.1). Copano Bay is a coastal plain estuary, composed of two drowned river mouths of the Mission and Aransas rivers. Aransas, Redfish, and Mesquite bays are bar-built estuaries, in which an offshore sand bar partially encloses a body of water. The bay systems are all shallow, and the mean low water varies from 0.6 m in Mission Bay to 3 m in Aransas Bay (Chandler et al., 1981).

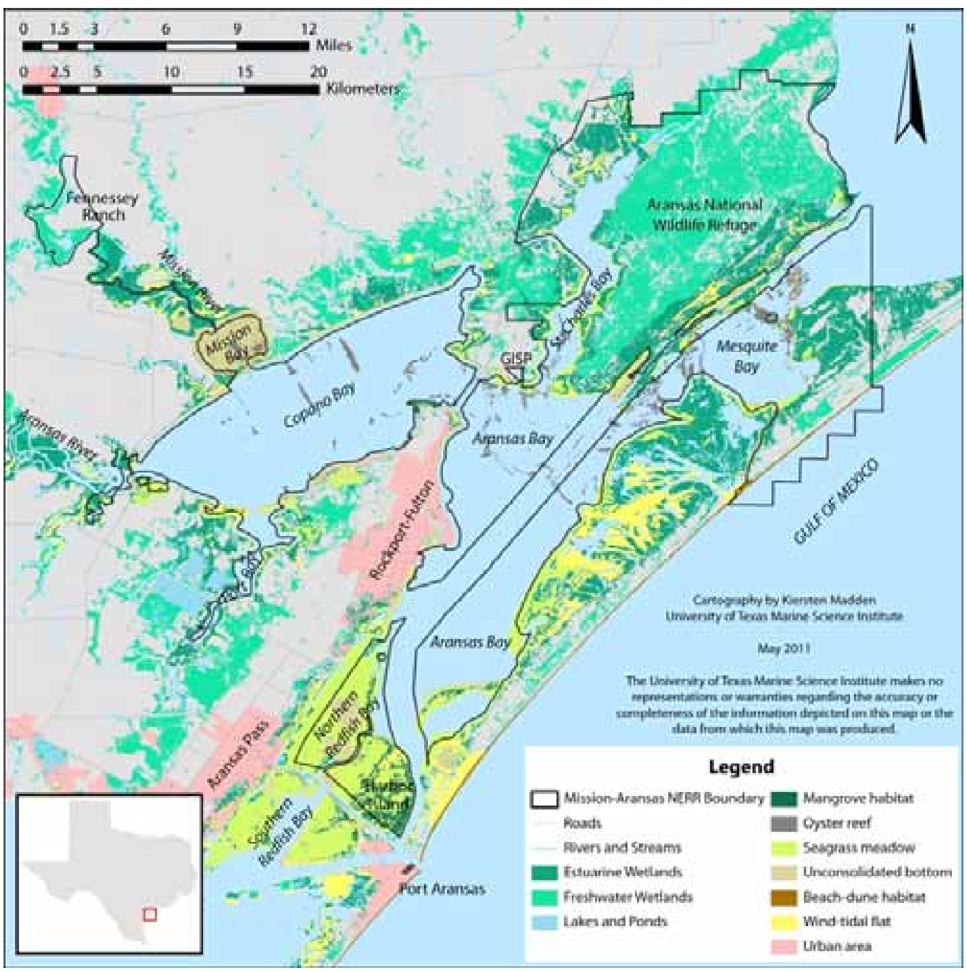

Figure 3.1. Mission-Aransas National Estuary Research Reserve boundary.

Tidal exchange in Copano and Aransas bays is driven by astronomical tides, meteorological conditions, and density stratification (Armstrong, 1987). Due to the shallow bay depths (1-4 meters at mid-tide) and a relatively small tidal prism, wind exerts a much greater influence on bay circulation than astronomical tides (Morton and McGowen, 1980; Armstrong, 1987). Wind-generated tides also result in substantial exchange of water between the Gulf of Mexico and Aransas Bay (Ward and Armstrong, 1997). Astronomical tides are predominately diurnal, but also have a semi-diurnal component. The greatest influence of astronomical tides is at the tidal inlet. Seasonal high tides occur during the spring and fall, while seasonal low tides occur during the winter and summer months.

The National Oceanic and Atmospheric Administration boundary requirements for a reserve are outlined in the federal register (915 CFR 921.11). These requirements include: (1) key land and water areas that approximate an ecological unit, (2) encompass areas with adequate controls, (3) management considerations, and (4) research/monitoring and education needs and goals. NOAA research reserve boundaries include two subcategories: key land and water areas (called “core areas”) and a buffer. Core areas are ecological units of a natural estuarine system that preserve a full range of significant physical, chemical, and biological factors contributing to the diversity of fauna, flora, and natural processes occurring within the estuary. The term, buffer, refers to the areas within the Reserve boundary that are adjacent to or surrounding core land and water areas and are essential to their integrity. Buffer zones protect the core area and provide additional protection for estuarine-dependent species.

The water core areas in the Reserve were chosen based on level of state control, habitats present, presence of active oil and gas wells, existing long-term records of research, and location for freshwater inflow analysis. The locations of the water core areas ensure adequate long-term state control which provides sufficient protection to ensure a stable environment for research. The land core areas provide essential key upland habitats and are divided into different units: Goose Island State Park (GISP), portions of the Aransas National Wildlife Refuge (ANWR), and Fennessey Ranch. The land core areas of GISP contain a wide variety of habitats including, live oak mottes, tidal salt marshes, and mud flats that attract many migratory bird species. The portion of the ANWR chosen as core area includes essential habitat (coastal prairie and marsh) for the endangered Whooping Crane. Although Fennessey Ranch is currently considered part of the Reserve buffer area (NOAA, 2006), it is anticipated that portions of the Ranch will become core land areas when the Reserve Management Plan undergoes revision. A conservation easement was purchased on this privately owned property by the University of Texas at Austin and the Mission-Aransas Reserve in 2006. The easement restricts development from occurring and ensures that the valuable habitats of the Ranch will continue to support wildlife well into the future. It also assures that traditional uses are compatible with the conservation values of the Reserve.

The boundary of the Reserve is set back 1000 feet from the shoreline along more densely populated areas and adjacent to private lands. The following areas are excluded from the Reserve boundary: the Gulf Intracoastal Waterway, Copano Bay Causeway, Cavasso Creek Bridge, Salt Creek Bridge, Farm Road 136 bridge at Copano Bay, Farm Road 2678 bridge over Mission River, State Highway 188 Bridge at Port Bay, GLO leased cabins, and Shell Bank Island.

The Aransas and Mission rivers are the two rivers that supply freshwater to the Mission-Aransas Estuary. These rivers are small and primarily coastal compared to other rivers in Texas. Neither the Mission nor the Aransas River has dams or other surface water supply structures and neither is used for city water supplies in the region. As a result, both rivers drain entirely into the Mission-

Aransas Estuary. The Mission River is formed by the confluence of Blanco and Medio Creeks in central Refugio County, runs for approximately 24 miles, and discharges in Mission Bay. The Aransas River begins in Bee County from the confluence of Olmos, Aransas, and Poesta creeks, flows south and southeast, and enters the western end of Copano Bay along the Refugio-Aransas county line. Stream flow from these rivers is generally low, with the highest pulses of freshwater occurring due to rainfall events. From 2007-2008, the Aransas River discharge ranged from 0.08 to 227.10 $m^3 s^{-1}$, with mean flow of 1.51 $m^3 s^{-1}$, and median of 0.18 $m^3 s^{-1}$. During the same time period the Mission River discharge was slightly higher and ranged from 0.01 to 356.79 $m^3 s^{-1}$, with mean flow of 4.31 $m^3 s^{-1}$, and a median of 0.34 $m^3 s^{-1}$ (Mooney, 2009).

The land within the Mission-Aransas NERR is comprised of federal, state, and privately owned land. Fennessey Ranch is privately owned and is managed to be environmentally sound as well as an economically viable business. The current economic base incorporates hunting, wildlife tours, photography, and cattle enterprises (Crofutt and Smith, 1997). It is composed of native tree/brush, prairie, freshwater wetlands, and Mission River riparian corridor. Wetlands at Fennessey Ranch cover approximately 500 acres, which contain temporary, seasonal, and semi-permanent flooded areas (White et al., 1998).

Buccaneer Cove Preserve is located at the mouth of Aransas River and contains 856 acres of wetlands, e.g., estuarine tidal flats and brackish marshes. This area is owned and managed by the Coastal Bend Land Trust whose primary goals are preserving and enhancing native wildlife habitat in the Coastal Bend. This is valuable habitat for Sandhill Cranes, Reddish Egrets, and other waterfowl. The state parcel of land in Mission Bay is also comprised of valuable wetland habitat.

Goose Island State Park (321.4 acres) is located between Aransas and St. Charles bays. The state park contains several habitats, including live-oak thickets (95 acres) and tidal salt marshes (40 acres), which support migrant birds such as rails, loons, grebes, common goldeneyes, red-breasted mergansers, and redheads. The park also is home to the "Big Tree" Live Oak, which is estimated to be around 1000 years old. The park was acquired in 1931-1935 by deeds from private owners and a legislative act setting aside Goose Island as a state park. The earliest park facilities were constructed by the Civilian Conservation Corps in the early 1930s. The park also has a coastal lease of submerged land adjacent to the park that includes seagrass beds (60 acres) and bay/Gulf of Mexico habitat (12 acres) which contain valuable nursery habitat and oyster reefs.

Goose Island State Park Trail

The Aransas National Wildlife Refuge (ANWR) is comprised of land on the Black Jack Peninsula (Aransas proper), Tatton Unit (NW of St. Charles Bay), and Matagorda Island. The refuge was established in 1937 to protect the endangered Whooping Crane and was created through an executive order signed by Franklin D. Roosevelt. Matagorda Island Wildlife Management Area and

State Park became part of the ANWR in 1982 and is managed through a memorandum of agreement between Texas Parks and Wildlife Department (TPWD) and US Fish and Wildlife Service (USFWS). Recently, the Johnson Ranch, a 245 acre tract located on Lamar Peninsula adjacent to St. Charles Bay, was incorporated into the ANWR boundary. The ANWR has a large portion of tidal and deltaic marshes. Upland vegetation is predominately coastal plain grasses interspersed with oak mottes, swales, and ponds (Stevenson and Griffith 1946; Allen 1952; Labuda and Butts 1979). Vegetation and wetlands at the Refuge support wildlife such as the Brown Pelican, Peregrine Falcon, white-tailed deer, javelina, coyote, wild pig, Rio Grande Turkey, raccoon, armadillo, the threatened American alligator, and the endangered Attwater's Prairie Chicken (last seen 1992).

Western Shoreline of Copano Bay

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Chapter 4 CLIMATE

Anne Evans

The weather in South Texas can be described as variable and extreme. The climate is subhumid to semiarid-subtropical with extreme variability in precipitation (Fulbright et al., 1990). Major climatic influences include temperature, precipitation, evaporation, wind, tropical storms, and hurricanes (Smith and Dilworth, 1999). Generally, the area experiences high temperatures along with deficiencies in moisture. Temperatures in South Texas vary from an average winter minimum range of 8.3 - 8.9°C to an average summer maximum range of 33.3 - 35.6°C. The major impacts of temperature within the Mission-Aransas NERR are freezes and radical changes with passing cold fronts (can drop 30-40°F within a few hours).

Along the Texas coast there is a distinctive gradient of decreasing rainfall from northeast to southwest. The rainfall gradient decreases by a factor of two from 142 cm yr^{-1} (56 in yr^{-1}) near the Louisiana border to 69 cm yr^{-1} (27 in yr^{-1}) near the Mexican border (Larkin and Bomar, 1983) (Figure 4.1).

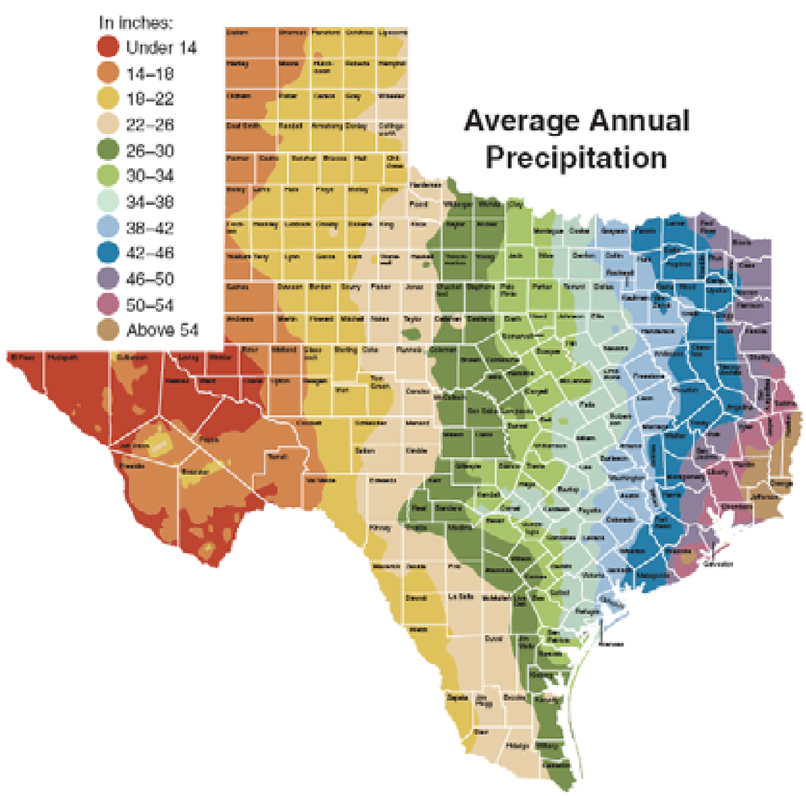

Figure 4.1. Precipitation patterns in Texas counties. Copyright Texas Almanac 2006-2007.

Average annual rainfall in the Reserve ranges from 91.4 cm in the north to 77.4 cm in the south. This range is comparable to cities such as Des Moines, IA, Rochester, NY, and Seattle, WA; but the patterns are very different. For example, the Pacific Northwest has a distinct pattern of high precipitation in the fall, winter, and spring and low in the summer months, while the Midwest states typically have dry winters and high precipitation in the summer. South Texas also has higher precipitation in the summer months, but the seasonality is less pronounced. This is due in part to the fact that most summer precipitation is produced by tropical storms and hurricanes and varies greatly between years. Due to extreme summer heat, annual precipitation values alone are not necessarily significant unless compared with precipitation deficiency caused by evapotranspiration (Orton, 1996). On average, gross annual evaporation (151.3 cm yr^{-1}) exceeds precipitation (88.6 cm yr^{-1}) in this region (Armstrong, 1982).

Sedimentologists stress the importance of winds affecting coastal processes along the Texas coast, noting that it is perhaps the most important agent that influences coastal development. Two principle wind regimes dominate the Mission-Aransas NERR: persistent, southeasterly winds from March through September and north-northeasterly winds from October through March (Behrens and Watson, 1973; Brown et al., 1976). The strongest winds occur during tropical storms and hurricanes, generating high velocity currents which move large quantities of sediment in relatively short periods of time (Morton and McGowen, 1980).

Variability in weather patterns between years in South Texas is very high due to precipitation rates and climate patterns. Annual precipitation can change drastically between years due to tropical storms or hurricanes. El Niño, the warming of surface temperatures in the tropical eastern Pacific Ocean, is another important factor and causes cooler and wetter years in South Texas (NOAA, 2010). La Niña years, the cooling of surface temperatures, are characteristically warmer and drier.

Issues of Concern for Climate

Climate Change

Estuaries are particularly vulnerable to climate variability. Change and potential impacts include changes in sea level, shifts in habitat extent, alterations in community structure, increased shoreline erosion, and deteriorating water quality. Specifically within the Mission-Aransas NERR, there will most likely be alterations in freshwater inflows from rivers, changes in estuarine ecosystem structure and function, more frequent and longer-lasting droughts, increased salinity within some coastal ecosystems, saltwater intrusion, changes in habitat extent due to sea level rise, further reductions in some estuarine dependent species (e.g., blue crabs, oysters, shrimp), and range expansions of other species (e.g., red and black mangroves).

Climate change is expected to intensify the historical pattern of variable and extreme climate in Texas. The Texas coast is likely to experience severe climate change impacts due to a combination of factors including the regional climate regime and coastal geology. The coastline has already been experiencing a long-term trend of increasing temperature. The overall average rate of increase is 0.0428ºC yr^{-1}, which translates into an increase of 1ºC in 23 yr (1ºF in 13 yr) (Montagna et al., 2009). The Texas coast is in a relatively warm climate zone and subject to very high rates of evaporation (Larkin and Bomar, 1983); therefore, changes in temperature or rainfall will have great impacts. In addition, climate change effects such as sea level rise are likely to be exacerbated due to the low lying coastal plains and high rates of subsidence (Anderson, 2007). The combined effects of these changes will affect the physical and biological characteristics of the Texas coast dramatically (Montagna et al., 2009).

Current climate predictions for the state of Texas indicate increasing temperatures with reduced precipitation and drier soil conditions. Texas's climate has always been variable and extreme and climate change may intensify this pattern. Average state temperatures have increased since the late 1960s, average rainfall has increased slightly, and extreme rainfall events have become more frequent. There is a projected change of 3-10ºF rise in winter lows and 3-7ºF rise in summer highs and the July heat index could rise by 10-25ºF. Rainfall and summer soil moisture are also likely to increase in coastal areas (UCS, 2009). By the year 2050, temperatures in Texas are expected to increase 2°C (+3.6°F) and precipitation is expected to decrease by 5% (IPCC, 2007). Worldwide, hurricane intensity is also expected to increase as a result of climate change (Knutson et al., 2010). Predictions about changes in hurricane frequency are much less certain, but regardless of this uncertainty, changes in tropical storm intensity could have a major impact on the Texas coast, which receives much of its summer moisture in the form of intense rainfall events. Overall, the future climate of Texas is likely to be characterized by more frequent intense rainfall events with longer, dry periods in between.

Future Plans in the Mission-Aransas NERR

Monitoring Programs

Through its environmental monitoring programs, the Mission-Aransas NERR is well-situated to address some of these challenges and can serve as a sentinel site for monitoring climate change impacts on coastal habitats. Long term monitoring of water quality, meteorological parameters, geographic extent of habitats, composition of vegetative habitats, water levels, and sediment elevations will provide valuable information for future modeling efforts, restoration, and education and outreach activities related to climate change.

Emergent salt marshes are highly affected by changing weather patterns and understanding responses to climate change stressors is important for understanding their ecological functions (Nicholls et al., 2007). Marsh communities provide invaluable services and a long-term monitoring program will allow resource managers to better understand climate stressors and mitigate the effects of extreme storm events. The Mission-Aransas NERR created a long-term monitoring program for submerged aquatic vegetation (SAV) and emergent marshes that will assess ecological responses of these communities in the Mission-Aransas Estuary using established NERRS protocols.

SWMP station in Copano Bay with weather instruments

Wind farm located in the Reserve watershed

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Chapter 5 HYDROGRAPHY AND OCEANOGRAPHY

Anne Evans and Sally Morehead Palmer

Hydrography is the measurement and description of the physical features of bodies of water and their land areas. Hydrographical measurements include information on tides, currents, and waves (NOAA, 2010). The primary climatic conditions that influence the hydrology in the Mission-Aransas Estuary are freshwater inflow and to a lesser extent tidal exchange. The Mission and Aransas rivers contribute the major freshwater inflows into the Mission-Aransas NERR. All drainage of the estuary occurs at the major Gulf of Mexico connection at Port Aransas called Aransas Pass.

The Reserve experiences large ranges in salinity, which is dependent upon freshwater inputs, tidal forcing, and evaporation rates. During much of the time, the Reserve has a large salinity gradient, ranging from high salinities in Redfish Bay to lower salinities in Mission Bay (Figure 3.1). During droughts, low river flows and high evaporation rates cause the Reserve to experience hypersaline water in shallow bays. Salinity structure within the Reserve is determined by isolated freshwater pulses that, once introduced, are retained within the system (NOAA, 1993). Freshwater pulses tend to lower salinities for long periods of time because of the shallowness of the bay and the restricted inlet connection. Salinity stratification is common following fresh water impulses and usually occurs in Copano Bay (NOAA, 1993). Salinity stratification can occur in secondary bays (e.g., Copano Bay), during summer when winds subside and evaporation causes dense water to sink (Morehead et al., 2002).

Tides

Tidal exchange in the Mission-Aransas Estuary is driven by astronomical tides, meteorological conditions, and density stratification (Armstrong, 1987). Because of shallow bay depths (1-4 m at mid-tide) and a relatively small tidal prism, wind exerts a much greater influence on bay circulation than astronomical tides (Morton and McGowen, 1980; Armstrong, 1987; NOAA, 1990). Wind-generated tides result in substantial exchange of water between the Gulf of Mexico and the Mission-Aransas Estuary (Ward and Armstrong, 1997). Astronomical tides are predominately diurnal, but also have a semi-diurnal component. The greatest influence of astronomical tides on the Mission-Aransas Estuary system is at the tidal inlet. Seasonal high tides occur during the spring and fall, while seasonal lows occur during the winter and summer months.

Aransas River Delta

Freshwater Inflow

Nothing is more fundamental to the functioning of an estuary than the quantity and timing of freshwater delivery to the mixing zone (Russell et al., 2006). Freshwater inflow is delivered from a watershed as a result of precipitation events, which are highly variable in South Texas. As a result of these episodic events, the typical flow regime in south Texas bays and estuaries is characterized by relatively small base flows punctuated by large inflow events from frontal systems and tropical storm activity (Russell et al., 2006).

The Mission and Aransas rivers are the primary sources of freshwater inflow into Copano Bay, the main secondary bay in the Reserve. The Aransas River flows directly into Copano Bay while the Mission River flows into Mission Bay, which is connected to Copano Bay. The Mission and Aransas rivers are characterized by low base flows with large pulses due to storm events. Upstream on each river, flow is continuously measured at a US Geological Survey (USGS) gage. The lower reaches of the rivers are tidally influenced due to a combination of the tidal range relative to the elevation change. The average tidal range in Copano Bay is 0.15 m. The USGS gage on the Mission River (near the city of Refugio) is 0.31 m above sea level and the gage on the Aransas River (near the city of Skidmore), is 22.06 m above sea level. Tidal forcing coupled with low elevations and low freshwater inputs creates long residence times in the lower reaches of the rivers. In the Aransas River tidal reach during low flow (~0.3 m^3s^{-1}) residence time is on the order of months and during high flow (~280 m^3s^{-1}) residence time is on the order of days (Johnson, 2009). During 2007 and 2008, measured salinity at locations in the tidal reaches of the Mission and Aransas rivers ranged from 0.04 to 20.2 psu and 0.04 to 5.9 psu, respectively (Mooney, 2009).

During large flood events, freshwater from the San Antonio and Guadalupe rivers can move along the southwest shoreline of San Antonio Bay and can flow into the northeastern portion of the Reserve boundary reaching Ayers Bay and Mesquite Bay (Longley, 1994). The higher elevation of flood waters in Mesquite Bay could lead to outflows to the Gulf of Mexico via Cedar Bayou. During large events, freshwater can also continue to flow southwest through the Intracoastal Waterway and enter Aransas Bay. During dry periods, evaporation in Ayers Bay and Mesquite Bay keeps water from flowing into the Reserve.

Issues with Freshwater Inflow in Texas

Two major forces are reshaping freshwater flows to estuaries worldwide: demographics and engineering. The coastal population is large and continues to grow, resulting in increasing demand for freshwater. Freshwater is required for municipal, industrial, and agricultural uses. Water use in the US has doubled since 1940 and is likely to double again by 2015 (Montagna et al., 2002b). As the population continues to grow, less water will be available to flow into estuaries (Montagna et. al., 2002b). The population of Texas is expected to more than double between the years 2000 and 2060, growing from approximately 21 million to 46 million. This growth will increase the US water demand from almost 17 million acre-feet to 21.6 million acre-feet between 2000 and 2060, a 27% increase (TWDB, 2007). Water budgets for the state of Texas for the year 2050 show a 5% reduction in downstream flows to the Texas coast when compared to 2000 values (Ward, 2009).

Freshwater inflow rates are changing in most estuaries because of changes in land use/land cover, water diversion for human uses, and climate change effects. These changes generally result in decreased freshwater inflow, loss of pulsed events, and changes in the timing of pulses. Climate change models predict a 2^oC increase in temperature and a 5% decrease in precipitation (IPCC, 2007). If this type of climate scenario is considered in conjunction with population growth, the Texas Coast will see a decrease in downstream flows of 30% over the next 50 years (Ward, 2009).

Droughts are historically common in Texas and have dramatic effects on downstream flows to the coast. The drought in the 1950s was so severe that many of the rivers stopped flowing altogether, resulting in hypersalinity, fish kills, loss of blue crabs and white shrimp, and invasions of stenohaline species (Copeland, 1966; Hoese, 1967). The severity of droughts in Texas is expected to increase as a result of climate change (Ward, 2009). Water budget scenarios that consider climate change, population growth, and drought predict a 74% decrease in freshwater inflow to the Texas coast compared to baseline conditions in 2000 (Ward, 2009).

Freshwater inflow enhances secondary production (Montagna and Kalke, 1992; Montagna et al., 2002a). In the Guadalupe and Nueces estuaries (two estuaries surrounding the Mission-Aransas NERR), invertebrate macrofauna diversity and meiofauna population size increased with salinity. A review of past benthic studies in these estuaries indicated that wet years with high inflow resulted in increased macrofaunal productivity and decreased macrofaunal diversity. It can be determined that the enhanced productivity is due to freshwater pulses and estuarine species that can tolerate low salinities (Montagna and Kalke, 1992). Anthropogenic modification of freshwater inflow can change the structure of South Texas estuarine ecosystems. Past damming of Rincon Bayou, Texas, reduced freshwater inflow by 55%. After restoring inflow to this sensitive area, infauna abundance, biomass, and diversity increased (Montagna et al., 2002a).

Minimum freshwater inflow levels are required by many states and countries to protect estuarine ecosystems, but there is no standard approach or criterion to set inflow levels. Texas legislation passed in 1957 requires water plans to give consideration to the effect of upstream development on bays, estuaries, and arms of the Gulf of Mexico. This inspired a series of assessments of all Texas estuaries, which were summarized by the Texas Department of Water Resources (TDWR, 1982). The reports were later followed up by a method to determine freshwater needs of Texas estuaries (Longley, 1994).

The Texas Water Development Board (TWDB) was also established in 1957 to provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas. As part of their mission, TWDB develops the state-wide water plan and guides regional water planning efforts. The current *State Water Plan* (TWDB, 2007) was established using a “bottom-up,” consensus-driven approach for water planning. Sixteen regional water planning groups were given guidelines for reviewing water use projections and water availability volumes in dry and drought-of-record conditions. When a water need was identified for a region, the planning groups were tasked with recommending water management strategies that would help meet the need. Once the regional plans were complete and approved by the TWDB, this information was combined with other sources to develop the state-wide plan.

In 2007, the Texas Legislature took actions to formally recognize the importance of freshwater inflow for supporting healthy rivers and bay systems. A new state law was passed to lay out a comprehensive approach for addressing the issue of environmental flow protection. The process strives to determine how much flow is needed to maintain a sound ecological environment and how to go about ensuring that this flow is protected. The best available science will be used to make flow recommendations for eleven areas in Texas (including the seven major bay systems; Figure 2.3), while stakeholder groups will be tasked with developing policy strategies for how to meet these flow recommendations. Once recommendations have been made by both groups, the Texas Commission on Environmental Quality (TCEQ) will legally adopt environmental inflow standards for the associated bay systems. This process will be implemented for the area containing the Mission-Aransas NERR from May 2009 – April 2012.

Future Plans for Freshwater Inflow in Texas

Senate Bill 3

Freshwater quality and quantity are the biggest challenges that Texas resource managers face today. Freshwater is a critical component of Texas estuaries but as water demand increases the amount of freshwater that reaches the coast is projected to decrease. Determining flow regimes in the face of land use and climate change is proposed as part of a NERR Science Collaborative. Texas Legislature recognized the need to establish environmental flow standards and adopted Senate Bill 3. This law created a public process by which state authorities would solicit input from committees of scientists (Basin/Bay Area Expert Science Teams, BBEST) and stakeholders (Basin/Bay Area Stakeholder Committees, BBASC) from each Texas bay/basin system. Recommendations from these groups would be used by the State to develop legal environmental flow standards for estuaries and rivers. The Guadalupe-San Antonio (GSA) bay/basin is located on the central Texas coast and includes the Guadalupe and Mission-Aransas estuaries and their watersheds. The GSA BBEST committee released a report that outlined their flow recommendations and highlighted several research gaps (social, climatic, physical, and biological) (GSA BBEST, 2011). The Mission-Aransas NERR will use a collaborative approach to address the research gaps and incorporate the BBASC as the primary user group that will utilize the information to refine environmental flow recommendations. Specific goals include: (1) examine effects of land use and climate change on freshwater inflows to the Guadalupe and Mission-Aransas estuaries, (2) improve inputs to the TxBLEND salinity model by measuring water exchange between adjacent bays, (3) collaborate with intended users to identify and conduct a priority research project, and (4) develop shared systems learning among the local stakeholders and scientists, and create a system dynamics model.

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Chapter 6 GEOLOGY

Anne Evans

Texas's changing landscape has been documented in the origins of rocks and rock layering. Mountains, seas, rivers, volcanoes, and earthquakes are part of the geologic history of Texas. Valuable natural resources produced by geologic phenomena include petroleum, coal, lignite, metals, ground water, salt, limestone, ceramic clays, and various soils (Bureau of Economic Geology, 2009).

Texas estuaries have a long and dynamic history of igneous activity, which includes structural deformation and geologic changes due to sedimentary processes. The history of the estuaries is recorded in the sedimentary layers from the Precambrian Era, several billion years ago, to the present (TSHA, 2010).

Along the southern Texas coast, growth faults occur sub-parallel to the coastline. Most faults are down-to-the-basin, but up-to-the-basin faults are also common (CCGS, 1967; McGowen and Morton, 1979). Faulting along the Gulf of Mexico coast is a result of structural activity, gravity sliding, motile salt beds, or basin subsidence (McGowen and Morton, 1979; Link, 1982). Faulting is concentrated outside the Mission-Aransas NERR on South Padre Island (Rio Grande - Port Mansfield Ship Channel), Mustang Island (Malaquite Beach - Port Aransas), Brazos-Colorado Delta (Colorado River - Bolivar Peninsula), and near Sabine Pass (McGowen and Morton, 1979). The surface exposures of the faults consist of mostly Cenozoic sandstone and shale strata that grow progressively younger toward the coast, which is indicative of coastal regression that has continued from the late Mesozoic Era to the present (Figure 6.1).

Hydrocarbons form in sedimentary environments, where organic material has been buried under layers of material. Accumulations of hydrocarbons are associated with major or concentrated fault zones that, in general, are located in shallow water sands (CCGS, 1967). On the southern Texas coast, most oil and gas reservoirs are hydrocarbon traps associated with down-to-the-basin gravity faults and related closures to their down thrown sides (Brown et al., 1976).

Mission-Aransas NERR Geologic Formation

The geology of the Mission-Aransas NERR is formed by many tectonic processes, such as uplifting, rifting, and glacial deposition. Texas is underlain by Precambrian rocks that are more than 600 million years old and are exposed in the Llano Uplift and a few areas in Trans-Pecos Texas. East Texas and the Gulf Coast Basin were created in the Mesozoic Era (245 million years ago (mya)) when the European and African plates broke away from the North American plate. Rift basins extending from Mexico to Nova Scotia were produced and sediment was deposited in the basins by streams eventually being buried beneath marine salt (Bureau of Economic Geology, 2009).

During the Cenozoic Era (66 mya), the East Texas Basin was filling with lignite-bearing deposits from rivers and deltas. The early Mississippi River flowed across East Texas while small deltas and barrier islands extended southwestward toward Mexico into the deeper waters of the Gulf. In the Gulf Coast Basin, Mesozoic salt that was deeply buried moved upward to form domes and are presently exposed throughout East Texas in broad belts (Bureau of Economic Geology, 2009).

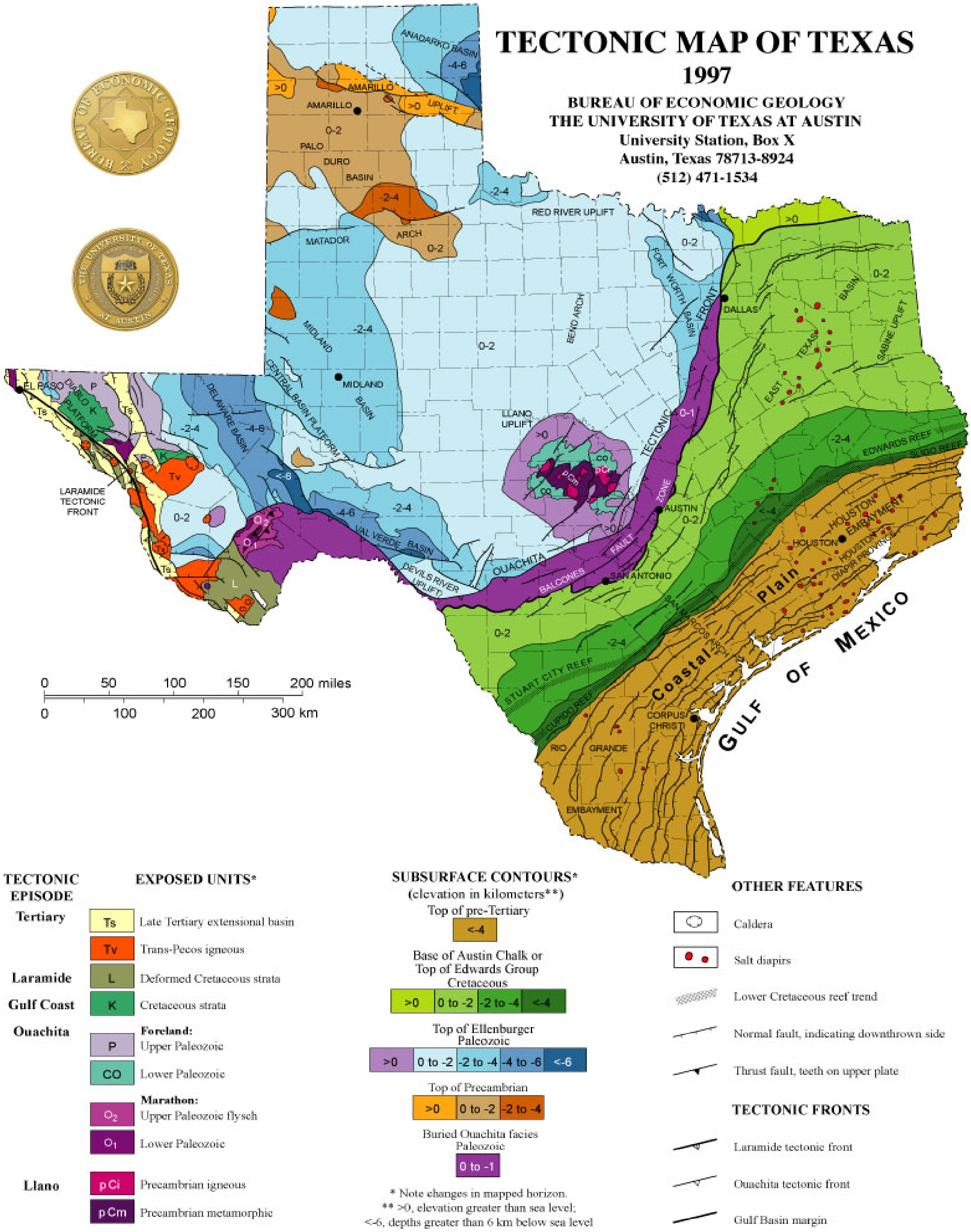

Figure 6.1. Tectonic map of Texas. Used with permission of Texas Almanac (www.TexasAlmanac.com).

Ice caps covered the northern part of the continent during the Pleistocene (1 mya) while streams traveled southeastward across Texas carrying water to the Gulf of Mexico. During the last one million years, the rivers (Colorado, Brazos, Red, and Canadian) entrenched their meanders as uplift occurred gradually across Texas. Sea level changes during the Pleistocene Ice Age alternately exposed and inundated the continental shelf. The current sea level reached its approximate position about 3,000 years ago and as a result, coastal-barrier, lagoon, and delta sediments were deposited along the Gulf Coast (Bureau of Economic Geology, 2009).

The current Texas Coastal Plain is a strip about one hundred miles wide extending from Nueces Bay to Galveston Bay underlain by sedimentary strata of Mesozoic and Cenozoic age. Topographically, the Plain consists of three major divisions that extend parallel to the Gulf Coast: (1) interior belt, consisting of an inner plain that was sculpted out of softer beds of the Upper Cretaceous; (2) coastal belt, a low flattish area, bordering on the Gulf of Mexico and underlain by the Beaumont clays and the Lissie formation, both of Pleistocene age (contains the coastline of Texas and Mission-Aransas NERR); and (3) central dissected belt, an intervening broad belt underlain by sands and nonlimy clays located east of the Mississippi River (TSHA, 2010).

Most estuaries are less than 10,000 years old, making them fleeting features in geologic time (Levinton, 1995). During the Pleistocene era large fluctuations in sea level as a result of glaciers set the framework for Texas coastal features. The highest sea levels on the Gulf Coast occurred around 130,000 years ago, and as the levels lowered (about 18,000 years ago) deep valleys were formed. During the Holocene era the valleys filled and dispersed sediments originating from deltaic headlands. Sea level reached its present level about 3,500 years ago when the coastal features we see today were formed. The paleo-rivers filled, marshes grew, and deltaic headland beaches, plains, barrier islands, and peninsulas were formed. Some of today's barrier islands formed on Pleistocene beach ridges while others grew and disappeared (McKenna, 2004). Currently, there are seven barrier islands along the Texas shoreline: Galveston, Follets, Matagorda, San Jose, Mustang, Padre, and Brazos.

Texas lagoons originated from impounded water behind barrier islands while estuarine bays originated as river valleys eroded during continental glaciations and flooded during rising sea level (Behrens, 1963). Aransas Bay resembles a lagoon although several small rivers feed it through Copano Bay, while St. Charles Bay (an estuarine bay) enters Aransas Bay at the north end. Behrens (1963) used a sonoprobe to identify the origins of Aransas Bay and found that the bay has a compound origin with a Pleistocene valley buried underneath. Cores suggest that a pre-existing barrier ridge lies underneath Aransas Bay and San Jose Island, which was flooded as sea level rose creating an open bay between Aransas and San Antonio bays. These conditions existed until the current San Jose barrier island grew and slowly created the enclosed bay and river influence environments that exist today (Behrens, 1963).

Geologic processes during the Pleistocene era created many of the current formations in the Mission-Aransas NERR. Copano Bay was formed and is the last remaining Pleistocene bay left on the Texas coast, as all other similar bays in Texas have been filled in (Behrens, personal communication). There is a historic river channel that connects Copano Bay to Aransas Bay that was formed by movement of glaciers through the area. The three peninsulas located in the Mission-Aransas NERR (Live Oak, Lamar, and Blackjack) were also formed during this era (Behrens, personal communication).

Geologic Processes

Three sources of sediment in the Mission-Aransas NERR are: (1) suspended and bedload material from the Mission and Aransas rivers, (2) Gulf of Mexico deposits from storms and inlets, and (3) dredge spoil from channels (Tunnell et al., 1996). The Mission-Aransas Estuary is in an intermediate stage of geological succession given that the filling of the estuary by riverine deposits is the final stage. In general, the intracoastal circulation (which affects formation of bays or lack thereof) takes sediment from south to north towards Matagorda Bay due to the southeastern winds. The shorelines of Copano and Aransas bays are in a state of erosion; whereas the bay side shoreline of San Jose Island is in a state of equilibrium or accretion (Chandler et al., 1981).

Sediment

The geologic framework of Texas combined with modern coastal processes has resulted in generally fine-grained sands and mixed sand and shell gravel on beaches. Some mud and clay outcrops can be found on mainland and deltaic headland shorelines (McKenna, 2004). The most common sediment type in the Mission-Aransas Estuary is mud, comprised of silt and clay (White et al., 1983). In Mesquite and St. Charles bays, the most common sediment type is sand to sandy silt (White et al., 1989). In comparison to these bays, Aransas and northern Copano bays have a higher proportion of clay, while the southern proportion of Copano Bay has a higher portion of silt. Around oyster reefs in Copano Bay the sediments have as high as 75% shell material. The margins of Copano and Aransas bays have a higher percentage of sand (White et al., 1983).

Erosion

Erosion of shorelines and islands caused by storms, hurricanes, floods, and powerful waves can expose structures, lead to the encroachment of seawater, and cause large property losses in coastal areas. Around 70% of the Earth's beaches are impacted by erosion and the Gulf coast shoreline has the highest erosion rate in the United States (61%) (Jones and Hanna, 2004; Morton et al., 2004; Feagin et al., 2005; Jones et al., 2010). It has been estimated around the Gulf of Mexico, erosion is responsible for 130 million dollars a year in property losses (Jones and Hanna, 2004). Erosion is likely to accelerate due to global climate change, rising mean sea levels, and increased wave activity (Jones et al., 2010).

Long-term, episodic, and human-induced erosion of Gulf of Mexico and Texas bay shorelines has resulted in habitat loss, navigational challenges, and coastal structures on public beaches (McKenna, 2004). Long-term erosion is caused by the rate of relative sea level rise and the lack of new sediment coming into the system (McKenna, 2004; CT2020). Episodic events, such as storms and hurricanes are the greatest cause of periodic coastal erosion in Texas. Additionally, many bay shorelines are eroding due to geology, setting (with respect to wind and wave direction), shoreline material, and the proximity to major ship traffic (CT2020).

Issues of Concern for Geologic Processes

Beach Erosion

If there are no barriers to restrict migration of the sediment, beach erosion results in a landward displacement of coastal environments. In Galveston, the coastline and city are protected by a seawall that has caused greater down-drift erosion by disrupting the natural sediment transport system, resulting in the need for additional shoreline protection measures (i.e., geotextile tubes) (Feagin et al., 2005). Mitigation techniques to reduce beach erosion include beach nourishment, planting vegetation, construction of seawalls and other hard structures, and use of dredged materials for coastal restoration sites (Feagin et al., 2005; Jones et al., 2010). In Texas, many structures are placed in areas without sufficient knowledge of the dynamics of the coastal ecosystem and changing shoreline (McKenna, 2004). Currently there is an information gap regarding this issue and partner researchers are needed. Reducing erosion hazards requires a lot of effort, funding, and coordination among interest groups. Funding is often a stumbling block for many projects (McKenna, 2004).

Oyster shell shoreline

Bay Shoreline Erosion

Bay shoreline erosion is influenced by composition of shoreline materials, orientation of the shoreline (with respect to prevailing wind direction), and wave fetch. Texas bay shoreline erosion is exacerbated by human activities, i.e., navigational dredging, ship wakes, and subsidence related to oil and gas development. Habitat is being lost due to erosion along the Gulf Intracoastal Waterway (GIWW) as wakes from barge traffic affect public and private lands. Freshwater inflow into the bays also affects erosion. The different salinity patterns result in the destruction of stabilizing vegetation and allow other types of less desirable vegetation to propagate. Loss of salt marsh due to subsidence, sea level rise, wave action, and insufficient sediment supply is also a major concern along the Texas gulf coast. Between 1950 and 1989 about 12% of the salt marshes of Galveston Bay were lost (Ravens et al., 2009). In the Trinity River Valley, sediment accretion rates have been documented to be less than the sea level rise rates possibly due to dam construction on the Trinity and Mississippi rivers (Ravens et al., 2009).

Future Plans for Geology

Climate and human-induced changes dramatically impact coastal ecosystems and greatly affect the sustainability of Texas coastal communities and economies. Research on factors impacting shoreline erosion is very important in the Mission-Aransas NERR. Circulation patterns, sediment accretion, land subsidence, and vegetation changes are areas of future research.

Coastal Texas 2020

Coastal Texas 2020 is a long-term, statewide initiative to unite local, state, and federal efforts to promote the economic and environmental health of the Texas Coast. The document provides tools to identify challenges and find solutions to the coastal problems. In 2003, the Texas coast was divided into five regions for *Coastal Texas 2020*: (I) Jefferson and Orange counties, (II) Brazoria, Chambers, Galveston and Harris counties, (III) Calhoun, Jackson, Matagorda, and Victoria counties, (IV) Aransas, Kleberg, Nueces, Refugio, and San Patricio counties, and (V) Cameron, Kenedy and Willacy counties. Regional Advisory committees were established for each region and included representatives from state and local government, natural resource agencies, academia, and nonprofit organizations. The committees were responsible for developing a list of key coastal issues and projects to help stop coastal erosion.

The Mission-Aransas NERR is located in region IV. Region IV geomorphologic features include bay shorelines of Aransas, Corpus Christi, Oso, Nueces, and Baffin bays, and the Laguna Madre. Gulf shoreline features include the high-profile barrier islands of San Jose, Mustang, and the northern portion of Padre. Aransas Pass separates San Jose Island from Mustang Island and is a jettied navigation channel that alters the littoral flow of sediment from the northeast.

The Gulf shoreline in this region is experiencing an erosional trend with an exception to the Aransas Pass south jetty that is gaining sand because of impoundment. The erosion of the shoreline is mainly due to low sand supply and a muddy offshore substrate. Critical erosion areas include a stretch of the Corpus Christi Ship Channel in Port Aransas due to ship traffic in the channel. To help reduce the erosion the establishment of a ‘no wake’ zone and stabilizing the shoreline with bulkheads and vegetation was recommended (McKenna, 2004). Twenty-two erosion response projects have been implemented to help minimize shoreline retreat. These include a bulkhead extension at Cove Harbor in Rockport, beach nourishment of Rockport Beach, and revegetation of shorelines in Copano and Mission bays (McKenna, 2004).

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Chapter 7 WATER QUALITY

Anne Evans

There has been increasing public concern about the quality of the Aransas-Copano-Mission Bay system. Prior to World War II, there were few reports or indications of perceived pollution problems in this area, but with accelerating population growth and urban development in the last two decades, public attention and concern for the Aransas-Copano-Mission Bay system has increased. Awareness of the potential impacts on the system has also increased, and maintenance of the health of the system has become a major issue (Smith and Dilworth, 1999).

Water Quality in the Mission-Aransas NERR

The Texas Commission on Environmental Quality (TCEQ) is required by the Clean Water Act to test the quality of all bodies of water on the Texas Coast. The TCEQ applies Texas Surface Water Quality Standards, which are found in the Texas Administrative Code (TAC), Title 30, Chapter 307 (TCEQ, 2009a), to determine which areas are impaired due to low dissolved oxygen levels, high bacteria concentrations, high mercury concentrations, and/or many other conditions. Once an area is determined as impaired, a Total Maximum Daily Loads (TMDLs) evaluation is completed. The TMDL program, organized and executed by TCEQ, determines the amount by which pollution needs to be reduced to restore water quality. TMDLs are developed using mass balance calculations and complex water quality modeling approaches.

Compared to the more industrialized counties of the upper Texas coast, the counties which contain the Mission-Aransas NERR have only a few TMDL projects currently underway (Table 7.1). The Mission-Aransas NERR is contained in five coastal counties: Refugio, Calhoun, Aransas, San Patricio, and Nueces County. Within these counties there are a total of eight TMDL projects currently in progress (TCEQ, 2009b). Projects include evaluating the safety of oyster harvesting, determining water quality for aquatic use, and the effect of dissolved oxygen, pH, zinc and total dissolved solids in several rivers and bays (Table 7.1).

Salt Lake near Rockport

Table 7.1. Number of TMDLs in Texas coastal counties in 2008 (TCEQ, 2009b). Counties in the Mission-Aransas NERR in bold.

County	Number of TMDLs	Projects
Jefferson	1	Toxicity
Chambers	4	PCBs, nickel, bacteria, low DO
Harris	17	Bacteria, low DO, toxicity, VOCs, dissolved solids, chlordane, PCBs, dioxin, nickel, pollutants
Galveston	11	Dissolved solids, chloride, VOCs, bacteria, chlordane, low DO, PCBs, dioxin, nickel
Brazoria	6	Dissolved solids, VOCs, bacteria, chlordane
Matagorda	3	Low DO, bacteria, pH
Calhoun	3	Water quality, low DO, pH
Refugio	5	Bacteria, low DO, pH
Aransas	1	Bacteria
San Patricio	4	Bacteria, low DO, pH, zinc
Nueces	4	Dissolved solids, zinc, bacteria, low DO
Kleberg	2	Dissolved solids, low DO, bacteria, pH
Kenedy	1	Low DO
Willacy	3	Low DO, toxicity
Cameron	4	Pollutants, organics, low DO, toxicity

Bacteria

E. coli vs. Enterococci

In 1986, the EPA established new guidelines for bacterial indicators. In freshwaters, the EPA recommends using *Escherichia coli* as the bacterial indicator while in marine waters it is recommended to use enterococci (USEPA, 1986). If *E. coli* or enterococci data is not sufficient for a water body, the historic standard for fecal coliform is applied. In Texas, bays that are classified for oyster use continue to use fecal coliform as the bacteria indicator. Under these circumstances, Copano Bay, classified as marine waters, should use enterococci as an indicator however fecal coliform is still used due to oyster water use standards (Gibson, 2006; Johnson, 2009).

Bacteria Regulations

Bacterial contamination is a frequently occurring impairment of Texas surface waters. In 2006, more than 70% of the impaired waters were listed for violating bacteria standards (TCEQ, 2008). Contamination due to bacteria stems from an overloading of enteric bacteria that originates from a variety of point and nonpoint sources, i.e., wastewater treatment plants, wildlife, and agricultural runoff (Johnson, 2009).

In the state of Texas, specific criteria are used to limit the fecal coliform content in contact recreations waters and oyster waters. In contact recreation waters, §307.7(b(1)(C):

(i) Fecal coliform content shall not exceed 200 colonies per 100 mL as a geometric mean based on a representative sampling of not less than five samples collected over not more than 30 days. In addition, single samples of fecal coliform should not exceed 400 colonies per 100 ml.

In oyster waters, §307.7(b)(3)(B):

(i) A 1,000 foot buffer zone, measured in the water from the shoreline at ordinary high tide, is established for all bay and gulf waters, except those contained in river or coastal basins as defined in §307.2 of this title (relating to Description of Standards). Fecal coliform content in buffer zones shall not exceed 200 colonies per 100 mL as a geometric mean of not less than five samples collected over not more than 30 d or equal or exceed 400 colonies per 100 mL in more than 10% of all samples taken during a 30 d period.

(ii) Median fecal coliform concentration in bay and gulf waters, exclusive of buffer zones, shall not exceed 14 colonies per 100 mL, with not more than 10% of all samples exceeding 43 colonies per 100 mL.

(iii) Oyster waters should be maintained so that concentrations of toxic materials do not cause edible species of clams, oysters, and mussels to exceed accepted guidelines for the protection of public health. Guidelines are provided by US Food and Drug Administration Action Levels for molluscan shellfish.

Nutrients

Coastal waters are among the most productive areas in the world, supporting approximately 20% of the total oceanic primary production (Hauxwell and Valiela, 2004; Elsdon et al., 2009). High productivity in estuaries and coastal ocean areas is due to the presence of nutrients essential for survival and growth of plants and algae. Examples of vital nutrients include nitrogen, phosphorus, iron, potassium, calcium, magnesium, sulphur, silicon, and boron (Hauxwell and Valiela, 2004). Nutrients can be derived from natural events, e.g., upwelling, storm events, and litter fall, as well as from human activities, e.g., sewage outfalls, leaching from cleared land, fertilizer runoff, and industrial and agricultural effluents (Carpenter et al., 1998; Elsdon et al., 2009; Quigg et al., 2009). Variation in nutrient concentrations can greatly affect the growth of phytoplankton, macroalgae, corals, mangroves, salt marsh vegetation, and seagrasses (Howarth et al., 2000; Hauxwell and Valiela, 2004).

The most important nutrients for primary production in coastal waters are nitrogen and phosphorus (Hauxwell and Valiela, 2004). Nitrogen is typically the limiting nutrient in coastal waters thereby restricting primary production (Gardner et al., 2006). Sources of nitrogen include atmospheric deposition, decomposition of organic matter, fertilizer application (e.g., lawns, turf, agriculture), and wastewater (Carpenter et al., 1998; Bowen and Valiela, 2001). In low-flow systems with low nutrient levels, an increase in nitrogen can cause a rapid increase in production usually resulting in algal blooms (Valiela et al., 1997; Carpenter et al., 1998; Bowen and Valiela, 2001; Quigg et al., 2009).

System-Wide Monitoring Program

The NERRS operates a System-Wide Monitoring Program (SWMP), a nationally-coordinated and standardized program. The SWMP tracks short term variability and long term changes in water quality, biotic diversity, and land use/land change (LULC) characteristics for the purpose of contributing to coastal zone management. The program provides valuable data on water quality and weather at 15 min time intervals. The program currently measures water quality parameters (e.g., pH, conductivity, temperature, dissolved oxygen, turbidity, and water level), weather, and a suite of nutrients. Nutrient samples are taken on a monthly basis at five datalogger stations and monthly diel samples at one datalogger station. Analyses for ammonium, nitrate, nitrite (or nitrate+nitrite), orthophosphate, and chlorophyll *a* are conducted on-site at Reserve facilities.

Mission-Aransas NERR SWMP stations provide baseline information on climatic and hydrological patterns that influence freshwater inflow. The Reserve encompasses a large area and to ensure adequate coverage datalogger stations are widely spaced apart. Copano Bay West provides hydrological data influenced by the Aransas River freshwater source. Copano Bay East provides data on water flow patterns between Copano and

Aransas bays (Figure 7.1). Mesquite Bay is considered a pristine site and is used as a control; this site also provides data on water flow patterns that are affected by San Antonio Bay to the north and the connection with Cedar Bayou and Gulf of Mexico. Cedar Bayou is currently a closed pass that divides Matagorda Island from San Jose Island. Aransas Bay South is a University of Texas Marine Science Institute (UTMSI) long-term monitoring site and provides data on the hydrological connection between Aransas Pass and San Antonio Bay. The last datalogger station is located on the end of the UTMSI pier in the Aransas Pass Ship Channel. This site provides data on the hydrological connection between the Gulf of Mexico and Aransas Bay.

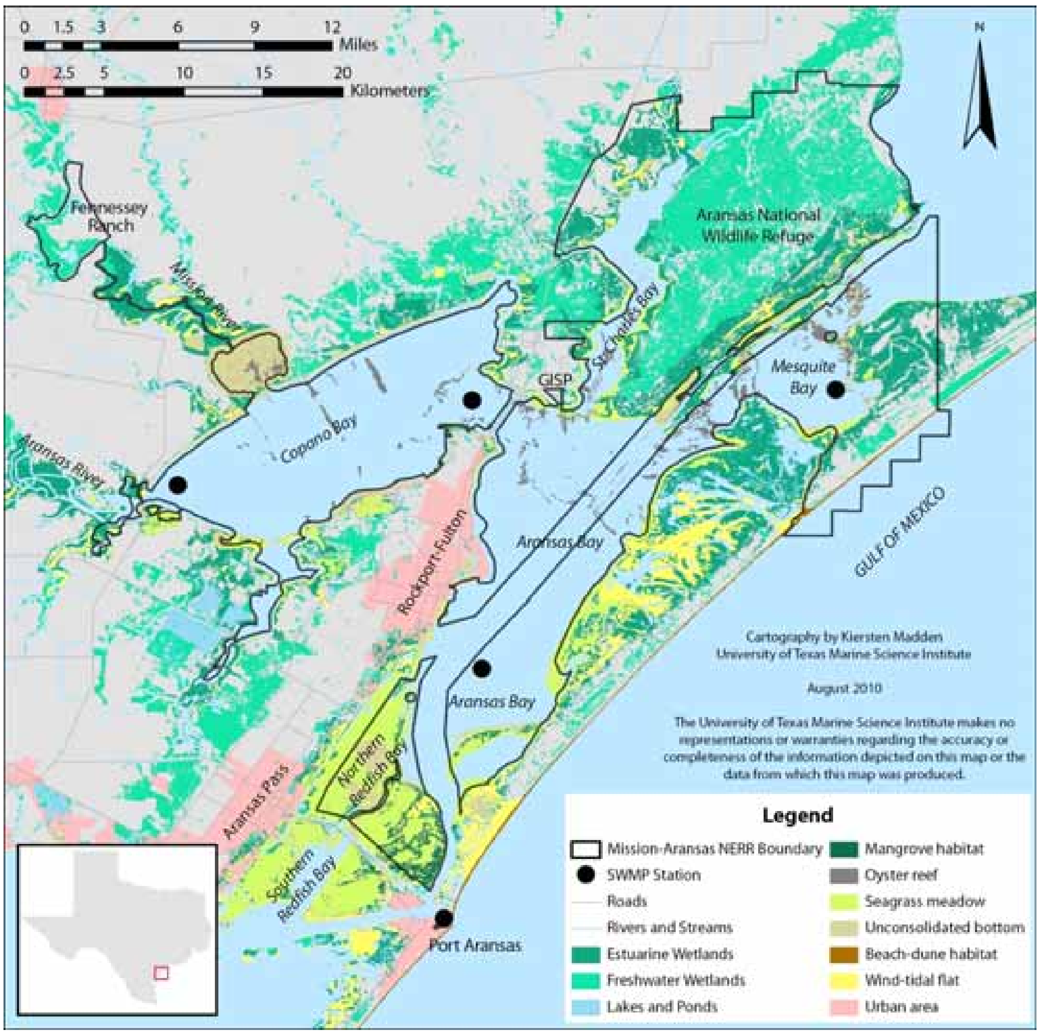

Figure 7.1. Mission-Aransas NERR system wide monitoring program stations.

Nutrients in the Mission-Aransas NERR

In the Reserve, adequate supplies of fresh water carrying nutrients and sediments to coastal wetland habitats is essential for the health and productivity of several commercial fisheries. Silicate, phosphate, and chlorophyll *a* concentrations decrease along the estuarine gradient from the rivers to the Gulf of Mexico (Figure 7.2). Nitrogen and ammonium concentrations are variable and often below detection limits. Nitrogen is the primary limiting nutrient in Texas estuaries and is supplied to the Reserve by the Aransas and Mission rivers (24%) and precipitation (28%). The final nutrient concentration is determined by estuarine processes, e.g., uptake by primary producers, geochemical trappings within sediments, regeneration by biological communities, and benthic-pelagic coupling (Tunnell et al., 1996).

Nitrogen inputs in arid coastal regions are usually limited; however, it has been suggested that nitrogen cycling rates in Texas coastal waters are comparable to rates observed in hypereutrophic ecosystems (Gardner et al., 2006). High nitrogen cycling rates are facilitated by ammonium production from sediments, nitrogen fixation, and denitrification. These processes provide critical supply and removal mechanisms for available nitrogen in South Texas estuaries. Further, during the frequent periods of drought, riverine nutrient inputs are low due to low flows (Gardner et al., 2006).

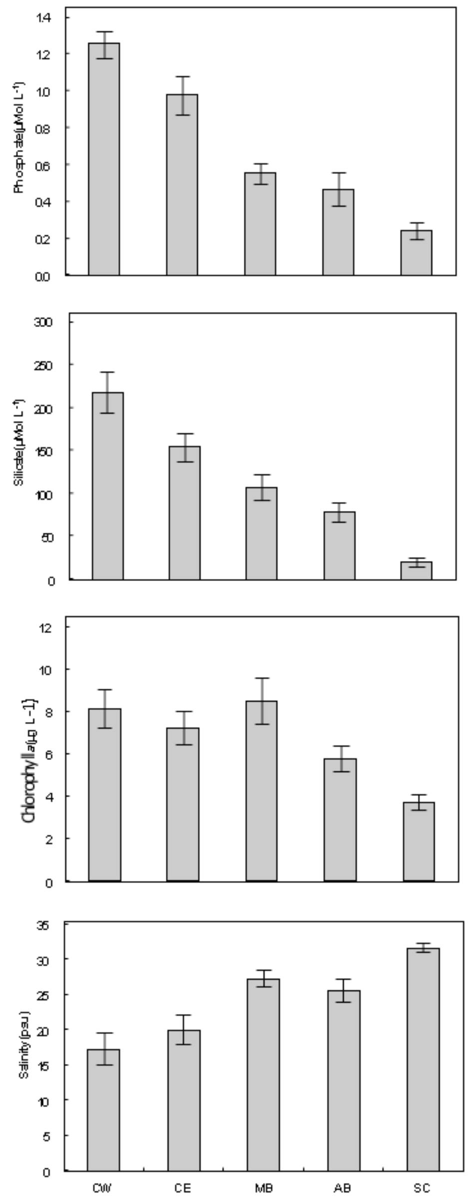

Figure 7.2. Nutrient concentrations and salinity of Mission-Aransas NERR SWMP stations. Data represent mean values from 2007-2009 monthly samples. Error bars represent standard error. CW=Copano Bay West, CE=Copano Bay East, MB=Mesquite Bay, AB=Aransas Bay, SC=UTMSI pier.

Issues of Concern for Water Quality

Bacterial Contamination

There are several segments in the Mission-Aransas Estuary that are listed as impaired due to bacterial contamination (TCEQ, 2008). The TCEQ segment 2472 (Copano Bay, Port Bay, and Mission Bay) and segment 2483 (Redfish Bay) are impaired by fecal coliform bacteria and do not support oyster use. Segment 2003 (Aransas River Tidal) and segment 2001 (Mission River Tidal) exceed enterococci bacteria water quality standards for contact recreation use. There are also impaired segments along the Gulf coast (including Port Aransas area). These waters have high concentrations of mercury in king mackerel greater than 43 inches and this impairment is listed as a high priority TMDL (TCEQ, 2008).

In 2006, a bacteria loadings model for Copano Bay was created to try and identify sources of bacteria in the watershed (Gibson, 2006). Wastewater treatment plants (WWTP), waterbirds, livestock, failing septic systems, and various other nonpoint sources originating from different types of land uses were identified as potential bacterial sources. The highest coliform concentrations in the watershed can be found in upstream rivers and streams and the highest concentrations in Copano Bay are at river and stream discharge sites into the Bay (Figure 7.3) (Gibson, 2006; Johnson, 2009). Several studies have determined the largest contributor of fecal coliform in Copano Bay to be cattle and horses and highest contamination occurring during high rainfall and river flow (Mott and Lehman, 2005; Gibson, 2006). Johnson (2009) determined spatial and temporal patterns of bacteria loadings typical of systems dominated by nonpoint sources and a high bacteria concentration in some of the WWTP effluents in the watershed.

A TMDL balance model was used to estimate the mean annual TMDL in the impaired waters of the Copano Bay watershed. A 78% reduction in the bacterial load to the Mission Tidal River, a 94% reduction to the Aransas Tidal River, and an 85% reduction in Copano Bay are necessary to achieve sufficient water quality standards (Johnson, 2009).

Livestock

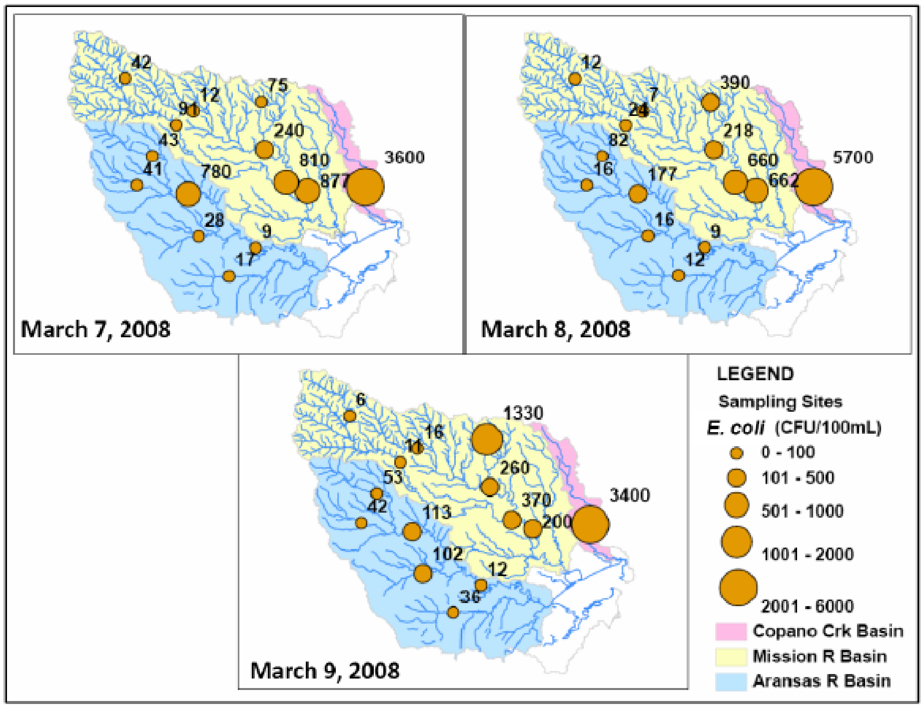

Figure 7.3. Spatial and temporal variation in *E. coli* concentrations (Johnson, 2009).

Land Use/Land Cover

Agriculture, urban, and industrial land uses can have dramatic impacts on estuarine environments (Bowen and Valiela, 2001; Martinez et al., 2007; Elsdon et al., 2009). Analysis of the world's coastal ecosystems revealed 18% of all lands within 100 km of the coast are considered altered, either by urbanization or agriculture (Martinez et al., 2007). Nutrient pollution caused by changing land use/land cover (LULC) patterns is a priority water quality issue in most coastal ecosystems, including the Mission-Aransas Estuary. Changes in LULC can cause an increase in the amount of land-derived nitrogen to estuaries, which can alter biogeochemistry and food webs (Bowen and Valiela, 2001). In addition to nutrients, changes in LULC also affect the export of water, organic matter, and sediment.

Generalizations on how different LULC cover influences coastal waters can be difficult to make due to variability of many factors. Each estuary is unique and has specific characteristics in LULC, runoff, and biological and physical processes that may not allow comparisons among rural and urban categories (Elsdon et al., 2009). The Mission-Aransas NERR watersheds have different LULC characteristics (Table 7.2). A large percent of the Aransas River watershed (drains 639.7 km^2) contains cultivated cropland, while the highest percent of land cover in the Mission River watershed (drains 1787.1 km^2) is shrub land.

Table 7.2. Land use/land cover characteristics of the Mission and Aransas watersheds. Data provided by NOAA (Mooney, 2009).

Land Use Land Cover Category	Aransas River Watershed %	Mission River Watershed %
Developed	3.20	1.24
Cultivated	44.65	6.30
Pasture/Grassland	22.63	36.45
Forest	3.35	8.55
Scrub/Shrub	22.09	42.60
Wetlands	3.26	3.68
Shore/Bare land	0.24	0.37
Water	0.58	0.80

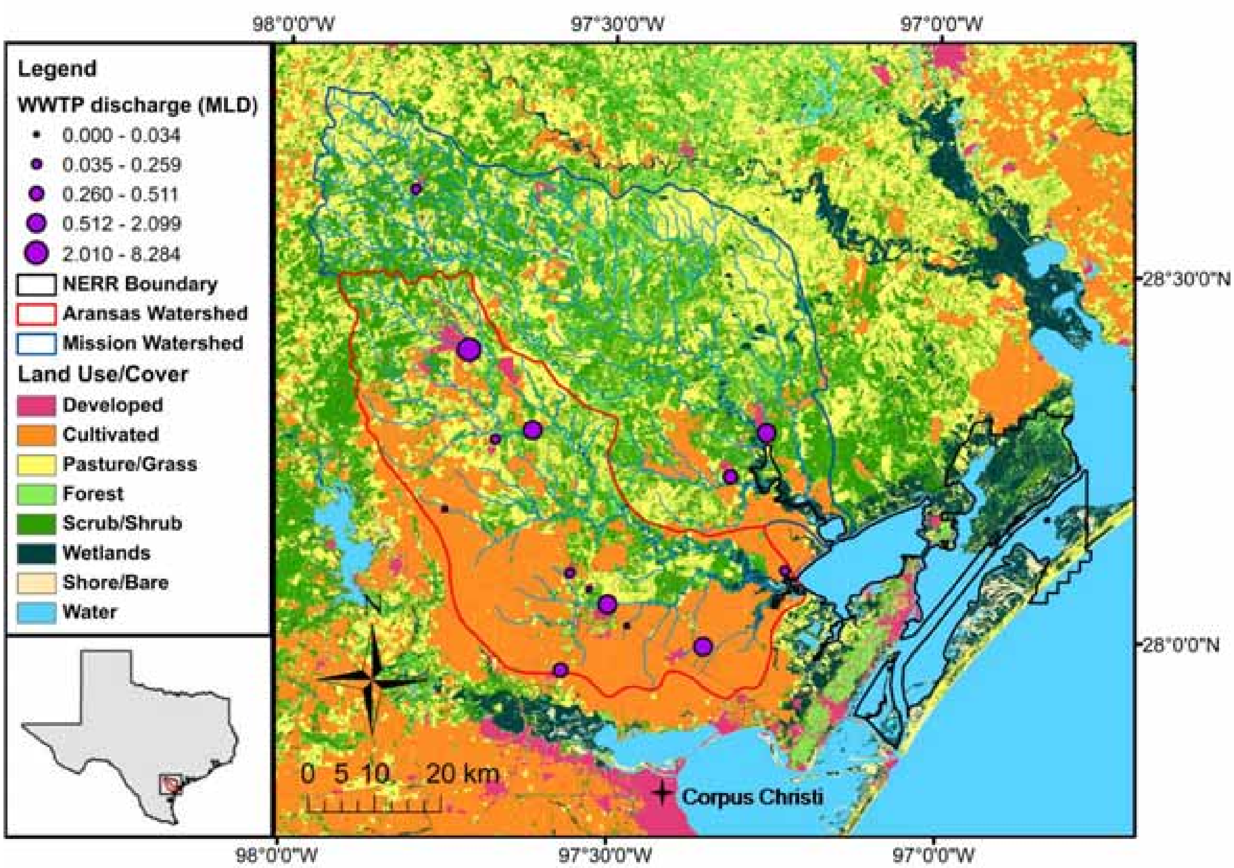

Figure 7.4. Land use/land cover of the Mission and Aransas watersheds. GIS data provided by NOAA. MLD is million liters per day (Mooney, 2009).

Urbanization

Populations in coastal areas are experiencing rapid growth. The population in Texas is expected to double between 2000 and 2050, and this growth will primarily be along the coast (Martinez et al., 2007; Quigg et al., 2009). This population increase is expected to have significant impacts on the quality of major estuaries.

Nutrient concentrations in urban areas are elevated due to increased levels of atmospheric and land-derived nitrogen loads (Elsdon et al., 2009; Quigg et al., 2009). In estuaries with heavily populated watersheds, wastewater is the largest source of nitrogen (Howarth et al., 2000). Other possible sources of anthropogenic nitrogen include fertilizer application, wastewater disposal, and inadequate or leaking sewage systems (Elsdon et al., 2009; Quigg et al., 2009).

Nutrients from the WWTPs may affect water quality. For example, excess nutrients could overstimulate growth of plants and algae which in turn consume dissolved oxygen and blocks light to deeper waters. The effects of this process could lead to a decrease in fish respiration, loss of seagrass, and eventual loss of use for fishing, swimming, and boating. The Mission and Aransas watersheds contain several permitted WWTPs (Figure 7.4). The Aransas watershed contains 10 treatment plants discharging 14.38 million L d^{-1} (MLD) while the Mission watershed contains three treatment plants discharging 1.89 MLD. A recent study on the Aransas River found elevated concentrations of nitrate and phosphorus and stable nitrogen isotope ratios ($\delta^{15}N$) of particulate organic nitrogen, which are indicative of wastewater effluents (Mooney, 2009).

Agriculture

There is a global trend in land use towards a decrease in agricultural land; however, with an ever increasing global population the demand for crops is increasing. This has spurred the escalating manufacture and use of synthetic fertilizers which has further intensified agriculturally-derived nitrogen loading in coastal waters (Bowen and Valiela, 2001). Howarth et al. (2000) stated the single largest change in the global nitrogen cycle occurred as a result of human reliance and subsequent increased use of synthetic inorganic fertilizer. Since the 1940s, the use of nitrogen fertilizer has increased exponentially resulting in the rise of nutrient concentrations in rivers, streams, and groundwater (Vitousek et al., 1997; Caffrey et al., 2007).

Soil erosion and loss of organic matter is more of an issue in agricultural areas (i.e., Aransas River watershed) than areas containing shrubs, grasslands, or forests (i.e., Mission River watershed). The Aransas River watershed is comprised of 44.65% cultivated cropland while the Mission River watershed has only 6.30%. Mooney (2009) determined the Aransas River has higher particulate organic matter concentrations during storm events due to a larger area of cultivated cropland.

Nutrient Pollution

Nutrient pollution along the coast is often a factor leading to eutrophication (elevated nutrient concentrations), harmful algal blooms, and hypoxia which may lead to fish kills, shellfish poisoning, and loss of seagrass beds (Howarth et al., 2000). Nutrient pollution may result from either point or nonpoint sources. Point source pollution is continuous, with little variability which facilitates monitoring and regulation, e.g., sewage treatment plants. Nonpoint source pollution cannot be traced to a single source, is derived from extensive areas of land, more intermittent, and usually linked to seasonal agricultural activity, storm events, or construction (Carpenter et al., 1998). Agriculture and the burning of fossil fuels contribute significantly to nonpoint source pollution from runoff and deposition from the atmosphere (Howarth et al., 2000). Nonpoint source pollution is difficult to measure and regulate and inputs are generally higher than point source pollution.

Climate Change and Water Quality

Large scale changes in environmental parameters and nutrient concentrations may be linked to changes in seasonal events such as weather patterns and freshwater inputs from runoff (Elsdon et al., 2009). Storms can cause acute, short-term adverse effects, e.g., flooding of wastewater treatment plants; however they can also help in system flushing and renewal, and enhance phytoplankton production (Burkholder et al., 2006; Caffrey et al., 2007). High rainfall can also cause elevated nutrient concentrations due to increasing runoff to streams and rivers which could lead to eutrophication. Conversely, global climate change may increase the occurrence and severity of droughts in some areas. Decreased precipitation may lower the amount of nutrients reaching the coastal zone, resulting in oligotrophication (i.e., nutrient poor conditions) and reduced fisheries productivity (Rabalais et al., 2009).

In South Texas, precipitation is highly variable within and between years (Dunton et al., 2001). Precipitation is lowest in the winter months and from May to September increased precipitation is usually due to tropical storms, the number and severity of which can vary between years. A study recently completed in the Mission-Aransas watershed focused on the effect of storms (or lack of storms) on the fluxes of water, nutrients, and organic matter to the system (Mooney, 2009). This study spanned 2007-2008 and included a relatively wet year (2007) and a relatively dry year (2008). Water collected from the Mission and Aransas rivers and Copano Bay was analyzed for concentrations of nitrate, ammonium, phosphorus, dissolved organic nitrogen and carbon, particulate organic nitrogen and carbon, and the stable carbon and nitrogen isotope ratios of the particulate organic matter. Organic matter concentrations in both rivers increased with flow and a shift from autochthonous (i.e., within the system) to allochthonous (i.e., outside the system) organic matter occurred during storm events. Nitrogen limitation was seen in Copano Bay through increases and quick draw down of nitrate and ammonium concentrations along with increases and slow draw down of soluble reactive phosphorus following storm events. It was determined that inputs generated from storm events can support increased production in the bay for extended periods (Mooney, 2009). These results provide important insights into how the Mission-Aransas NERR may respond to the impacts of global climate change.

Other studies completed in the Guadalupe and Nueces estuaries surrounding the Mission-Aransas NERR determined that increased freshwater inputs resulted in increased benthic macrofauna productivity and biomass whereas meiofauna density decreased (Montagna and Kalke, 1992). These studies show important implications for freshwater use issues that are becoming more important as populations are growing.

Future Plans for Water Quality

Water Quality Research in the Mission-Aransas NERR

Several studies have been completed that assess water quality and nutrient issues in the Mission-Aransas Estuary. Changing LULC characteristics, freshwater inflow, climate change patterns, and population size can impact ecosystem dynamics in sensitive estuarine ecosystems (Montagna and Kalke, 1992; Bowen and Valiela, 2001; Burkholder et al., 2006; Gardner et al., 2006; Caffrey et al., 2007; Martinez et al., 2007; Elsdon et al., 2009; Mooney, 2009; Rabalais et al., 2009). As the population size increases in South Texas, excess nutrients from WWTP, increase of pollutants from runoff due to impervious surfaces and river discharge, and decrease in freshwater inflow could negatively impact water quality in this area. Eutrophication and hypoxia could also become more prevalent leading to decrease in diversity and abundance of plants and animals.

It is estimated that global climate change will result in an increase in water temperature, stronger stratification, and an increase in freshwater inflows and nutrients to coastal areas. Rabalais et al. (2009) hypothesized these changes will lead to enhanced primary production, higher phytoplankton and macroalgal stocks, and more frequent and severe hypoxia. As temperatures increase bacterial contamination will also likely increase. Bacterial contamination is a serious human health concern and can lead to closure of oyster and recreational waters. Increase in storm events and higher precipitation rates could also decrease the salinity of coastal waters thereby impacting populations of benthic infauna causing a shift from estuarine environments to freshwater environments (Montagna and Kalke, 1992).

During the two summers (2009 and 2010) coliform bacteria has been monitored on a bi-weekly basis at all SWMP stations. The concentrations of coliform bacteria away from shore, where SWMP stations are located, are typically within the recommended guidelines for recreational use. Samples collected by the Texas Department of Health's Beach Watch program, collected near shore, often exceed recommended levels. In the future, we hope to investigate the causes of the high coliform bacterial levels that are often found in Copano Bay.

Detecting Petroleum Hydrocarbons

The Deepwater Horizon oil spill in the Gulf of Mexico during the summer of 2010 has focused attention on the importance of being prepared to monitor oil spills and other pollution events within the Reserve. This is especially important since the Gulf Intracoastal Waterway is a marine transportation canal that is used by barges carrying large volumes of chemicals and refined petroleum products through the Reserve. In addition, tankers carrying crude and refined petroleum products enter the ship channel on a daily basis, and there are numerous active oil and natural gas production platforms located in the Bays. We are hoping to install and test sensors on the pier laboratory within the Aransas Ship Channel that will be capable of detecting petroleum hydrocarbons. If these prove useful, we may expand the placement of these sensors to other SWMP stations.

Development of Pilot Nutrient Criteria Project

A three year project recently funded in the Mission-Aransas NERR by the Gulf of Mexico Alliance is focused on developing nutrient criteria for the Gulf of Mexico. The goal of the project is to characterize the nutrient dynamics, in terms of the sources, transport, fate, and effects, in coordination with the Gulf of Mexico Alliance Nutrient Priority Issue Team to develop protective nutrient criteria for coastal ecosystems. Nutrient loads will be determined by measuring total nitrogen and phosphorus, and nutrient inputs from rivers, runoff, atmospheric deposition, and groundwater. Biogeochemical transformations will be determined for nutrients in the water column and sediments. As ecological endpoints, the effects of nutrient load on oxygen concentrations, phytoplankton biomass, frequency of harmful algal blooms, changes in seagrass beds, and macroinvertebrate communities will be examined. Nutrient dynamics will be modeled in the Mission-Aransas Estuary to help understand the fate of nutrients, make recommendations on design of regional monitoring programs for the Western Gulf of Mexico, develop pilot nutrient criteria, and make predictions for future climate change.

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Chapter 8 MARINE HABITATS

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Unconsolidated Bottom

Unconsolidated bottom habitat, one of the prominent habitat types in coastal ecosystems, is located throughout the majority of the open water areas of the Mission-Aransas Estuary, with exception of oyster reef and seagrass bed areas. Within the Mission-Aransas NERR, this habitat is typically found in areas less than three meters deep, with the exception of the Gulf Intracoastal Waterway (Douglas, 1996). Unconsolidated bottom is defined as an area of loose substrate with less than one percent colonization by sessile organisms (Kendall et al. 2005). This type of habitat may be composed of many different types of sediment and is commonly classified based on the percentage of rubble, sand, silt, and clay (Montagna and Kalke, 1992).

Unconsolidated bottom habitat is not homogenous, rather it varies horizontally and vertically based on sediment type, depth, and environmental parameters (e.g., salinity and oxygen), which vary seasonally and yearly (Douglas, 1996). The relative abundance of gravel-sized shell fragments, sand, and mud (silt and clay) have similar distributions in Aransas and Copano bays. A perimeter of sand gradually increases in mud content towards the bay center, with over 75% mud in the deeper central bay area. The increase in mud content is due to a lower energy environment that allows small grains to settle. This trend varies between bays, i.e., Aransas Bay has larger grain sizes (medium to fine silt) while Copano Bay has smaller grain sizes (fine silt to clay) (Morton et al., 1983).

Unconsolidated bottom habitats are not currently subject to any special protection measures, but they are subject to indirect management due to the importance of local shrimp and crab fisheries. Regionally, long-term trends in abundance and diversity of shrimp and crab populations have not been observed, but there have been localized short-term trends of decline due to drought, dredging, and the presence of natural gas platforms (Peterson et al., 1996; Ritter and Montagna, 1999; Palmer et al., 2008).

Benthic Communities

A high abundance and diversity of macrobenthic infauna (> 0.5 mm), e.g., polychaetes, nematodes, mollusks, and crustaceans are present within unconsolidated bottom sediments. In most estuarine systems, polychaete and mollusk assemblages dominate unconsolidated bottom habitats. Macrobenthic infauna are primary and secondary consumers and help maintain high levels of diversity and productivity by functioning as a food source for higher trophic levels, e.g., shrimp, crabs, larger mollusks, and fish (Worm et al., 2006).

There are several environmental variables that control the composition of macrobenthic communities, e.g., water depth, sediment type, grain size, and salinity (Calnan et al., 1983; Gray and Elliott, 2009). Water depth is a controlling factor because it limits the amount of oxygen available to the organism due to stratification and water exchange with sediment, as well as controlling food sources that often have high light requirements. Grain size and sediment type affect burrowing infauna because it determines how deep they can burrow and still maintain a high water/oxygen flow. Clay based sediments often have lower oxygen content because of the close proximity of individual grains, thereby preventing water flow and therefore oxygen transport through the organism's habitat. Salinity has a more direct physiological effect on organisms because each individual requires a specific intracellular balance used for transportation of nutrients (Armstrong, 1987; Gray and Elliott, 2009).

The macroinvertebrate benthic assemblages of Aransas and Mission bays are controlled by different environmental factors. Mission Bay has a river-influenced assemblage that is characterized by mollusks, *Macoma mitchelli* and *Texadina sphinctostoma*. Aransas Bay has high water circulation and tidal influence, and the benthic macroinvertebrate assemblage is dominated by the mollusk, *Donax variabilis*, crustacean, *Acetes americanus*, and polychaetes, *Paraprionospio pinnata, Gyptis* sp., *Haploscoloplos fragilis*, *Owenia fusiformis,* and *Armandia agilis* (Calnan et al., 1983). Copano Bay assemblage is highly influenced by the presence of oyster reefs, with high numbers of mollusks, *Macoma mitchelli*, *Mulina lateralis*, *Texadina sphinctostoma*, and polychaete, *Glycinde* cf. *solitaria*.

Benthic organisms in Copano and Aransas bays follow a seasonal trend, with high abundance during winter and spring and low abundance in fall (Armstrong, 1987). Abundance levels in Aransas Bay range from 800-2500 organisms m^{-2} and in Copano Bay range from 180-5000 organisms m^{-2} (Armstrong, 1987). The relative levels of diversity show a decreasing gradient moving towards the inner shelf. Aransas Bay has the highest level of diversity (mean Shannon-Weiner diversity value (H') of 2.305), followed by Copano Bay (mean H' value of 2.095), and lastly Mission Bay (H' values ranging from 0.000-1.499) (Calnan et al., 1983). Although there is higher diversity in Aransas Bay, the relative abundance of molluscan and crustacean individuals in Copano Bay is higher. However, Aransas Bay does have a high relative abundance of polychaete individuals (Calnan et al., 1983).

Oyster, Crassostrea virginica

Oyster Reefs

The oyster contributes ecologically and economically to coastal ecosystems. The eastern oyster (*Crassostrea virginica*) ranges from St. Lawrence Bay, Nova Scotia, down the Atlantic coast, around the Gulf of Mexico to the Yucatan Peninsula, out to the West Indies, and may extend to Brazil (King et al., 1994). Commercial oyster production in Texas, second to Louisiana, comprised 20% of the nation's harvest from 2000 to 2005 (NOAA, 2007).

Estuaries with substantial freshwater inflows, i.e., Chesapeake Bay on the Atlantic coast and Galveston Bay in Texas, support relatively large populations of oysters. Along the Texas coast, bays with productive shellfish industries also tend to have high rates of freshwater inflow (Montagna and Kalke, 1995). Oysters in Laguna Madre have adapted to hypersaline conditions and are considered atypical. Mean annual rainfall in this semiarid estuary is approximately 64 cm, less than half the precipitation received along the upper Texas coast. This precipitation pattern, in association with a lack of major river inflow and increased evaporation, results in a north-south salinity (and temperature) gradient along the Texas coast. The Mission-Aransas Estuary is located near the center of this north-south gradient.

Oyster reefs filter solids from the water column, influence hydrological patterns, and provide habitat for a variety of species (Buzan et al., 2009). The reef structure is usually long and narrow, orientating perpendicular to prevailing water currents or parallel to channels, and has a tendency to grow out at right angles from shore in order to maximize feeding and waste removal (Price, 1954). The development of a reef is dependent on several hydrological variables such as salinity, water temperature, current flow, dissolved oxygen levels, and sedimentation.

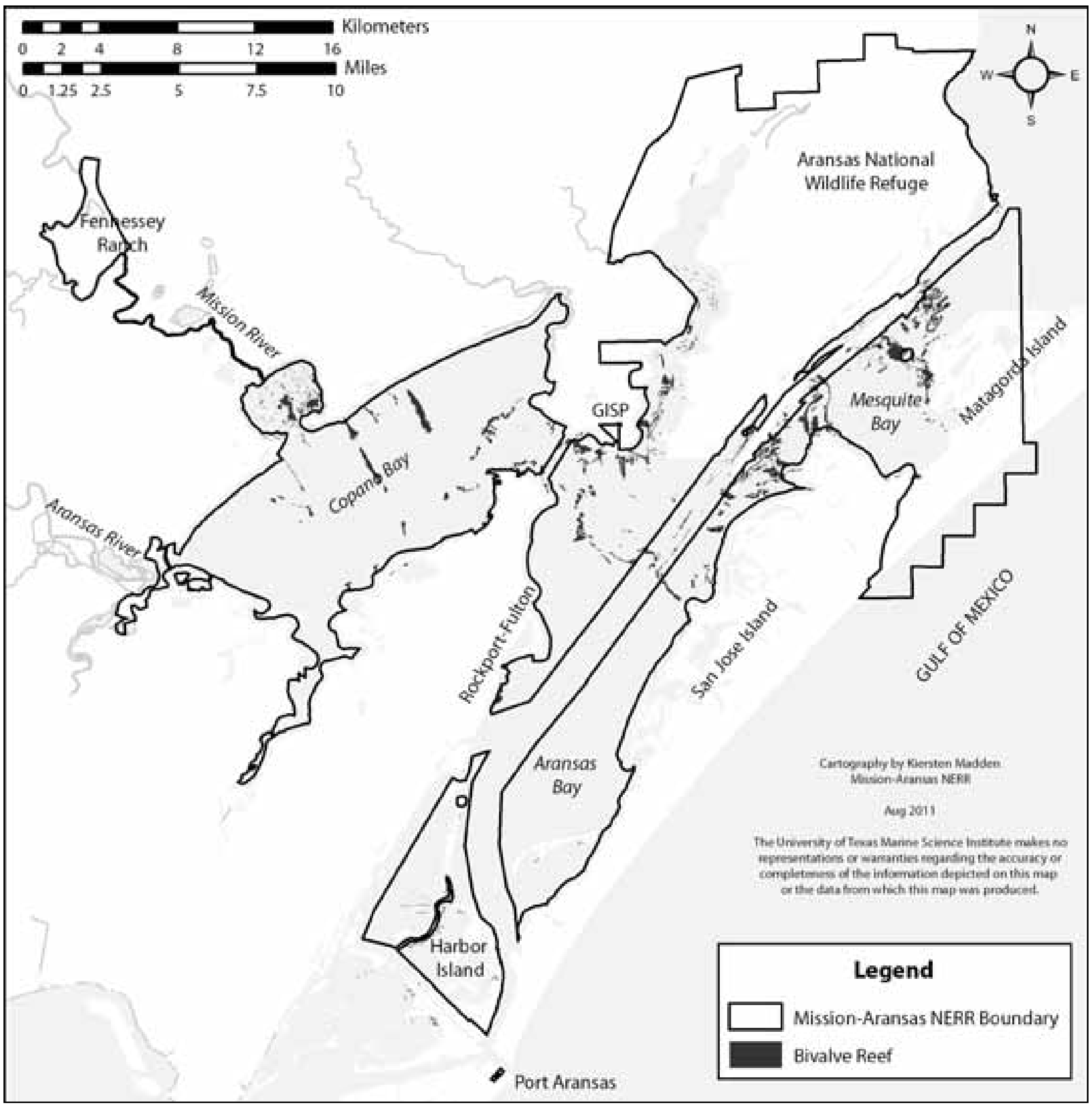


Figure 8.1. Location of oyster reefs in the Mission-Aransas NERR.

Oyster reefs within the Mission-Aransas NERR are concentrated in Copano, Aransas, and Mesquite bays (Figure 8.1). *Crassostrea virginica* is the primary species creating oyster reefs in the Mission-Aransas NERR and is found in a salinity range of 10-30 psu (Aransas Bay 10-20 psu and Copano Bay 10-15 psu) (White et al., 1989). Mollusks, *Odostomia impressa* and *Ischadium recurvum*, are also found on the reefs (Calnan, 1980). Primary production is enhanced by a thin algal film on the surface of oyster reefs (Bahr and Lanier, 1981). Invertebrates are the most abundant consumers of the algae with arthropods, such as amphipods, brachyuran crabs, and caridean shrimp dominating communities. Oyster reefs are frequented by redfish, *Sciaenops ocellatus* (Miles, 1951). Birds and feral hogs are the primary consumers of the oysters and have been reported using reefs as crossings during low tides often appearing to forage as they cross (McAlister and McAlister, 1993; A. Drumright, unpublished data).

Natural and man-made reefs occur in Copano Bay. In 2008, the Nature Conservancy deposited 200 cubic yards of oyster shell in Copano Bay as part of a pilot project to restore ecologically important oyster beds that are in decline in the Gulf of Mexico. The oyster shell was distributed over a one-acre area. The benefits of a constructed reef include the restoration of oyster reef that serves as the preferred settling area for oyster spat, as well as the associated diversity created by providing new reef habitat. The reef also provides critical information on the estimation of water filtration rates that aid in ecosystem management of the whole bay and ultimately the Gulf of Mexico.

Oyster Reef Restoration

The Harte Research Institute (HRI), Texas General Land Office (TGLO), Water Street Restaurants of Corpus Christi, and the Port of Corpus Christi have established an oyster shell reclamation, storage, and recycling program for oyster reef restoration (www.oysterrecycling.org). The program takes large quantities of shells that are typically discarded in landfills and puts them back in the bay to create new habitat. The goal of the project is to replace at least an acre of habitat. Existing oyster reefs are being assessed by the HRI and TGLO based on oyster biology and reef health and are used to determine suitable locations for future restoration projects. Hydrologic and oyster data are being used to create maps to help identify the best locations for restoration. Areas under consideration to place the used shells include sites in Copano and Aransas bays.

Oyster shells are blown into Copano Bay from a barge in The Nature Conservancy's oyster-reef restoration pilot project. Photo credit Mark Dumesnil/The Nature Conservancy

Current and Ongoing Studies

Oysters are used as bioindicators of freshwater inflow. In the Mission-Aransas Estuary, the role of flood disturbance in oyster population maintenance is used to determine the effects of changes in freshwater inflow on oyster biology and population dynamics (Beseres Pollack et al., 2011). Additionally, determining the salinity level that stimulates peak oyster populations will assist managers with future water planning.

Several other studies on oysters in the Mission-Aransas NERR include the use of Geographic Information Systems (GIS) to identify suitable sites for oyster reef restoration. This approach provides an objective and quantitative tool for planning future oyster reef restoration efforts. The aim was to develop a restoration suitability index model and reef quality index model to characterize locations based on their potential for successful reef restoration (Beseres Pollack et al., 2012). Additionally, the Harte Research Institute and Dr. Sammy Ray from Texas A&M University-Galveston partnered on a long-term oyster sampling program to monitor for *Perkinsus marinus* (Dermo) oyster disease in the Mission-Aransas Estuary. Data is collected along the Gulf coast and available online (www.oystersentinel.org).

Dinophysis, captured by the FlowCam, is a red tide species which bloomed in 2008 causing oyster fisheries to shut down. Effects on humans include diarrhetic shellfish poisoning. Photo credit Jena Campbell

Seagrass

Seagrass beds are critical habitats that influence the physical, chemical, and biological environments of coastal ecosystems (Wright and Jones, 2006). They provide numerous important ecological services to the marine environment (Costanza et al., 1997). Seagrasses stabilize sediments, which prevent erosion (Christiansen et al., 1981), act as biological indicators of ecosystem health and water quality (Dennison et al., 1993), and produce large amounts of organic matter that form the basis of the estuarine food web. Seagrasses also provide nursery habitat for commercially and recreationally important fishery species, as well as provide a direct food source for fish, waterfowl, and sea turtles (Beck et al., 2001).

Seagrass beds have seen an overall decrease in worldwide populations (Short and Wyllie-Escheverria, 1996) and it is believed that the Texas coast is experiencing similar trends (Pulich and White, 1991; Quammen and Onuf, 1993; Onuf, 1994). The decline in overall seagrass populations is thought to be attributed to several anthropogenic disturbances, including decreased water clarity due to dredging, nutrient loading, and mechanical damage from boating activities (Tomasko and Lapointe, 1991; Quammen and Onuf, 1993; Onuf, 1994; Short et al., 1995; Dunton and Schonberg, 2002; Uhrin and Holmquist, 2003).

Seagrass Protection and Management

There are several federal and state regulations that protect seagrasses and seagrass habitat. The two main goals of the regulations are: (1) to ensure water and sediment quality that is beneficial to seagrasses and (2) to protect seagrass beds through the effective mitigation sequence: avoidance, minimization, and compensation. The primary federal and state regulations that help protect seagrasses in the state of Texas are Section 404 and 401 Permits of the Clean Water Act (CWA) and Texas Coastal Management Program (TCMP). Section 404 applies to the discharge of dredged or fill material within US waters while section 401 protects seagrass through water quality regulations.

Section 404 (40 CFR 230.10(d)) specifically states that “no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem.” Section 401 acts to protect seagrasses through the regulation of water quality certification. This process regulates whether the state will allow federal permits for the discharge of material into surface waters.

Texas Parks and Wildlife Department currently operates a Seagrass Conservation Management Plan. Redfish Bay State Scientific Area (RFBSSA) was established as a scientific area under this conservation management plan in 2000 (32,144 acres). The northern portion of this area is within the Mission-Aransas NERR.

Distribution and Trends in the Mission-Aransas NERR

Geographic overviews of the distribution of seagrasses along the Texas coast provide important background information that allows for the design of effective programs in research, management, and education. Current seagrass coverage along the coast is estimated at 235,000 acres (Pulich et al., 1997). Copano Bay and Aransas Bay within the Mission-Aransas NERR contain approximately 8,000 acres of seagrass beds, which converts roughly into 3.4% of the total area of seagrasses statewide (Figure 8.1). Copano Bay contains *Halodule* and *Ruppia* species, while Aransas Bay contains *Halodule, Ruppia, Halophila, Thalassia,* and *Syringodium* species. Over the past few decades the status and trends of seagrasses have experienced drastic changes all along the Texas coast. The largest stand of seagrass beds within the Mission-Aransas NERR occurs within Redfish Bay, which is at the Reserve's southernmost boundary (Table 8.1). Redfish Bay contains all five major species of seagrass, e.g., *Halodule, Ruppia, Halophila, Thalassia and Syringodium* (Table 8.1). Directly adjacent to the Mission-Aransas NERR boundary is Harbor Island, another extensive area of seagrass beds. Redfish Bay and Harbor Island contain approximately 14,000 acres of seagrass beds (Pulich et al., 1997). Data indicates that total seagrass acreage within Redfish Bay has remained stable over the past forty years, despite local changes in seagrass bed distribution (Pulich and Onuf, 2003). Past inventories from the Redfish Bay system in 1958, 1975, and 1994 show an increase of 2,023 acres in seagrass coverage from 1958 to 1975, but a decrease in coverage of 1,205 acres from 1975 to 1994, for a net increase of 815 acres (Pulich and Onuf, 2003).

Although there has been an increase in overall seagrass bed coverage, there has been an overall decrease in contiguous grass beds. Past landscape analysis has shown that certain areas of Redfish Bay and Harbor Island show more impacts and loss of seagrasses (Pulich and Onuf, 2003). From the late 1950s to the mid- 1970s Redfish Bay showed a slight decrease in both patchy and continuous seagrass beds, while the nearby Harbor Island showed a substantial increase in both patchy and continuous seagrass beds (Table 8.2). From the mid- 1970s to 1994 Redfish Bay and Harbor Island had a decrease in continuous seagrass coverage, while both locations show an increase in patchy seagrass bed (Table 8.2).

Seagrass coverage is believed to be in decline within Redfish Bay due mainly to bed fragmentation (Figure 8.2). In addition the accumulation of wrack, drift macroalgae, and epiphytes suggest water quality problems in the bay (Pulich and Onuf, 2003). Other areas of concern include increased input of nutrients from new development on the north side of Redfish Bay and the widespread physical damage of shallow beds from boat propeller scarring and navigation channel impacts (Dunton and Schonberg, 2002).

Table 8.1. Current status and trends in seagrass (Pulich et al., 1997).

Bay System	Current Acreage	Percent of Coastline	Genus*	Trends
Copano			Hd, Rup	
St. Charles	8000	3.4	Hd, Rup	
Aransas			All five	
Nueces**			Hd, Rup	Fluctuates with inflow**
Corpus Christi***	24600	11.2	All five	Acreage stable, some bed
Redfish***			All five	fragmentation***

*Hd = *Halodule*, Rup = *Ruppia*. Other seagrasses include: Hph = *Halophila*, Th = *Thalassia*, Syr = *Syringodium*

Table 8.2. Changes in continuous and patchy seagrass beds in Redfish Bay and Harbor Island segments between late 1950s to mid- 1970, and mid- 1970s to 1994. Values are in ha and values in parenthesis are ac, unless otherwise noted (Pulich and Onuf, 2003).

Time Period	Redfish Bay		Harbor Island	
	Continuous	Patchy	Continuous	Patchy
Late 1950s	3,100 (7,660)	1,080 (2,669)	1,016 (2,511)	182 (450)
Mid- 1970s	2,969 (7,337)	1,016 (2,511)	1,776 (4,389)	436 (1,077)
1950s-1970s net	-131 (-324)	-64 (-158)	+760 (+1,878)	+254 (+628)
Percent change	**-4.2%**	**-5.9%**	**+74.8%**	**+139.6%**
Mid-1970s	2,969 (7,337)	1,016 (2,511)	1,776 (4,389)	436 (1,077)
1994	1,669 (4,124)	1,976 (4,883)	1,320 (3,262)	744 (1,838)
1970s-1994 net	-1,300 (-3,212)	+960 (2,372)	-456 (-1,127)	+308 (+761)
Percent change	**-43.8%**	**+94.5%**	**-25.7%**	**+70.6%**

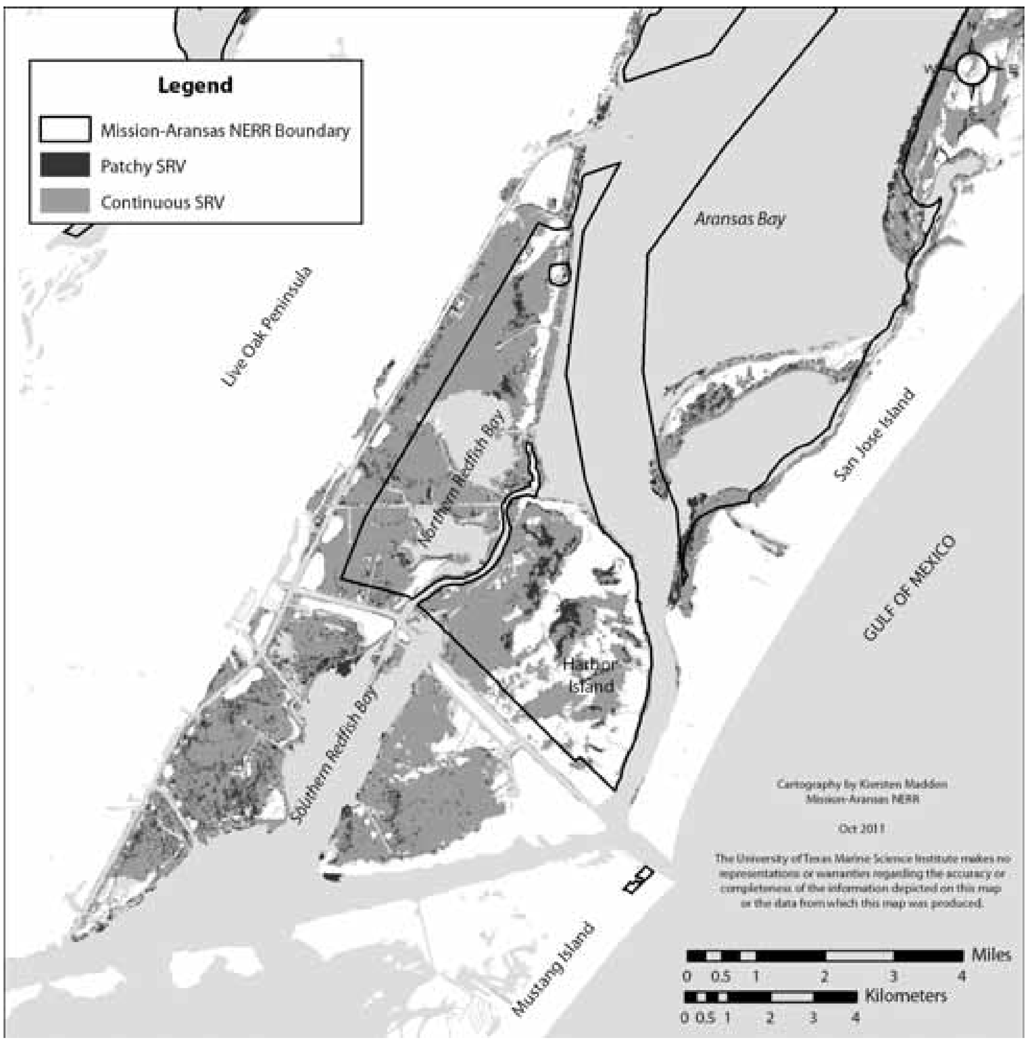


Figure 8.2. Map of seagrass beds in Redfish Bay.

Monitoring Programs

In 1999, the TPWD, along with the TGLO and the TCEQ, drafted a *Seagrass Conservation Plan* that proposed a seagrass monitoring program for the state of Texas (TPWD, 1999). The primary purpose of the Texas Seagrass Monitoring Program (TSGMP) was to establish a method for detecting changes in seagrass habitats prior to actual seagrass mortality. The monitoring program calls for a hierarchical strategy for establishing quantitative relationships between physical and biotic parameters that ultimately control seagrass condition, distribution, and longevity (Dunton et al., 2007). The three tiers of the hierarchical approach are: (1) remote sensing, (2) regional rapid assessment program using fixed stations sampled annually, and (3) landscape approach that includes permanent stations and transects that are aligned with high resolution photography (Dunton et al., 2007).

A similar hierarchical approach has been adopted by the NERRs (Moore, 2009). The two-tier NERRS biological monitoring protocol for submerged (and emergent) vegetation requires: (1) mapping and monitoring of overall habitat distribution and (2) long-term monitoring of vegetative characteristics, e.g., percent cover, shoot density, leaf length. The overlap between this methodology and Tiers 1 and 3 of the TSGMP was acknowledged in the *Implementation of a Seagrass Monitoring Program for Texas Coastal Waters* (Dunton et al., 2007).

The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC), in conjunction with TPWD and Texas A&M University-Center for Coastal Studies, completed a benthic habitat mapping project to support the TSGMP. The project was completed in phases; phase one mapped the major bays contained within the Reserve, i.e., Redfish, Copano, and Aransas bays. The use of existing digital camera (ADS 40) images, originally collected by the National Agriculture Imagery Program, was the primary data source for constructing the benthic habitat maps. The benthic habitat maps created from this project will aid the seagrass monitoring program by helping to locate, monitor, and protect seagrass beds.

More recently, the Mission Aransas NERR worked with the NOAA Environmental Cooperative Science Center (ECSC) and other collaborating universities on a hyperspectral imagery project aimed at classifying vegetation habitats and water characteristics. One of the principal thematic research objectives of this project was to determine the spatial distribution of submerged aquatic vegetation (SAV), including seagrasses, and salt marsh habitats within Redfish Bay. The results from this mapping effort (as well as the previous benthic mapping project) directly support the TSGMP, as well as Tier 1 of the NERRS biological monitoring protocols.

The Mission-Aransas NERR was recently funded to begin implementation of Tier 2 of the biological monitoring protocols, i.e., long-term stations to monitor vegetation characteristics. Implementation of both phases of the NERRS biological monitoring protocols will support both a nationwide initiative to assess change in submerged vegetation at Reserves and a statewide initiative to use standardized protocols for monitoring seagrass on the Texas coast.

Water Column

Plankton

Plankton are a diverse group of tiny organisms living in the water column, unable to swim effectively against currents. These organisms rely on water circulation to make substantial movement through the estuary. Plankton are divided into two groups: autotrophic photosynthesizers known as phytoplankton and heterotrophic consumers known as zooplankton. As photosynthesizers, phytoplankton abundance can be used as a measurement of primary production in the estuary. Likewise, abundance of zooplankton can be considered a measurement of secondary production.

A large portion of the Mission-Aransas NERR, including the majority of Mission, Aransas, and Copano bays is considered open bay habitat. Phytoplankton are the main source of primary production in this habitat. They serve an extremely important ecological function in open bay food webs by supplying carbon directly to pelagic consumers of higher trophic levels and indirectly as detritus to consumers in the benthic zone (Armstrong, 1987).

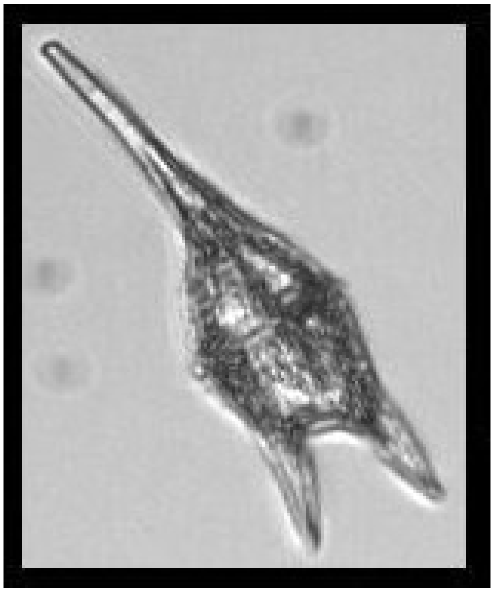
Phytoplankton in the Mission-Aransas NERR

Spatial and temporal distribution of phytoplankton is not uniform in the Mission-Aransas Estuary as evidenced by variations in abundance or biomass (Longley, 1994). Phytoplankton abundance is often estimated from the level of chlorophyll found in the water column. Typically, chlorophyll concentrations are higher in the upper regions of the estuary, i.e., closer to the source of fresh water and nutrient discharge. Chlorophyll data collected from the System Wide Monitoring Program (SWMP) supports this conclusion. Mesquite Bay and Copano Bay West stations tend to have higher chlorophyll concentrations while the Ship Channel and Aransas Bay have lower concentrations (Figure 7.2).

Although the distribution of phytoplankton changes over time, a three-year study of Corpus Christi, Copano, and Aransas bays found the general composition of local phytoplankton remained uniform (Holland et al., 1975). Phytoplankton include photosynthetic unicellular protists and bacteria (Johnson and Allen, 2005) and assemblages in open bay communities typically are composed of representatives from four major taxonomic groups: diatoms, dinoflagellates, green algae, and blue-green algae. Previous studies have determined the composition of phytoplankton species in the Mission-Aransas Estuary to be 63% diatoms, 18% dinoflagellates, and 11% green algae (Holland et al., 1975).

In most Texas estuaries, phytoplankton populations change with seasons. Diatoms dominate during winter and share dominance with dinoflagellates during summer months (Armstrong, 1987). A study of phytoplankton in Aransas Bay indicated diatoms to be the dominant flora, exhibiting a winter peak of *Coscinodiscus* sp. and a summer peak of *Rhizosolenia alata* (Freese, 1952). Green algae were found to be present year-round, experiencing spring or fall blooms (Armstrong, 1987).

The temporal and spatial patterns displayed by phytoplankton are commonly associated with salinity and zooplankton grazing (Holland et al., 1975). The average chlorophyll level in the Mission-Aransas Estuary is approximately 6.6 $\mu g\ L^{-1}$.



Ceratium sp., a common dinoflagellate in the Mission-Aransas National Estuarine Research Reserve
Photo credit Jena Campbell

Zooplankton in the Mission-Aransas NERR

Zooplankton species include both unicellular and multicellular organisms from a range of sizes and life history patterns. Zooplankton can be divided into the following three size categories: microzooplankton (20-200 µm), e.g., tintinnids, non-loricate ciliates, copepod nauplii, and protozoans; mesozooplankton (0.2-2.0 mm), e.g., copepods, rotifers, barnacle larvae, crab zoea, and mollusk veligers; and macrozooplankton (2.0-20 mm), e.g., jellyfish, ctenophores, shrimps, and larval fishes (Tunnell et al., 1996; Johnson and Allen, 2005).

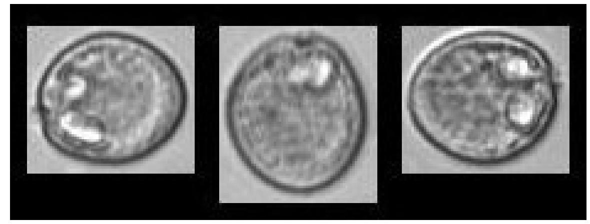
Zooplankton can also be divided into two life history modes. Holoplankton are individuals that remain planktonic for their entire lives and include such organisms as copepods, cladocerans, and chaetognaths. Meroplankton spend only a portion of their lives in a planktonic stage (typically during the larval development), after which they join the free-swimming nekton or benthic assemblages. Examples of meroplankton include larval fish, crabs, shrimp, worms, and mollusks (Armstrong, 1987; Johnson and Allen, 2005). Economically important local species that spend time as meroplankton include brown shrimp, blue crab, white shrimp, grass shrimp, and oysters.

Zooplankton communities are unique to each individual bay system, displaying differences not only in seasonal maxima and minima, but also in species composition and abundance (Matthews et al., 1974). One exception is the dominant copepod, *Acartia tonsa*, which is ubiquitous in nearly all estuarine and coastal waters of the Gulf of Mexico, and regulated by temperature, salinity, currents, and turbidity (Matthews et al., 1974; Holland et al., 1975; Armstrong, 1987; Longley, 1994; Johnson and Allen, 2005).

Microzooplankton abundance in Texas estuaries is 30-60 million m^3. Abundance levels are an order of magnitude greater than other temperate bays and estuaries, i.e., Buzzards Bay, Chesapeake Bay, Gulf of Maine, Lime Cay, Long Island Sound, Maine Estuary, Narragansett Bay, and Passamaquoddy Bay (Buskey, 1993). High abundance can be attributed to the rapid generation times of microzooplankton, which are typically on the order of days. Quick reproduction strategies allow these organisms to respond rapidly when environmental conditions are favorable. Large populations can be established that can greatly influence nanophytoplankton (<20 µm) standing crops through grazing, making microozooplankton a significant component of water column secondary production (Stockwell, 1989; Buskey, 1993).

Mesozooplankton populations inhabiting the Mission-Aransas NERR are dominated by the copepod species *Acartia tonsa*, *Parvocalanus crassirostris*, *Pseudodiaptomus coronatus*, *Oithona* spp., along with barnacle nauplii (Holland et al., 1975). The calanoid copepod, *Acartia tonsa,* dominates zooplankton assemblages throughout the Reserve, making up 40-60% of the population (Holland et al., 1975; Buskey, 1993). Stable populations of this euryhaline species are typically present year-round in a range of salinities, with lowest abundances occurring at times of extremely low salinity (Holland et al., 1975; Johnson and Allen, 2005). The cyclopoid copepod, *Oithona* spp., exhibits peaks during the warmer months of spring and summer in Copano and Aransas bays (Holland et al., 1975; Tunnell et al., 1996). These copepods prefer high salinities and feed on dinoflagellates during early life stages, but upon reaching maturity they become carnivorous (Johnson and Allen, 2005). *Parvocalanus crassirostris*, an herbivorous calanoid copepod, also favors high salinities (Johnson and Allen, 2005). This species is unable to establish large populations in Copano Bay due to low salinity conditions; however, large abundances are present in both Corpus Christi Bay and Aransas Bay, displaying no seasonal patterns (Holland et al., 1975). The calanoid, *Pseudodiaptomus coronatus,* flourishes during spring, summer, and fall, but abundance decreases in the winter months (Holland et al., 1975). Barnacle nauplii, which represent meroplankton, are abundant throughout the year in the Mission-Aransas Estuary, displaying highest abundances during the cold winter months (Holland et al., 1975; Buskey, 1993).

Depending on season, *Centropages furcatus*, *Centropages hamatus*, and *Noctiluca scintillans* are neritic species of zooplankton that can commonly be found in the Mission-Aransas Estuary. *Centropages furcatus* is a warm water, stenohaline species present primarily in Aransas Bay and lower Corpus Christi Bay. *Centropages hamatus* is a cool water, euryhaline species that has been found throughout Corpus Christi, Copano and Aransas bay systems in high abundances during cold winter months (Holland et al., 1975). Both of these species are calanoid copepods that eat large phytoplankton, ciliates, larval copepods, and larval mollusks (Johnson and Allen, 2005). *Noctiluca scintillans* is a dinoflagellate, but functions as a heterotroph consuming diatoms, dinoflagellates, copepod eggs, and possibly fish eggs (Johnson and Allen, 2005). This species is not well established in either Copano or Aransas bays (Holland et al., 1975), but is often present in samples collected from the Aransas Pass Ship Channel (Buskey, 1995; Hyatt, unpublished data).



Prorocentrum, a dinoflagellate, can form toxic blooms, but no toxic blooms from this species have occurred in the Mission-Aransas NERR.
Photo credit Jena Campbell

Macrozooplankton, e.g., jellyfish and ctenophores, are the largest size group of zooplankton. Most jellyfish are predatory pelagic cnidarians, using an array of nematocysts to catch planktonic or nektonic prey items. Common representatives in nearshore coastal waters belong to the class Scyphozoa. The most abundant jellyfish inhabitant of Texas bays is the large cabbagehead, *Stomolophus meleagris*, which enters through tidal inlets during late summer and early fall. Ctenophores, known as comb jellies, are transparent, gelatinous planktonic predators that utilize eight rows of cilia to move through the water. During the summer months, *Mnemiopsis leidyi*, a brightly luminescent, carnivorous ctenophore, is also found in Texas coastal waters (Britton and Morton, 1989).

Overall, research has shown zooplankton populations in Texas estuaries typically increase shortly after phytoplankton blooms in the spring and fall (Holland et al., 1975; Armstrong, 1987; Buskey, 1993). This is evidence for strong predator-prey relationships existing between the two classes of plankton. Because of this influential relationship, estuarine zooplankton abundance may be controlled by food availability (Buskey, 1993).

Nekton

The term nekton refers to the group of aquatic organisms that are able to move independently of water currents (Day et al., 1989). This group of organisms consists primarily of fishes (therefore, these terms will be used interchangeably throughout the document), but can also include organisms such as squid, crabs, lobsters, shrimp, and seals (Day et al., 1989). Nekton are a key component in all aquatic ecosystems and estuaries contain the greatest biomass of higher trophic levels of fishes (Woodwell et al., 1973; Haedrich and Hall, 1976).

Local fisherman with red drum

Distribution and Abundance

Estuaries are extremely productive and support many nekton species. Types of species that live in these areas include oceanodromous (migrate to other parts of the ocean), diadromus (use both marine and freshwater habitats during their life cycle), anadromous (live mostly in the ocean but spawn in fresh water), and amphidromous (travel between fresh and salt water) (Day et al., 1989; Beck et al., 2001).

Nekton are distributed in three different environmental zones: shallow, pelagic, and bottom (Day et al., 1989). Shallow water nekton include small adult fishes, e.g., killifish. Pelagic zone nekton include larger predatory fishes, e.g., Atlantic croaker. Finally, bottom environment nekton species are flatfish, e.g., croakers and catfish (Day et al., 1989). The majority of the nekton community is estuarine dependent, relying on the estuary for food and shelter during at least one portion of their lifecycle. Typically, adults spawn offshore, larvae are transported back into the estuary, metamorphose, grow to subadult stages, and finally, subadults move to adult habitat to restart the cycle (Gunter, 1967; Day et al., 1989; Beck et al., 2001).

Common Species

Red drum *(Sciaenops ocellatus)* is a popular game fish in coastal waters ranging from Massachusetts to Mexico. Distinguished by one large black spot on the upper part of the tail base, red drum can be found in shallow waters along bay edges, preferring areas with submerged vegetation. Red drum are fast growing fish, reaching 28 cm (11 in) and 0.5 kg (1 lb) in the first year. The red drum record in Texas is 27 kg (59.5 lbs) and the largest fish ever caught was on the east coast and weighed 43 kg (94 lbs). These fish live in bays for the first three years of life and migrate to the Gulf of Mexico as adults where they spawn from mid-August through mid-October. Young red drum feed on small invertebrates and as they grow feed on large crabs, shrimp, and small fish.

Black drum *(Pogonias cromis*) is an important recreational and commercial fishery from Nova Scotia to Florida, the Gulf of Mexico, and the southern Caribbean coast. They are silvery grey to very dark in color and juveniles have four or five vertical bars on their sides that disappear with growth. In the first year black drum reach 15 cm (6 in) long, 30 cm (12 in) during the second year, 41 cm (16 in) during the third year, and grow about 5 cm (2 in) every year after that. Most black drum weigh 14 to 18 kg (30 to 40 lbs), in Texas the record is 35 kg (78 lbs), and the largest fish caught weighed 66 kg (146 lbs). Black drum (family

Sciaenidae) are usually associated with sand and sandy mud bottoms in coastal waters, and feed mainly on crustaceans, mollusks, and fishes.

Southern flounder *(Paralichthys lethostigma*) is an estuarine dependent species distributed from North Carolina to Florida on the Atlantic Coast and from Florida to Northern Mexico in the Gulf of Mexico. It is an important commercial and recreational fishery that is declining due to habitat loss and overfishing. Southern flounder remain within the estuary during the majority of their lifespan, only leaving in late fall (at age two when mature) to go offshore for spawning. Recruits return to the estuary in late January. Young flounder grow rapidly and reach 30 cm (12 in) in length by the end of their first year. Males normally stay around 30 cm (12 in) but females can grow to 64 cm (25 in). Their diet consists of other fishes, crabs, and shrimp.

Spotted seatrout *(Cynoscion nebulosus*) is another important recreational and commercial fishery distributed from Massachusetts to the Yucatan peninsula. Seatrout prefer shallow bays and estuaries around oyster reefs and seagrass beds. Males grow to approximately 48 cm (19 in) and females grow to approximately 64 cm (25 in), with both sexes weighing 1 to 1.3 kg (2 to 3 lbs). This species has dark gray or green coloration on their back and distinct round spots on their back, fins, and tail. Their primary prey varies with size, i.e., small spotted seatrout feed on small crustaceans, medium size seatrout feed on shrimp and small fish, and large seatrout feed exclusively on other fish. The alligator gar, striped bass, Atlantic croaker, tarpon, and barracuda are their primary predators. Spotted seatrout are sexually mature at one or two years. They spawn from May to July between dusk and dawn within coastal bays in grassy areas, which provide cover from predators. As temperatures fall, the fish move to deeper bay waters and the Gulf of Mexico.

Blue crabs *(Callinectes sapidus*) are a common estuarine crustacean. The shell is approximately 17 cm (7 in) wide by 10 cm (4 in) long. They are dark or brownish green with a large spine on each side. Blue crabs are found along the east coasts of North and South America as well as the Gulf of Mexico. Blue crabs are predators that feed on clams, oysters, mussels, plant and animal matter, as well as freshly dead or freshly caught young crabs. Predators are red drum, Atlantic croaker, herons, sea turtles, and humans. Most importantly, they are a major prey source for the endangered Whooping Crane. Whooping Cranes migrate to the Aransas National Wildlife Refuge Complex during winter months where they feed primarily on blue crab. Low abundance of blue crabs has been reported as a major threat to the survival of Whooping Cranes.

Blue crab

Major commercial fisheries for blue crabs exist along the Atlantic and Gulf Coasts of the U.S., making it the largest crab fishery in the U.S. (NMFS, 2009). U.S. landings in 2009 totaled over 70,000 metric tons for a wholesale value of over $150 million (NMFS, 2011). In Texas, blue crabs support the third largest fishery in terms of landings (Sutton and Wagner, 2007), averaging 1.27 million kg annually from 2005-2009 for a value of ~$2.3 million per year (NMFS, 2011). Many states including Texas (Sutton and Wagner 2007) have seen declines in blue crab populations in recent years. Data from the Texas Parks and Wildlife Department Coastal Fisheries Resource Monitoring Program has shown a general decline in catch rate of blue crabs on all Texas bays, including the San Antonio Bay and Mission/Aransas Bay systems over the past 20 years.

Kemp's Ridley sea turtles *(Lepidochelys kempii*) are an endangered species found in the bays of the Gulf of Mexico and Atlantic Ocean. They are primarily located in the open ocean and gulf waters but the females come to shore to lay their eggs in beach sand. The females come back to the same beach every year to lay their eggs. Kemp's Ridley sea turtles grow to 67 to 81 cm (27-32 in) and weigh on average 34 to 45 kg (75-100 lbs). Their diet consists of crabs, shrimps, snails, clams, sea jellies, sea stars, and fish. Their primary predators are humans due to hunting, boat propellers, nets, and refuse.

Green sea turtle on the beach
Photo credit National Park Service, Padre Island National Seashore

Green sea turtles (*Tortuga blanca*) can be found throughout the world. They are considered endangered in Florida waters and the Pacific coast of Mexico and are threatened in the remainder of their distribution. Adults grow to approximately 1.3 m (51 in) long and weigh 113 to 204 kg (250 to 450 lbs). They are herbivores and feed primarily on seagrasses and marine algae. The females begin nesting onshore from June through October. The primary concern for green sea turtles is consumption of their meat and eggs as a food source for humans.

Dolphins are distributed worldwide in tropical and temperate waters. Bottlenose dolphins *(Tursiops truncatus*) are the most common cetacean of the Gulf of Mexico and along the Texas coast. Bottlenose dolphins may reach 3.4 m (11 ft) and may be seen in large groups or smaller social units of 2 to 15. In Texas waters they eat fishes including, but not limited to, tarpon, sailfish, sharks, trout, pike, rays, mullet, and catfish. They consume 18 to 36 kg of fish each day. Other species of dolphin found in the area include spinner dolphins *(Stenella longirostris*), Atlantic spotted dolphins *(Stenella frontalis*), and Risso's dolphins *(Grampus griseus*).

The Texas shrimp fishery is an extremely large industry, consisting of white, brown, and pink shrimp. White shrimp (*Penaeus setiferus*) is an important fishery dating back to 1709. White shrimp, brown shrimp (*Penaeus aztecus*), and pink shrimp *(Penaeus duorarum*) are distributed along the western Atlantic Ocean, throughout the Gulf of Mexico, and brown and pink shrimp are found around the Yucatan Peninsula. All three species have similar life cycles; they spawn in the Gulf of Mexico and are found within the estuaries and bays as juveniles. The three species of penaeid shrimp together comprise more than 99% of the commercial landings in the Gulf of Mexico shrimp fishery. Annual landings vary considerably from year to year and these fluctuations have been attributed to environmental influences, i.e. severe winter weather (GSA BBEST, 2011).

Aransas Pass bait stand

Nekton Monitoring and Sampling

Juvenile, subadult, and adult stages of finfish and shellfish have been monitored in Aransas Bay since 1977 as part of the Texas Parks and Wildlife Department (TPWD) Resource and Sport Harvest Monitoring Program. Sampling sites were chosen randomly from 1-minute latitude and longitude grid cells consisting of a minimum of 15 m of shoreline. Juvenile nekton are sampled monthly using 18.3 x 1.8 m bag seines (Martinez-Andrade et al., 2009) with 20 bag seines deployed per month. Seines are deployed perpendicular and are carried parallel to the shoreline for 15.2 m. Hydrologic information (e.g., dissolved oxygen, temperature, salinity, and turbidity) are taken in the surface water (0 – 15 cm), 3.1 m from shore (where seining begins). Collected fishes are identified to species level with total length, standard length, and fork length measured.

Subadult and adult finfish are monitored twice per year (fall and spring) using gill nets (Martinez-Andrade et al., 2009). Fall sampling begins the second full week of September and spring sampling starts the second full week of April. Both sampling periods continue for 10 consecutive weeks. Ninety nets are deployed yearly (45 seasonally). Sampling locations are selected by separating each bay into 5-second gridlets which are then randomly selected for sampling, provided the location contains at least 15 m of shoreline. Gill nets are 183 m in length and are set perpendicular to shore at or near sunset and are retrieved the following day within a few hours of sunrise. Hydrologic data (e.g., temperature, salinity, dissolved oxygen, and turbidity) are collected at the gill net point farthest from shore both when the nets are set and again when they are retrieved. Organisms are counted and identified to the lowest taxonomic level possible and length measurements (e.g., standard, fork, and total length) are taken. A maximum of 19 individuals of the same species per gill net are counted and measured. The data are compiled into a database that is used by TPWD for analyzing long-term trends in fisheries. The database is also available for public use.

Juvenile spotted seatrout
Photo credit Cynthia Faulk

Nekton Status and Trends

Juvenile red drum (*Sciaenops ocellatus*) have remained stable since monitoring began in 1977, except from 1983 – 1986, when low numbers were hypothesized to have occurred due to a freeze (1983) and red tide (1986). Subadult and adult catch rates have shown an increasing trend, with catch rates historically higher during the fall than the spring (Lacson and Lee, 1997; Choucair et al., 2006).

Bag seine monitoring has indicated a decline in juvenile spotted seatrout *(Cynoscion nebulosus*) since 1984. Conversely, gill net monitoring has indicated an increase in subadult and adult catch rates between 1984 and 2004 (Choucair et al., 2006). Prior to 1984, there were no significant trends (Lacson and Lee, 1997).

Juvenile, subadult, and adult black drum *(Pogonias cromis*) declined in 1983 due to a freeze (Lacson and Lee, 1997). Since 1983, black drum have increased (Lacson and Lee, 1997; Choucair et al., 2006) due to peak recruitment years (Choucair et al. 2006).

Young-of-the-year Atlantic croaker *(Micropogonias undulatus*) had high numbers in 1984 (Lacson and Lee, 1997) and low numbers from 1986 to 1987 due to red tide (Lacson and Lee, 1997). Since 1989, young Atlantic croaker have increased (Lacson and Lee, 1997; Choucair et al., 2006). There was no reported change in the abundance of adult Atlantic croaker (Lacson and Lee, 1997; Choucair et al., 2006).

Juvenile, subadult, and adult southern flounder *(Paralichthys lethostigma*) populations have declined over the past years (Lacson and Lee, 1997; Choucair et al., 2006). Reduction of southern flounder has been attributed to overfishing, excessive by-catch from shrimp fishery, and reductions in habitat quality (VanderKooy, 2000). In an effort to prevent overfishing, regulations for recreational fishing have been implemented. In March 2009, Texas adjusted regulations from a 10-fish possession law to a 5-fish possession law for every month but November. In November (when adults migrate off shore to spawn) anglers are limited to a 2-fish possession law. Within the Mission-Aransas NERR, a study is currently being conducted to determine the role of abiotic and biotic factors on essential fish habitat for southern flounder. This study will provide more information on the requirements needed for southern flounder to flourish as well as critical information on the location of southern flounder within the reserve (study by B. Froeschke).

Juvenile, subadult, and adult Gulf menhaden *(Brevoortia patronus*) have also declined (Lacson and Lee, 1997; Choucair et al., 2006). There is no recreational fishery for this species but there is a large commercial fishery. Currently the total allowable catch from Texas state waters is 31,500,000 pounds per year.

Red Drum Research

Research within the Mission-Aransas NERR has focused primarily on red drum. Studies completed have investigated larval dispersal (Rooker and Holt, 1997; Brown et al., 2004), growth rates (Rooker and Holt, 1997; Herzka et al., 2001), dietary shifts (Herzka and Holt, 2000; Holt and Holt, 2000), and spawning sites (Holt, 2008). Rooker and Holt (1997) collected 1,891 red drum larvae and young-of-the-year from September through December 1994. Densities ranged from 0.0 to 3.4 individuals m^{-2} and varied significantly between habitats *(Halodule wrightii* and *Thalassia testudinum)* and sites. Peak values of larval red drum occurred in mid to late October and otoliths indicated hatch dates that ranged from early September to late October. Growth rates were highest for mid-season cohorts and were relatively uniform between habitats and sites (Rooker and Holt, 1997). The results indicated that the Aransas Estuary serves as a nursery ground for red drum (Rooker and Holt, 1997). The study also indicated that spatial trends in the density of red drum were not explained by growth differences (Rooker and Holt, 1997).

Newly settled red drum
Photo credit Cynthia Faulk

Spawning sites and spawning behavior of red drum within Aransas Bay have been evaluated using hydrophones (Holt, 2008). Two classes of sound were determined: (1) low frequency rumble, and (2) a clearly distinguishable call made by individuals or small groups of red drum (Holt, 2008). The results of the hydrophone array transects suggest that most spawning occurred among widely dispersed individuals along the nearshore region of the Texas coast and was not concentrated at tidal inlets (Holt, 2008).

CCA lab flounder study at UTMSI FAML
Photo credit Joan Holt

Prey abundance for red drum and spotted seatrout larvae were determined in Aransas Bay in late August to early October, 1990 (Holt and Holt, 2000). Plankton and benthic-sled tows were conducted every 2 hr for 26 hr on 4 different dates from a single site in the Lydia Ann Channel, a tributary channel of the Aransas Pass Inlet near Port Aransas. The catch was split up into three different size categories; small (< 3.0 mm), medium (3.0 to 4.5 mm), and large (> 4.5 mm) (Holt and Holt, 2000). Results of gut content analysis suggested that calanoid copepods were the dominant prey for all size-classes of red drum larvae whereas copepod nauplii, bivalve larvae, and barnacle larvae were important for juvenile red drum. Important prey items for spotted seatrout consisted of calanoid copepods, bivalve larvae, gastropods, dinoflagellates, soft-bodied organisms, barnacles, invertebrate eggs, foraminifera, copepods (Holt and Holt, 2000). The diet of small and medium juvenile (3.0 to 4.5 mm) fish of both species had the highest percentage of similarities (67% overlap) but large fish had distinct diets (44% prey overlap) (Holt and Holt, 2000). Diets for large red drum consisted of calanoid copepods (52%), soft-bodied organisms (30%), dinoflagellates (22%), and copepod nauplii (4%) (Holt and Holt, 2000). Diets for large spotted seatrout consisted of calanoid copepod (64%), gastropod veliger (27%), copepod egg sacs (27%), and bivalve larvae (18%) (Holt and Holt, 2000). Additionally, larvae of both species were successful at feeding under all conditions and there was no significant difference between current speed and gut fullness (Holt and Holt, 2000).

Isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) have been used to estimate size at settlement, time since settlement, growth rates, and dietary shifts for juvenile red drum (Herzka and Holt, 2000; Herzka et al., 2001). Patterns of $\delta^{13}C$ and $\delta^{15}N$ were correlated with growth rates (Herzka and Holt, 2000). There was no effect on $\delta^{13}C$ and $\delta^{15}N$ with 4 d of food deprivation. Additionally, isotopic composition for newly settled red drum exhibit a shift within 1-2 d and stabilizes 10 days following settlement (Herzka and Holt, 2000). An empirical model based on measurements of $\delta^{13}C$ and $\delta^{15}N$ was used to estimate size at settlement and time since settlement for red drum in the Aransas Estuary (Herzka et al., 2001). Most of the changes in $\delta^{13}C$ and $\delta^{15}N$ were attributed to growth rates but it was also suggested that metabolic turnover significantly accelerated the rate of isotopic change. There was a distinct difference between $\delta^{13}C$ of newly settled larvae (-19.3‰) and large individuals that had equilibrated to estuarine foods (-16.5 ‰). However, $\delta^{15}N$ could not be used as a tracer of settlement because of differences in pre- and post- settlement (Herzka et al., 2001). The most abundant larvae settlement size for wild-caught fish was 5 to 6 mm standard length. Using published growth rates it was estimated that settlement events occurred over several consecutive days.

Other Fish Studies

Rooker et al. (1998) conducted biweekly monitoring of sciaenid larvae using epibenthic sleds within seagrass meadows in Aransas Estuary from 1994-1995. A total of 5,443 larvae and young-of-the-year sciaenids were collected. Out of these samples, eight species were identified and 99.9% consisted of the following five species: silver perch *(Bairdiella chrysoura*), spotted seatrout *(Cynoscion nebulosus*), spot *(Leiostomus xanthurus*), Atlantic croaker *(Micropogonias undulatus*), and red drum *(Sciaenops ocellatus*). Silver perch, spotted seatrout, and red drum remained in the seagrass beds throughout their early juvenile stage, whereas Atlantic croaker and spot were only temporary residents (Rooker et al., 1998).

Habitat use patterns of newly settled southern flounder have been evaluated within the Aransas-Copano watershed (Nañez-James and Stunz, 2009). The experimental design consisted of three zones at varying distances from the Aransas Pass inlet and three different habitats (seagrass, marsh and non-vegetation) sampled in January-March 2004 and 2005 (Nañez-James and Stunz, 2009). Abundance of newly settled southern flounder was highest near tidal inlets and vegetated sandy areas. Long-term data obtained from TPWD indicated that it is common for juvenile southern flounder to be found in higher abundance closer to the inlet (Nañez-James and Stunz, 2009).

The effects of boat propeller scarring on the abundance and growth of pinfish *(Lagodon rhomboides*) and white shrimp *(Litopenaeus setiferus*) were examined in seagrass beds of Redfish Bay (Burfeind and Stunz, 2006; Burfeind and Stunz, 2007). Ten sites consisting of four different seagrass scarring intensities (reference = 0%, low ≤ 5%, moderate = 5-15%, and severe > 15%) were sampled from 2003-2004. Eight taxa dominated all of the samples (pinfish, pipefish, code goby, darter goby, killifish, blue crab, Atlantic mud crab, and grass shrimp) over all seasons and all scarring intensities and there was not a significant difference in nekton density (Burfeind and Stunz, 2006). White shrimp had lower growth rates in highly scarred areas, whereas growth rates of pinfish did not appear to be affected by scarring (Burfeind and Stunz, 2007).

Artificial Substrate

Artificial substrate has been used in the marine environment for economic, recreational, and safety purposes (e.g., oil rigs, surf breaks, sea walls). The substrate is constructed out of materials that have the capacity to withstand the erosive and corrosive forces present in a high-energy saline environment. The ecological impact of artificial substrate has long been a topic of discussion because of the fish attracted to these features for food or habitat and the possibility of exploiting these stocks for economic and recreation purposes.

Early studies of artificial substrate observed fish aggregating near sunken ships and other manmade structures that created reefs unintentionally (Bohnsack and Sutherland, 1985; Hixon and Beets, 1989). Along urbanized coasts, seawalls and concrete bulkheads have also been shown to create microhabitats which can enhance biodiversity in areas where natural patterns have been disrupted (Chapman and Blockley, 2009). In the Gulf of Mexico, the Texas Artificial Reef Program was designed to allow decommissioned oil platforms to be left in the Gulf and converted into artificial reefs. This program also developed provisions for the deployment of other types of artificial reefs to stimulate fish populations and improve fishing opportunities (Kaiser, 2006).

Community Composition Associated with Artificial Substrate

The construction and degree of complexity of the artificial structure affect species composition. Complexity, e.g., number of holes, variation in whole size, orientation of surfaces, and number of surfaces, is a factor that controls benthic and fish communities on large artificial reefs (Hixon and Beets, 1989; Glasby and Connell, 2001). The type of material used in construction can also affect the type of species that settle on an artificial structure. Generally, larvae prefer to settle on fibrous or porous surfaces rather than hard, smooth surfaces. Higher species abundances have been found on concrete and plywood when compared to aluminum and fiberglass, i.e., barnacle larvae prefer to settle on rougher materials that are dark in color (Anderson and Underwood, 1994). Shading created by artificial substrate can create microhabitats that affect benthic community structure and fish that use the shadows for predator avoidance (Glasby, 1998).

Differences in community composition on artificial reefs is also dependent on the type of organisms that live in the unconsolidated bottom, which serve as a food source for many pelagic species associated with reefs (Glasby and Connell, 2001). The benthic communities associated with different substrate types vary based on their location in the bay system. Differences arise from the range of sediment properties that occur naturally between bays. Therefore, variations in substrate can result in different composition of predators at artificial reefs located in different parts of the bay.

Types and Distribution

Artificial substrate is associated with coastal erosion protection structures, harbor/marina walls, boat ramps, hunting blinds, petroleum associated structures, and a few unintentionally sunken vessels that are exploited by the local fishing industry. The distribution of substrate types varies based on the intended purpose, i.e., long homogeneous structures along harbor walls and bulkheads or widely dispersed discrete structures such as oil and gas wells in the open bay. The most abundant substrate material in the area is concrete. Concrete is used within marinas, boat ramps, and on support structures for bridges and various platforms within the bay area. Marinas and boat ramps are located mainly on the western shore of Aransas Bay (

Figure 8.4). Wood and metal are also present on structures but in lower abundance.

Fulton marina
Photo credit Zac Hart

Oyster Reefs

Oyster reefs are concentrated in Copano, Aransas, and Mesquite bays (

Figure 8.4). Most oyster reefs within the Mission-Aransas NERR were created naturally; however, there has been an effort to restore oyster reefs using recycled shell material. In 2007, the Nature Conservancy and the Coastal Bend Bays & Estuaries Program worked together to deposit 200 yd^3 of oyster shell into two half-acre areas in Copano Bay. The shell was placed in the system as an effort to create new shelter for oysters to settle and to provide future habitat for other marine animals, such as juvenile sport fish.

Oil and Gas Production

The Western Gulf of Mexico has abundant hydrocarbon deposits, and no part of the region is without oil or gas wells and pipelines, including all wetland and open water habitats (Warner, 1939). Past oil and gas production in the Reserve has depleted deposits; however recent drilling at deeper depths has been successful and it is likely that further exploration and drilling will continue in this area. The benefits of offshore oil and gas platforms as artificial reef habitats has been documented (Montagna et al., 2002), but the effects of inshore oil and gas activities on estuarine habitats are not well known, thus presenting a great opportunity for future NERR research.

The first well drilled in the Reserve was in 1940. To date, there have been 649 oil and gas wells drilled. Of these wells, only 315 have produced oil or gas and there are currently 40 active wells (Figure 8.3). There is an existing network of pipelines that transports oil and natural gas from wells to onshore facilities. Future activity of oil and gas may increase the number of pipelines to the existing network; however, it is common practice that existing pipelines are used whenever possible to prevent disturbance and minimize cost.

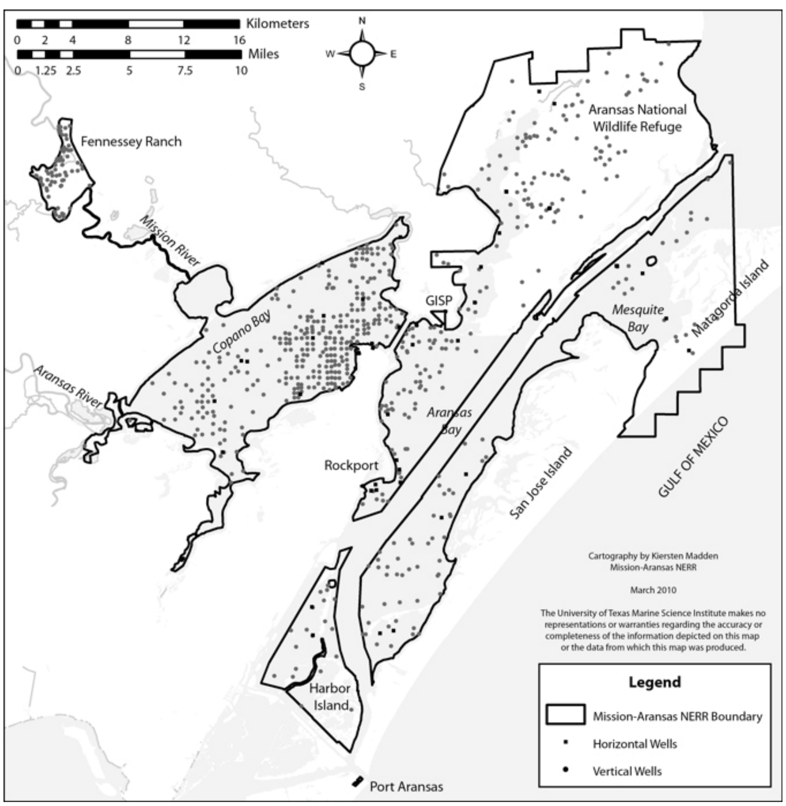


Figure 8.3 Oil and gas well locations in the Mission-Aransas NERR.

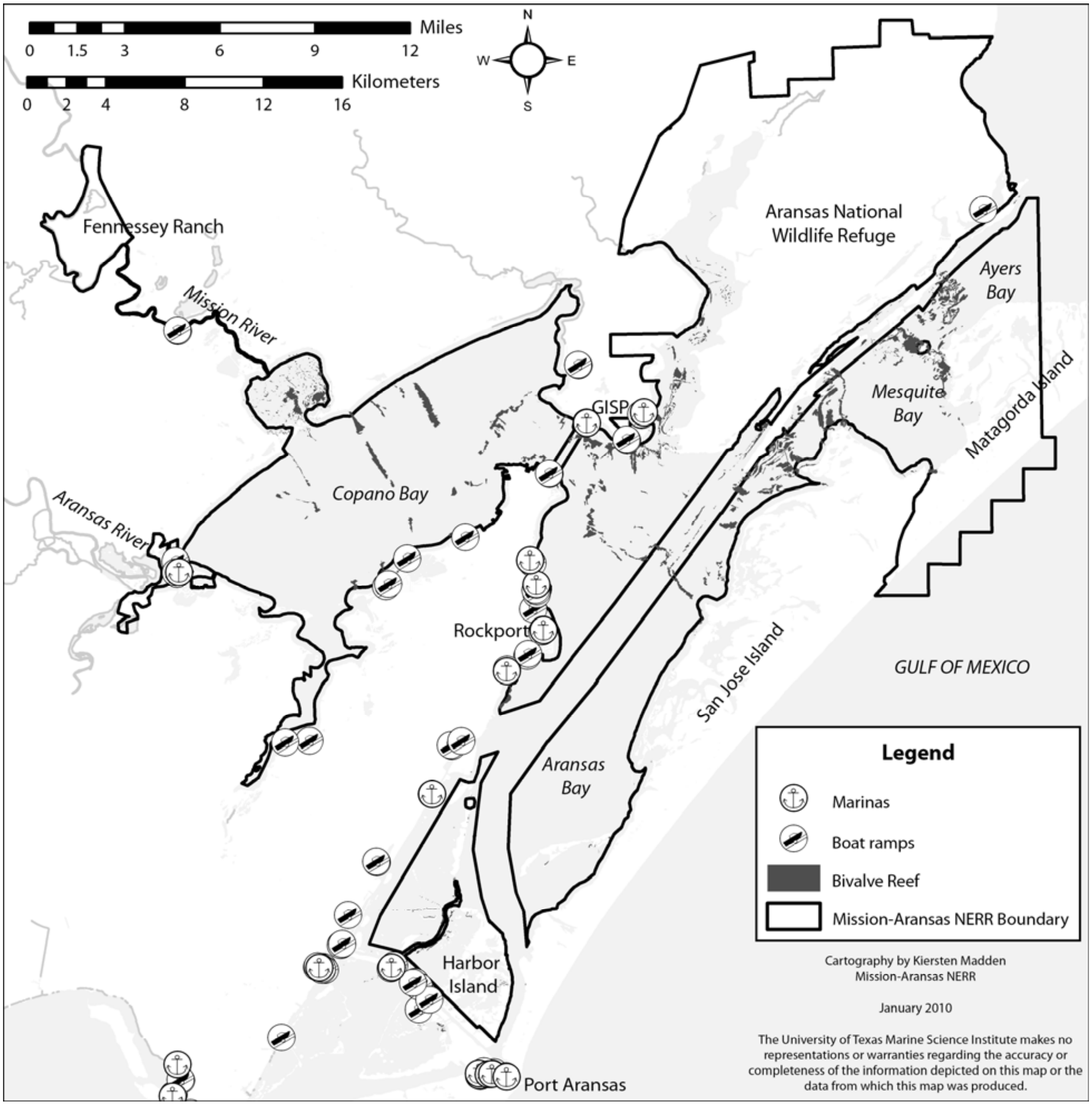


Figure 8.4. Location of oyster reefs and various types of artificial substrate within the Mission-Aransas National Estuarine Research Reserve.

Issues of Concern for Marine Habitats

Dredging

Dredging is an obvious anthropogenic stressor on unconsolidated bottom habitat in areas of the Mission-Aransas NERR. Mining sand for management of recreational beaches and other purposes has several effects on the benthic invertebrate communities, some of which have been shown to persist for more than two years, i.e., defaunation when sand is removed (Brooks et al., 2006). Changes in the water column, e.g., water stratification and hypoxia, can also occur over dredging pits and can have an effect on macrobenthic communities (Palmer et al., 2008). Studies show that within dredging pits, invertebrates have lower biomass and biodiversity compared to areas outside the pit. Furthermore, the species present inside the dredge pit are usually not pioneer fauna, but instead, are the remnants of the preexisting community (Palmer et al., 2008).

Dredging and filling of coastal waterways has also been identified as a major anthropogenic disturbance to seagrass beds in Texas waters (Dunton, 1999). The most obvious and direct effect of dredging is seagrass mortality by the burial of seagrasses by dredge material. Indirect effects of dredging include the disturbance of sediments during the dredging process. Suspension of previously settled sediment decreases light availability to seagrasses and thus decreases photosynthetic activity (Onuf, 1994). Dredging may also result in hypoxic conditions by increasing the biological demand for oxygen due to the decomposition of the exposed organic material (Zieman, 1975, Nessmith, 1980). The alteration of the hydrology may also result in erosion of seagrasses (Dunton, 1999).

Oil and Gas Platforms

The presence of drilling platforms in the Gulf of Mexico impacts unconsolidated bottom fauna. Within the Mission-Aransas NERR, there are numerous small gas pipe platforms that can release small amounts of hydrocarbons into the sediment over long periods of time (Figure 8.3). Noticeable effects have been observed 2-6 km from the platform after several years of exposure (Olsgard and Gray, 1995). The greatest impacts of hydrocarbon discharges are organic enrichment and metal toxicity, which can cause a shift in the dominant species to less sensitive polychaetes and oligochaetes (Peterson et al., 1996). The meio- and macrobenthic organisms which show the highest levels of sensitivity to metal toxicity are echinoderms, amphipods, and copepods. Polychaetes, oligochaetes, and nematodes have a higher resistance to the toxins, and can therefore take advantage of the organic enrichment that occurs simultaneously with the metal toxicity associated with hydrocarbon leakage around oil and gas platforms (Peterson et al., 1996).

Changes in Community Structure

Macrobenthic infauna are frequently used as model systems for studying community structure and biodiversity, as well as how changes in the environment affect ecosystems (i.e., indicator species). Benthic communities exhibit a range of responses (both physiological and behavioral) to environmental changes and stressors because of their variable life histories and different generation times among species (Peterson et al., 1996; Ritter and Montagna, 1999). Shifts in the dominant organism are the most common response to disturbance, and this can lead to a complete change in the overall community structure and nutrient flow through the system. Dominant species can change due to changes in the frequency and type of predation events, i.e., fish predators taking advantage of exposed infauna during a hypoxic event that they normally wouldn't have access to (Ritter and Montagna, 1999).

Changes in the physical properties of water also impact macrobenthic infauna communities. Extreme cases of hypersalinity, hypoxia, and hypercapnia can occur independently or simultaneously. The effects of just one of these events are enough to completely alter composition of the resident community, but when they occur in conjunction, the effects can be devastating.

Salinity

Around the Gulf of Mexico, hypersalinity is a common issue in many estuaries. Hypersalinity is caused by a combination of low freshwater input and high evaporation in shallow areas. Invertebrates often have weak osmoregulatory abilities and do not have the physiological ability to survive outside a narrow range of salinities. Most benthic invertebrates cannot tolerate hypersaline or brackish conditions and only certain euryhaline species are able to exist in these conditions (Guerin and Stickle, 1992). Variations around moderate salinity levels have even been shown to affect the distribution of larval benthic macroinvertebrates (Holland et al., 1987).

Conversely, large freshwater influxes can change the community composition based on the tolerance of preexisting species. In South Texas, precipitation levels can vary within and among years, causing pulses of freshwater during different seasons (Dunton et al., 2001). Bursts of lower salinity may cause the resident benthic communities to change drastically based on physiological limitations and the ability of some benthic species to take advantage of increased availability of nutrients from runoff. For example, in the nearby Nueces Estuary the dominant species, *Littoridina sphinctostoma* and *Mulinia lateralis,* take advantage of the nutrients that come with high freshwater pulses (Montagna and Kalke, 1992).

Copano Bay

Hypoxia

Hypoxic conditions (when oxygen water saturation levels drop below 2 mg L^{-1}) often occur during hypersaline conditions when warm, shallow waters of the Texas coast become stratified (Pihl et al., 1992; Ritter and Montagna, 1999; Morehead and Montagna, 2003). Hypoxia can elicit behavioral responses from macrobenthic organisms, such as rising to the surface or coming completely out of the substrate (Ritter and Montagna, 1999). An annual cycle of hypoxia has been observed within the Mission-Aransas NERR, and the dominant organism in local hypoxic areas is the opportunistic oligochaete, *Streblospio benedicti* (Ritter and Montagna, 1999). These opportunistic species are often shallow dwelling and typically have lower biomass and productivity levels (Dauer et al., 1992).

Climate Change Effects on Bottom Habitats

Three factors of climate change may impact unconsolidated bottom habitats: elevated temperature, elevated concentrations of carbon dioxide (CO_2), and changes in precipitation. Studies have shown that although calcium carbonate minerals will increase with rising temperature they will decrease with lower pH, caused by increased CO_2 levels in water (Fabry et al., 2008). Calcium carbonate saturation is essential for organisms that incorporate these minerals into their external skeletons, such as corals, echinoderms, and hard-shelled mollusks. Elevated CO_2 has a greater effect on the larval stage of these organisms, i.e., when secreting a skeleton there may be malformations (Kurihara and Shirayama, 2004). Organisms that live within unconsolidated sediments are commonly soft bodied or chitin based. At lower pH intracellular functions such as oxygen transport and protein synthesis within these organisms are altered (Henry and Wheatly, 1992; Langenbuch and Portner, 2002). Higher temperatures also increase the duration and occurrence of hypoxic events, especially in environments like the Mission-Aransas NERR where seasonal hypoxia already occurs (Ritter and Montagna, 1999; Findlay et al., 2008). Climate change is also expected to cause changes in the amount of precipitation in Texas. The combination of temperature and precipitation changes will likely lead to subsequent changes in salinity and/or stratification which could affect the abundance, distribution, and diversity of the benthic invertebrates in the Mission-Aransas Estuary.

Plankton and Climate Change

Abiotic factors, e.g. temperature, salinity, and dissolved oxygen, can be detrimental to fragile coastal ecosystems. No studies have been published about climate change affecting species in the Mission-Aransas NERR; however, literature examining global climate change in other areas and its general effects on estuaries worldwide is advancing. Oviatt (2004) determined average annual increases of 1°C substantially alter coastal marine community dynamics by changing distribution and abundance of individual species. Other studies have shown how climate change may disturb ecological interactions between trophic levels and how zooplankton may be key indicators of these changes (Mackas et al., 1998; Beaugrand et al., 2002; Bonnet and Frid, 2004; Beaugrand, 2005; Molinero et al., 2005). Precipitation changes as a result of global climate change could change zooplankton distribution patterns in the Mission-Aransas NERR. Furthermore, nutrient inputs could change as a result of changes in runoff, which could impact the productivity of phytoplankton in the system (Justić et al., 1997).

Impacts on Oyster Reefs

In 2009, the Nature Conservancy released the first-ever comprehensive global report on the state of shellfish at the International Marine Conservation Congress in Washington, DC. Eighty-five percent of oyster reefs have been lost worldwide and they are the most severely impacted marine habitat on the planet. The condition of oyster reefs along most North American coasts is listed as poor or functionally extinct. Most reefs along the Gulf of Mexico were listed as fair, indicating hope for restoration (Beck et al., 2009). The driving forces behind the decline of oyster reefs include destructive fishing practices, coastal over-development, and associated effects of upstream activities such as altered river flows, dams, poorly managed agriculture, and poor water quality.

Freshwater inflow is a critical factor influencing oyster abundance. Lengthy periods of low flow allow salinities to rise and oyster mortality from predation and parasitism to increase. Floods ensure long-term survival of oyster populations by reducing oyster predators and parasites such as the oyster drill (*Stramonita haemastoma*) and dermo (*Perkinsus marinus*). However, floods of sufficient magnitude may reduce oyster harvest by both killing oysters in parts of the bay and increasing the amount of time the bay is closed to harvest. Flooded areas are soon colonized by new oysters, beginning a new cycle of growth with reduced numbers of predators and parasites. Long-term data from Galveston Bay, Texas, shows that the abundance of market-sized eastern oysters frequently increases one to two years after periods of increased freshwater inflow and decreased salinity (Buzan et al., 2009).

Nutrient Loading

Nutrient loading is quickly being recognized as a major problem to coastal and estuarine ecosystems as populations near the Texas coast continue to rise (Hinga et al., 1991). Increased nutrient loading from agricultural fertilizers and human waste increases turbidity and leads to reduced light availability for seagrasses, which contributes to lower productivity and growth (Bulthius, 1983; Dennison and Alberte, 1985; Cambridge et al., 1986; Czerny and Dunton, 1995; Campbell et al., 2003). Shrimp and fish mariculture have also been recognized as contributors to nutrient loading in some areas along the southern Texas coast (Whitledge, 1995). Growth of epiphytic and drift macroalgal communities stimulated by increased nutrients have been found to reduce or completely eliminate seagrasses (Valiela et al., 1992). Leaf surfaces of the plant are shaded, which causes decreased photosynthetic activity (Dennison et al., 1993), which in turn creates toxic sulfurous conditions further hindering seagrass communities (Sorensen et al., 1979).

Prop Scarring

Damage from boating activities, termed mechanical damage, has been linked to the destruction of large areas of seagrass beds. Mechanical damage can include destruction from anchors and mooring chains, boat propeller blades, and hull groundings (Tomasko and Lapointe, 1991; Quammen and Onuf, 1993; Onuf, 1994; Short et al., 1995; Dunton and Schonberg, 2002; Uhrin and Holmquist, 2003). Damage from boat motors can vary in extent from cutting off the upper canopy of the seagrasses to complete removal of the root and rhizome system (Kenworthy et al., 2002). Anchor and mooring activities frequently occur in areas known for recreational boating and often lead to a reduction of seagrass densities and habitat fragmentation (Hastings et al., 1995; Creed and Filho, 1999; Milazzo et al., 2004). Propeller scarring results in the upheaval of the root and rhizome system and the removal of fine sediment which often leaves large unvegetated regions (Kenworthy et al., 2002). During vessel grounding, the hull of vessels disturbs seagrasses on a large scale by creating cavities or blowouts of unvegetated substrate that can be meters deep and hundreds to thousands of meters in area (Whitfield et al., 2002; Kirsch et al., 2005). Once these types of disturbances occur, they are further exacerbated by natural occurrences such as wind, waves, and currents creating larger, more damaging effects (Zieman, 1976; Durako et al., 1992; Rodriguez et al., 1994; Hastings et al., 1995; Dawes et al., 1997; Prager and Halley, 1999; Kenworthy et al., 2002; Whitfield et al., 2002).

Redfish Bay, a shallow water bay within the Mission-Aransas NERR, contains the highest density of seagrasses within the Reserve. It is the most susceptible area of the reserve to mechanical damage from boats, particularly prop scarring. Due to the susceptibility to prop scarring, Texas Parks and Wildlife has deemed Redfish Bay a state scientific area and placed educational signage warning boaters about prop scarring.

TPWD has also enacted laws protecting the seagrass within Redfish Bay.

Brown Tide

The small, unicellular phytoplankton species, *Aureoumbra lagunensis* (also known as "Texas brown tide"), experienced a widespread and uninterrupted bloom in the Laguna Madre and surrounding bays from December 1989 through October 1997 (Table 8.3) (DeYoe et al., 1997; Buskey et al., 2001). During this bloom other phytoplankton species were extremely limited, particularly diatoms (Buskey and Stockwell, 1993). The brown tide alga may be toxic to certain species of zooplankton (i.e., *Strombidinopsis* sp., *Acartia tonsa* nauplii) at cell concentrations similar to those of the natural population and is a poor food source for additional species of zooplankton to which it is not toxic (*Noctiluca scintillans* and *Brachionus plicatilis*) (Buskey and Hyatt, 1995). *Acartia tonsa* exhibited decreases in adult body size and egg release rates when fed *A. lagunensis*, illustrating that the brown tide is probably an inadequate food source (Buskey and Stockwell, 1993; Buskey and Hyatt, 1995). The abundance of some mesozooplankton communities was depressed during the onset of the brown tide another indication of an inadequate food source (Buskey and Stockwell, 1993). Adult fish, shellfish, and other invertebrates were unaffected by the extended brown tide conditions (Buskey and Hyatt, 1995, Buskey et al., 1996).

Example of prop scarring in Red Fish Bay (May 14, 2011)
Photo credit Ken Dunton/Kim Jackson

Table 8.3. List of publications on brown tide in the Mission-Aransas NERR.

Subject of Study	Publications
Formation/Persistence of Bloom	Buskey and Stockwell, 1993 Stockwell et al., 1993 Whitledge, 1993 DeYoe and Suttle, 1994 Buskey et al., 1996 Buskey et al., 1997 Buskey et al., 1998 Lopez-Barreiro, 1998 Buskey et al., 1999 Liu and Buskey, 2000a,b Buskey et al., 2001
Effects on Ecosystem (inhabitants)	Buskey and Stockwell, 1993 Buskey and Hyatt, 1995 Buskey et al., 1996 Rhudy et al., 1999

Red Tide

Harmful red tides have occurred in the Mission-Aransas NERR due to blooms of toxic dinoflagellates, *Karenia brevis* or *Alexandrium monilata* (Table 8.4) (Buskey et al., 1996). Both species carry neurotoxins that cause widespread mortality in fish and invertebrates (Sievers, 1969; Buskey et al., 1996). In 1935, a major red tide event occurred that stretched south of Padre Island for 84 mi. Reports have documented only four *K. brevis* blooms and approximately six *A. monilata* blooms along the entire Texas coast since 1935 (Snider, 1987; Buskey et al., 1996).

Karenia brevis is a harmful alga that can negatively impact a large variety of species. *Acartia tonsa* experiences decreased grazing and fecundity when fed *K. brevis*. Experimental findings suggest that *K. brevis* is probably not toxic to copepods, but may lack the necessary nutrition required to produce normal numbers of offspring or may be unfamiliar causing copepods to ingest fewer cells (Breier and Buskey, 2007).

Neurotoxic Shellfish Poisoning, or NSP, is caused when humans ingest shellfish contaminated by red tide. Symptoms may include dizziness, nausea, tingling sensations felt in the extremities, dilated pupils, and hot-cold reversals that last for a few days. The most common effect of red tide is due to the aerosols released that cause coughing, sneezing, headaches, cold and flu congestion, and watery eyes (Buskey et al., 1996).

Table 8.4. List of publications on red tide in the Mission-Aransas NERR.

Subject of Study		Publications
History of Bloom Events		Trebatoski, 1988
		Magaña et al., 2003
		Collier, 1958
		Aldrich and Wilson, 1960
		Steidinger and Ingle, 1972
		Steidinger, 1975
		Roberts, 1979
		Seliger et al., 1979
		Baden and Thomas, 1989
		Pierce et al., 1990
Formation/Persistence of Blooms		Roszell et al., 1990
		Buskey et al., 1996
		Smayda, 1997
		Tester and Steidinger, 1997
		Arzul et al., 1999
		Sugg and VanDolah, 1999
		Magaña et al., 2003
		Kubanek et al., 2005
		Magaña and Villareal, 2006
		Mitra and Flynn, 2006
Effects on Ecosystem (inhabitants)	FISH	Lund, 1936
		Sievers, 1969
		Trebatoski, 1988
		Steidinger and Vargo, 1988
		Buskey et al., 1996
	COPEPODS	Ives, 1985
		Huntley et al., 1986
		Uye, 1986
		Ives, 1987
		Turner and Roff, 1993
		Jeong, 1994
		Turriff et al., 1995
		Teegarden, 1999
		Teegarden et al., 2001
		Breier and Buskey, 2007
	SHELLFISH	Sievers, 1969
		Wardle et al., 1975
		Baden, 1989
		Buskey et al., 1996
		Buskey et al., 1996
	HUMANS	Hemmert, 1975
		Buskey et al., 1996
		Magaña et al., 2003
	WHOOPING CRANES	Buskey et al., 1996

Invasive Species

Invasive species have the ability to outcompete local flora and fauna and dominate an ecosystem due to the lack of natural predators. Invasive species are often unintentionally introduced into the marine environment as a result of shipping, aquarium trade, live seafood restaurants, and the live bait industry (Ruiz et al., 2000; Ray, 2005; Weigle et al., 2005).

One of the most well-known invasive zooplankton species in the Gulf of Mexico is the Australian spotted jellyfish, *Phyllorhiza punctata* (Ray, 2005). It is believed that the polyp form was transported via ship ballast water from the Pacific Ocean to the Atlantic Basin over 45 years ago. Ocean circulation (specifically the Gulf Stream) then transported members of this species to the Gulf of Mexico. In 2000, a large bloom of *P. punctata* occurred in the northern Gulf of Mexico along the coasts of Louisiana, Alabama, and Mississippi (Graham et al., 2003).

While the invasion of any non-native species can harm an ecosystem by disturbing food webs, the harmful effects of exotic medusae are especially high. Medusae typically feed on eggs and larvae of commercially important fish and invertebrates at very high rates, which can be detrimental to the local economy (Cowan and Houde, 1992; Purcell and Arai, 2001). Evidence suggests that blooms of *P. punctata* affect zooplankton through direct predation on copepods, but also indirectly through disturbances to the chemical and/or physical characteristics of the water. Jellyfish shed large amounts of mucus which increases viscosity, and may cause toxins to be more abundant as mucus-bound nematocysts are released (Shanks and Graham, 1988; Graham et al., 2003). In addition, jellyfish blooms are known to hinder the shrimping industry by clogging shrimp nets, damaging boat intakes and fishing equipment, and effectively closing areas to fishing efforts (Ray, 2005).

Human Impacts on Nekton Habitat

Nekton are a crucial component of aquatic ecosystems and depend on the quantity and quality of habitat. Human impacts have depleted more than 90% of estuarine species, degraded water quality, accelerated species invasions, and destroyed more than 65% of seagrass and wetland habitat (Lotze et al., 2006). Estuarine fish communities represent a key trophic link between primary production and higher trophic levels, therefore community structure may be a useful indicator of ecosystem condition and processes (Deegan et al., 1997). It is crucial to acquire more information on the interactions between the health of the environment and fishes to help protect these species.

Use of Artificial Substrate

The use of artificial substrate can create a disruption in the natural abundances of species present in the area, or it can allow for the invasion of new species to the point of excluding all native species. However, these effects may have a positive, regenerative effect in areas that have suffered from overexploitation and can often increase habitat heterogeneity in an otherwise barren landscape resulting in enhanced diversity and production (Anderson and Underwood, 1994).

The construction of hard structures results in a local loss of soft-bottom habitats and associated assemblages of plants and animals. Along the coast of the north Adriatic Sea construction of new structures has affected over 60% of the native intertidal and shallow subtidal habitats. Changes in species composition can have important consequences for the functioning of the ecosystem through modifying productivity and nutrient cycling (Airoldi et al., 2005). These changes can ultimately lead to effects on natural resources and ecological services.

Future Plans for Marine Habitats

Oyster Reef Management

Texas Department of State Health Services (TDSHS) regulates oyster harvest to protect human health from pathogens and the bioaccumulation of algal neurotoxins. The current system for closing oyster harvest areas has been in place since the early 1980s. Harvest areas are frequently closed following rainfall events because of elevated bacterial levels in the water (Buzan et al., 2009).

Proper management is necessary to maintain healthy estuaries, oyster communities, and the coastal communities that rely on them. Understanding the unique relationship between freshwater inflow and ecosystem health for each estuary is crucial. The growing ability to capture and manage water in watersheds may potentially reduce the frequency and magnitude of freshwater inflow events. The reduced flow would eventually cause salinities to increase to unhealthy levels for oyster populations (Buzan et. al., 2009).

Plankton Monitoring

Scientists are currently working on several research initiatives that will deepen our understanding of plankton within the Mission-Aransas NERR. A new program has been established that monitors the local zooplankton assemblages. Samples are collected monthly at System-Wide Monitoring Program (SWMP) stations to quantify and identify organisms, as well as to estimate biomass. The composition of microplankton is analyzed using an imaging flow cytometer (FlowCAM). FlowCAM is a continuous cytometer designed to characterize particles in the microplankton size range (10-200 μm). Samples are pumped through a thin glass chamber, which is illuminated by a laser as a video camera captures images of each object. Samples are currently analyzed for the presence of *K. brevis* and other harmful algal species, but potential new ventures include analyzing samples for fecal coliforms in the Reserve. These projects are aimed at expanding the body of knowledge that currently exists about plankton and the conditions in which they live so that we may gain insight into the uniqueness of the Mission-Aransas NERR.

Monitoring Seagrass on the Texas Coast

The Mission-Aransas NERR has started a long-term monitoring program for submerged aquatic vegetation and emergent marshes. This sustainable monitoring program is a representative of the Texas coastal zone and will assess the changes that occur due to anthropogenic and natural perturbations. The NERRS biomonitoring protocol has a hierarchical design in which “tier 1” includes mapping and monitoring the overall distribution of emergent and submerged vegetation within reserve boundaries and “tier 2” includes long-term monitoring of the vegetative characteristics of estuarine submersed and emergent vegetation communities.

The Mission-Aransas NERR has completed tier 1 and has high resolution spatial data on the overall distribution of emergent and submerged vegetation. This detailed information was gathered through a variety of sources. The NOAA Coastal Services Center, in conjunction with Texas Parks and Wildlife Department and Texas A&M University-Center for Coastal Studies, completed a benthic habitat mapping project to support the Texas Seagrass Monitoring Program. The benthic habitat maps created from this project will aid the seagrass monitoring program by helping to locate, monitor, and protect seagrass beds. Starting in the summer of 2011, “tier 2”, or the transect portion of the program will begin. Dr. Ken Dunton and his lab at the University of Texas Marine Science Institute have chosen two sites, Northern Redfish Bay and Mud Island, and will be installing the transects and making the first measurements.

The Mission Aransas NERR is also working with the NOAA Environmental Cooperative Science Center and other collaborating universities on a hyperspectral imagery project aimed at classifying vegetated habitats and water characteristics. One of the principal thematic research objectives of this project is to determine the spatial distribution of SAV beds and emergent marsh.

Larvae Recruitment

Many of the commercially and recreationally important fish and invertebrate species within the Mission-Aransas NERR have estuarine dependent life cycles. Adults release eggs into the Gulf of Mexico and larvae must recruit back to the estuaries to develop and grow. Examples of important species with this life history pattern include white and brown shrimp, blue crabs, red drum, and others. A nearly continuous barrier island system isolates the coastal bays and estuaries of south Texas from the Gulf of Mexico, with only a limited number of exchange passes between the two. The most direct pass between the Gulf of Mexico and the Mission-Aransas Reserve, the Cedar Bayou pass, has been closed by natural siltation processes for several years. Larvae recruiting from the Gulf of Mexico must enter the Reserve through the Aransas ship channel, on the southernmost boundary, or through Pass Cavallo, to the north of the next adjacent bay system, San Antonio Bay. Most of the studies of recruitment of invertebrate larvae to estuaries have taken place in east coast estuaries, with higher inputs of fresh water and larger tidal ranges than south Texas estuaries. It is thought that vertical stratification of the water column in these systems allows for selective tidal stream transport, where larvae vertically migrate in and out of layers with flows moving in or out of the estuary. South Texas estuaries are typically shallow and well mixed, with smaller freshwater inflows and microtidal exchanges with the Gulf. There is no paradigm to explain how larvae successfully recruit past the high energy passes to the interior of the estuaries. In the future, we would like to study the detailed hydrodynamics of water movement from the passes to the head of the estuaries, to understand how water moves within the estuary and how these currents are used to transport plankton, including larval fishes and invertebrates. More specifically, we would especially like to conduct an intensive study of circulation and larval recruitment within Mesquite Bay. Plans are underway to reopen Cedar Bayou in the near future, so it is an important opportunity to measure the change in circulation and larval recruitment after it is reopened.

Essential Fish Habitat

Due to the ecological and economic significance of nekton, it is urgent that the relationship between nekton and estuaries be analyzed (e.g., morphological, physiological, behavioral adaptations, life history, and estuarine ecology). Additionally, a shift towards an ecosystem-based management approach (i.e., recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues or species in isolation) is imperative for the future status of nekton. This type of approach will depend on efficiently and effectively assessing relationships between organisms and their habitat, and thus identifying Essential Fish Habitat (EFH). Essential Fish Habitat is defined by the Magnuson-Fishery Conservation Act of 1996 as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” It is assumed that there is a positive relationship between the quantity of EFH and fish abundance or productivity (Hayes et al. 1996). Declining populations of important fish stocks such as southern flounder in the Mission-Aransas NERR accentuates the importance of defining critical habitats as well as the processes that contribute to habitat quality.

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Chapter 9 ESTUARINE HABITATS

Anne Evans, Kiersten Madden, Samantha Myers

Estuarine Wetlands

Estuarine wetlands typically have one or more of the following attributes: (1) at least periodically, the land predominantly supports hydrophytes (i.e., plants adapted to living in aquatic environments), (2) the substrate must primarily consist of undrained hydric soils, and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al., 1979). Wetlands develop due to the presence of several factors, including a gradual slope, low relief, periodic flooding from tidal and/or freshwater inflow, and protection from high energy processes. The physical features of individual wetlands are determined by interactions between sediment and shoreline structure, climate, and vegetative structure (Tunnell et al., 1996).

Wetlands provide many important ecological functions. They dissipate the effects of erosion, moderate effects of floods, improve water quality, support extensive food chains, recharge and discharge groundwater, and retain, transform, and export a variety of important nutrients (e.g., nitrogen, carbon, phosphorus). In addition to their ecological functions, they also serve as important recreational, economic, and historic sites. In Texas, this includes benefits such as commercial and recreational fishing, hunting, birdwatching, dissipation of storm surges, minimization of coastal water pollution, and contribution to a growing tourist industry.

Estuarine wetlands represent dynamic and biologically important habitats where freshwater mixes with saltwater. They are often subdivided into two groups based on salinity regime, i.e., saltwater and brackish wetlands. Saltwater wetlands (often referred to as salt marsh) receive daily tidal inundation and typically maintain salinities between 20 and 35 psu. Brackish wetlands (often referred to as brackish marsh) receive daily tidal inundation, as well as storm surge, but typically maintain lower salinities between 5 and 19 psu (Tunnell et al., 1996).

Estuarine wetland at the Aransas National Wildlife Refuge

Estuarine wetlands can also be categorized into groups based on vegetation type and height. Common categories include: forested (perennial woody vegetation >5 m), scrub/shrub (perennial woody vegetation <5 m), and emergent (annual or perennial herbaceous plants) (NOAA, 1995). Vegetation within estuarine wetlands occurs in zones and primarily consists of salt-tolerant grasses; however, algae, phytoplankton, and woody perennials are also present and account for some of the primary productivity. Differing plant tolerances to changing water and soil salinity concentrations leads to zonation in these areas.

Adaptations to survive in higher salt concentrations allow certain species to settle in a habitat that would otherwise be bare. Community composition can be explained by an inverse relationship between competition and abiotic stress, i.e., subordinate plants dominate stressful habitats while superior plants dominate habitats where abiotic stress is mild (Pennings and Callaway, 1992; Greiner La Peyre et al., 2001; Forbes and Dunton, 2006).

Stability of wetlands is dependent on a balance between sediment accretion (causes the marsh to expand outward and upward in the intertidal zone) and coastal subsidence. Lower and upper boundaries of wetlands are usually determined by the tidal range, in particular the mechanical effects of waves, sediment availability, and erosional forces. The structure and function of wetlands is shaped by physical and chemical variables, such as frequency and duration of tidal flooding, soil salinity, and nutrient limitation, particularly nitrogen (Forbes and Dunton, 2006).

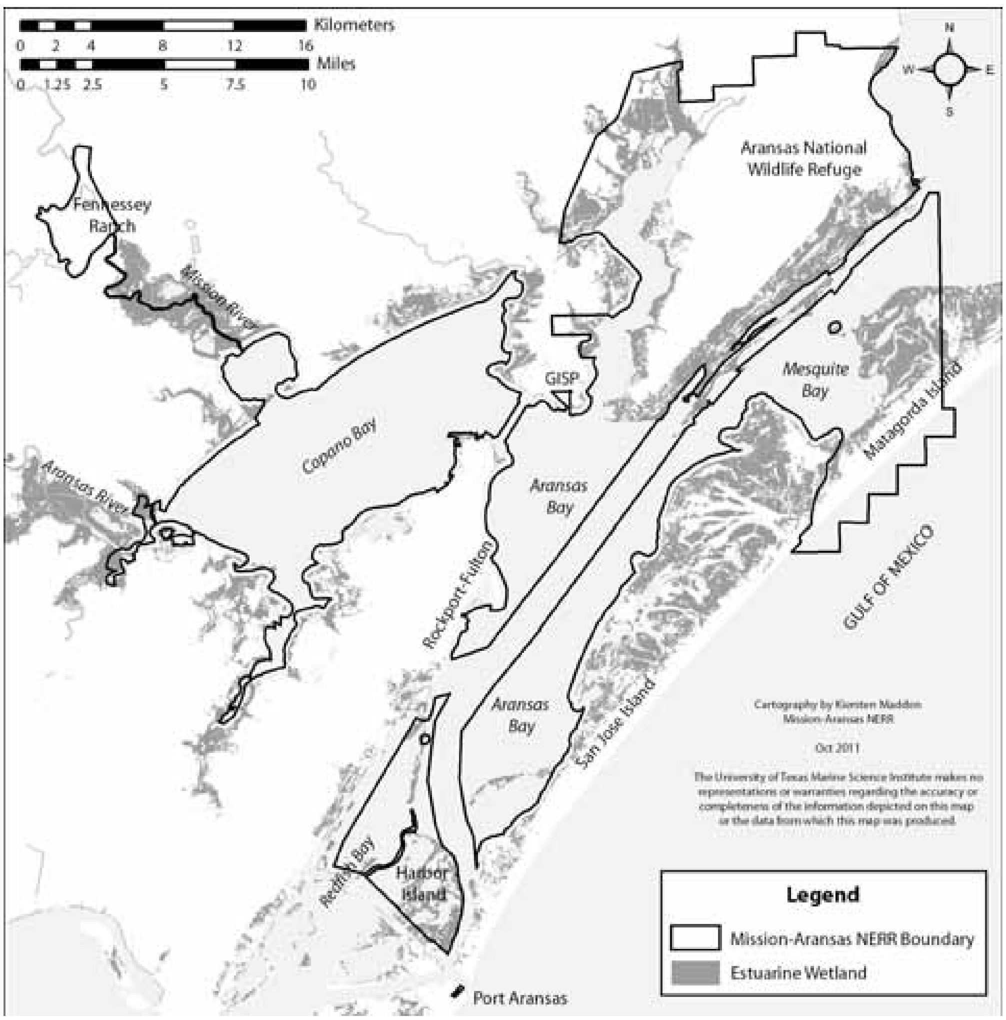

Figure 9.1. Map of estuarine wetlands in the Mission-Aransas NERR.

Estuarine Wetlands within the Mission-Aransas NERR

In general, estuarine wetlands along the Gulf of Mexico coast are found near river mouths, bays, lagoons, and on protected coastlines (Mitsch and Gosselink, 1986). Based on 2005 imagery from the NOAA Coastal-Change Analysis Program (C-CAP), the predominate type of estuarine wetland found in the Mission-Aransas NERR is estuarine emergent (32 mi^2). A very small amount of estuarine scrub/shrub (0.01 mi^2) is also located in the Reserve boundary, but no estuarine forested wetlands are present (Figure 9.1). A similar pattern is observed in the Reserve watershed, i.e., 93 mi^2 of estuarine emergent wetlands and very small amounts of estuarine forested and scrub/shrub wetlands (0.003 and 0.03 mi^2 respectively). Saltwater wetland habitats are found along much of the coastline directly adjacent to the Reserve boundary, and within the Reserve boundary high concentrations are found on the shoreline of the Aransas National Wildlife Refuge (both St. Charles Bay and Aransas Bay) and Harbor Island. Brackish wetlands are primarily found in tidal creeks and tributaries of Port Bay (small bay off of southside of Copano Bay) and adjacent to the Mission River.

Estuarine emergent wetlands, i.e., salt marshes, are highly productive habitats that support diverse plant and animal communities. At low elevations, salt marsh habitats within the Reserve are dominated by monotypic stands of smooth cordgrass (*Spartina alterniflora*) (Brown et al., 1976). Turtleweed (*Batis maritima*), dwarf glasswort (*Salicornia bigelovii*), perennial glasswort (*Salicornia perennis*), and Gulf cordgrass (*Spartina spartinae*) are also found at low elevations. Saltgrass (*Distichlis spicata*) is typically found at slightly higher elevations (Brown et al., 1976). The higher elevations along the bay side of San Jose and Matagorda Islands, as well as the Aransas Bay and St. Charles Bay shorelines of the Aransas National Wildlife Refuge, also have *Batis maritima*, *Borrichia* sp., *Monanthochloe* sp., *Suaeda* sp., and *Distichlis spicata* (Brown et al., 1976).

Common invertebrate species found in the saltwater wetlands of the Mission-Aransas Estuary include polychaetes *Mediomastus californiensis* and *Streblospio benedicti*. *Paraprionospio pinnata* is the dominant polychaete of Aransas Bay and *Glycinde solitaria* and *Paraprionospio pinnata* are dominate in Copano Bay (Calnan et al., 1983). Dominant mollusks are *Macoma mitchelli* and *Mulinia lateralis*, and the dominant crustacean is *Lepidactylus* sp.

Cordgrass

Consumers within these habitats include the ribbed mussel (*Geukensia demissa*), salt marsh periwinkle (*Littorina irrotata*), fiddler crabs (*Uca pugnax*), Virginia Rail (*Rallus limicola)*, King Rail (*Rallus elegans),* and the Clapper Rail (*Rallus longirostris*) (Stewart, 1951; Kerwin, 1972; Tunnel et al., 1996). Other common species in marsh ecosystems include killifish (*Fundulus* sp.), mullet (*Mugil cephalus)*, silversides (*Menidia menidia)*, American Egrets (*Ardea alba)*, Snowy Egrets (*Egretta thula)*, and Great Blue Heron (*Ardea herodias)*.

Current Status and Trends

The distribution and abundance of estuarine wetlands are affected by agricultural/urban development (Shine and Klemm, 1999) and climate change (Nicholls et al., 2007). However, the distribution of estuarine wetlands is increasing (Table 9.1). In 2004 the Corpus Christi Bay National Estuary Program (CCBNEP) contained 10,821 ha of estuarine wetlands, with large distributions along the Copano Bay mainland, Lamar peninsula, Mission River, Aransas River, Live Oak Peninsula, Redfish Bay, Nueces River Delta, Corpus Christi Bay, Oso Bay, and Encinal peninsula. Estuarine wetlands experienced an increase in total area from the 1950s to 1979, followed by a decrease in area from 1979 to 2004. Overall there was a total net gain of 1,956 ha in the CCBNEP study area from the 1950s (Tremblay et al., 2008). The increase in wetland area has occurred where tidal flats or palustrine wetlands have been converted as the saltwater wedge migrates up rivers due to fluid extraction and subsequent rates of local sea level rise (Tremblay et al., 2008).

Table 9.1. Total area of estuarine wetlands in the 1950s, 1979, and 2004 in the CCBNEP area (Tremblay et al., 2008).

Year	Value in ha (acres in parenthesis)
1950s	8,856 (21,874)
1979	11,749 (29,020)
2004	10,821 (26,728)

Tidal Flats

Tidal flats are sand or mud areas found in estuaries that typically lack any recognizable plant life. They are neither terrestrial nor aquatic and are harsh, unpredictable environments (Dilworth and Withers, 2010). Tidal flats are periodically exposed to arid climates, flooded by marine waters, and receive sediments surficially and interstitially from land and sea (Morton and Holmes, 2009). Along the Texas coast, tidal flats are typically called 'wind-tidal flats' because wind, rather than tides, causes them to be flooded or exposed (Dilworth and Withers, 2010).

Wind-tidal flats are a dominant coastal habitat type in South Texas (Onuf, 2006). Tidal flats are common in the central and southern coast of Texas because of regional climate and hydrology, i.e., little freshwater inflow from rivers and low precipitation (Onuf, 2006; Dilworth and Withers, 2010). From Corpus Christi Bay south through the Laguna Madre to the mouth of the Rio Grande, there are only 8 km^2 of coastal marsh as compared to 960 km^2 of wind-tidal flats (Onuf, 2006). Wind-tidal flats are also abundant in the Mission-Aransas NERR and can be found along the bay side of San Jose and Matagorda Islands, Cedar Bayou, deltas of the Mission and Aransas rivers, and scattered along the bay margins of Copano and Redfish bays (Figure 9.2) (Brown et al., 1976; Morton and McGowen, 1980; Withers and Tunnell, 1998).

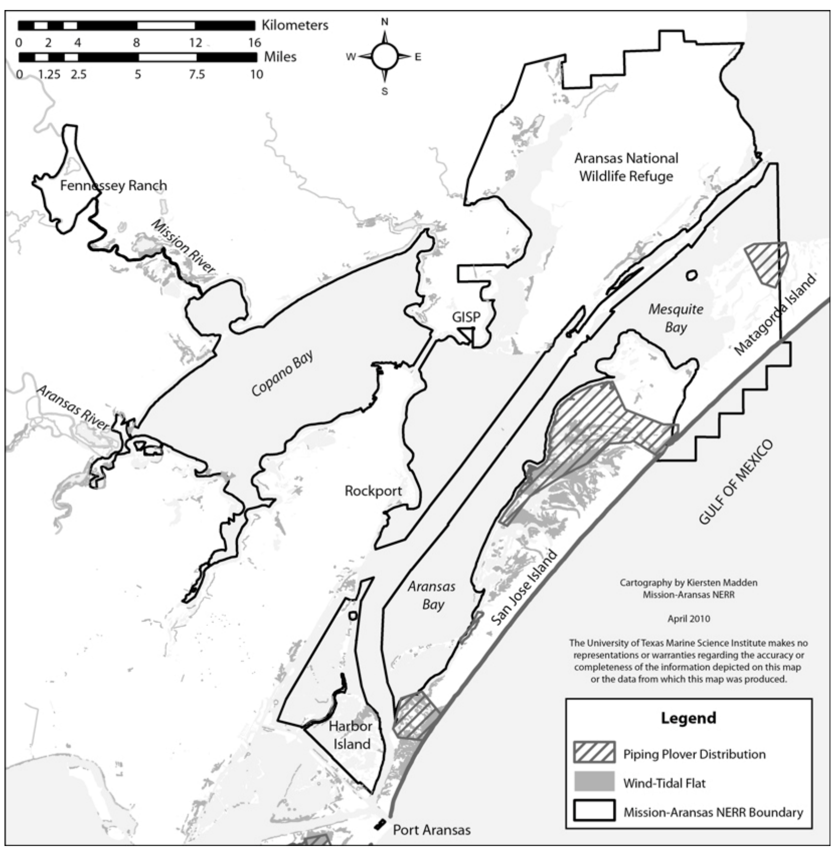

Figure 9.2. Location of tidal flats in the Mission-Aransas NERR.

The flats may appear to be barren wastelands but they are highly productive areas that support large numbers of animals, particularly shorebirds. In fact, these are the most significant feeding areas for aquatic bird life on the Gulf Coast (Withers and Tunnell, 1998) and they function as essential habitat for a suite of rare and endangered bird species, e.g., Piping Plover (Figure 9.2). Large areas of the flats are typically covered in dense mats of blue green algae that support a large array of consumers. This filamentous alga provides food for dense invertebrate assemblages that support Piping Plovers. In turn, the plover populations support Peregrine Falcons on their only staging area in the US during spring migration (Withers and Tunnell, 1998; Zonick, 2000). When flooded, fish exploit the flats, and the tidal flats then become principal foraging areas of threatened Reddish Egrets (Onuf, 2006).

Mangroves surrounding Lighthouse Lakes Trails

Mangroves

Mangroves are littoral plants that occur on tropical and subtropical coasts worldwide. These woody plants grow at the interface between land and sea, where they endure high salinity, extreme tides, strong winds, high temperatures, and muddy, anaerobic soils (Montagna et al., 2009). In the Gulf of Mexico, there are four species of mangrove that exist: red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), black mangrove (*Avicennia germinans*), and button mangrove (*Conocarpus erectus*) (Sherrod and McMillan, 1981).

Black Mangroves

The black mangrove is the primary mangrove found in Texas and is recognized as the only native woody vegetation of the marsh-barrier island ecosystem. This species grows to approximately six feet high and is sparsely distributed in the southern coast along tidal channels in bays and estuaries (Pulich and Scalan, 1987; Judd, 2002; Tunnell, 2002; Withers, 2002). The historical northern limit of black mangroves is Galveston Island, but this species has recently started to appear on the Louisiana coast (Sherrod and McMillian, 1981; Twilley et al., 2001). On the Texas coast, there are four primary populations: Port Isabel, Harbor Island (Aransas Pass), Port O'Connor (Cavallo Pass), and Galveston Island (Sherrod and McMillian, 1981). Port Isabel and Harbor Island contain the densest and largest populations (Britton and Morton, 1989). Approximately 600 ha of dense stands of black mangrove are found on Harbor Island, a flood-tidal delta located near the mouth of Aransas Pass inlet, which separates Mustang Island and San Jose Island (Britton and Morton, 1989). In the Mission-Aransas NERR, black mangroves are found in scattered stands on bay margins and islands in Redfish and Aransas Bay, as well as along the bay-side of Matagorda and San Jose Islands (Sherrod, 1980) (Figure 9.3).

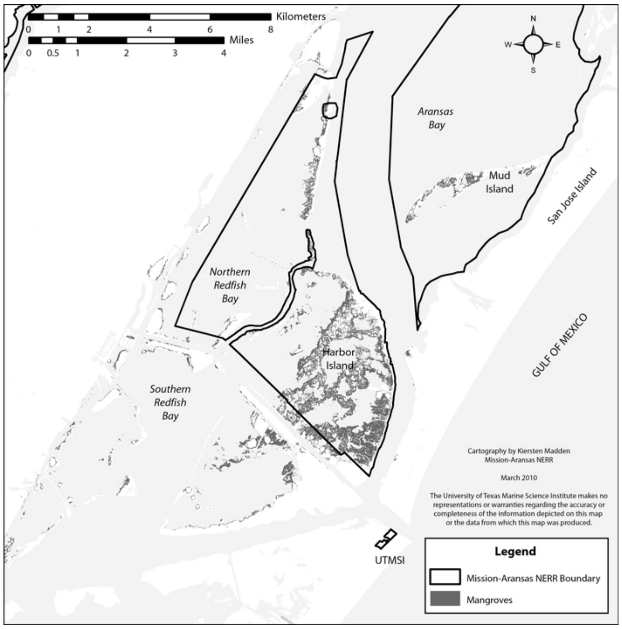

Figure 9.3. Location of mangroves in the Mission-Aransas NERR.

Mangrove habitats are among the world's richest repositories of biological diversity and primary productivity (Tomlinson, 1986). Mangrove habitats help maintain coastal diversity, serve as coastal protection, provide refuge for many species, and serve as a nursery ground for commercially important fisheries. Black mangrove stands are usually interspersed with marsh plants such as *Spartina* spp., *Salicornia* spp., and *Batis* spp. (Sherrod and McMillian, 1981).

Temperature and salinity are the main factors limiting the distribution and survival of black mangroves. Black mangrove, *Avicennia germinans*, is the only mangrove species known to be tolerant Texas winters (Sherrod and McMillan, 1981; Tunnell, 2002). Different climatic periods have had a large influence on mangrove populations during the past two centuries. For example, historical evidence suggests that black mangrove populations expand and contract due to fluctuations in freezing temperatures (Sherrod and McMillian, 1981, 1985; Everitt and Judd, 1989; Everitt et al., 1996). A large freeze in 1989 decreased abundance of black mangrove stands in South Texas, but since then populations have recovered (Everitt et al., 1996).

Anthropogenic disturbances, such as modifications of habitat due to dredging and channel construction have also been responsible for a decrease the abundance of mangrove populations (Montagna et al., 2009).

Red Mangroves

Red mangroves (*Rhizophora mangle*) have been observed in low numbers on the southern coast of Texas since 1983 (Tunnell, 2002). Extreme storm events, such as hurricanes, transport propagules to the Texas coast and facilitate the invasion of red mangroves. Since the 2005 hurricane season, individual red mangrove plants have been observed in bays between South Padre Island and Matagorda Island (Montagna et al., 2007). The northernmost occurrence of red mangrove is in St. Johns County, Florida on the Atlantic Ocean side suggesting that all mangrove species are expanding their ranges northward (Zomlefer et al., 2006).

Black-necked Stilt

Mangroves represent a well-defined niche in coastal zonation and therefore are likely to be early indicators of the effects of global climate change as warmer temperatures facilitate the expansion of this tropical species northward. The Texas coast is also expected to experience greater impact from climate change due to its low lying coastal plains and high rates of subsidence (Anderson, 2007). Climate change effects such as an increase in sea level, a change in the number of days below freezing temperatures, and a change in the frequency and intensity of hurricane strikes will greatly impact the mangrove populations in Texas (Field, 1995; Sherrod and McMillian, 1985; Montagna et al., 2007; Ning et al., 2003; Tremblay et al., 2008).

Local Mangrove Studies

Long-term abundance of black mangroves at Harbor Island has been determined with aerial photographs ranging from 1930 to 2002 (Montagna et al., 2009). Color aerial photography has also been used in previous studies to determine mangrove abundance along the entire Texas coast (Sherrod and McMillian, 1981; Everitt and Judd, 1989). For analysis, the spectrum was adjusted to show vegetation as red and all other forms of land cover were adjusted to different colors (Montagna et al., 2009). With color infrared photos, mangroves have a visible red reflectance of 0.63-0.69 µm. An overall increase in total cover area of 131% over the 74 yr study period was found although the increase was not linear. From 1979 to 1995, there was a 47% decrease in mangrove cover in Harbor Island, most likely due to freeze events in four different years (1982, 1983, 1985, 1989) (Montagna et al., 2009). There have been very few freeze events since 1989, and mangrove abundance is believed to be increasing. In 2008, the Mission-Aransas NERR acquired hyperspectral imagery that will be used to determine abundance of black mangroves in the region of Harbor Island.

Issues of Concern for Estuarine Habitats

Plant Dieback

Plant dieback is a phenomenon that causes wetland plants to undergo rapid senescence and subsequent mortality (Alber et al., 2008). Causes of dieback can be both abiotic, e.g., temperature change, and biotic, e.g., fungus pathogens. In the past decade an increasing number of dieback events have occurred. It is possible for areas that have experienced dieback to recover; however, in areas of subsidence, dieback of plants is more likely to persist as the ground can be considered more of a mudflat than marsh habitat (Alber et al., 2008).

Urban Development

Urban development contributes to losses of wetlands. Some of the major losses of wetlands in the Mission-Aransas NERR have been attributed to development of communities such as Key Allegro on Live Oak Peninsula in Rockport (Figure 9.4). In some instances, marsh was converted to open water when quarries were excavated for sand resources (Tremblay et al., 2008).

Figure 9.4 . Urban development 1952-2005 contributed to the loss of seagrass, intertidal flats, and estuarine and palustrine marshes on Key Allegro, Live Oak Peninsula (Tremblay et al., 2008).

Extreme Weather and Climate Change

Hurricanes have a great potential for affecting wetlands along the Gulf Coast by influencing the dominant and keystone species. During a storm, the level of plant devastation depends on several factors, e.g., angle of approach, wind speed, proximity, storm surge, and rainfall amount (Cahoon, 2006). Salinity, flooding, and high wind can cause shifts in the regeneration patterns of coastal wetlands, affecting species composition. Salt marshes often have reduced seed germination and seedling recruitment of vegetation in high water and salinity (Michener et al., 1997; Middleton, 2009). Uncertainty exists about the effect of climate change on hurricane frequency, but hurricane intensity is projected to increase as sea temperatures warm (IPCC, 2007).

Climate change is expected to cause an increase in summer temperatures of 3 to 7ºC in the Gulf of Mexico region and a decrease in precipitation rates in South Texas coastal regions (Twilley et al., 2001). Distributions of mangroves are strongly affected by temperature (Duke, 1992). An increase in global temperatures is expected to cause a northern shift in the freeze line and cause changes in abundance of mangroves, i.e., additional red mangroves will invade and black mangroves will move farther north (Ellison, 1994; Field, 1995; Twilley et al., 2001; Ellison and Farnsworth, 2001).

Human Impacts on Tidal Flats

There are several types of anthropogenic impacts that affect the structure and function of wind-tidal flats. The use of off-road vehicles creates scars and damages benthic infaunal and epifaunal organisms. This also alters organic matter recycling, resulting in lower nutrient levels in sediments. Off-road vehicle tracks can even alter natural hydrology by channeling water, which can lead to increased runoff and erosion (Martine et al., 2008). Use of off-road vehicles in wind-tidal flats is all too common at the Padre Island National Seashore, located just south of the Mission-Aransas NERR. Photography and image analysis techniques have been used to examine the persistence and recovery of the flats from vehicle tracks. Results showed that these areas have sustained considerable damage, and vehicle tracks can persist for at least 38 years (Martine et al., 2008).

Interrupting the natural flow of water between bays and wind-tidal flats can also cause serious effects, such as succession to other types of habitat. Disposal of dredged material along navigation channels can alter the flow of water and change habitat characteristics by providing a good environment for succulent vascular plants to colonize (Onuf, 2006). In 1952, a causeway was built across tidal flats to facilitate patrol of Horse Island off of Padre Island National Seashore. This completely cut off water exchange from Laguna Madre. In the 1990s, resource managers noticed that the succulent halophyte, *Salicornia bigelovii*, covered large areas to the north of the causeway while the flats to the south remained bare. As scientists learned of the importance of tidal flats to the endangered Piping Plover, the causeway was removed to allow the flats to return to their presumed historic condition (Onuf, 2006).

Sea Level Rise

The Texas coast is also expected to experience greater impact from climate change due to its low lying coastal plains and high rates of subsidence (Anderson, 2007). Climate change effects such as an increase in sea level, a change in the number of days below freezing temperatures, and a change in the frequency and intensity of hurricane strikes will greatly impact the mangrove populations in Texas (Field, 1995; Sherrod and McMillian, 1985; Montagna et al., 2007; Ning et al., 2003; Tremblay et al., 2008). Mangroves represent a well-defined niche in coastal zonation and therefore are likely to be early indicators of the effects of global climate change as warmer temperatures facilitate the expansion of this tropical species northward.

On the low-lying Texas coast, local sea level rise is a major concern for tidal flats. If the flats become more frequently flooded, rates of blue green algae aggregation will slow, reducing primary production. Eventually the flats will become permanently submerged thereby diminishing this valuable habitat (Morton and Holmes, 2009). A major decrease has been observed in tidal flat size within the CCBNEP area, which includes the Mission-Aransas Estuary (net decrease of 6,551 ha between 1950’s and 2004). This decrease is attributed, at least partially, to sea level rise and the transition of tidal flats to estuarine wetlands and seagrass beds (Tremblay et al., 2008).

Future Plans for Estuarine Habitats

Predicting Effects of Climate Change

Estuarine wetlands are highly affected by climate and weather patterns. For example, extreme variability in climate produces disturbances (extreme temperatures, drought, etc.) that are followed by germination of ruderal species in bare areas (Forbes and Dunton, 2006). Understanding how estuarine wetlands will respond to climate change is important for understanding how estuarine function may change over time. This information will allow resource managers to more accurately predict and take action to reduce the effects of potential changes due to climate. Predictions for climate change in the south Texas coastal region include higher summer temperatures and more frequent and intense rainfall events with longer dry periods in between, which could create disturbances among established wetland species (Twilley et al., 2001).

Abundance estimates of mangroves could be a useful indicator of climate change. Currently, mangrove fossil records are used as indicators of warm temperatures and their presence is used to determine historical climate change (Somboon, 1990; Khandelwal and Gupta, 1993; Mildenhall, 1994; Plaziat, 1995; Ellison, 1996; Lezine, 1996; Zhang et al., 1997). On the Texas coast, black mangroves occur in monospecific stands (makes determining abundance easier and more accurate), have intertidal zonation, and are at their northern limit for temperature. These factors will allow the long term abundance of black mangroves to serve as a good indicator for local climate change.

Surface Elevation Tables

To understand the impacts of land use change and sea level rise on the sustainability of coastal ecosystems, accurate and precise measurements of land and water elevations are needed. Currently the Mission-Aransas NERR is installing and monitoring Surface Elevation Tables (SET), which are a method for gathering high precision measurements of land elevation (Figure 9.5). Results will be used to compare elevation change between different habitats of the Reserve. The SETs are located in salt marsh habitat at the Aransas National Wildlife Refuge, Goose Island State Park, and Mud Island. They are also located in a mud tidal flat at Mud Island and a mangrove habitat at Harbor Island. The SET infrastructure helps support specific habitat change research and other opportunities within the Reserve.

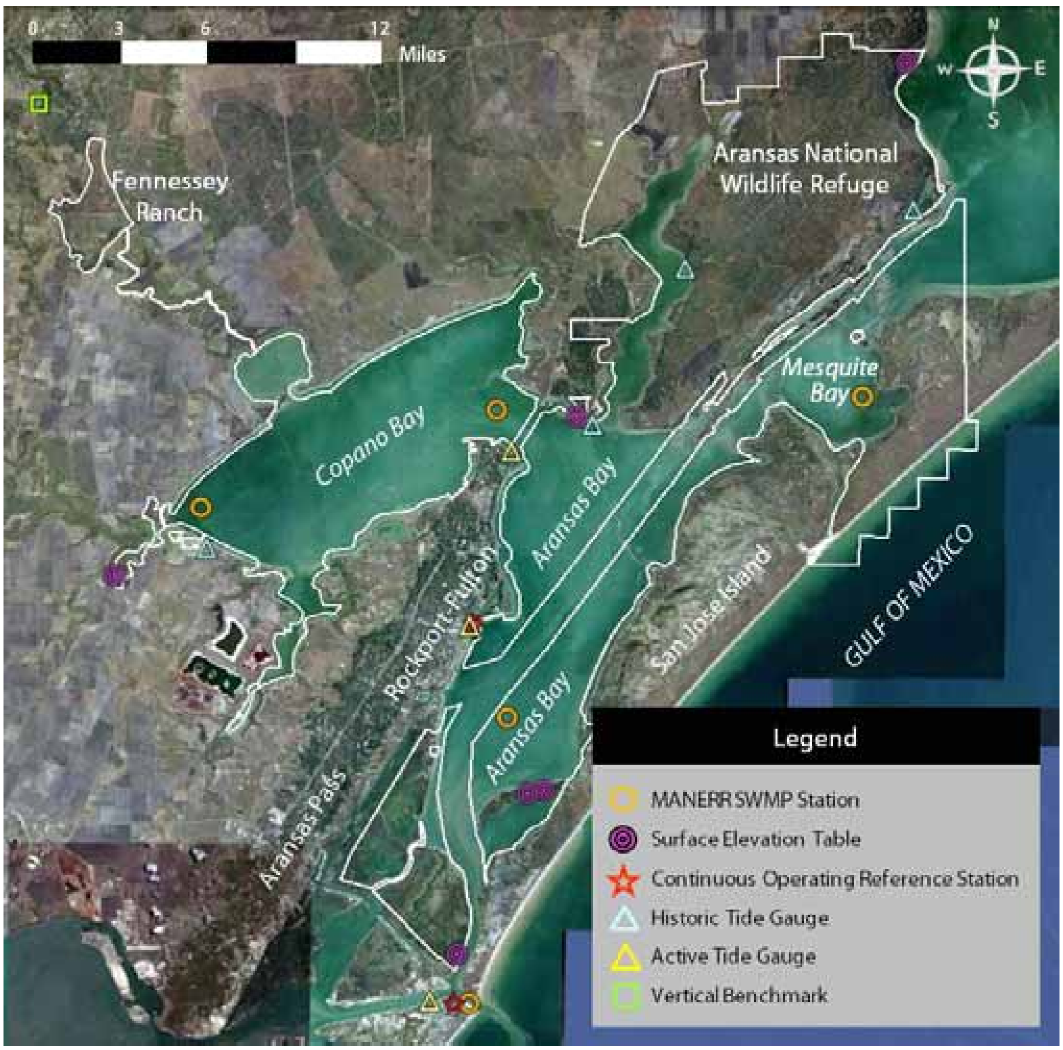

Figure 9.5 . Vertical control map showing surface elevation tables, continuous operating reference stations, Mission-Aransas NERR SWMP stations, and active/historic tide gauges within the Reserve.

Restoring Tidal Flats

Currently, natural resource managers are considering various measures to restore water exchange and reduce the encroachment of vascular plants to many wind-tidal flats. Once deemed barren wastelands, tidal flats have proven to serve the area as an important food source and habitat for many species. Research, conservation, and protection of these areas are crucial, but very little is currently being done.

Mangrove Management

In 2001, the United States had 197,648 ha of mangroves and reported the second largest rate of loss (Montagna et al., 2009). Mangroves are under high protection in areas such as the Everglades National Park in Florida. The main drivers of change in mangrove communities are competition for land for aquaculture, agriculture, infrastructure, and tourism. At a regional scale, hurricanes also represent a serious threat to mangroves and can cause significant loss in the US (FAO, 2007).

In 2005, 15.2 million ha of mangroves were estimated to exist worldwide, down from 18.8 million ha in 1980 (Montagna et al., 2009). Conservation of mangrove habitats is crucial for maintaining biodiversity and supporting human societies that depend on the ecosystem services that mangrove habitats provide.

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Chapter 10 FRESHWATER HABITATS

Anne Evans

Palustrine Wetlands

Palustrine, or freshwater, wetlands represent transitional areas between terrestrial and freshwater aquatic environments (Batzer and Sharitz, 2006). They are non-tidal aquatic habitats with salinity between 0 - 0.5 practical salinity units (psu) and are dominated by trees, shrubs, and persistent hydrophytic vegetation (Tunnell et al., 1996; Smith and Dilworth, 1999). Freshwater marshes may receive tidal inundation, but only during extreme storm surges, i.e., hurricanes that increase water levels but typically do not alter salinity levels (Tunnell et al., 1996). Palustrine wetlands are often categorized into three groups: forested, scrub/shrub, and emergent. Palustrine forested wetlands are comprised of perennial woody plants > 5 m tall, scrub/shrub wetlands consist of perennial woody plants < 5 m tall, and emergent wetlands are dominated by annual or perennial herbaceous plants (NOAA, 2009).

Palustrine Wetlands in the Mission-Aransas NERR

Based on 2005 data from the NOAA Coastal-Change Analysis Program (C-CAP), the dominant type of freshwater wetland found in the Mission-Aransas NERR is palustrine emergent (27 mi^2). Palustrine forested and scrub/shrub wetlands are also present, but in smaller numbers (2 and 17 mi^2, respectively). Palustrine wetlands can be found along the Copano Bay mainland, Fennessey Ranch (i.e., Fennessey Flats and McGuill Lake), along the Aransas and Mission rivers, and throughout the Aransas National Wildlife Refuge (Figure 10.1). A similar pattern is observed within the watershed of the Reserve with palustrine emergent wetlands (77 mi^2) occupying a greater area than palustrine forested and scrub/shrub wetlands combined (64 mi^2 total).

McGuill Lake, located at Fennessey Ranch, is one of several palustrine emergent wetlands located within the Mission-Aransas NERR

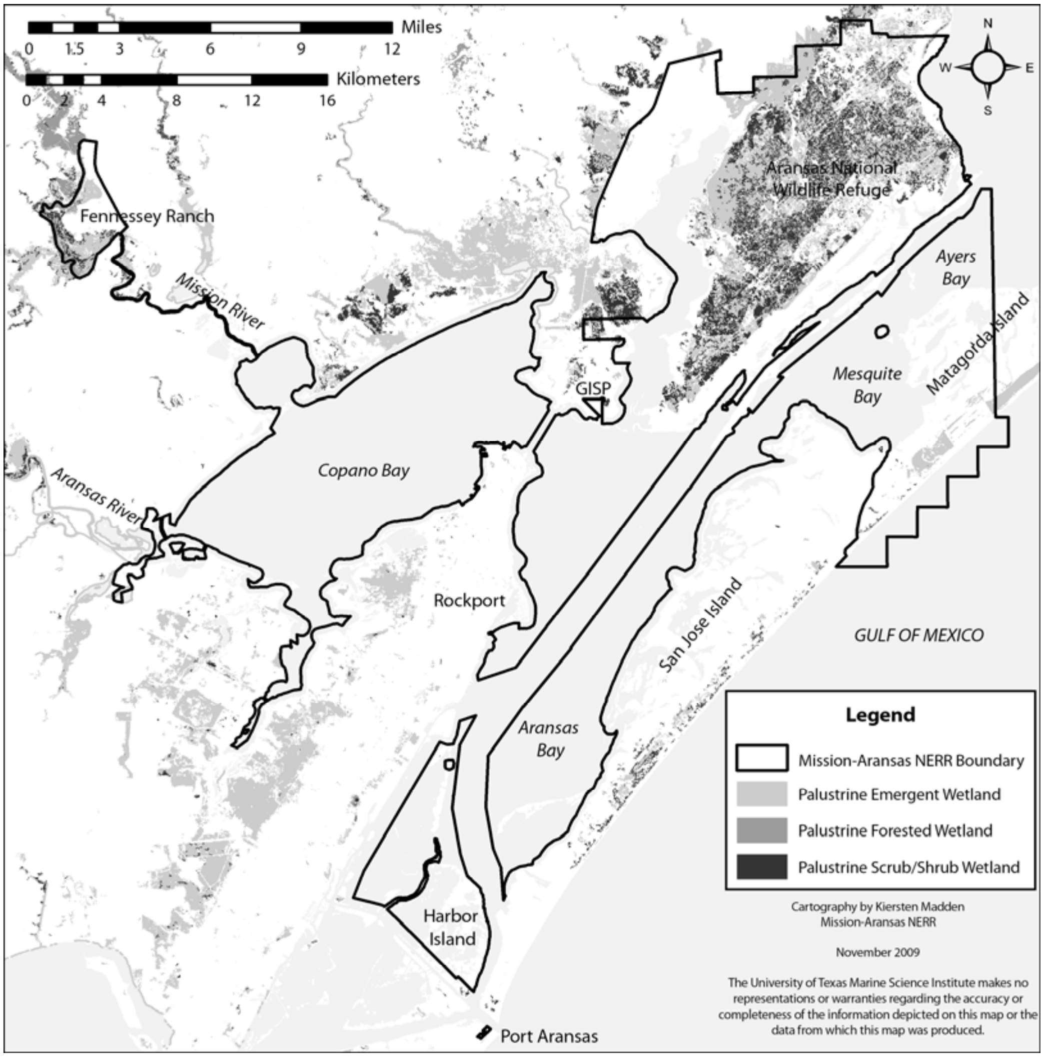

Figure 10.1. Distribution of palustrine wetlands in the Mission-Aransas NERR and surrounding area.

Vegetation within palustrine wetlands represents a wide variety of emergent species, the type of which depends on a number of environmental factors, including, but not limited to, latitude, nutrient availability, and soil salts (Mitsch and Gosselink, 1986). The primary species of emergent vegetation in the Coastal Bend Bays & Estuaries Program (CBBEP), an area that includes the Mission-Aransas NERR, are: seashore paspalum (*Paspalum* spp.), southern cattail (*Typha domingensis*), three-square bulrush (*Schoenoplectus pungens*), spikerush (*Eleocharis* spp.), coastal water-hyssop (*Bacopa monnieri*), salt marsh camphor-weed (*Pluchea purpurascens*), Gulf cordgrass (*Spartina spartinae*), sea ox-eye (*Borrichia frutescens*), saltmeadow cordgrass (*Spartina patens*), flatsedge (*Cyperus* spp.), coastal-plain penny-wort (*Hydrocotyle bonariensis*), frog fruit (*Phyla* sp.), spiny aster (*Aster spinosus*), panic (*Panicum* spp.), smartweed (*Polygonum* sp.), bushy bluestem (*Andropogon glomeratus*), and Bermuda grass (*Cynodon dactylon*) (Tremblay et al., 2008). Other common primary producers include sedges (*Carex* spp.) and slough grass (*Beckmannia syzigachne*) (Brown et al., 1976).

Most scrub/shrub and forested palustrine wetlands occur along rivers, bayous, and creeks, on the margins of reservoirs, and in small depressions. Within the CBBEP boundary, palustrine scrub/shrub wetlands are typically characterized by black willow (*Salix nigra*), retama (*Parkinsonia aculeata*), huisache (*Acacia smalli*), rattlebush (*Sesbania drummondii*), and salt cedar (*Tamarix* spp.). Palustrine forested wetlands include a large mixture of tree species, such as black willow, retama, huisache, ash (*Fraxinus* spp.), cedar elm (*Ulmus crassifolia*), hackberry (*Celtis* spp.), and anacua (*Ehretia anacua*) (Tremblay et al., 2008).

Palustrine forested wetlands are located near the Mission River

Invertebrate communities within freshwater wetlands change with the changing water level. During periodic droughts isopods dominate, but as water level rises and subsequent emergent vegetation surfaces, amphipods, chironomid larvae, and other insect larvae dominate. As water levels continue to rise, emergent vegetation gives way to floating aquatic plants and copepods dominate the marsh system (Craft, 2001).

Major consumers found in freshwater marshes typically include the Virginia Rail (*Rallus limicola*) and King Rail (*Rallus elegans*) (Tunnell et al., 1996), while alligator gar (*Atractosteus spatula*) and common carp (*Cyprinus carpio*) are among the dominant freshwater fishes (TPWD, 2009).

Current Status and Trends

Freshwater wetlands face severe threats from agriculture, urban development, and climate change (Shine and Klemm, 1999; Kundzewicz et al., 2007). In 2004, the CBBEP contained approximately 5,630 ha of palustrine wetlands, with a large distribution along the Copano Bay mainland and the Mission River Valley. This represents a 20% decrease in the extent of freshwater marshes within this area since the 1950s, and the margin of decline appears to have grown in more recent years (Table 10.1). The Lamar Peninsula, located directly adjacent to the Mission-Aransas NERR, has seen some of the most significant losses (77% decline) of palustrine wetlands. Construction of drainage ditches, in addition to a long term drought, may account for this loss, as well as an increase in sea level and expansion of saltwater marshes around Copano Bay (Tremblay et al*.,* 2008).

Table 10.1. Total area of palustrine marshes in the 1950s, 1979, and 2004 in the CBBEP area (Tremblay et al., 2008).

Year	Value in ha (acres in parenthesis)
1950s	8,489 (20,968)
1979	7,120 (17,586)
2004	5,630 (13,906)

Riparian Woodlands

Riparian woodlands are found along rivers and streams. These woodlands are communities of tall trees with a dense to sparse understory. Periodic flooding is a common event in riparian woodlands, and the many species which inhabit these areas are adapted to these episodic events. Most of the dominant woody plant species have deep root systems that anchor the plant in place, and some have flexible stems that allow the plant to bend with current and recover after the flooding recedes.

The understory is usually composed of dwarf palmetto (*Sabal minor*) and common trees are anaqua (*Ehretia anacua*), cedar elm (*Ulmus crassifolia*), live oak (*Quercus virginiana*), pecan (*Carya illinoinensis*), sugar hackberry (*Celtis laevigata*), net-leaf hackberry (*Celtis reticulata*), Mexican ash (*Fraxinus berlandieriana*), and black willow (*Salix nigra*).

The animals found in riparian forests are adapted to periodic flooding. Many species only tolerate it, while others require it to complete their lifestyles. Examples of animals found in the riparian woodlands include the Green Kingfisher (*Chloroceryle americana*), Ringed Kingfisher (*Megaceryle torquata*), Mexican treefrog (*Smilisca baudinii*), Rio Grande chirping frog (*Eleutherodactylus cystignathoides*), Rio Grande river cooter (*Pseudemys gorzugi*), ocelot (*Leopardus pardalis*), and jaguarundi *(Puma yagouaroundi)* (Jacob et al., 2003).

Riparian zones are important in ecology, environmental management, and engineering because of their role in soil conservation, biodiversity, and influence on aquatic ecosystems. This zone serves as a natural biofilter by protecting aquatic environments from excessive sedimentation, runoff, and erosion. These areas are also very important stopovers for migrating birds. The riparian forest along the Mission River is a vector for migrant landbirds moving inland in spring. During migration, the trees vibrate from the sound of hummingbirds feeding on turk's cap and hawking insects. Other migrant birds found along the Mission River include Ringed Kingfishers, Green Jays, hawks, kites, and falcons.

Mission River flood event showing inundation of adjacent riparian woodlands and prairie wetlands

Riverine

The Texas landscape has 15 major rivers that play a role in protecting water quality, preventing erosion, and providing nutrients and habitat for fish and wildlife. The rivers and streams flow into 7 major estuaries, supporting over 212 reservoirs, countless riparian habitats, wetlands, and terrestrial areas. Each year Texas Rivers provide recreational opportunities to millions of people.

Volunteers monitor riparian habitat along the Mission River

The Mission and Aransas rivers supply freshwater to the Mission-Aransas Estuary. These rivers are small and primarily coastal compared to other rivers in Texas. The Aransas River drains 536 sq mi of the coastal prairie of south Texas, and the Mission River drains 488 sq mi. The rivers are gentle sloping streams with pools and few riffles. Only a few tributaries to these rivers are perennial streams, most are intermittent and seasonal (TNRCC, 1994). Significant creeks include the Medio Creek, Poesta Creek, West Aransas Creek, Blanco Creek, Copano Creek, and Artesian Creek. The creeks and rivers are all relatively short streams that flow slowly through shallow river beds, riparian wetlands, and salt marshes to empty into Hynes Bay, St. Charles Bay, Mission Bay, Aransas Bay, and Redfish Bay (GSA BBEST, 2011). No dams or surface water supply structures are constructed and neither river is used for city water supplies in the region. Stream flow from these rivers is generally low with the highest pulses of freshwater occurring due to rainfall events.

Mission River

The Mission River, formed by the confluence of Blanco and Medio creeks in central Refugio County, runs for approximately 24 mi, and discharges in Mission Bay. From 1999-2008, the Mission River discharge ranged from 0.005 to 908.97 m^3 s^{-1}, with mean flow of 4.41 m^3 s^{-1} and a median of 0.57 m^3 s^{-1} (Mooney, 2009). The Mission River has extensive freshwater wetland habitat (Bauer et al., 1991) that is home to many waterfowl species and native slough grasses.

Aransas River

Aransas River

The Aransas River begins in Bee County from the confluence of Olmos, Aransas, and Poesta creeks, flows south and southeast, and enters the western end of Copano Bay along the Refugio-Aransas county line. From 1999-2008, the Aransas River discharge ranged from 0.0065 to 829.68 m^3 s^{-1}, with mean flow of 1.39 m^3 s^{-1} and median of 0.18 m^3 s^{-1} (Mooney, 2009). The Aransas River has extensive estuarine wetland habitat and significant habitat value. Several threatened or endangered species use the habitat created by the river including, Reddish Egret (*Egretta rufescens*), Piping Plover (*Charadrius melodus*), Snowy Plover (*Charadrius alexandrinus*), White-faced Ibis (*Plegadis chihi*), Wood Stork (*Mycteria americana*), and Brown Pelican (*Pelecanus occidentalis*) (TPWD, 2000).

Other Freshwater Sources

Copano Creek originates in northeastern Refugio County and runs for 24 mi before emptying into Copano Bay, northeast of the Mission River. The area surrounding this creek is flat and rolling prairie, supporting hardwoods, pines, and prairie grasses. Melon Creek rises in southeastern Goliad County and runs for 25 mi to its mouth on the Mission River. The creek traverses flat to rolling terrain, supporting hardwoods and grasses. Chiltipin Creek runs for 45 mi starting in west central San Patricio County and ending on the Aransas River in western Aransas County. In the past, the creek flowed with fresh water; however, by 1990 the freshwater seeps were gone and saltwater discharges from oil wells had contributed to erosion and pollution problems (TSHA, 2010).

River Studies

River flow in Texas can vary greatly and water flowing into bays has a strong influence on productivity. In 2007 and 2008, Mission and Aransas river water was collected and analyzed for a variety of nutrient concentrations and riverine export was calculated using the USGS LOADEST model (Table 10.2). The first year of the study (2007) was a relatively wet year while the second year (2008) was a relatively dry year (Mooney, 2009). The percentage of annual constituent export during storms in 2007 was much greater than in 2008. Concentration-discharge relationships for inorganic nutrients varied between rivers, but concentrations were much higher in Aransas River due to wastewater contributions. Organic matter concentrations increased with flow in both rivers, but particulate organic matter concentrations in Aransas River were two fold higher due to large percentages of cultivated crop land. In the Mission-Aransas Estuary, inputs due to storms can support increased production for extended periods after heavy rainfall.

Table 10.2. Nutrient concentration ranges measured in Mission and Aransas rivers in 2007-2008. All measurements in µM unless otherwise indicated (Mooney, 2009).

	MISSION RIVER		ARANSAS RIVER	
Nutrients Measured	**Upper River (Refugio)**	**Lower River (Mission Bay)**	**Upper River (Skidmore)**	**Lower River (Copano Bay)**
Nitrate	0.25 – 11	~0.25 – 15	3 – 627	~0.25 – 15
Ammonium	0.25 – 3	~0.25 – 3	0.25 – 9	~0.25 – 7
Soluble Reactive Phosphorus	0.25 – 3	~0.25 – 4	3 – 76	~0.25 – 15
Dissolved Organic Carbon	177 – 1100	200 – 1090	231 – 888	200 – 715
Dissolved Organic Nitrogen	10 – 51	15 – 54	2.5 – 42	8 – 44
Particulate Organic Carbon	25 – 254	50 – 560	25 – 505	95 – 666
Particulate Organic Nitrogen	3 – 38	8 – 76	3 – 60	14 – 96
Stable carbon Isotope	-33 – -21‰	-35 – -21‰	-29 – -18‰	-29 – -19‰
Stable nitrogen isotope	-1 – -7‰	~-2 – 7‰	1 – 17‰	~-2 – 8‰

The Texas Estuarine Mathematical Programming (TxEMP) model was developed to determine optimal inflows to maintain productivity of economically and ecologically important fish and shellfish species in major Texas bays (Chen et al., 2006). The Mission-Aransas drainage basin is relatively undeveloped, and no dams or reservoirs have been constructed or proposed within the watershed. Water supplies for surrounding cities are taken from the Nueces River and groundwater. It is recommended that an inflow of 86 thousand acre-feet per year be reserved to ensure the optimal potential for fishery productivity. In the case of prolonged drought, a minimum inflow of 32 thousand acre-feet per year is recommended to sustain wildlife and ecological function in the Mission-Aransas Estuary (Chen et al., 2006). Discharge data from 1999-2008 show that two years fell below the 32 thousand acre-feet per year minimum recommendation, six years were above the recommended 86 thousand acre-feet per year, and two years were in between. Annual inflows for the Mission-Aransas Estuary are compared to those of the central Coastal Bend and south Texas below the Reserve (Table 10.3).

Bay/Basin Expert Science Teams

Historically, little thought has been given to the freshwater needs of estuaries and the species that depend on them for shelter and food. This changed, however, when the Texas Legislature recognized the need to establish environmental flow standards and adopted Senate Bill 3. The law created a public process by which state authorities would solicit input from scientists and stakeholders before establishing legal environmental flow standards for Texas estuaries and rivers. The legislation called for the creation of Bay/Basin Stakeholder Committees (BBASC) and Bay/Basin Expert Science Teams (BBEST) in the seven major bay/basin systems in Texas.

The BBEST is made up of scientists and technical experts with knowledge of region-specific issues and/or experience in developing flow recommendations. They develop flow regime recommendations based on best-available-science and provide their findings to the BBASC. The BBASC is composed of 17 members, reflecting various stakeholder groups (e.g., agriculture, recreational water use, municipalities, commercial fishing, regional water planning, etc.). The stakeholders are tasked with considering the BBEST recommendations in conjunction with water policy information and making a separate recommendation to the Texas Commission on Environmental Quality (TCEQ). TCEQ will consider recommendations from both groups before establishing the legal minimum flow standards.

The Guadalupe-San Antonio (GSA) bay/basin is located on the central Texas coast and includes the Guadalupe and Mission-Aransas estuaries and their watersheds. The GSA BBEST released their environmental flow recommendations on March 1, 2011, and the BBASC will have until September 1, 2011 to review the BBEST report and make their own recommendations to TCEQ. TCEQ is then responsible for determining legal flow standards for the GSA bay/basin by September 1, 2012.

Table 10.3. Comparison of freshwater inflows in acre-feet per year in three estuaries along the lower Texas coast (Smith and Dilworth, 1999).

Estuary	Minimum Annual Inflow	Maximum Annual Inflow	Median Inflow	Mean Inflow	Inflow-Volume Ratio
Aransas	7,503	1,542,142	324,228	429,189	0.64
Corpus Christi-Nueces	42,551	2,744,260	414,337	633,597	0.71
Upper Laguna Madre	0	818,000	73,000	156,928	0.40

Issues of Concern for Freshwater Habitats

Loss of Habitat

Drastic ecological changes occur as palustrine wetlands are converted to dry land for urban development and agriculture (Meyer, 1996). In addition to the obvious loss of wetland habitat, conversion to agriculture and other land uses decreases biodiversity across taxonomic groups and alters animal behavior and plant reproductive ecology by affecting the size, shape, and habitat patch similarity of wetlands within developed areas (Ehrenfeld, 2000; Gopal, 2000; Lougheed et al., 2008). Waste from urban development introduces excess nutrients to the environment that can be mitigated by undisturbed wetlands through plant uptake over short-term periods and through sediment accumulation over long-term periods (Hemond and Beniot, 1988). A reduction in palustrine habitat reduces the amount of wetland plants available to act as sinks and will result in increased amounts of nitrogen in runoff that reaches the groundwater supply and surrounding water bodies leading to acidification or eutrophication (Camargo and Alonso, 2006; Hayakawa et al., 2006; Hatterman et al., 2008). Fertilizer use on farmland also contributes excess nitrogen to runoff, and when combined, these problems can cause persistent eutrophication, hypoxia, and “dead zones” in freshwater wetlands (Mitsch and Gosselink, 2007).

Human impacts have affected the natural plant communities in riparian woodlands. Impacts include tree removal for firewood and lumber, housing developments in the flood plain, grazing cattle, and artificially channelizing and damming waterways for flood protection and water supplies. The most common disturbance involves clearing of vegetation and converting the area to other uses such as cropland and urban areas. Overgrazing can be devastating because livestock tend to congregate for extended periods, eat much of the vegetation, and trample stream banks. Even recreational development can destroy natural plant diversity and structure, lead to soil compaction and erosion, and disturb wildlife. Potential impacts to riparian areas are a major problem because these vital habitats are limited in size and are very susceptible to disturbances.

Riparian corridors perform many important functions, including providing exceptional habitat for migrating birds and wildlife. The riparian woodlands of the lower Rio Grande Valley provide a home to many birds that cannot be found elsewhere in the US, attracting birdwatchers from across the country. This tourism is very important to the regional economy (Jacob, et al., 2003), but must be managed properly in order to protect these vital habitats and reduce disruption to wildlife.

Climate Change and Freshwater Wetlands

Climate change has the potential to affect palustrine wetland habitats through changes in precipitation, temperature regimes, or through changes in sea level. Climate change models predict that increasing global temperatures will lead to higher precipitation extremes in warmer climates as well as an increase in droughts during summer months (Kundzewicz et al., 2007). This could have severe consequences for coastal freshwater wetlands, i.e., those found on the Texas coast that rely on freshwater, precipitation, rising and falling of rivers, overflowing lakes, and groundwater to maintain water levels (Mitsch and Gosselink, 1986). The nature and variability of the wet season and the number and severity of storm events will affect the biogeochemistry, sediment loading, and soil chemistry and will play important roles in determining regional and local impacts (Nicholls et al., 2007).

Changes in freshwater inflows attributed to climate change could also have significant impacts on palustrine wetlands. For example, prolonged droughts during the summer months cause a decrease in freshwater inflow and a subsequent drop in water levels. This could, in turn, lead to an increase in carbon emissions to the atmosphere (Kusler, 1999). Wetlands are natural carbon sinks and the dissolved organic carbon that is produced in situ by phytoplankton or from vegetation in the surrounding terrestrial habitats serves as food sources for the microbial community and increases carbon recycling and retention (Fukushima et al., 2001; Wetzel, 2001). Changes in the microbial food web due to alterations in freshwater inflow could contribute to the already pressing issue of greenhouse gases and climate change.

Sea Level Rise

Estimates suggest that the global average rate of sea level rise in the 20th century has been approximately 0.1 – 0.2 cm yr^{-1}. Data from recent years suggests that this rate is increasing and global sea level rise rates are now estimated to be closer to 0.3 cm yr^{-1} (Bates et al., 2008). Local mean sea level rise rates, however, may vary significantly from global rates due to the effect of local hydrodynamic forces on water levels and regional and local land movements, such as deep and shallow subsidence. In the Gulf of Mexico, sea level rise and compactional subsidence associated with withdrawal of water and oil/gas are both important components of the relative sea level rise equation. Local sea level rise rates in the Gulf of Mexico are estimated at 1.2 cm yr^{-1} (Swanson and Thurlow, 1973; Penland et al., 1988), four times the global average.

When compared to long-term trends, short-term rates of relative sea level rise can often show different trends due to climatic factors such as droughts and periods of high precipitation and river discharge. Local, long-term tide data is available for the Mission-Aransas NERR from the Rockport tide gauge, located along the western shore of Aransas Bay. Water levels at this tide gauge show an average rate of relative sea level rise of 0.4 cm yr^{-1} from the 1950's through 1993. However, rates increased to a much higher rate of 1.7 cm yr^{-1} from the mid-1960's to mid-1970's (Tremblay et al., 2008).

On the low-lying Texas coast, small increases in the rate of sea level rise can have dramatic ecosystem effects. A recent report suggests that sea level rise may already be impacting habitat distribution and abundance along the Texas Coast (Tremblay et al., 2008). The report identifies a major decrease in the distribution of tidal flats and palustrine wetlands in the Coastal Bend region over the past 50 years. This decrease is due to a concomitant increase in the extent of estuarine marshes (i.e., tidally-influenced marshes) and seagrass beds which can be attributed, at least partially, to sea level rise (Tremblay et al., 2008).

As saltwater marshes encroach on freshwater wetlands, the animals and aquatic plants which rely on these areas for habitat will diminish. Exponential decay models predict freshwater faunal extinction rates that are three times higher than those of coastal marine fauna and five times greater than terrestrial fauna (Ricciardi and Rassmusen, 1999). For example, waterfowl that rely on palustrine habitats for food and drinking water could be greatly affected by decreases in the abundance of palustrine habitats (Woodin, 1994; Tietje and Teer, 1996). Ultimately, this could have negative effects on socio-economic functions of freshwater wetlands, such as hiking, bird watching, recreational fishing, hunting, and kayaking.

Invasive Species

Riparian lands are connected to uplands by the hydrology of the river. Through river connectivity, these habitats act as a dispersal network for plant species; consequently, riparian corridors are one of the most sensitive habitats to plant invasion.

Many of the woodlands are dominated by invasive species such as saltcedar (*Tamarix* spp.) and mesquite (*Prosopis* spp.) (Jacob et al., 2003). Saltcedars are fire-adapted species with long roots that take up large amounts of water from deep water tables and interfere with natural aquatic systems. These trees affect natural plant communities by disrupting the structure and stability and degrade natural habitat by depositing large amounts of salt (Muzika and Swearingen, 2009). Mesquite is an extremely hardy, drought-tolerant plant with a long tap root system that also draws a lot of water. Ranchers consider the mesquite tree a nuisance because it competes with rangeland grasses for moisture (Dailey, 2008). Invasion by exotic plant species (*Elaeagnus, Eucalyptus*) can also adversely impact riparian areas by outcompeting the native vegetation. As these species become dominant, the overall vegetation diversity decreases, which results in less favorable habitat for wildlife.

Brush Management

Brush management is the removal, reduction, or manipulation of tree and shrub species and is designed to control the target woody species and protect desired species. This is accomplished by mechanical, chemical, biological, or a combination of these techniques. The practice is also planned and applied to meet the habitat requirements of fish and wildlife. Brush management is used to accomplish one or more of the following: restore natural plant community balance, create the desired plant community, manage noxious woody plants, restore vegetation to control erosion and sedimentation, improve water quality, enhance stream flow, and maintain or enhance wildlife habitat including habitat for threatened and endangered species (Montgomery, 1996).

Freshwater Inflow

Freshwater inflow from rivers into estuaries is the most important determinant in estuarine productivity (TPWD, 2010). The timing and amount of inflow can reduce the overall productivity, which can change the character of the bay and adversely impact fisheries. Freshwater inflows are important to coastal ecosystems because they maintain proper salinity for juvenile fish and shrimp, provide nutrients, flush pollutants, sustain a variety of habitats (e.g., salt marshes, grass flats, oyster reefs, etc.), and signal fish to spawn or move to a new habitat (TPWD, 2010). However, more and more water is being drawn from rivers and streams to meet the growing needs of industry, agriculture, and municipalities.

Mission River at Fennessey Ranch

Increasing water demand for human consumption and irrigation are the top two threats that lead to a decrease in freshwater inflow to palustrine wetlands (Bobbick et al., 2006). Water demand for human use often leads lawmakers to compromise when making decisions regarding conservation of wetlands and the need for freshwater. Rapidly increasing populations within the Mission-Aransas NERR watershed have already affected the water supply for municipalities in the area (Morehead et al., 2007). Total water consumption for the Texas Coastal Bend is expected to increase 49.8% from 2000 to 2060 (Nueces River Authority, 2006). The extent and productivity of palustrine wetlands within the Mission-Aransas NERR could be profoundly affected by the increasing population and water usage.

When examining future freshwater inflows to Texas estuaries, it is especially important to consider the potential impacts of climate change. Texas is projected to have an average 2°C increase in temperature and a 5% decrease in precipitation over the next 100 years (IPCC, 2007). If this climate scenario is considered in conjunction with population growth, the Texas coast is expected to see a decrease in downstream flows of 30% over the next 50 years (Ward, 2011).

Land cover changes that result from increasing population growth and development can also impact water supplies through changes in runoff and infiltration. In Texas, runoff is produced during and immediately following infrequent but intense thunderstorm events. Numerous dams have been constructed throughout the state to establish reservoirs and capture runoff in order to meet water needs. However, these reservoirs only capture a small portion of the higher river flows and the remaining water flows through the dams (Ward, 2011). Land cover changes that result in increased runoff are likely to have an impact on the ability of current reservoirs to hold runoff, which will ultimately affect downstream flows to the coast. The extent of impervious surfaces could also decrease aquifer recharge by lowering infiltration capacity. In a state that depends heavily on both surface water and groundwater, this could be very important for both future water needs and freshwater inflows to the coast.

Future Plans for Freshwater Habitats

Freshwater Wetland Conservation and Restoration

The goal of freshwater wetland conservation and restoration is to ensure the existence and creation of habitats that provide the important resources and functions associated with palustrine ecosystems (Zedler, 1990). Successful restoration of freshwater wetlands can be achieved through the reintroduction of water and sediments (Boesch et al., 1994). Construction of new wetlands is not simple and depends on establishing accurate hydrology, something that is subject to both abiotic and biotic factors (Hammer, 1992). Substrate, vegetation, and fauna of natural palustrine habitats can be used for guidance and provide a good source for comparison between man-made wetlands and natural systems (Race and Christie, 1982). Historically, success rates of restored freshwater wetlands have been difficult to measure. Evidence suggests that the majority of wetlands failed to recover due to hydrological issues (Mitsch and Gosselink, 1998).

Conservation and restoration of palustrine habitats are further complicated by the need for buffer zones that surround these freshwater ecosystems. Buffer zones begin at the boundary of wetland vegetation and extend outward towards other land uses (Allen and Walker, 2000). These zones offer protection for both wetlands and surrounding upland areas by reducing flooding and removing sediments/pollutants from surface runoff (Boyd, 2001; McElfish, 2008). Size and nature of restored buffer zones are dependent on the reasons for which the wetland and associated zone were constructed; but in general, well designed buffer zones will improve overall wetland health and ensure greater restoration success.

Entrance to Fennessey Ranch

Long-term Management

For long-term management of freshwater wetlands to succeed, growth must exceed deterioration caused by human factors and natural conversion to saltwater marsh. Guidance and cooperation of multiple agencies, universities, non-profit organizations and local stakeholders is necessary for this to occur (Smith and Dilworth, 1999). The Mission-Aransas NERR and its numerous partner organizations (e.g., University of Texas Marine Science Institute, Texas Parks and Wildlife Department, United States Fish and Wildlife Service, Nature Conservancy, and Fennessey Ranch) bring together various groups and provide a geographic area where palustrine wetland conservation and restoration are priority issues.

Monitoring Programs

The Mission-Aransas NERR benefits from the existence of short- and long-term research projects and monitoring programs that provide important information on the status and trends of palustrine habitats within the NERR boundary and the surrounding watershed. The acquisition of Fennessey Ranch, a 3,300-acre upland habitat that contains several freshwater wetland habitats, was crucial for research on the effects of freshwater inflow from rivers and adjacent freshwater wetlands on palustrine habitats (NOAA, 2006). The exchange of water between freshwater wetlands, rivers, and groundwater has not been fully defined for the Reserve. However, Fennessey Ranch presents a great location to conduct the type of research that will help define these relationships due to its abundance of freshwater habitats, artesian aquifers, and adjacency to the Mission River. Initial analysis of river dynamics, such as CDOM and nutrient loading after storm events have been completed, which provides good baseline information to conduct continued inquiry into the exchange between water flows. In turn, Fennessey Ranch has received great economic benefits from its palustrine habitats by offering ecotourism activities such as wildlife tours, photography, and hunting. This is an example of how the preservation of freshwater marshes can be more economically efficient than trying to compensate wetland loss through mitigation (Zedler, 2000).

Recommendations for riparian areas include conducting a periodic national inventory, increase research, acquire high spatial resolution imagery, and emphasize these areas in conservation policies and programs. Currently there are estimates of the extent of riparian areas but this does not describe the condition. Using a standard classification system and evaluation procedure to complete a national inventory will help fill these gaps. More research is needed on the function of riparian areas to help support management decisions. Obtaining high resolution images will provide information on riparian communities, structure, and quality at a lower cost than with traditional field mapping (Montgomery, 1996).

Assistance Programs

The US Department of Agriculture, Natural Resources Conservation Science (NRCS) programs help reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters. The public benefits from enhanced natural resources that sustain agriculture and environmental quality while supporting economic development, recreation, and scenic beauty.

There are many programs offered and some of the relevant programs for the Mission-Aransas NERR are the Grazing Lands Conservation Initiative, Watershed Program, Wetlands Reserve Program, and Environmental Quality Incentives Program (NRCS, 2011). The Grazing Lands Conservation Initiative provides decision makers an ecological understanding of the resources to help make wise land management decisions. This program provides technical assistance for the latest and best technology that will help conserve and enhance private grazing land resources (NRCS, 2011). The Watershed Program provides technical and financial assistance to plan and implement authorized watershed project plans for the purpose of watershed protection, flood mitigation, water quality improvements, soil erosion reduction, etc. (NRCS, 2011). The Wetlands Reserve Program is a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. The NRCS goal is to achieve the greatest wetland functions and values, along with optimum wildlife habitat (NRCS, 2011). The Environmental Quality Incentives Program is a voluntary program that provides financial and technical assistance to agricultural producers. These contracts provide financial assistance to help plan and implement conservation practices that address natural resource concerns and for opportunities to improve soil, water, plant, animals, air, and related resources on agricultural land and non-industrial private forestland. In addition a purpose of this program is to help producers meet Federal, State, Tribal, and local environmental regulations (NRCS, 2011).

Freshwater Inflow Projects

The recently released GSA BBEST report (GSA BBEST, 2011) clearly identifies several social, climatic, physical, and biological research gaps that are barriers to providing higher quality environmental flow recommendations. Fortunately, the Senate Bill 3 process is based on an adaptive management approach that requires further review of the initial flow recommendations. The proposed project will use a collaborative approach to not only address the research gaps that have been identified in the BBEST report, but to also incorporate the BBASC (along with the BBEST and other stakeholders) as user groups that will ultimately utilize the information to refine environmental flow recommendations. Specific goals include: (1) examine the effects of land use and climate change on freshwater inflows, (2) improve inputs to the TxBLEND salinity model by measuring water exchange between adjacent bays, (3) collaborate with intended users to identify and conduct priority research projects related to one of the focal species mentioned in the GSA BBEST report, and (4) create a system dynamics model.

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Chapter 11 UPLAND HABITATS

Anne Evans

Terrestrial habitats within the Mission-Aransas NERR include coastal prairies, oak mottes, spoil islands, and dune habitats. All of these habitats provide shelter and food for many significant flora and fauna.

Prairie at the Aransas National Wildlife Refuge

Coastal Prairies

The coastal prairie found along the western gulf coast in southwest Louisiana and southeast Texas is the southernmost portion of the tallgrass prairie system of the Midwest. It is estimated that over nine million acres of prairie once existed in these areas; however, less than one percent remains today. Remnants in Louisiana total less than 100 acres and less than 65,000 acres in Texas (Allain et al., 1999). Most of the original prairie has been (1) converted to pasture for cattle grazing, (2) altered for growing rice, sugarcane, and grain crops, or (3) urbanized.

Coastal prairies are characterized and maintained by soil type, fire, rainfall, and grazing. The prairies receive 142 cm (56 in) of rainfall annually, which typically would produce forests rather than grasslands; however, a hard clay layer underneath the topsoil inhibits root formation of larger forest trees. The establishment of woody plants is also prevented by drought, fire, and competition from adapted plant species. These factors combine to maintain a grass-dominated ecosystem (Allain et al., 1999).

Coastal Prairie Flora and Fauna

Coastal prairie vegetation consists of grasses, a variety of wildflowers, and other plants. Nearly 1,000 plant species have been identified and almost all are perennials with underground structures that help the plants survive after fire (Allain et al., 1999).

There are four types of coastal prairies in the Mission-Aransas NERR: (1) cordgrass prairie with gulf cordgrass *(Spartina spartinae)* and marshhay cordgrass *(Spartina patens)*; (2) sand mid-grass prairie with seacoast bluestem *(Schizachyrium scoparium* var. *littorale)* and panamerican balsalmscale (*Elyonurus tripsacoides)*; (3) clay mid-grass prairie with little bluestem *(Schizachyrium scoparium)* and trichloris *(Chloris pluriflora)*; and (4) short-grass prairie with silver bluestem *(Bothriochloa saccharoides)*, buffalo grass *(Buchloe dactyloides)*, and trichloris (Figure 11.1). Clumps of mesquite *(Prosopis glandulosa)*, oak *(Quercus* sp.*)*, huisache *(Acacia farnesiana)*, and prickly pear cactus *(Opuntia lindheimeri)* are also often found in coastal prairies (McLendon, 1991; Chaney et al., 1996).

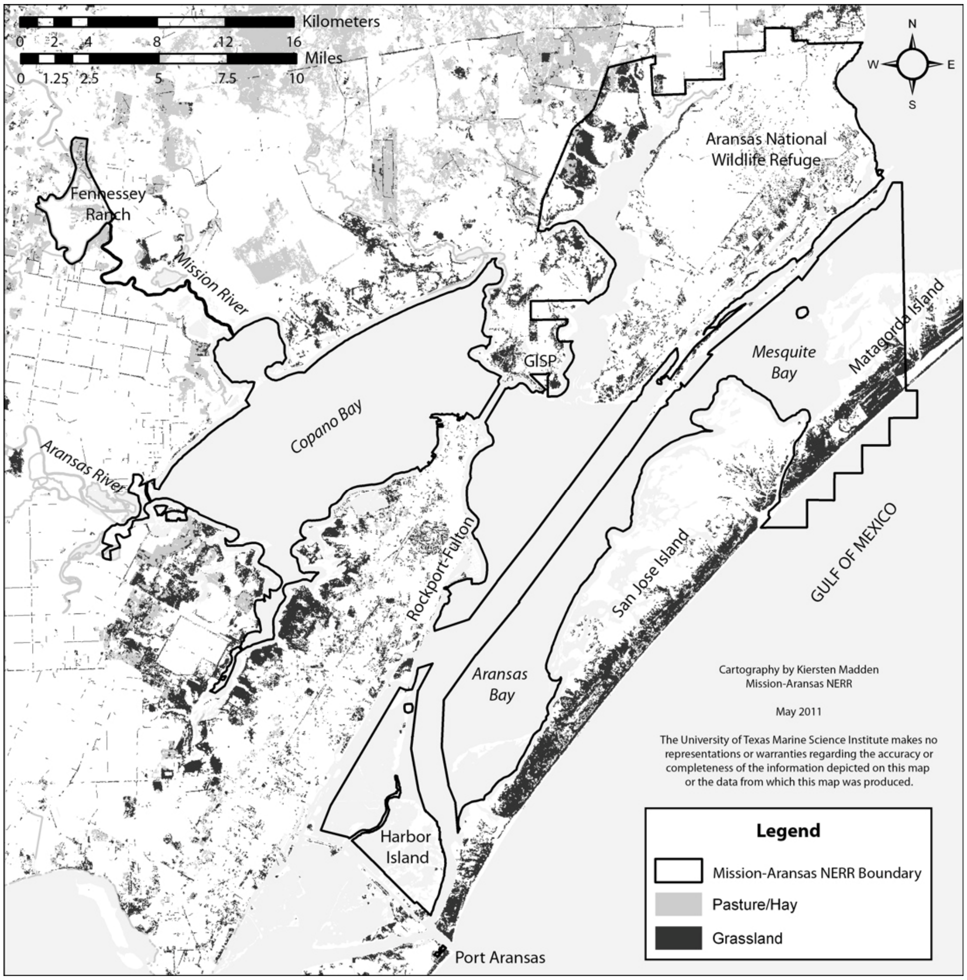

Figure 11.1. Pasture and grassland in the Mission-Aransas NERR watershed.

Coastal prairies and adjacent marsh areas provide habitat for waterfowl and thousands of other wildlife species. Coastal prairies host more Red-Tailed Hawk *(Buteo jamaicensis)*, Northern Harrier *(Circus cyaneus)*, White Ibis *(Eudocimus albus)*, and White-faced Ibis *(Plegadis chihi)* than any other region in the United States (Allain et al., 1999). Waterfowl, sandpipers, and other shorebirds are abundant during the fall, winter, and spring months. Additionally, prairie lands provide habitat and plentiful supplies of nectar, which results in a unique insect diversity including butterflies, dragonflies, bees, wasps, ants, grasshoppers, beetles, and preying mantis.

Oak Motte

Live oak forests and mottes (i.e., isolated groves) are a unique, ecologically important, and ancient component of the South Texas landscape. Live oaks *(Quercus virginiana)* occur primarily in sandy soils of the two million acres of coastal sand plain (Carey, 1992; Fulbright, 2008). They are a common, dominant tree in maritime forests bordering coastal and inland marshes. Live oaks also occur as co-dominants with other woody plant species such as mesquite and blue-wood and are found in parts of Bee, San Patricio, Goliad, and Refugio counties (Fulbright, 2008). Texas live oak is often associated with Texas persimmon *(Diospyros texana)*, Texas red oak (*Q. texana)*, post oak *(Q. stellata)*, and honey mesquite

(Prosopis glandulosa). Texas mallow *(Callirhoe scabriuscula)*, ground cherry *(Physalis pruinosa)*, Texas grass, little bluestem *(Schizachyrium scoparium)*, yaupon *(Ilex vomitoria)*, beautyberry *(Callicarpa americana)*, greenbriar *(Similax* sp.*)*, mustang grape *(Vitis mustangensis)*, and muscadine *(Vitis rotundifolia)* commonly occur beneath the canopy (Chaney et al., 1996; Fulbright, 2008).

"The Big Tree"

Live oak trees are shrubby to large, spreading, long-lived, and nearly evergreen. They grow as large trees in deep soils along streams and as large shrubs in canyon headers. In the spring, they drop their leaves and grow new leaves within several weeks. Trees average 50 feet (15 m) in height and can have trunks up to 79 inches (200 cm) in diameter. The bark is furrowed longitudinally and the small acorns are long and tapered. Tree canopies usually have rounded clumps of ball moss or thick drapings of Spanish moss (Carey, 1992).

Texas live oak varieties frequently have a shrubby stature which is thought to be soil and moisture dependent. Live oaks grow in moist to dry environments, withstanding occasional floods but not constant saturation. They grow best in well-drained sandy soils and loams, but are also capable of growing in clay and alluvial soils (Carey, 1992). Live oaks are resistant to salt spray and high soil salinity, making the Texas coast an ideal site for growth. Goose Island State Park is home to "The Big Tree," a massive coastal live oak. The Big Tree presides in an oak motte on Lamar Peninsula on St. Charles Bay. Estimates place The Big Tree's age at well over 1,000 years and it is the largest live oak tree in Texas (Fulbright, 2008).

Although wood from live oaks is heavy and strong, little is used commercially. In the past, live oaks did serve multiple purposes in the US. Early Americans used live oak for ship building. Before that, Native Americans produced oil comparable to olive oil from live oak acorns and it is believed that they used live oaks as trail markers by staking saplings down, causing them to grow at extreme angles (Carey, 1992).

South Texas' live oak forests are critical wildlife habitats. They have high value for game species and migratory birds, and many rare wildlife species inhabit them. Acorns are an important food source for many animals and oak mottes provide shade from the hot Texas sun. Many suburban areas of South Texas have live oaks planted in yards providing habitat for urban wildlife. White-tailed deer *(Odocoileus virginianus)*, northern bobwhite *(Colinus virginianus)*, Rio Grande wild turkeys *(Meleagris gallopavo intermedia)*, and javelina (Tayassuidae) are the primary game species associated with live oak forests of the Coastal Sand Plain (Fulbright, 2008).

Oak mottes

Migratory songbirds require coastal oak mottes to provide needed stopover habitat where they can find good cover for resting and an abundance of insects for food. More than 80% of the 332 species of long-distance North American migrants travel through the Texas Coastal Bend and a reduction of live oaks could negatively affect these populations. For example, the Tropical Parula *(Parula pitiayumi)*, a small New World Warbler, nests almost exclusively in live oaks. Live oaks provide essential nesting habitat for many species, including the Hooded Oriole *(Icterus cucullatus)*, Ferruginous Pygmy-owl *(Glaucidium brasilianum)*, Red-billed Pigeon *(Patagioenas flavirostris)*, Northern Beardless Tyrannulet *(Camptostoma imberbe)*, Couch's Kingbird *(Tyrannus couchii)*, Painted Bunting *(Passerina ciris)*, and Rose-breasted Grosbeak *(Pheucticus ludovicianus)* (Fulbright, 2008).

Marsh and spoil islands at sunset

Spoil Islands

Natural and artificial dredged spoil islands are present in the Mission-Aransas NERR. Artificial spoil islands result from the deposition of material that has been dredged for the production and/or maintenance of navigation channels. Both dredging and placement of dredge material affect water movements within the bay. Dredging makes portions of the bays deeper than they would be naturally and allows more water to circulate. The deposition of dredge material for spoil islands may inhibit the flow of water in some locations; however, spoil islands are important roosting and nesting grounds for a variety of birds (Robertson et al., 1991; Montagna, 1996).

Birds using spoil islands as nesting areas include the Great Blue Heron *(Ardea Herodias)*, Snowy Egret *(Egretta thula)*, Tricolored Heron *(Egretta tricolor)*, Green-winged Teal *(Anas crecca)*, Northern Shoveler *(Anas clypeata)*, Black-necked Stilt *(Himantopus mexicanus)*, American Avocet *(Recurvirostra americana)*, Black Skimmer *(Rynchops niger)*, White Pelican *(Pelecanus onocrotalus)*, and Brown Pelican *(Pelecanus occidentalis)* (White and Cromartie, 1985).

Plant communities common on spoil islands include mesquite, salt cedar *(Tamarix* spp.*)*, popinac *(Leucaena leucocephala)*, granjeno *(Celtis laevigata)*, and oleander (*Oleander* spp.*)* (Chaney et al. 1996).

Dune Habitat

Barrier islands are dynamic environments in which sand is constantly being moved due to the interactions of geology, climate, and vegetation (Stallins and Parker, 2003). Sand dunes serve as defense for inland areas against storm surge and beach erosion by absorbing the impact of waves and the intrusion of water. Dunes also hold sand to replace eroded beaches and buffer sand and salt spray.

A typical barrier island is composed of a series of dunes. Foredunes, the newest and largest, are created on the exposed ocean side where sediment is deposited. Foredunes are the first clearly distinguishable, vegetated dune formation landward of the water. Interdune areas, located behind the foredunes, are lower and more level due to overwash and flooding. Finally, backdunes are found on the bayside of the island and tend to slowly erode (Miller et al., 2010).

Dune development varies with sediment supply to the beach. The quantity of sand carried offshore, amount of sediment discharged by rivers, and the degree of human interference with natural sand transport (i.e., jetties and groins) determine how dunes are formed. Throughout most of the year on the Texas coast, waves average two to four feet. These calm waves transport sand from offshore bars and the surf zone to the beach, causing the beach to gradually build up. In time, sand is blown onto the foredune, where it is trapped by vegetation and stored until displaced by storms (TGLO, 2005).

Plants play an important role in dune building and stabilization. There are three groups of dune plants: dune builders (grow upward, stabilize using roots), burial-tolerant stabilizers (can withstand overwash, use rhizomes to stabilize), and burial intolerant stabilizers (long-lived, found in low energy back areas) (Miller et al., 2010). Foredune areas are highly disturbed, have the lowest species richness, and are dominated by the dune stabilizer, *Uniola paniculata*. Interdunes are dominated by clonal grasses *(P. vaginatum)* and clonal forbs *(P. nodiflora).* The highest diversity is found on the low protected backdunes which harbor long-lived woody species (Miller et al., 2010).

Three species of highly erosion-resistant and easily established dune grass are found on the Texas Coast: bitter panicum *(Panicum amarum)*, sea oats *(Uniola paniculata)*, and marshhay cordgrass *(Spartina patens)*. Bitter panicum is the best species for dune stabilization due to its high salt tolerance and rapid growth. New plants are generated from tillers, shoots that grow from nodes on the roots. The seeds of bitter panicum are sterile and will not propagate new plants. Sea oats are native to the Texas coast. This grass has stems that grow to three feet or more in length, but it is less tolerant of salt spray than bitter panicum; however, it can grow rapidly enough to avoid being smothered in rapidly shifting sand. Marshhay cordgrass is a small, wiry perennial which spreads by rhizomes. This grass can easily be buried by shifting sands, and therefore prefers to be on the landward side of dunes, rather than the beachside.

Other species of herbaceous plants found are beach morning glory *(Ipomoea imperati)* and seagrape vines *(Coccoloba uvifera),* which form a dense cover on the seaward side. Low-growing plants and shrubs found on the back side of dunes include seacoast bluestem *(Schizachyrium scoparium* var. *littorale*), cucumberleaf sunflower *(Helianthus debilis)*, rose ring gallardia *(Gaillardia pulchella)*, partridge pea *(Chamaecrista fasciculata)*, prickly pear *(Opuntia lasiacanta)*, and lantana. Many of these are flowering plants, an attractive alternative to dune grasses though less effective as dune stabilizers.

Dune Habitat on the Texas Coast

Vegetated and relatively stable dunes occur on Mustang Island and North Padre Island. On Matagorda and San Jose islands, where there is limited shorefront development, there is a continuous, well-defined foredune ridge averaging 15 to 20 ft above sea level. Highly developed dune formations are found in Nueces and northern Kleberg counties, where there is a foredune ridge consisting of several rows of dunes that average 20 to 25 ft in height (TGLO, 2005).

As rainfall decreases southward along the Texas Coast, dunes have less of the vegetative cover necessary for stabilization. Migrating dunes bare of vegetation and highly susceptible to wind erosion are common in the arid environment of the lower coast. On Padre Island and in Kenedy, Willacy, and Cameron counties, the foredune ridge is poorly developed and breached by numerous washovers and blowouts.

Dune habitat

Issues of Concern for Upland Habitats

Rare and Endangered Species

Historically, bison and pronghorn antelope were common on coastal prairies, but today these herds have disappeared and this ecosystem is listed as "critically imperiled" (USGS, 2010) Extinct species of the coastal prairie include the prairie vole *(Microtus ochrogaster)* and the Louisiana Indian paintbrush *(Castilleja coccinea)*. The black-lace cactus *(Echinocereus reichenbachii* var. *albertii)* and Texas prairie dawn *(Hymenoxys texana)* are on the endangered species list and more than a dozen other plant species are listed as imperiled. The federally endangered Attwater's Prairie Chicken *(Tympanuchus cupido attwateri*; North America's most endangered bird) and Whooping Crane *(Grus americana)* both use coastal prairies for their home for at least part of the year. Critically imperiled animals of the coastal prairie include the Gulf coast hognosed skunk *(Conepatus leuconotus)* and the Cagle's map turtle *(Graptemys caglei)* as well as a number of rare migratory grassland birds (Allain et al., 1999; USGS, 2010).

Urbanization

Development poses the greatest risk to what remains of coastal prairies. Most remnants of coastal prairies are privately owned with only a small percentage preserved on government land. The largest and most pristine coastal prairie remnants in Texas are hay meadows, which are in danger of development or conversion to farmland (USGS, 2010).

Land cover changes due to human population growth and impacts on fishery habitat, adjacent uplands, water quality, and living marine resources occur faster and more pervasively than we previously have been able to monitor. Information about the extent and rate of habitat degradation and loss is needed for sound resource management decisions (CSCOR, 2007).

Quantifying changes is critical for linking land-based human activities to coastal ocean productivity. The Coastal Change Analysis Program (C-CAP) uses satellite imagery and aerial photography to monitor areal extent, functional status, and change in critical habitats. C-CAP is cooperating with EPA's Environmental Monitoring and Assessment Program, the U.S. Fish and Wildlife Service's National Wetlands Inventory, the U.S. Geological Survey, and other Federal and State agencies to produce inventories of coastal intertidal areas, wetlands, and uplands (CSCOR, 2007; Digital Coast, 2011).

In Texas, C-CAP continues to provide technical assistance to the Texas Parks and Wildlife Department to work on the capability to detect change. Change analysis has been completed from coastal Galveston Bay to the Texas-Louisiana border and processing is underway for the coast from Galveston Bay to the Texas-Mexico border (CSCOR, 2007).

A characterization and analysis of land cover in the Mission-Aransas NERR watersheds was completed to support the needs of NERRS management, research, education, stewardship, and coastal training program sectors using the C-CAP program. Trends in land use and land cover within reserves and their watersheds were investigated along with how these trends are linked to the quality of estuarine habitats. From 1996 to 2005 not a lot of land cover change has been seen within the Mission-Aransas NERR. There was a 2 square mile gain in developed and agricultural land, a three square mile loss in grassland, scrub/shrub, and forest land, and a one square mile gain in palustrine wetlands, unconsolidated shore, and bottom land (Clement, Personal communication).

Cattle

Overgrazing

Overgrazing by cattle can also be detrimental to several important prairie species, such as big bluestem *(Andropogon gerardii)*, Indiangrass *(Sorghastrum nutans)*, and eastern gamagrass *(Tripsacum dactyloides),* which cannot tolerate close grazing. Overgrazing can decrease diversity and impact the effectiveness of fire (USGS, 2010).

Grazing management is the planned manipulation of livestock numbers and grazing intensities to increase food, cover, or improve structure in the habitat of selected species. Grazing management includes not overstocking or overgrazing any area on Fennessey Ranch. A grazing system is implemented to provide planned periodic rest for pastures by controlling grazing intensity and duration. Cattle are excluded from the no grazing zone and all fenced riparian zones to prevent trampling and for vegetative recovery (Fennessey Ranch Management Plan, 2006).

Controlled burn at Fennessey Ranch

Burning

Burning is the natural mechanism by which the prairie renews itself. The suppression of fire allows remnant prairies to become overgrown with native shrubs and invasive exotic plants. Fire prevents woody plants from establishing, stimulates seed germination, replenishes nutrients, and allows light to reach young leaves. Historically, prairie fires occurred in the summer as a result of lightning strikes. Native Americans often burned prairie in the winter and early spring. It is most common to burn when plants are dormant, but an occasional burn during the growing season enhances diversity. When fire is not an option, the area may be mowed or hayed, but this may affect long-term species survival. Weeds may have to be sprayed with herbicide or physically removed, especially from wet spots where fire does a poor job of control. After burning, it will take several years before a coastal prairie patch begins to mature, but when it does, most weedy exotics will be excluded naturally (Allain et al., 1999; USGS, 2010).

Fire has played an important role in coastal ecosystems for millions of years, but the number of wildfires has decreased dramatically due to improved fire suppression and prevention techniques. This has major impact on the plants and animals living in fire-dependent habitats. Today, resource managers must replicate wildfires using a technique known as prescribed burning – the planned application of fire. Prescribed burning is used in different areas of Fennessey Ranch to improve wildlife habitat, increase plant diversity, control competing vegetation, and reduce risk of intense fires (Fennessey Ranch Management Plan, 2006).

Prescribed fire is the primary management tool used to help wintering Whooping Cranes at the Aransas National Wildlife Refuge. Since the 1980s, several units are burned annually on the Blackjack Peninsula and Matagorda Island for the cranes. The Refuge fire program has also made progress in recent years renovating upland pastures that had become overrun with brush. The main objectives for prescribed fire are to maintain and restore coastal savannah and improve acorn and other forage opportunities for endangered Whooping Cranes, migratory birds, and native wildlife (Fennessey Ranch Management Plan, 2006).

When burning wetlands with salt grass, a burn permit must be obtained from Texas Commission on Environmental Quality and a burn plan must be submitted to Natural Resources Conservation Service. In Fennessey Ranch, Fennessey Flats should be burned every three years in January and St. John's Prairie and invasive bull rush should be burned in the summer. Burns should also occur in uplands where there is a high abundance of invasive huisache or retama that impedes diversity and chokes out other flora (Fennessey Ranch Management Plan, 2006).

Invasive and Aggressive Species

Invasive and exotic species are "non-native" plants or animals whose introduction adversely affects an ecosystem. At Fennessey Ranch, these plants and animals are controlled in order to minimize impacts to native wildlife and habitats. The method chosen to control these "invaders" is dependent on the species and the severity of the invasion. For example, Ranch staff must decide whether to use burning, manual removal, or application of herbicide.

Huisache is a common plant on rangeland and pasture in the eastern half of Texas. It is a tough, aggressive, invasive species that limits forage production and decreases the value of the wildlife habitat. It is a perennial warm small tree or brush that can reach 15 feet tall. The control of plant species such as huisache and other plants that invade a variety of rangeland sites is often warranted. When these species dominate an area they diminish plant diversity and the quality of habitat for most wildlife species. Vegetation manipulation may be in the form of prescribed burning, mechanical, biological, or chemical control of trees, brush, or weeds. Most of the practices require the use of specialized equipment or machinery for plowing, bulldozing, spraying, or other vegetation or soil manipulation procedures.

Guinea grass is a tufted perennial that forms dense stands in open pastures and disturbed areas. Guinea grass can suppress or displace local plants on fertile soils in pastures. It is resistant to drought and can build up a dangerous mass of plant material so when fires occur, the blaze is fiercer and native plants that have not built up fire-tolerance are wiped out. As guinea grass survives fire, it can dominate the ground after a fire.

Texas is home to an estimated two million feral hogs, approximately 50 percent of the entire United States' population. The term "feral hogs" applies to Eurasian Wild Boars, domesticated hogs that have become feral. Their high reproductive rate and ability to adapt to different environments have resulted in a population explosion. They prefer to live in areas with moist soils, such as riparian woodlands, lakes, ponds, and wetlands. Their flat snouts have special cartilage reinforcement that allows them to root for food through almost all soil types. Although prized by hunters, most landowners consider feral hogs to be a nuisance because of the damage they can cause to agricultural lands, natural habitats, and native wildlife.

Oak Motte Disease

Wilt disease is caused by the fungus, *Ceratocystis fagacearum,* and is a serious threat to Texas live oaks and live oak varieties in other states. Oak wilt is considered the most destructive of all pathogens because few phytopathogenic microbes have the capacity to kill their tree hosts as fast (Wilson and Lester, 2002). Fungicides are not effective because the fungus colonizes deep in the sapwood. Trenching, or cutting root connections, to control root transmission of the fungus has been done for many years. The Texas Forest Service has administered the Texas Oak Wilt Suppression Project which has installed over 650,000 m of trenches to reduce root transmission (Wilson and Lester, 2002). Live oak firewood should not be transported into wilt-free areas because the fungus survives in dead wood for up to one year.

Dredging Contaminants

Contaminants such as petroleum hydrocarbons, heavy metals, and pesticides enter Texas bay systems from agricultural activities, oil and gas exploration/production, petrochemical refining, ore processing plants, urban runoff, and wastewater discharges (Robertson et al., 1991). Due to their hydrophobic nature, contaminants tend to adsorb to suspended solids and sediments and settle onto bay bottoms. Dredging of sediments causes contaminants to be resuspended into the water column, usually at much higher levels due to accumulation (Robertson et al., 1991).

Sediments and biota from dredge spoil islands adjacent to the Aransas National Wildlife Refuge (ANWR) were examined for organochlorine, trace elements, and petroleum hydrocarbon contaminants. Trace elements were 200-500% higher in spoil sediments than local bays and detected at moderate levels in most biota samples (Robertson et al., 1991). The majority of contaminants evaluated were below levels of concern however, chromium, copper, and lead were detected at elevated levels in both sediment and biota (Robertson et al., 1991).

Spoil Island Bird Populations

Most studies conducted on spoil islands have focused on the avian species that inhabit the islands (Cahn, 1922; McMurray, 1971; Simersky, 1972, 1971; Depue, 1974; Mrazek, 1974; Chaney et al., 1978). The islands have minimal low-lying vegetation with no shade and few inhabitants. The presence of people and other disturbances were found to negatively impact the breeding success. (Cooper et al., 2005).

The Colonial Waterbird and Rookery Island Management Plans include field observations and management recommendations based on historical surveys. The plans encompass rookery islands along the central and lower Texas coast. The purpose is to characterize coastal rookeries, identify habitats and impacts, and to summarize historical population trends. Site-specific recommendations provide resource managers with strategies to improve waterbird breeding success. In the CBBEP area, populations of birds are indicators of healthy bay systems and several species are showing declining numbers. If birds are disturbed during nesting they may fly the coop, leaving eggs or baby chicks vulnerable to predators and heat. Landing a boat, wade fishing, kite surfing, and kayaking all can cause birds to react. Nesting islands are already protected under state laws, requiring people to stay away from February through August. Disturbance can lead to loss of an entire season’s breeding effort for thousands of birds and potentially the complete abandonment of the island by birds in the following years (CBBEP, 2011).

Based on the Texas Colonial Waterbird Survey, bird counts show decreasing numbers of waterbird species on the spoil island within Padre Island National Seashore boundaries, but participants in the waterbird survey provide varied explanations to suggest why the decrease is occurring. Explanations include habitat loss, disappearance of nesting grounds, marine debris, depletion of food sources, windmills impeding flight, and light pollution affecting migratory patterns (NPS, 2011).

Coyote climbing dune
Photo credit Jimmy Johnson

Dune Erosion

During a storm, high energy waves flatten the beach and erode sand by washing against the base of the foredunes. Retreating waves carry sand offshore and deposit it just seaward of the surf zone in large bars. If the supply of sand remains constant, the natural exchange between beach, dunes, and offshore areas will repair and rebuild dunes. If the height of approaching storm waves exceeds the height of depressions between dunes, water will overflow and wash down the landward side, eroding sand and carrying it inland. Under continual wave attack, these washover areas deepen and widen allowing large volumes of water to spill across. Evidence of hurricane washovers is apparent on many Texas barrier islands (TGLO, 2005).

Washouts may also be formed during storms. Washouts are similar to washovers, except the flow of water is in the opposite direction. Rainwater collects in the valleys between dunes and may overflow onto the beach carrying sand with it. These can also be formed by retreating bay waters; as hurricanes pile water into bay systems washouts may cut across low areas of dunes (TGLO, 2005).

Eventually, following a storm, the natural beach/dune system can recover its pre-storm shape if enough sediment is available. In Texas, this process can take up to five years. It occurs first by beach accretion, then by dune formation, expansion, and finally vegetation colonization. Loss of vegetation can inhibit recovery by making the beach and dunes more susceptible to wind and water erosion (TGLO, 2005).

Seawalls, bulkheads, and groins may protect property against erosion. However if waves persist, these structures can enhance shoreline erosion of adjacent properties and beach. By withholding sand that would otherwise be transported alongshore, erosion-control structures such as groins inhibit dune development in areas down drift of them.

Disturbance of foredunes by vehicles, pedestrians, construction work, or grazing animals can promote wind erosion. As trails are established along frequently used routes, the vegetation is destroyed and the wind begins to carry sand from the exposed area (TGLO, 2005). If unchecked, this erosion can lead to almost complete removal of dunes, depleting the supply of sand available for exchange during storms.

Sea Level Rise

Sand dunes contain unique plant habitats that are threatened by rapidly rising sea levels and over-development. Beach and dune protection is important along the Texas Gulf Coast, particularly in areas experiencing shoreline erosion and urban development. Sand dunes not only serve as a natural defense against storm surges, but the endangered Kemp's Ridley Sea Turtles also use the dunes for part of their life cycle (TGLO, 2005). Protecting dunes also preserves and enhances the beauty of the coast and coastal ecosystems.

Avocets
Photo credit Jimmy Johnson

Human Disturbances

Vehicles and trampling can severely damage dune habitat by causing fragmentation and deterioration of the dunes. Recreational vehicles driven up and down dunes can cause displacement of sand and destroy dune vegetation, in addition to disturbing shorebirds and their nests, eggs, and young (Brown and McLachlan, 2002). Damage to vegetation and fauna, as well as physical impact, can influence soil moisture, runoff, erosion, vegetation, and microorganisms. The vegetation that secures sand is destroyed, sand is lost, and the dune line is breached. Dune damage that results from human activities accelerates the damage caused by wind and wave erosion (TGLO, 2005).

Litter left behind by human visitors has also become a big problem. Non-biodegradable plastic materials have become the number one item of litter that impacts the fauna living in the dunes (Brown and McLachlan, 2002). An important negative feature of litter is it detracts from the aesthetic value of the beach.

Future Plans for Upland Habitats

Coastal Prairie Conservation, Restoration, and Management

There are a number of private groups and conservation organizations that are diligently trying to restore coastal prairies and educate the public about the functions, benefits, and threats to these ecosystems. Many government agencies are also assisting with conservation efforts by restoring/managing coastal prairies and by providing private land owners with incentive programs such as conservation easements. For example, the US Fish and Wildlife Service (USFWS) lists restoration of coastal prairies as one of its top priorities in the Gulf coast area. A few national wildlife refuges including Anahuac, Aransas, Attwater, Brazoria, Cameron Prairie, Lacassine, and Sabine are restoring and managing prairie on federal lands.

The Coastal Prairie Conservation Initiative is a partnership between the USFWS, the US Department of Agriculture's Natural Resources Conservation Service, local soil and water conservation districts, and private landowners along the middle and upper Gulf coast region of Texas. Their goals are to conserve and restore the coastal prairie ecosystem, reintroduce captive-bred Attwater's Prairie Chickens on private lands, and provide private landowners with incentives directed at coastal prairie conservation.

The US Geological Survey's National Wetlands Research Center (NWRC) is dedicated to management and restoration by providing assistance to land managers for the revegetation, restoration, and management of the Gulf coast prairie. Projects include providing information on planting procedures of native grasses, effects of natural and prescribed fire, and control and management of the Chinese tallow tree.

The coastal prairie is a unique and vital habitat that has almost vanished within the last 100 years. Future restoration efforts must focus not only on replanting native species but also on controlling invasive species and encroachment by urban sprawl and agriculture.

The Mission-Aransas NERR works with its land owning partners to conduct restoration projects. Due to the mission and capacity, the Reserve is not able to be the lead agency on restoration projects but works with partners to facilitate restoration efforts. Key partners include USFWS, Fennessey Ranch, TPWD, and CBBEP. For example, Mission-Aransas NERR partners with TAMU-College Station to assist them with identifying areas for restoration research specifically at Fennessey Ranch. Fennessey Ranch is trying to maintain native prairies by managing huisache, i.e., cutting, treating, and burning. The vegetation monitoring that is completed provides pre- and post-habitat information for upland areas that can be used to assess the effectiveness of the burn.

Prescribed fire is the primary management tool used to help wintering Whooping Cranes at Aransas. Since the 1980's, Aransas has been burning several units annually on the Blackjack Peninsula and Matagorda Island for the cranes. The Refuge fire program had made great progress in recent years renovating upland pastures that had become overrun with brush. Management tools used were rollerchopping and conducting summer prescribed burns (USFWS, 2011).

One of the largest and highest-quality expanses of coastal tallgrass prairie remaining in Texas is the Refugio-Goliad Prairie, which spans 500,000 acres along the Gulf Coast between Houston and Corpus Christi in a triangle bounded by the towns of Victoria, Goliad, and Refugio. While some of the coastal tallgrass prairie is intact, these grasslands need careful management to thrive. The Coastal Prairie Conservation Initiative (CPCI) was formed in 1998 to restore habitat and maintain the economic viability of agricultural lands. The partnership includes private landowners, the Grazing Land Conservation Initiative, the US Fish and Wildlife Service, Texas Parks and Wildlife Department, the Natural Resource Conservation Service, a division of the US Department of Agriculture, and the Conservancy. The CPCI offers assistance to landowners who want to conduct prescribed burns on their land and combat invasive species. It also assists ranchers in developing grazing and habitat management plans (The Nature Conservancy, 2011).

Oak Motte Management

Proper management for maintaining or improving live oaks includes: (1) avoiding destruction of live oak trees, (2) avoiding fragmentation of live oak forests, (3) placing roads around live oak mottes, (4) avoiding construction of unnecessary roads, and (5) being careful when applying herbicides. Live oak forests near the coast are particularly vital for migrating and nesting birds, therefore avoiding damage to these forests is essential. Live oak forests and mottes should be a high priority for conservation because of their significant role in the ecology of South Texas and their importance for a broad variety of wildlife (Fulbright, 2008).

Within Aransas County live oak trees are protected from clear cutting by ordinance 1-2010. Before removing any live oak tree, a tree plan application must be filed with and approved by the Aransas County Environmental Department. This ordinance applies to trees six inches or more in diameter determined at four feet above ground level. Trees may be removed if they are found to be hazardous, causing damage from root systems, within power line easements, or cause other safety problems. If a live oak is removed it is to be replaced by two to five trees depending on the height of the tree removed.

Conservation and Protection of Spoil Islands

Maritime commerce is vital and essential for the region's economy. Dredging is required to maintain the region's navigation channels and keep maritime commerce flowing safely. Until the 1970s, almost all of the dredged material excavated in channel construction and maintenance was placed in unconfined areas, generally a short distance from the channel. This creation of spoil islands covered large areas of shallow bay bottoms, creating either short-term or permanent disruption of biological productivity in these areas.

Despite losses of bay bottom habitat, dredged material placement has produced notable environmental enhancements, including the creation of nesting habitat on the islands. Pelican Island, created by dredged material, is the largest Brown Pelican nesting area in Texas.

The CCBEP is working with partners to examine the benefits of dredged material. Beneficial uses of dredged material include habitat creation or renourishment or shore protection against erosive wave energy. The Port of Corpus Christi Authority in conjunction with the Corps of Engineers and other stakeholders are supported by CCBEP to achieve a consensus on a long-term dredged material management plan that will make use of sound dredging practices and maximize the beneficial use of dredge material (CBBEP, 1998).

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Chapter 12 ENDANGERED SPECIES

Colt Cook, Sally Morehead Palmer

The Texas Parks and Wildlife Department (TPWD) and the US Fish and Wildlife Service (USFWS) provide lists of threatened and endangered species that may occur in the Mission-Aransas NERR (Table 12.1). Species listed by the USFWS have confirmed sightings in Nueces, Refugio, Aransas, San Patricio, or Calhoun County. Statewide or area-wide migrants are also included. Inclusion in the list does not imply that a species is known to occur in the Reserve, but only acknowledges the potential for occurrence. State-endangered or threatened species have no legal status under federal law and are not protected under the Endangered Species Act. The information in this chapter is from the Texas Parks and Wildlife Department, Wildlife Facts Sheets (TPWD, 2009).

Table 12.1. USFWS and TPWD list of threatened and endangered species in the Mission-Aransas NERR.

Common Name	Scientific Name	USFWS	TPWD
Plants			
South Texas ambrosia	*Ambrosia cheiranthifolia*	E	E
Black Lace cactus	*Echinocerus reichenbachii var.albertii*	E	E
Slender rushpea	*Hoffmannseggia tenella*	E	E
Fish			
Opossum pipefish	*Microphis brachyurus*		T
Amphibians			
Sheep frog	*Hypopachus variolosus*		T
Black-spotted newt	*Notophthalmus meridionalis*		T
Reptiles			
American alligator	*Alligator mississipiensis*	TSA	
Loggerhead sea turtle	*Caretta caretta*	T	T
Texas scarlet snake	*Cemophora coccinea lineri*		T
Green sea turtle	*Chelonia mydas*	T	T
Leatherback sea turtle	*Dermochelys coriacea*	E	E
Indigo snake	*Drymarchon corais*		T
Speckled racer	*Drymobius margaritiferus*		T
Hawksbill sea turtle	*Eretmochelys imbricata*	E	E
Texas tortoise	*Gopherus berlandieri*		T
Kemp's Ridley sea turtle	*Lepidochelys kempii*	E	E

Northern cat-eyed snake	*Leptodeira septentrionalis septentrionalis*		T
Texas horned lizard	*Phrynosoma cornutum*		T
Mammals			
Gulf Coast jaguarundi	*Herpailurus yagouaroundi cacomitli*	E	E
Southern yellow bat	*Lasiurus ega*		T
Ocelot	*Leopardus pardalis*	E	E
Atlantic spotted dolphin	*Stenella frontalis*		T
Rough-toothed dolphin	*Steno bredanensis*		T
West Indian manatee	*Trichechus manatus*	E	E
Birds			
Texas Botteri's Sparrow	*Aimophila botterii texana*		T
White-tailed Hawk	*Buteo albicaudatus*		T
Zone-tailed Hawk	*Buteo albonotatus*		T
Northern Beardless-tyrannulet	*Camptostoma imberbe*		T
Piping Plover	*Charadrius melodus*	E, T	T
Reddish Egret	*Egretta rufescens*		T
American Yellow-tailed Kite	*Elanoides forficatus*		T
Northern Aplomado Falcon	*Falco femoralis septentrionalis*	E	E
American Peregrine Falcon	*Falco peregrinus anatum*		T
Whooping Crane	*Grus americana*	E, EXPN	E
Bald Eagle	*Haliaeetus leucocephalus*	DM	T
Wood Stork	*Mycteria americana*		T
Eskimo Curlew	*Numenius borealis*		E
Rose-throated Becard	*Pachyramphus aglaiae*		T
Brown Pelican	*Pelecanus occidentalis*	DM, E	E
White-faced Ibis	*Plegadis chihi*		T
Least Tern	*Sterna antillarum*	E	E
Sooty Tern	*Sterna fuscata*		T
Attwater's Greater Prairie Chicken	*Tympanuchus cupido attwateri*	E	E

1 USFWS: E - Endangered; T - Threatened; DM- Delisted Taxon, recovered, being monitored first five years; EXPN - Experimental population, non-essential; TSA - Threatened due to similarity of appearance. Texas American alligator hides and parts are protected because of similarity of appearance to protected crocodilians (USFWS website)

2 TPWD: E - Endangered; T - Threatened (TPWD Website)

South Texas Ambrosia *(Ambrosia cheiranthifolia)*

Currently, this species occurs at six locations in Nueces and Kleberg County. South Texas ambrosia is an erect, silvery to grayish-green, perennial, herbaceous plant, 10 to 30 cm (4 to 12 in) tall. This ambrosia blooms in late summer and fall, but its flowers are not showy and may be missed by the casual observer. It may occur in association with slender rushpea, which is also federally listed as endangered. South Texas ambrosia occurs in open grasslands or savannas on soils varying from clay loams to sandy loams. Associated native grasses found at the existing sites include Texas grama *(Bouteloua rigidiseta*), buffalograss *(Bouteloua dactyloides*), Texas wintergrass *(Nassella leucotricha*), and tobosa *(Hilaria mutica*). Native woody species found scattered throughout the existing sites include mesquite *(Prosopis* sp.), huisache *(Acacia smallii*), huisachillo *(Acacia tortuosa*), granjeno *(Celtis pallida*), and lotebush *(Ziziphus obtusifolia*). While South Texas ambrosia does not appear to survive continual plowing, sporadic disturbance may enhance its growth and spread.

Black Lace Cactus *(Echinocereus reichenbachii* var. *albertii)*

There are known populations of the black lace cactus located in the county of Refugio. Black lace cactus is found in grassy openings on South Texas rangeland invaded by mesquite and other shrubs. The outer spines are straight and white with dark purple tips and resemble teeth in a comb. The stems are 3 to 15 cm (1-6 in) tall and 3 to 5 cm (1-2 in) wide. The black lace cactus blooms pink and purple flowers (5-8 cm wide) from April to June producing fruit after the blooms fall off. As the small, spiny, green fruits ripen, the seeds fall or are washed to the ground by the rain. This plant is endangered because its rangeland habitat has been cleared or planted for crops and people have uprooted them to take home or sell for their large, attractive flowers.

Slender Rushpea *(Hoffmannseggia tenella)*

Currently, the slender rushpea has four populations in Nueces and Kleberg counties. Slender rushpea is a perennial legume, 8 to 16 cm (3-6 in) tall, with spreading stems. Its leaves are twice compound, with 3-7 primary divisions each with 5-6 pairs of leaflets. The slender rushpea's tiny blooms are produced between early March and June, and sporadically thereafter depending on rainfall. Slender rushpea may be particularly susceptible to competition from non-native grass species such as King Ranch bluestem *(Bothriochloa ischaemum* var. *songarica*), Kleberg bluestem *(Dichanthium annulatum*), and bermuda grass *(Cynodon* spp.). Mowing at a sufficient height and at appropriate times may not be detrimental to this species; however, mowing during reproductive stages should be avoided. Conversion of coastal prairie habitat to other land uses is likely the most important factor contributing to the decline of slender rushpea. Slender rushpea grows on clay soil of blackland prairies and creek banks in association with short and midgrasses such as buffalograss *(Bouteloua dactyloides*), Texas wintergrass *(Nassella leucotricha*), and Texas grama *(B. rigidiseta*). Woody plants such as mesquite *(Prosopis* sp.), huisache *(Acacia smallii)*, huisachillo *(Acacia tortuosa*), spiny hackberry *(Celtis ehrenbergiana*), bridal broom *(Retama monosperma*), lotebush *(Ziziphus obtusifolia*), tasajillo *(Cylindropuntia leptocaulis*), and prickly pear *(Opuntia* spp.) are also common at the known sites.

Leatherback, Hawksbill, and Kemp's Ridley Sea Turtle

The distribution range of the leatherback, hawksbill and Kemp's Ridley sea turtles includes the coastal waters and bays of the Gulf of Mexico, and these species can be found throughout the Reserve.

The leatherback *(Dermochelys coriacea*) is the largest of all sea turtles, with weights up to 590 kg

(1,300 lbs) and a carapace length up to 2.5 m (8 ft). This turtle is unique because of the smooth leathery skin covering its carapace. Adult leatherbacks can be distinguished from all other species of sea turtles by their large size, spindle-shaped bodies, and leathery, unscaled carapaces. Research on captive turtles indicates that leatherbacks grow faster than any other marine turtle. These giant turtles live on average 30 years and can live up to 50 years or more. Adults are believed to reach sexual maturity between three and four years of age, although the age at which wild turtles reach maturity may be greater. Unlike most sea turtles, which nest in the spring and summer, leatherbacks usually nest in fall and winter. They arrive at the nesting beaches in large groups, forming "arribazones", where groups of females move onto the beach to lay their eggs over a period of a few days. The leatherback prefers the open ocean and moves into coastal waters only during the reproductive season. Although small groups may move into coastal waters following concentrations of jellyfish, these turtles seldom travel in large groups. Leatherbacks inhabit primarily the upper reaches of the open ocean, but they also frequently descend into deep waters from 200 to 500 m in depth.

The hawksbill sea turtle *(Eretmochelys imbricata*) is a small to medium sized turtle with shell lengths up to 91 cm (36 in) and can live from 30-50 years. Adults mate every two to three years during the nesting period, generally April through November, off the nesting beaches. Hawksbill turtles nest primarily at night, but there are reports of daytime nesting, usually on uninhabited beaches. Hawksbill turtles live in clear offshore waters of mainland and island shelves. They are the most tropical of all sea turtles and are more common around coral reef formations.

Although many sea turtle species are in danger, the Kemp's Ridley sea turtle *(Lepidochelys kempii*) is the most endangered species worldwide. Kemp's Ridley sea turtles grow to 69 to 80 cm (27-32 in) long and weigh on average 34 to 45 kg (75-100 lbs). Distinguishing characteristics include a dark gray to gray-green carapace (upper shell), cream to tan plasteron (lower shell), streamlined shells, and appendages shaped like flippers. The turtle's dark, spotted head and flippers contrast sharply with its pale body. The male Kemp's Ridley spends its entire life in the water while the female only comes ashore to nest, sometimes joining large groups of nesting females called arribazones. A female will only lay eggs during the day and she will come back to the same beach to nest year after year. The Kemp's Ridley prefers open ocean and gulf waters with the females only coming ashore to lay eggs in beach sand. Young Kemp's Ridley sea turtles can be found in coastal waters and bays and floating on large mats of sargassum (a type of brown algae) in the Gulf of Mexico and Atlantic Ocean.

Gulf Coast Jaguarundi *(Herpailurus yagouaroundi cacomitli)*

The jaguarundi is slightly larger than a domestic cat, weighing four to seven kg (8 - 16 lbs) and can live 16 to 22 years in captivity. Its coat is a solid color, either rusty-brown or charcoal gray. Jaguarundis eat birds, rabbits, and small rodents, hunting during early morning and evening. Although jaguarundis hunt mostly on the ground, they also climb trees easily and have been seen springing into the air to capture prey. They are solitary except during the mating season of November and December. Jaguarundis are active mainly at night, but also move around during the day, often going to water to drink at midday. Jaguarundis are endangered because the dense thorny shrubland that provides habitat has been cleared for farming or urbanization. Jaguarundis still exist in Mexico, but they are now very rare in Texas.

Ocelot *(Leopardus pardalis)*

The ocelot is a species of wild cat that grows to approximately 76 to 100 cm (30-41 in) long, weigh seven to 14 kg (15-30 lbs), and can live 20 years in captivity. Ocelots have cream colored fur with reddish-brown spots outlined in black and two stripes extending from the inside corner of the eyes and over the back of the head. Ocelots are carnivores and hunt rabbits, small rodents, and birds at night, and rest in the brush during the day. They live within an area (home range) of about 1 to 4 mi^2. Females prepare a den for their kittens in thick brush. Ocelots are endangered because their habitat has been cleared for farming and urbanization. In 1995 it was estimated that 80 to 120 individuals lived in Texas. Now only about 30 to 40 ocelots live in the shrublands remaining at or near the Laguna Atascosa National Wildlife Refuge near Brownsville, Texas. Dense, thorny, low brush such as spiny hackberry *(Celtis ehrenbergiana*), lotebush *(Ziziphus obtusifolia*), and blackbrush *(Coleogyne ramosissima*) offer the ocelot the best habitat. Historical records indicate that the ocelot could be found throughout South Texas, the southern Edwards Plateau, and along the Coastal Plain. Today, its range is the South Texas brush country and lower Rio Grande valley.

West Indian Manatee *(Trichechus manatus)*

West Indian manatees are large, grayish, nearly hairless, aquatic mammals without hind limbs, a tail broadened into a horizontal, rounded paddle, and front paddlelike limbs. Near the turn of the century manatees were not uncommon in the Laguna Madre, however, manatees are now extremely rare in Texas waters. Texas records also include specimens from Cow Bayou, near Sabine Lake, Copano Bay, the Bolivar Peninsula, and the mouth of the Rio Grande. West Indian manatees occur chiefly in the larger rivers and brackish water bays although they are able to live in salt water. They are extremely sensitive to cold and may be killed by a sudden drop in water temperature to as low as 8ºC, which limits their northward distribution in North America. Their irregular occurrence along the Texas coast suggest that they do considerable wandering; specimens from Texas probably represent migrants from coastal Mexico.

Pair of Whooping Cranes at ANWR

Whooping Crane *(Grus americana)*

One of the most well-known endangered species that inhabits the Mission-Aransas NERR is the Whooping Crane. This species winters along the south Texas coast at the Aransas National Wildlife Refuge (ANWR). Historically, the winter range of the Whooping Crane extended from Mexico to Louisiana. Extremely low populations of this species were first noticed in the late 1930's. The ANWR was established in 1937 and the Whooping Crane is making a comeback from a low of 15 birds in 1941 to 270 individuals in 2009 (Stehn, 2009). Critical habitat of Whooping Cranes, as determined by USFWS, within the Mission-Aransas NERR is centered in the ANWR, Matagorda Island, and extends to the northern tip of San Jose Island (Figure 12.1).

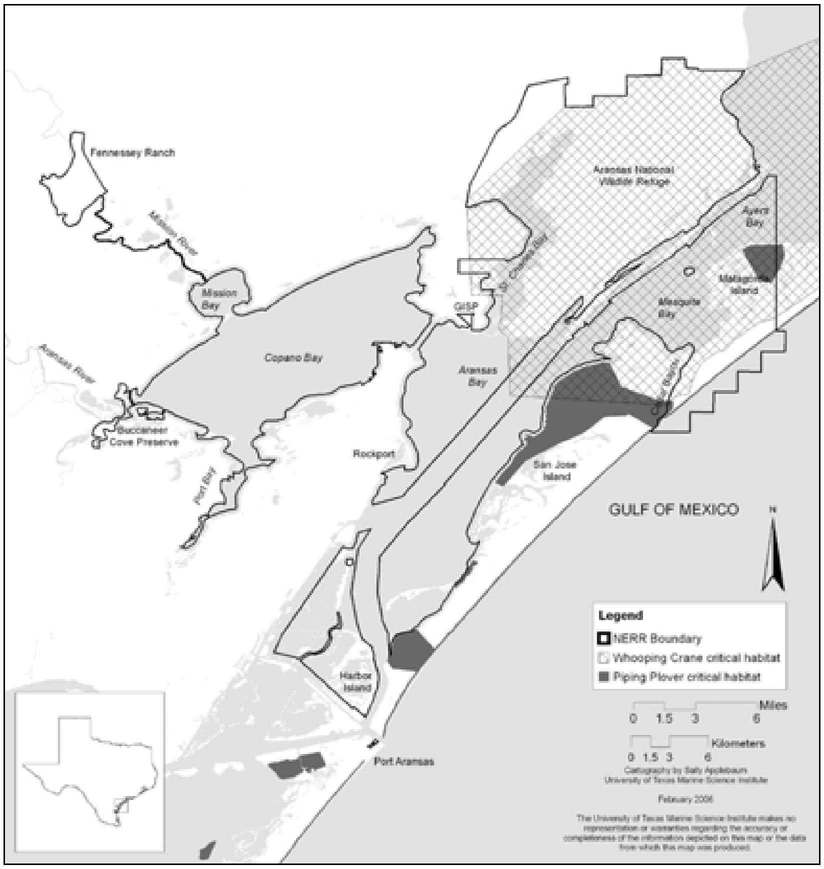

Figure 12.1. Critical habitats of Whooping Cranes and Piping Plovers.

Piping Plover *(Charadrius melodus)*

The Piping Plover is a threatened species in the Reserve area. The Piping Plover is a small shore bird, about 18 cm (7 in) long with a 38 cm (15 in) wingspan, who lives on sandy beaches and lakeshores. Distinguishing characteristics include sandy-colored feathers with grayish-brown crowns and backs, white foreheads, and dark bands across their crowns. They are small, stocky, sandy-colored birds that resemble sandpipers, with short, stubby bills. There are just over 5,000 known pairs of breeding Piping Plovers. Piping Plovers migrate through the Great Lakes along the river systems through the Bahamas and West Indies. Gulf Coast beaches from Florida to Mexico and Atlantic coast beaches from Florida to North Carolina provide winter homes for plovers. Texas is the wintering home for 35 percent of the known populations of Piping Plovers. They begin arriving in late July or early August, and will remain for up to nine months. Critical habitat of Piping Plovers, as determined by the USFWS, includes locations on barrier islands, i.e., San Jose, Matagorda, and Mustang Islands (Figure 12.1).

Northern Aplomado Falcon *(Falco femoralis)*

Aplomado Falcons are listed as endangered by both USFWS and TPWD. They have a steel grey back, red breast, black sash on their belly, and striking black markings on the top of their head, around the eyes, and extending down the face.

These falcons are most often seen in pairs, who work together to find and flush prey out of cover. Aplomado Falcons do not build their own nests, but use stick nests built by other birds. They are fast fliers, and often chase prey animals as they try to escape into dense grass. Parents make 25-30 hunting attempts per day in order to feed their young, who are fed 6 or more times each day. Aplomado Falcons are endangered because their grassland habitat have been altered by overgrazing, brush invasion, and agriculture destroying large areas of habitat. Contamination from pesticides entering the food chain has also reduced the number of Aplomado Falcons.

Brown Pelican *(Pelecanus occidentalis)*

The Brown Pelican is a well-known endangered bird species that is present within the Reserve. It is the smallest of the eight species of pelican: 100 to 137 cm (42 - 54 in) long, 3 to 6 kg (6-12 lbs), with a wingspan of 2 m (7 ft). Brown Pelican populations began declining in the 1930's, and numbers dropped dramatically between 1952 and 1957 (Tunnell et al., 1996). Less than 100 individuals were believed to be present on the Texas coast from 1967 to 1974, due to hurricanes, disease, and pesticides (King et al., 1977). Populations have been increasing since the 1970's and the increase is correlated with the discontinued use of DDT in 1972 and conservation efforts. The primary nesting sites for Brown Pelicans are located on the outskirts of the Reserve on Sundown Island in Matagorda Bay and on Pelican Island in Corpus Christi Bay (Tunnell et al., 1996).

Least Tern *(Sternula antillarum)*

Least Terns are the smallest North American tern. Adults average 20 to 25 cm (8-10 in) long with a 50 cm (20 in) wingspan. Breeding adults are gray above and white below, with a black cap, black nape and eye stripe, white forehead, yellow bill with a black or brown tip, and yellow to orange legs. Hatchlings are about the size of ping pong balls and are yellow and buff with brown mottling. Fledglings are grayish brown and buff colored, with white heads, dark bills and eye stripes, and stubby tails. Interior Least Terns arrive at breeding areas from early April to early June, and spend 3 to 5 months on the breeding grounds. Least Terns nest in colonies, where nests can be as close as 3 m but are often 9 m or more apart. The nest is a shallow depression in an open, sandy area, gravel patch, or exposed flat. In portions of the range, shorebirds such as the piping and Snowy Plovers often nest in close proximity. The Interior Least Tern is migratory, breeding along inland river systems in the United States and wintering along the Central American coast and the northern coast of South America from Venezuela to northeastern Brazil.

Attwater's Prairie Chicken *(Tympanuchus cupido attwateri)*

The Attwater's Prairie Chicken is a small, brown bird about 43 cm (17 in) long, with a short, rounded, dark tail. Males have large orange air sacs on the sides of their necks. During mating season, males make a "booming" sound, amplified by inflating the air sacs on their necks that can be heard half a mile away. Attwater's Prairie Chickens live on coastal prairie grasslands with tall grasses such as little bluestem *(Schizachyrium scoparium)*, Indian grass *(Sorghastrum nutans)*, and switchgrass *(Panicum virgatum)*. The birds like a variety of tall and short grasses in their habitat. They gather to choose a mate in an area of bare ground or short grass where the males can be easily seen by the females. Hens build their nests in tallgrass and usually lay 12 eggs during nesting season, which hatch in April or May. Small green leaves, seeds, and insects form the diet of the Attwater's Prairie Chicken. Attwater's Prairie Chickens live about two to three years in the wild and are found only on the coastal prairies of Texas, which are essential to the survival of this species. Prairie chickens are endangered because the tallgrass prairie has been plowed for farmland and urbanization. Habitat has also been lost because of heavy grazing by cattle, although some cattle ranches maintain good grassland habitat suitable for prairie chickens. Their population has declined dramatically since 1993, when an estimated 456 Attwater's Prairie Chickens existed in the wild. In 1994, that estimate dropped to 158 birds. By 1996, only 42 of these rare birds were left; however, in 2009, it was reported that due to successful breeding there were 90 birds.

Issues of Concern for Endangered Species

Land Protection

Land protection plays a major role for conserving habitat for endangered species. The Texas Nature Conservancy (TNC) works to protect key areas with conservation easements placed on buffer areas as a means for people and wildlife to coexist (Stehn, 2010). A new federal land protection program by the National Resources Conservation Service (NRCS) is able to offer approximately $1,700 an acre for conservation easements. The NRCS is now recognizing salt marsh as habitat important for waterfowl and using funds to protect coastal marshes (Stehn, 2010). Locally, the Whooping Crane is an emphasized species. In 2009, the CBBEP moved to protect 168 acres of salt marsh just south of Holiday Beach that is occupied by Whooping Cranes. The TPWD worked with CBBEP to apply and receive a section 6 grant to purchase the tract (Stehn, 2010).

Habitat Loss

Habitat loss is a big threat to resident plants and animals. Endemic species have limited ranges that are most affected by habitat destruction. In the Mission-Aransas NERR, a growing coastal population is a big threat, which can lead to a loss in habitat for urban or agricultural land. Consequences of land use changes can be decreases in biodiversity and altering animal behavior and plant reproductive ecology.

Future Plans for Endangered Species

The Mission-Aransas NERR does not have many research opportunities that directly research the abundance or populations of endangered species. These research opportunities are usually completed by the USFWS. However the Reserve does have monitoring programs that support efforts of partners (USFWS and other land owners) in managing the resources that these species depend upon.

Animal Rehabilitation Keep (ARK)

The Animal Rehabilitation Keep (ARK) at UTMSI rehabilitates birds, sea turtles, terrestrial turtles, and tortoises. The ARK also deals with stranded sea turtles and marine mammals along with Sea Turtle Stranding and Salvage Network and the Texas Marine Mammal Stranding Network. The activities at the ARK support conservation and restoration of endangered birds and sea turtles in the area. The mission of the ARK is to (1) rescue and rehabilitate wildlife found sick or injured in the area adjacent to and including Mustang, San Jose, and Padre islands, including the Mission-Aransas NERR, Corpus Christi Bay, and the Upper Laguna Madre, (2) to release recovered animals back to their native habitat, and (3) educate public about problems of local wildlife and the increasing human population and development, (4) increase knowledge on care and treatment of animal patients using up-to-date wildlife techniques to increase release success rates, and (5) improve facilities to ensure proper conditions for year-round care of turtles and birds.

Whooping Crane Conservation

Whooping Cranes are the rarest crane species unique to North America (ANWR, 2011). The only natural wild flock nests in Wood Buffalo National Park in the Northwest Territories of Canada. They migrate south to winter at the Aransas National Wildlife Refuge, usually arriving by December. Threats to the flocks include land and water development in Texas, the spread of black mangrove on the wintering grounds, the long-term decline of blue crab populations in Texas, sea level rise/land subsidence, and wind farm and power line construction (ANWR, 2011). The Aransas National Wildlife Refuge provides protected areas to ensure the survival of wintering Whooping Cranes. The Whooping Crane Habitat Protection Project was launched in 2006 by the Nature Conservancy of Texas, and includes a partnership with the Texas General Land Office, US Fish and Wildlife Service, Texas Parks and Wildlife, and the Bi-National Whooping Crane Recovery Team. Through the purchase of selected land tracts and conservation easements, permanently protected coastal habitat is being secured for the cranes.

Blue Crab Research

Blue crabs are the Whooping Cranes' primary food. When water inflows from rivers are high blue crabs are abundant. However, as more water is being taken up by growing cities and periods of drought extend, water inflows will decrease, which will cause a decrease in blue crab populations (Stehn, 2010). The GSA BBEST recognized the need for more research on the habitat condition versus salinity requirements of focal species like the blue crab. Scientists and stakeholders at the *Blue Crab Workshop*, hosted by the Mission-Aransas NERR, also identified a need to better understand the role of recruitment of blue crab larvae and newly settled juveniles as the recently observed population declines. A proposed project is in the works which would try to determine seasonal patterns of abundance and physical mechanisms regulating megalopal ingress through Aransas Pass inlet into the Estuary. This research would also assess (1) the relative abundance of megalopae outside the Aransas Pass inlet, in the Aransas pass channel, and in Aransas Bay, (2) the relative timing of settlement among different locations, and (3) determine seasonal and spatial trends in abundance of early juvenile blue crabs in the Mission-Aransas Estuary.

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Chapter 13 HUMAN DIMENSION

Sally Morehead Palmer and Carolyn Rose

The human dimensions of our environment greatly influence the effectiveness of coastal management. Human dimensions are characterized by the social, cultural, economic, and political aspects of our surrounding environment. Changes to these aspects influence human perception and behaviors, which affect resource management decisions. An examination of the human dimensions can provide a better understanding of not only resource flow, but also how human perception and behaviors are linked to resource flow. This knowledge can be used to develop decision support tools that will increase state and local managers' capacity to address the human dimensions of coastal management.

Social patterns and land/water uses of counties within the watershed that drain into the Mission-Aransas NERR greatly affect water quality and health of the Mission-Aransas Estuary. The current population dynamic is small, rural communities transitioning into densely populated urban areas along the coast. The counties that lie within the watershed of the Reserve are Aransas, Refugio, Calhoun, Nueces, San Patricio, Karnes, Goliad, Bee, and Live Oak. Five of these counties, Aransas, Refugio, Calhoun, Nueces, and San Patricio, contain land and water within the Mission-Aransas NERR boundary.

The majority of the counties in the Reserve receive their water supply from surface water resources (TWDB, 2007). The cities and towns in the Mission-Aransas NERR region are largely served by the city of Corpus Christi and groundwater (well water) systems. The city of Corpus Christi operates two dams on the Nueces River, and is the major water wholesaler to municipal and county water resellers. The majority of the surface water is used to supply municipalities and manufacturing, but groundwater supplies are also a source of water for the Reserve (Table 13.1). The Reserve's watershed lies above the vast Gulf Coast Aquifer, which stretches the length of the entire coastal plain of Texas.

Table 13.1. Water use estimates for Reserve counties from Texas Water Development Board's water survey. Data is provided for surface water uses from 2007 and data for ground water estimates are from 2003 (http://www.twdb.state.tx.us/wushistorical./). Surface use estimates are in acre-feet[1] (groundwater use estimates are in parenthesis).

County	Municipal	Manufacturing	Mining	Steam Electric	Irrigation	Livestock
Aransas	3042 (153)	149 (21)	0 (81)	0 (0)	0 (0)	71 (26)
Calhoun	2575 (299)	38452 (0)	0 (28)	0 (0)	12270 (0)	327 (263)
Nueces	50429 (1923)	35713 (2181)	230 (49)	1653 (0)	716 (0)	198 (281)
Refugio	1017 (993)	0 (0)	0 (6)	0 (0)	439 (0)	557 (582)
San Patricio	10594 (3468)	13202 (8)	0 (192)	1797 (0)	6395 (7095)	271 (583)

Figure 13.1. Watershed sub-basins that drain into the Mission-Aransas NERR. The Mission River sub-basin is Hydrologic Unit Codes (HUC) 12100406 and the Aransas River sub-basin is HUC 12100408.

Five small watershed sub-basins drain into the Reserve and are hereafter referred to as the Mission-Aransas NERR watershed (Figure 13.1). The largest sub-basins in the area drain the Mission and Aransas rivers. The Mission and Aransas rivers are small and primarily coastal compared to other rivers in Texas. Neither the Mission River nor the Aransas River has dams, or are used as water supplies for cities in the region.

Texas law (first passed in 1957) ensures that sufficient flows are maintained for "the maintenance of productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent" (Texas Water Code, ' 11.147). In 2007, the Texas legislature adopted Senate Bill 3, which requires all Texas watersheds to develop a plan to regulate freshwater inflows to the coast. Two groups have been tasked with recommending an environmental flow regime that supports a sound ecological environment and maintains the productivity, extent, and persistence of key habitats for each bay-basin system. These groups include the Bay-Basin Stakeholder Committee and the Bay-Basin Expert Science Team.

The Mission-Aransas Estuary is one of the few estuaries on the Texas coast that still receives sufficient inflows of surface fresh water to maintain a healthy ecosystem. The National Wildlife Federation recently published a report that described the health of Texas estuaries based on full use of existing freshwater permits (Johns, 2004). Out of the seven bay systems studied, Mission-Aransas Estuary was one of two bay systems that received a good ranking. Existing water use permits for the Mission and Aransas rivers authorize 1,900 acre-feet of surface water diversions. At the current time, surface waters in Mission and Aransas rivers are not at risk, however, future growth of south Texas cities will require additional water resources (Johns, 2004). This is one reason why characterization of the community will be invaluable for resource managers.

Land Use

Patterns of land use indicate the spatial extent of human alteration and can be a valuable tool in determining how the natural resources in the area are utilized by humans. In particular, land use can help explain non-point source pollution, patterns of natural habitat, water quality, aesthetic characteristics of developed lands, and can also help identify areas for conservation.

The state of Texas is primarily comprised of rangeland in the west, forested land in the east and central areas, and agricultural land in the panhandle and the west (Morehead et al., 2007). The northern coast of Texas is mostly agricultural while the southern coast is primarily rangeland. The sub-basins of the Mission-Aransas NERR are primarily comprised of forested land and rangeland (Figure 13.2). At a closer look, San Patricio and Bee County have high percentages of agricultural land in the sub-basin (HUC 1200407) that drains the Aransas River into Copano Bay. Bee, Goliad, and Refugio counties primarily have forested and rangeland within the sub-basin (HUC 1200406) that drains the Mission River into Copano Bay. The urban areas are primarily confined to cities such as Corpus Christi, Rockport/Fulton, and Sinton. The land adjacent to the Mission-Aransas NERR is largely rural with low populations (Table 13.2).

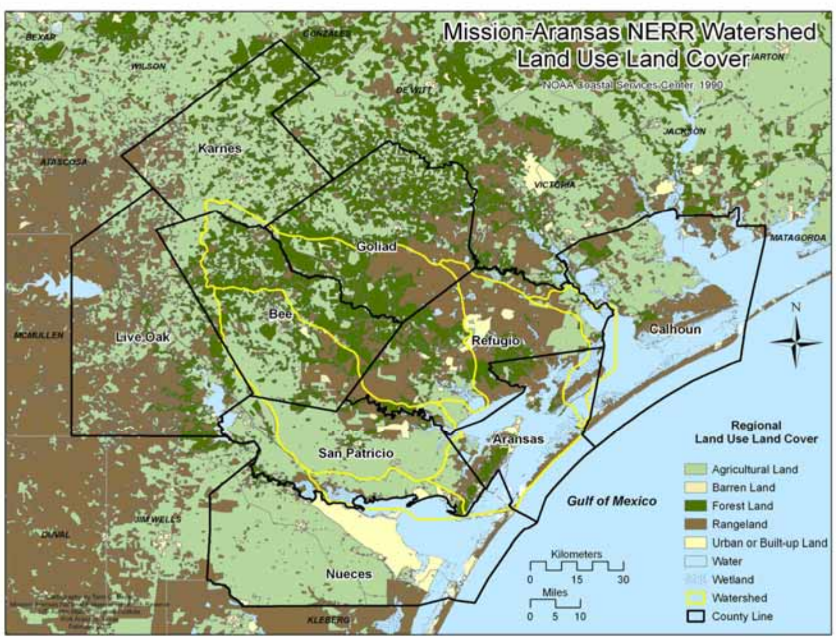

Figure 13.2. Land use/land cover information for the Mission-Aransas NERR watershed.

Table 13.2. Estimated population density in counties surrounding the Mission-Aransas Estuary. Data generated from the US Census Bureau, www.census.gov.

County	2008 Population Estimate	Area, Square Miles	Persons per Square Mile
Aransas	24,900	252	99
Calhoun	20,406	512	40
Refugio	7,350	770	10
San Patricio	68,399	692	99
Nueces	322,077	836	384
State of Texas	24,326,974	261,797	93

San Patricio County encompasses a very small portion of the Mission-Aransas NERR including Buccaneer Cove Preserve and the southern tip of Port Bay. The Aransas River watershed includes Chiltipin Creek and other unnamed tributaries which drain approximately two-thirds of San Patricio county including the cities of Sinton, Odem, and Taft. This drainage includes more than 250,000 acres of intensely managed cotton, grain, and sorghum row crop farms. Some of the Aransas River watershed lies within the land holdings of the Welder Wildlife Foundation (7,800 acres), whose primary purpose is wildlife management and conservation.

In contrast, Aransas County has the highest percentage of both bare and developed lands. Most bare lands in this area are delineated as bay shoreline beaches, creating a significant tourism focus in the county and extensive urban development. Refugio has the most rural land use with the majority of land identified as agriculture or ranching. Limited urban development is centered in and around the towns of Refugio, Woodsboro, Bayside, Tivoli, and Austwell. Like San Patricio County, Nueces County encompasses a very small portion of the Mission-Aransas NERR, including the University of Texas Marine Science Institute property located in the city of Port Aransas. The city of Corpus Christi, also located in Nueces County, has a 2008 population of over 280,000 and is the largest city in the area and as a result, the Nueces Estuary generally has more anthropogenic activities than the Mission-Aransas Estuary (Montagna et al., 1998). The Port of Corpus Christi is the seventh largest port in the United States, making marine transportation a dominant industry in the area (US Port ranking by cargo volume for 2005). The Port houses several facilities including liquid bulk docks, cargo terminals, Rincon Industrial Park, Ortiz Center, and a cold storage terminal. All ship traffic enters through Aransas Pass, which lies just south of Mission-Aransas NERR.

Table 13.3. Annual economic estimates for the state of Texas of primary uses within the Mission-Aransas NERR.

Industry	Amount	Estimated Value	Year and Source
Commercial Finfish	5,620,000 lbs	$10,585,000	2004, TPWD
Commercial Shellfish	42,096,000 lbs	$117,583,000	2004, TPWD
Gulf Intracoastal Waterway shipping	>74,160,000 short tons	>$25,000,000,000	2006, TxDOT Legislative Report 2007-2008
Oil Production	551,202,120 bbl	$1,436,879,156 in tax	2008, RRC and Texas Comptroller
Gas Production	10,821,861,433 mcf	$2,684,647,510 in tax	2008, RRC and Texas Comptroller

The primary industries within the Mission-Aransas NERR include oil and gas activities, recreational and commercial fishing, ground and surface water withdrawal, tourism, and shipping (Table 13.3). Estuaries along the Gulf of Mexico, including Texas, are rich in oil and gas deposits. Every estuary in the Western Gulf of Mexico Biogeographic Sub-region has oil and gas wells and pipelines. Most of the oil and gas reserves within the Reserve have been depleted; however, recent testing indicates that there is interest in deeper exploration and drilling in the area. As drilling technology continues to improve, deeper depths become prospective. As of 2007, the Mission-Aransas Estuary has a moderate number of oil and gas leases and production (Figure 13.3; Table 13.4).

The Mission-Aransas NERR has a large tourism economy due to accessible beaches, abundant recreational fishing opportunities, and a high diversity of bird species. In addition, recreational and commercial landings of finfish, shrimp, and shellfish appear to be on an upward trend. Abundance of finfish, shrimp, and blue crab harvests were nearly equal to each other from 1972 - 1976. After 1976, the percentage of finfish harvests began to decrease in relation to shrimp and blue crab harvests. From 1981 until the present, shrimp harvests increased in relation to finfish and blue crab harvests, and are now the major fishery for the Mission-Aransas Estuary (Robinson et al., 1994).

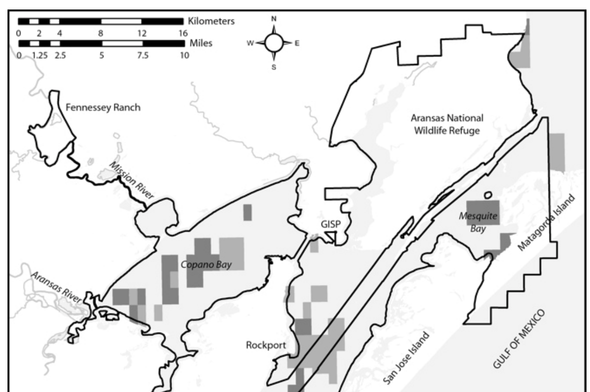

Figure 13.3. Active and producing oil and gas subleases.

Table 13.4. Number of active and producing leases and production of oil and gas wells in coastal Texas counties. (Leasing source: Texas General Land Office http://www.glo.state.tx.us/gisdata.html; Production source: Texas Railroad Commission http://www.rrc.state.tx.us/data/index.php). Abbreviations: Bbl=barrel (42 US gallons), Mcf=thousand cubic feet.

	Leasing for 2007		Production for 2008	
County	**Number of Leases**	**Total Acreage of Leases**	**Oil (Bbl)**	**Gas (Mcf)**
Jefferson	87	50,019	905,777	62,169,666
Chambers	127	43,835	747,786	9,015,249
Harris	7	892	1,403,604	23,340,257
Galveston	141	68,520	536,794	21,785,428
Brazoria	64	38,915	1,961,523	29,600,628
Matagorda	135	63,620	348,029	53,374,044
Calhoun	238	92,527	224,779	12,105,038
Aransas	122	42,064	83,362	11,647,407
San Patricio	1	231	405,021	18,926,354
Nueces	199	80,048	449,198	38,492,972
Kleberg	43	19,867	449,198	37,178,972
Kenedy	29	11,343	60,232	51,110,974
Willacy	3	785	392,827	23,934,691
Cameron	92	32,935	633	101,298

Archeological and Historical Use

Although it is estimated that humans have inhabited the area surrounding the Reserve for at least the last 12,000 years, evidence of the earliest inhabitants is scarce due to the post Pleistocene inundation of coastal archeological sites by global warming induced sea level rise. However, prehistoric human occupation of the area is well documented for the last 7,500 years, based on radiocarbon dating of archeological deposits. Data from these deposits indicate that from 7,500 to 4,200 years before the present (B.P.), prehistoric hunter-gatherers fished for estuarine-dependent shellfishes and fishes in local estuaries (Ricklis, 2004). The archeological evidence suggests that these people occupied cool-season estuarine fishing camps from fall through early spring and riverine hunting camps during the warmer months. Although there was apparently a brief hiatus in exploitation of estuarine resources after 4200 B.P., by 3100 B.P. exploitation of estuarine resources intensified dramatically. This intensification may have occurred as sea level stabilized, allowing the development of the modern estuarine environment (Ricklis, 2004). Several archaeological sites are located within and surrounding the site boundary (Hester, 1980; Ricklis, 1996) (Figure 13.4).

In 1528, the shipwrecked Alvar Núñez Cabeza de Vaca and his companions encountered native occupants of the central Texas Coast who were almost certainly Karankawas or their relatives (Ricklis, 1996; Krieger, 2002). This historic encounter is the earliest recorded contact between Europeans and native inhabitants of the Texas coast. Cabeza de Vaca's descriptions of the Indian's subsistence and seasonal mobility patterns match the patterns interpreted from the archeological data, lending evidence of a cultural link between the historic Karankawas and the prehistoric people who preceded them. The Karankawas navigated coastal bays in dugout canoes, from Matagorda Bay to Corpus Christi Bay, and exploited the seasonal offerings of the estuarine environment. They collected oysters and clams and fished for redfish, black drum, and spotted sea trout during the fall, winter, and early spring. During warmer months they moved further inland to hunt deer and collect plant foods along the rivers (Ricklis, 1996; Krieger, 2002). Despite their superb adaptation to the estuarine environment, the Karankawas eventually succumbed to the combined effects of European diseases, warfare, dispersal, and absorption into other native populations and they became culturally extinct by the mid-19th century (Ricklis, 1996).

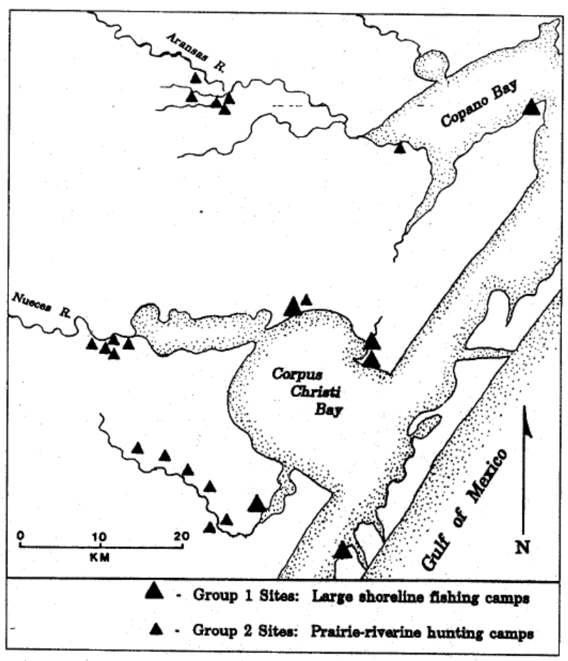

Figure 13.4. Locations of known large shoreline fishing camps (Group 1 sites) and smaller prairie-riverine camps (Group 2 sites) in the area. (From The Karankawa Indians of Texas: An Ecological Study of Cultural Tradition and Change by Robert A. Ricklis, Copyright 1996. Courtesy of the University of Texas Press)

The first European settlement in the Reserve area occurred with the development of Spanish missions on the central Texas coast during the early 18th century. In 1785, the Spanish established the port of El Copano on the northwestern shore of Copano Bay. El Copano became the main supply port for the Spanish settlements at Refugio, Goliad, and San Antonio. Early 19th century Texas colonists from Ireland and Mexico passed through the Port of El Copano en route to Spanish land grant settlements. The port was used by Mexicans and those fighting for Texas independence during the Texas Revolution and by blockade runners during the Civil War. As railroads gained prominence, the port of El Copano and the town that formed around it declined until the towns were abandoned in 1880 (Huson, 1935). The remains of the port and town of El Copano are located just outside the Reserve boundary.

Other sites of historical interest located within or near the Reserve boundary include the Lydia Ann Lighthouse and the remains of a 19th century brickyard. Originally known as the Aransas Pass Light Station, the Lydia Ann Lighthouse was established in 1855 and is listed on the National Register of Historic Places. The lighthouse is located on Harbor Island in the Lydia Ann Channel. It was seriously damaged during a Confederate attack in December 1862, which destroyed the top of the tower. It was rebuilt in 1867 and was decommissioned in 1952 (Holland, 1972). The current private owner had the light re-commissioned in 1988. Table 13.5 lists other archaeological sites presently known in the Mission-Aransas NERR.

The banks of the Cedar Bayou inlet, which separates San Jose Island from Matagorda Island, contain the remains of a 19th century brickyard. At this site, large complexes of brick kilns, huge open cisterns, and associated brick foundations are relics from the onset of the industrial age (Fox, 1983). Industrialization and development have continued in the site area, resulting in today's mixed economy that is driven by the diverse industries of tourism, agriculture, oil and gas, petrochemicals, and maritime shipping.

Table 13.5. Archaeological sites presently known in the Mission-Aransas NERR.

Location	Camp Type	Items Found
Mustang Lake (ANWR)	Large shoreline fishing and hunting camp	Shells, fish bones, pot shards, animal bones, perforated oysters, shell tools, chert flakes
North of Mustang Lake (ANWR)	Prairie-riverine hunting camp	Shells, fish bones, pot shards, animal bones, perforated oysters, shell tools, chert flakes
South of Mustang Lake (ANWR)	Prairie-riverine hunting camp	Shells, fish bones, pot shards, animal bones, perforated oysters, shell tools, chert flakes
Aransas River Mouth	Large shoreline fishing camps	Arrow points, small unifacial end scrappers, prismatic blades, pottery, Rangia clams, fish and animal bones
Moody Creek (Aransas R.) flood plain	Prairie-riverine hunting camps	Cultural debris, Rangia clams, fish and animal bones

Social Aspects of the Watershed

Population

Population growth is an important factor in determining anthropogenic impacts on the natural resources of the Mission-Aransas NERR and its surrounding area. Rapid population increases are a large concern among coastal communities because impacts associated with population growth (e.g., reduced flood control, increased pollution, subsidence, habitat loss) have tremendous impacts on the relatively sensitive adjacent estuarine systems. Although the watershed of the Mission-Aransas NERR has relatively low populations, it is predicted that populations will increase because the south Texas coast is one of the few coastal areas in the United States that remains relatively undeveloped.

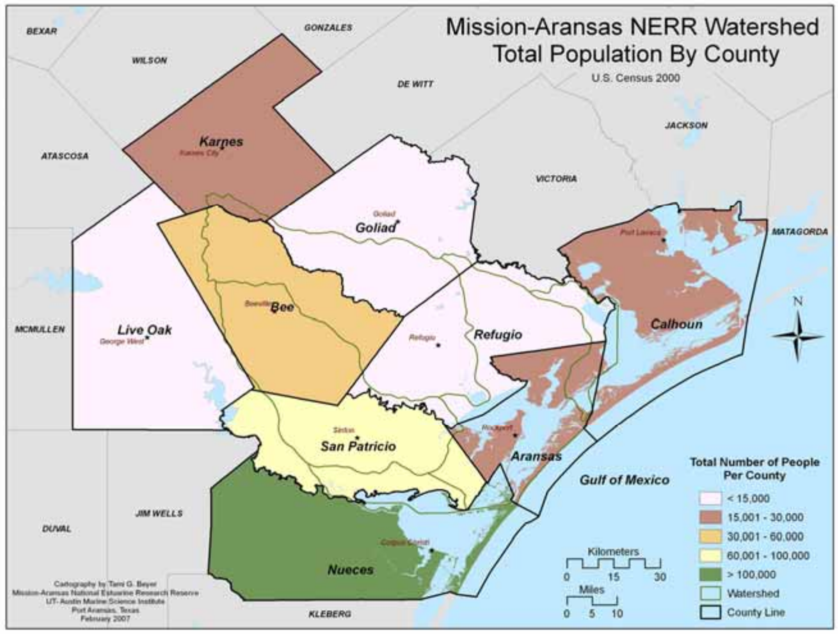

Figure 13.5. Total population values for Mission-Aransas NERR watershed by county.

In 2000, 281.4 million people were counted in the United States and of those, 20.85 million resided in Texas making it the second most populated state behind California. The majority of the Texas population is centered around metropolitan areas and there is a greater number of people along the coast and in the northeast region of the state near the metropolises of Houston and Dallas. Parts of the southern coast, including the Mission-Aransas NERR, have some of the lower population estimates. In particular, the northern counties of the watershed that drain into the Mission-Aransas NERR are some of the least populated in the state with <25,000 people (Figure 13.5). Bee and San Patricio counties make up the majority of the sub-basin that drain the Aransas River and these counties have higher population totals (25,001 - 75,000). On a smaller scale, people are centered near cities and towns with large rural tracts in between (Figure 13.6). It is interesting to note that there are small numbers of people around the lower portions of the Mission and Aransas rivers. The census blocks in the city of Rockport and the Live Oak Peninsula show high numbers of people, which is likely not reflected at the county level because of the low numbers associated with the unpopulated areas of the Aransas National Wildlife Refuge and San Jose Island.

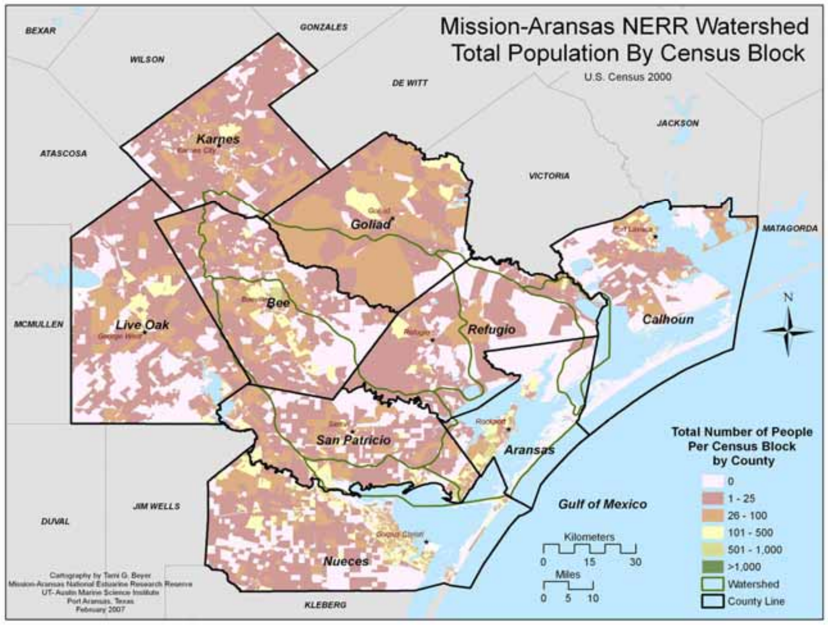

Figure 13.6. Total population values for the Mission-Aransas NERR watershed by census block.

Population density can indicate the severity of the anthropogenic impact humans have on the natural environment. In Texas, the densest populated areas are around metropolitan areas. In particular, the cities of Houston, Dallas, and San Antonio have high densities of people (>1,000 people per square mile (people mi^{-2}) (US Census, 2000). There is also a corridor of high population densities extending from San Antonio to Dallas and surrounding Houston. The population densities in the Mission-Aransas NERR watershed are very low with higher densities occurring in Nueces (>100 people mi^{-2}), Aransas, and San Patricio Counties (51-100 people mi^{-2}). The higher population densities of Aransas and San Patricio County can have a greater influence on the Aransas River sub-basin and the Mission-Aransas Estuary. High densities in Nueces County could also affect the Mission-Aransas Estuary because of its close proximity.

In 2000, the United States experienced the largest decadal population increase in American history (13.2%) (Perry and Mackun, 2001). Texas experienced a large proportion of the US population growth with a 22.8% increase from 1990 to 2000. The metropolitan areas of Dallas, Houston, Austin, McAllen, and San Antonio accounted for the majority of the population growth increase, while most of the non-metropolitan counties in the state recorded either slow growth or population decline. In comparison to other metropolitan areas in the US, Austin and McAllen are among the top ten fastest growing (Perry and Mackun, 2001). The Mission-Aransas Estuary and its watershed are situated between these two metropolitan areas. At the watershed level, all of the counties, except for Refugio, had a population increase above the US average of 5.3%. The counties of Aransas, Bee, and Live Oak have seen the greatest change (+25-50%) in population from 1990 - 2000. Historical trends also reflect a population increase in the local municipalities adjacent to the Mission-Aransas NERR (Figure 13.7).

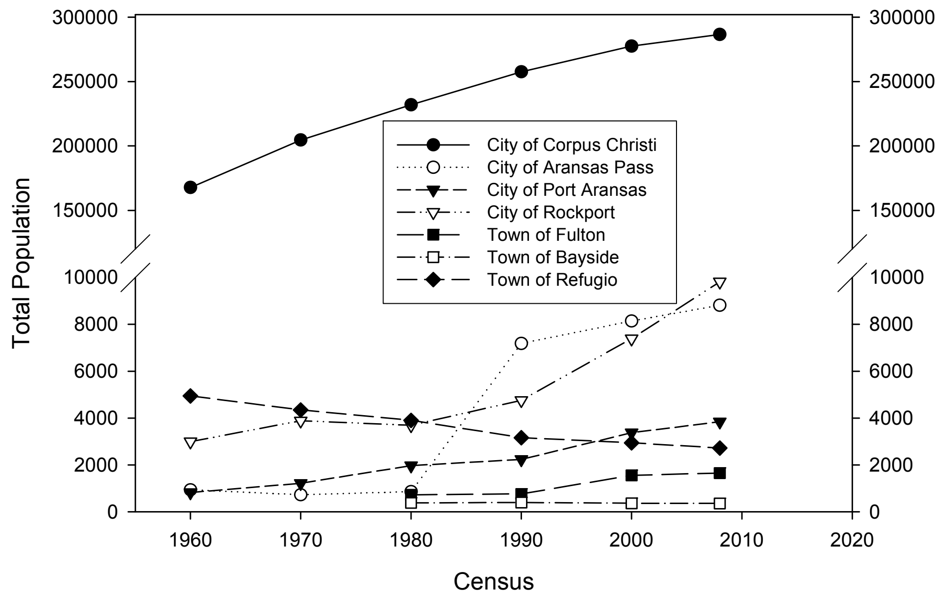

Figure 13.7. Decadal census counts for local municipalities. Numbers from 2008 are Census Bureau estimates.

Population Cycles

Population cycles (e.g., changes in the number of people fitting the categories of age, income, or ethnicity over time) provide guidance and predictability to the flow of human actions. As these cycles change, they can help resource managers better predict how resources in the estuary will be used. Age distribution is an indicator of population cycles because the proportion of children to elderly will influence the flow and need/use of different resources. Seasonal residence is also an indicator of population cycles because it will influence the flow of resources during tourist seasons.

Age distribution is a population cycle that can indicate what types of resources are currently being used, and changes to age distribution can further indicate future resource needs of the area. Age distribution is determined as the proportion of children under the age of 18 to those people over the retirement age of 65. In general, communities have a greater number of children, so the proportion of children to retired is always above one. Therefore, the lower the value, the greater the proportion of retired people and vice versa. Information about age distribution can help identify such needs as number of school systems, requirements of medical resources, availability of volunteers, and recreation patterns. In Texas, there are a greater proportion of those over the age of 65 in the "hill country" (west of San Antonio and Austin) and in northwest Texas (US Census, 2000). In the watershed of the Mission-Aransas NERR, there is a greater proportion of children in San Patricio and Nueces counties, and a greater proportion of people over the age of 65 in Aransas, Goliad, and Live Oak County.

Seasonal cycles of residence are indicators of yearly flow of natural resources and can also help explain behavior patterns. For example, high seasonal fluxes of residence may lead to apathy about the natural resources in the area. In the Mission-Aransas NERR, Aransas, Calhoun, and

Live Oak counties have the largest numbers of seasonal, recreational, and occasional use residents at >15% in 2000 (Morehead et al., 2007). The coastal communities of Rockport/Fulton, Port Lavaca, and Sea Drift rely heavily on tourism with the natural resources of local estuaries and beaches being the primary draw for tourism. Tourism for the coastal communities is largest during the summer months followed by a peak tourism period from December to March from "winter Texans" (visitors from out of state who come from the north to escape the cold winters). The ANWR also experiences an influx of winter Texan populations and has visitation peaks from October through April during Whooping Crane season.

Social Order

The social order of a population describes the identity that a person affiliates with himself/herself. Identity can have a large effect on behavior patterns and resource utilization. Social order has both class and ethnic origins. The term class implies individuals sharing a common situation within a social structure (Dalton, 2005). For example, educational achievement can be used to indicate class, and spatial patterns of this indicator can help resource managers determine the level of content for outreach materials. In Texas, central and northern regions tend to have higher education achievement of both high school level and bachelor degrees (US Census, 2000). Classes with high percentages of bachelor degrees (40.1-50%) are concentrated around the metropolitan areas of Austin and Dallas. Classes with low percentages of bachelor degrees are concentrated along the southern border with Mexico. In the counties within the watershed of the Mission-Aransas NERR, Karnes County has the lowest percentage of high school graduates, while Aransas and Nueces have the highest (Figure 13.8). A similar pattern is described by those achieving a bachelor degree. However, all counties within the watershed are below the national average for bachelor degree achievement (24.4%).

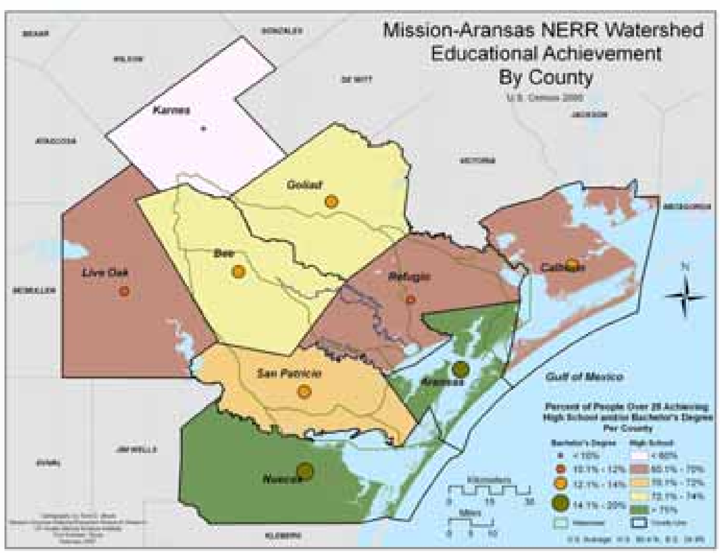

Figure 13.8. Educational achievement by high school and bachelor's degree for counties within the Mission-Aransas NERR watershed.

Ethnic origin is also an important variable of identity. Spatial distributions of ethnic origin can help explain language patterns. This has an important effect on outreach materials that often is overlooked by resource managers. Texas has a large percentage of the population self-identifying as Hispanic (US Census, 2000). Percentages of this population follow a latitudinal gradient from south to northeast. The majority of counties in the Mission-Aransas NERR watershed claim Hispanic origin (25.1-75%), with the exception of Aransas County. The Hispanic population distribution is displayed separately from ethnic distribution because the federal government considers race and Hispanic origin to be two separate and distinct concepts (Grieco and Cassidy, 2001). The Census questionnaire does not distinguish or define Hispanic populations as ethnicity or race (i.e., an individual can identify themselves as Hispanic and white). The largest ethnic identity of counties within the Mission-Aransas NERR watershed is white followed by an unknown "other" (Figure 13.9). Aransas County has the highest percentage of the white majority and Bee County has the greatest percentages of minorities.

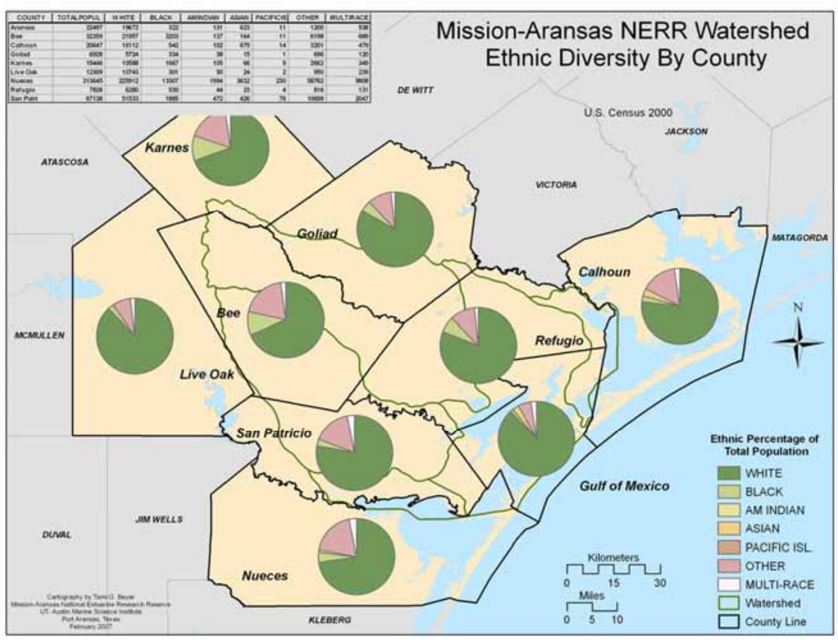

Figure 13.9. Ethnic distribution in counties within the Mission-Aransas NERR watershed.

Economic Aspects of the Watershed

Labor

Labor is an indicator of what type of anthropogenic impacts occur to natural resources. Industry can be used as an indicator of labor because it describes the products created that impact natural resources.

Education is the dominant industry of all counties in the Mission-Aransas NERR watershed (US Census, 2000). As an educational institution, the Reserve can have a large impact in a watershed whose dominate industry is education. Of the dominant industries in the Reserve watershed (Table 13.6), agriculture is likely to have the greatest direct effect on natural resources. Refugio, Live Oak, and Goliad counties have the greatest dominance of agriculture for industries in the watershed.

Capital

Capital describes the financial resources, resource values, and human ability to manipulate these resources. The availability of capital can alter consumption levels of natural resources. In the human ecosystem framework, capital is defined as the economic instrument of production that can affect and manipulate financial resources and resource values. In 2008, the Census Bureau estimated that the US median household income average was $52,029 (US Census, 2008). Most of the state of Texas is lower than the national average, with more affluent areas around metropolitan areas of Houston, San Antonio, Austin, Midland, and Amarillo. In comparison to the rest of the state, the median household income of people within the Mission-Aransas watershed is low (Figure 13.10). Karnes, Bee, and Refugio counties had the lowest household income means, while Nueces, San Patricio, Goliad, and Calhoun had higher means.

Table 13.6. Top three dominant industries for each county in the Mission-Aransas NERR watershed are listed in order.

County	Industry
Refugio	Education, agriculture, manufacturing
Calhoun	Manufacturing, education, construction
Aransas	Education, arts, construction
San Patricio	Education, retail, construction
Nueces	Education, retail, construction
Bee	Education, public administration, retail
Live Oak	Education, agriculture, public administration
Goliad	Education, agriculture, construction

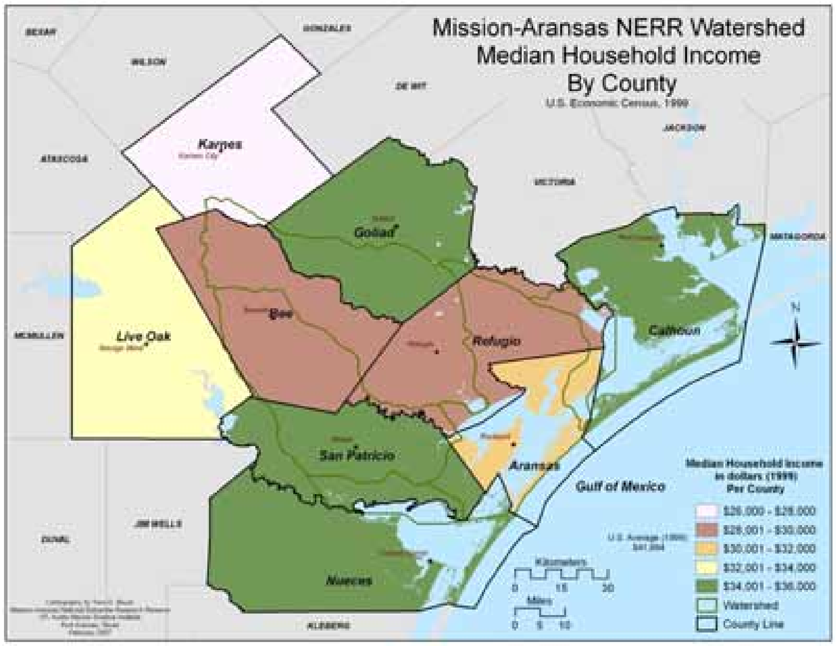

Figure 13.10. Median household income for counties within the Mission-Aransas NERR watershed.

Wealth

Wealth is an indicator of hierarchy because it defines access to material resources, and wealth distributions can explain social inequality and opportunity (Dalton, 2005). In this study, the inverse of wealth is defined as the rate of poverty. In 2000, the Census defined the poverty threshold for those under 65 years of age at $8,959 and for those 65 years and older at $8,259. In the Mission-Aransas NERR watershed, Nueces County had the greatest number of people living in poverty (Figure 13.11). Live Oak, Goliad, and Refugio counties had the fewest number of people living in poverty.

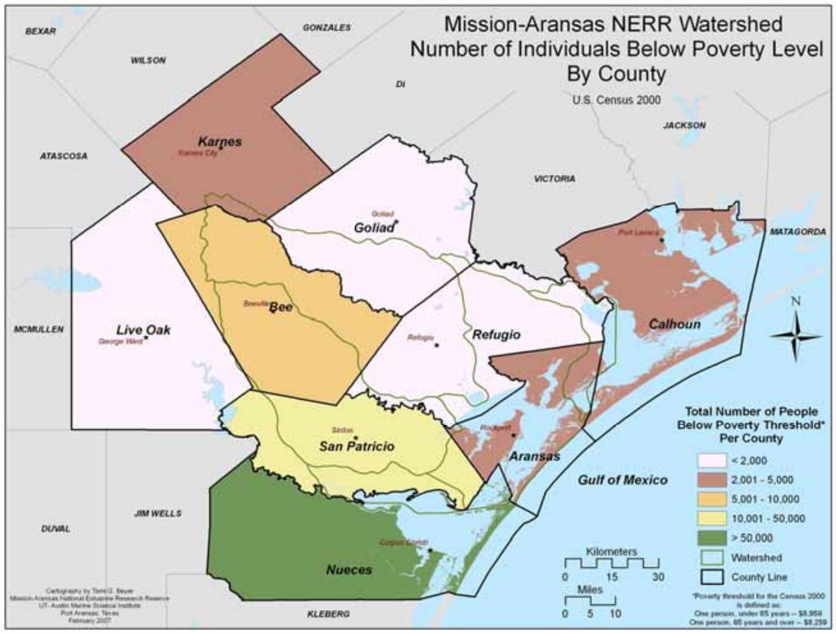

Figure 13.11. Number of individuals below the poverty level for counties within the Mission-Aransas NERR watershed.

Power

Social power is the ability to alter other's behavior (Dalton, 2005). It usually consists of the individuals with political or economic power that have considerably better access to resources than the average person. Power is measured in terms of the number of households with income greater than $100,000. In the Mission-Aransas NERR watershed, Bee County had the lowest percentage of households with income greater than $100,000 (Figure 13.12). Nueces and Aransas counties have the greatest percentage of households with income greater than $100,000. The US Census Bureau conducted an American Community Survey for 2005-2007 and although some of the counties within the NERR watershed have not yet been determined, the general trends of power remain the same. These statistics indicate that Nueces and Aransas counties have the most individuals with power, but both counties are still below the national percentage of 12.3%.

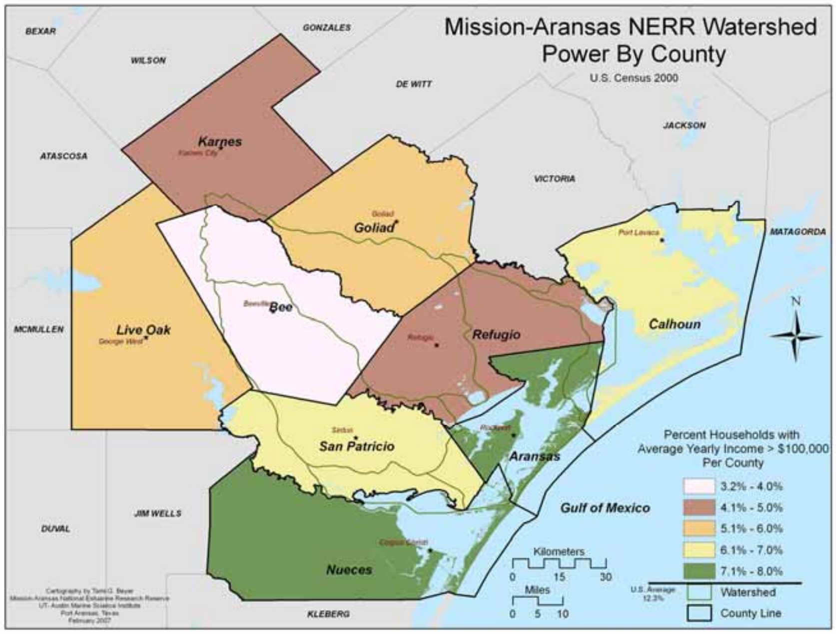

Figure 13.12. Power estimate (average yearly income >$100,000) for counties within the Mission-Aransas NERR watershed.

Summary

Although five counties are included in the Mission-Aransas NERR, three counties (Aransas, Calhoun, and Refugio) comprise nearly 97% of the area. The majority of the Mission-Aransas NERR (75%) lies in Aransas County, while other major counties include Calhoun (12%), Refugio (10%), and Nueces (3%). Only 0.1% of San Patricio County lies in the Reserve. The most populous counties on both a regional and state level are Nueces and San Patricio, which both lie predominantly outside the Reserve. Consequently, the Mission-Aransas NERR is likely one of the lowest density sites in the NERR System.

The counties of the Reserve have respective densities of less than 25 people mi^{-2} in Calhoun and Refugio counties compared to a modest 89 people mi^{-2} in Aransas County. Similarities among all three counties include a predominantly white population with a low poverty level, a relatively low proportion of children to retired (ratio 1.2-2.5), and a majority of the population with at least a high school degree. Urban development throughout the area is very low (<5%).

Of the three dominant counties adjacent to the Mission-Aransas NERR, Refugio has the lowest proportion of individuals that earn in excess of \$100,000 yr^{-1}. The low financial and social power of this county is also reflected in the lowest median income, very few seasonal homes, and a higher proportion of employment in agriculture. Among all these indicators, the most profound is the lack of population change for Refugio County, compared to significant increases for all other neighboring counties in the region. The lack of a population increase (or perhaps a slight decrease) is in stark contrast to most Texas counties which showed some growth, and to the southern half of the state as a whole. The causes for the slowdown in growth for Refugio County are not apparent, but may be related to the immense amount of area committed to rangeland and the lack of job opportunities for young people.

It is clear that Aransas County is characterized by the greatest amount of wealth in the region. This is likely related to the abundance of desirable waterfront property as reflected in higher incomes, second homes, and a greater median age (and fewer adults under 18) than the adjacent counties.

The four remaining counties in the Reserve watershed are Bee, Goliad, Karnes, and Live Oak counties. These counties are almost exclusively rural and characterized by lands that are either forested, used for agriculture, or pastures for free ranging cattle. Consequently, population densities are very low (<25 people/square mile). The human characteristics among the four counties are diverse, with Bee county displaying high educational achievement (>72% completing high school) compared to Karnes (<60%). Bee County is also unique in a relatively higher number of single-parent households (11-12%), lowest median age, and a higher ratio of children under 18 relative to adults over 65 compared to the other three counties. All four counties exhibited high population growth (range 10 to 50%) and generally very low poverty (Bee County was average). The low population density of these counties, combined with very low urban land use, is favorable to the continued health of the Mission-Aransas watershed, although population increases are an important consideration for future planning.

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Chapter 14 CONCEPTUAL ECOSYSTEM MODEL

Sally Morehead Palmer, Mark Harwell, Michael Reiter, and Jack Gentile

Researchers from NOAA's Environmental Cooperative Science Center (ECSC) developed a Conceptual Ecosystem Model (CEM) for the Mission-Aransas NERR. The conceptual modeling methodology utilized by ECSC attempts to integrate social and environmental factors into a unified picture of key interactions between activities in an ecosystem and the important components of that ecosystem. A "two-component" modeling approach was utilized for this project. The first component links changes in ecological indicators to natural and anthropogenic stressors and identifies ecosystem attributes that are most at risk from these various stressors. The results of this component highlight areas for monitoring or future mitigation. The second component of the model identifies links between stressors and their origin (i.e., societal and natural drivers). By examining this set of connections, it is possible to ascertain the relationship between drivers and changes in ecosystem parameters. Once completed, the "two-component" conceptual ecosystem model can be used to help identify the behaviors or actions causing environmental deterioration (Reiter et al., 2006).

Although the Mission-Aransas NERR model only utilized the "two-component" CEM, there is also a "four-component" that elaborates on the procedure described above. This approach incorporates a third component that connects changes in environmental parameters with changes in ecosystem services (i.e., benefits obtained by people from the environment). The result of this step provides a framework within which the value of environmental change can be investigated and/or quantified. The fourth component closes the model loop by designating the effect of ecosystem service changes on drivers. By describing losses in both ecosystem services and valued ecosystem components, the political decision making process can be more fully informed of the consequences of its actions (or lack thereof) in readily understandable terms (Reiter et al., 2006). The Mission-Aransas NERR would like to complete the third and fourth components of the CEM at a future date.

The information required for the CEM was gathered from stakeholders during a workshop hosted at Mission-Aransas NERR. Participants included scientists with experience in Mission-Aransas NERR habitats, outside researchers with expertise in the Reserve habitats, scientists with expertise in conceptual model development and ecological risk assessments, and managers/representatives of particular stakeholder interests.

The CEM workshop led participants through a systematic process that identified (1) the habitats of the Mission-Aransas NERR, (2) the natural and societal drivers (e.g., tourism, climate change, development), (3) associated environmental stressors (e.g., nutrient loading, invasive species, habitat alteration), (4) valued ecosystem components (e.g., aerial extent of habitats, nutrient dynamics, aesthetics), and (5) effect of stressors on valued ecosystem components (e.g., high, medium). Matrices were produced based on the results from the workshop and were the basis for the creation of graphical CEMs.

At the workshop, the Mission-Aransas NERR was partitioned into 20 habitats and separate matrices were developed for each habitat. Similarly, each habitat had its own graphical CEM, many requiring more than a single graphic to capture all of the information in the matrices. A total of 36 pages of CEMs was needed to characterize all of the habitats, drivers, associated stressors, and valued ecosystem components (Figure 14.1).

The main objective of the graphical CEMs is to highlight the important linkages that affect each valued ecosystem component. This allows users of the model to trace back the potential stressors that affect each valued ecosystem component and the drivers that led to those conditions. Alternatively, they could also be used to identify what potential valued ecosystem components might be affected by various drivers and stressors. In essence, each linkage constitutes a hypothesis of causality concerning how the Mission-Aransas NERR ecosystem functions. The overarching goal of a resulting conceptual model is that it will eventually be used as a guide to identify research and monitoring needs for the coupled human environment system, as well as to provide a useful tool for communication among scientists, between scientists and managers, and between the Mission-Aransas NERR and its stakeholders.

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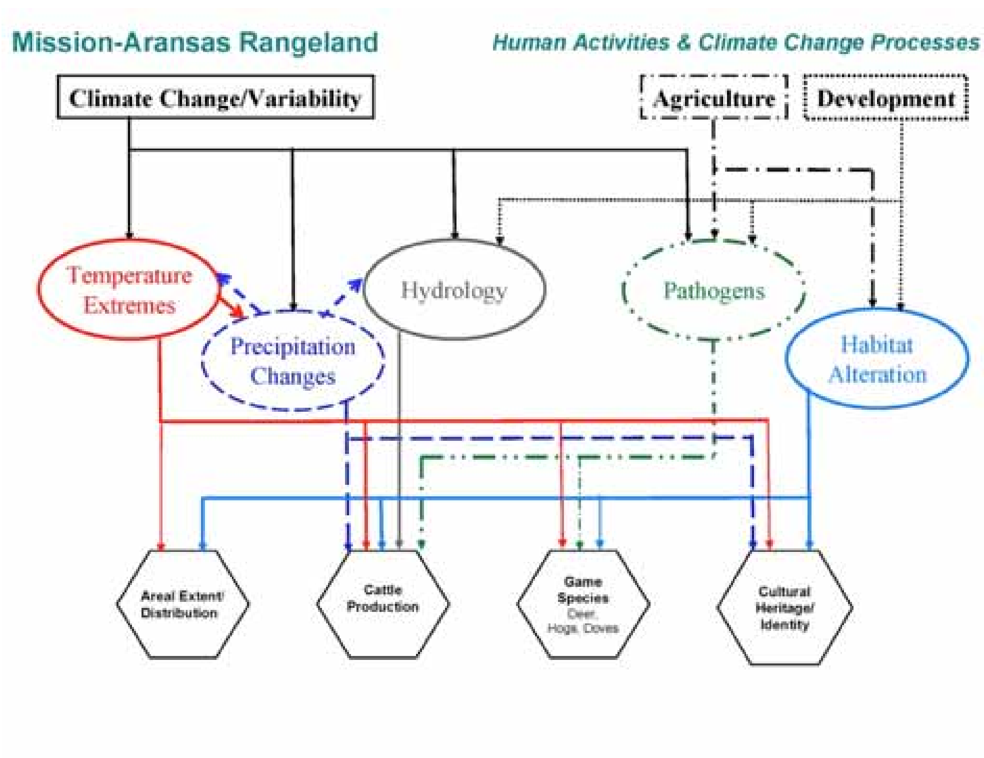

Figure 14.1. Example of one of the graphical models developed with results from the workshop. Black rectangles are the natural process or human activity. Black lines represent links from each process/human activity to resulting environmental stressors (shown in ovals). Colored line thickness represents the strength of connection. Black hexagons represent habitat-specific valued ecosystem component.

Chapter 15 FUTURE PLANS IN THE MISSION-ARANSAS NERR

Ed Buskey and Kiersten Madden

Table 15.1. Future Research Plans within the Mission-Aransas NERR.

Future Research Plans	Purpose
System Wide Monitoring Program	Measure weather, water quality, phytoplankton biomass
Harmful Algal Bloom Monitoring	Identify *Karenia brevis, Dinophysis* spp.
Pilot Nutrient Criteria Project	Information on total amount of nutrients entering estuary available to support primary production
Community Metabolism Measurements	Estimate gross primary production, community respiration, and net ecosystem metabolism
Zooplankton Monitoring	Investigate relationships between freshwater inflow, nutrient loading and transformation, phytoplankton primary production and zooplankton secondary production
Coliform Bacteria Monitoring	Investigate causes of the high coliform bacteria levels found in Copano Bay
Submerged Aquatic Vegetation and Marsh Grass Monitoring	Assess changes in seasgrass and marsh grass that occur due to anthropogenic and natural perturbations
Larvae Recruitment	Understand importance of Gulf passes for recruitment of important species
Detecting Petroleum Hydrocarbons	Detect and monitor oil spills
Establishment of Vertical Control	Provide a common vertical elevation framework for data analysis, modeling, restoration, and conservation.
Habitat Mapping and Change Plan	Track and evaluate short-term variability and long-term changes in habitat types and examine how these changes are related to anthropogenic and climate related stressors
Bay/Basin Expert Science Teams	Examine effects on freshwater inflows, improve salinity models
Coastal Texas 2020	Bay and beach erosion projects, beach nourishment, and revegetation of shorelines
Fennessey Ranch Management	Research the exchange of water between freshwater wetlands, rivers, and groundwater
Blue Crab Research	Determine spatial trends and seasonal patterns of abundance

System Wide Monitoring Program

The weather and water quality components of the System Wide Monitoring Plan (SWMP) have been in place since the summer of 2007, within one year of the beginning of funding for Mission-Aransas NERR. Additional research focus to date has been centered on plankton monitoring, including the addition of YSI chlorophyll sensors to all sondes at SWMP stations, measuring size-fractionated chlorophyll to determine the relative proportions of net plankton chlorophyll *a* (> 20 µm), nanoplankton chlorophyll *a* (20 – 5 µm), and total chlorophyll *a*. These size fractions provide insight into the phytoplankton biomass available to different grazers within the food web.

Harmful Algal Bloom Monitoring

The research program also monitors for the presence of harmful algal blooms (HABs). In collaboration with Dr. Lisa Campbell from Texas A&M University and researchers from Woods Hole Oceanographic Institution, the microplankton community entering the estuary from the Gulf of Mexico in the Aransas Ship Channel is continually monitored using the Imaging FloCytobot. The FloCytobot was initially funded by The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). This system takes a high resolution picture of each cell and compares them to images and other information collected on known HAB species. In addition to the continual monitoring at one site, samples are also collected for microplankton twice monthly to monitor for HABs within the Reserve. These whole seawater samples are processed through the FlowCAM, a bench-top instrument that performs similar analyses. These two systems have already proved very useful in identifying the initiation of several harmful algal blooms, including blooms of *Karenia brevis*, which causes neurotoxic shellfish poisoning and *Dinophysis* spp., which causes diarrhetic shellfish poisoning. We hope to continue this program in the future and develop a long scale time series of plankton community composition and frequency of HABs.

Developing Pilot Nutrient Criteria Project

Intensive studies of nutrient loading and nutrient transformation within the Mission-Aransas NERR have started with funding from the Environmental Protection Agency. Measuring inorganic nutrient concentrations alone does not provide information on the total amount of nutrients entering the estuary that are available to support primary production. Based on three years of inorganic nutrient monitoring data, the Mission-Aransas Estuary appears to be highly nitrogen limited. Ratios of inorganic nitrogen (nitrate, nitrite, and ammonium) to phosphate are on average less than one at all SWMP stations except the ship channel, where tidal exchange occurs with the Gulf of Mexico. This is well below the Redfield ratio of 16:1 N:P, which suggests that the estuary is very nitrogen limited. The new research program will begin to measure possible organic sources of nitrogen in the Reserve. A special effort is also being made to measure nutrient loading during storm events. Recent studies have indicated that a large proportion of the annual nutrient load to this system may occur during short lived storm and flooding events. In addition, the importance of microbially mediated nutrient transformations is unknown within the estuary, and experimental studies to quantify the rates of these transformations within the Reserve have been started. The two sources of nutrient input that are not being monitoring with current studies are groundwater additions and atmospheric deposition. These are topics we would like to see investigated by reserve scientists or outside scientists in the future.

Community Metabolism Measurements

Oxygen data along with wind speed measurements have started to be collected to make estimates of community metabolism at each SWMP station.

Using the method of Caffrey et al. (2004), with the addition of a dynamic calculation of the air-sea exchange coefficient, gross primary production, community respiration, and net ecosystem metabolism within the water column and benthos at each SWMP site can be estimated. These estimates will be most accurate within Copano and Mesquite bays, where tidal exchange of waters is minimal. We hope that this method will provide insight into possible changes between net autotrophy and net heterotrophy during periods of high freshwater inputs and droughts. In the future, we would like to calibrate this method with direct measures of primary production rates using stable carbon isotopes.

Zooplankton Monitoring

Zooplankton monitoring is occurring on a monthly basis at all SWMP stations. Zooplankton samples are collected using 153 µm mesh plankton nets fitted with flow meters to measure the volume of water sampled. Samples are processed for biomass (dry weight) and organisms are identified to major taxonomic categories. In the future, we hope to investigate and model the relationships between freshwater inflow, nutrient loading and transformation, phytoplankton primary production, and zooplankton secondary production using the well-established "N-P-Z" (nutrient-phytoplankton-zooplankton) models pioneered by Gordon Riley (Riley, 1946).

Coliform Bacteria Monitoring

During the past two summers (2009 and 2010) coliform bacteria have been monitored on a twice monthly basis at all SWMP stations. The concentrations of coliform bacteria away from shore, where SWMP stations are located, are typically within the recommended guidelines for recreational use. Samples collected by the Texas Department of Health's Beach Watch program, collected near shore, often exceed recommended levels. In the future, we hope to investigate the causes of the high coliform bacterial levels that are often found in Copano Bay.

Submerged Aquatic Vegetation and Marsh Grass Monitoring

The Mission-Aransas NERR has started a long-term monitoring program for submerged aquatic vegetation and emergent marshes. This sustainable monitoring program is a representative of the Texas coastal zone and will assess the changes that occur due to anthropogenic and natural perturbations. The NERRS biomonitoring protocol has a hierarchical design in which "tier 1" includes mapping and monitoring the overall distribution of emergent and submerged vegetation within reserve boundaries and "tier 2" includes long-term monitoring of the vegetative characteristics of estuarine submersed and emergent vegetation communities. The Mission-Aransas NERR has completed tier 1 and has high resolution spatial data on the overall distribution of emergent and submerged vegetation. Starting in the summer of 2011, "tier 2", or the transect portion of the program will begin. Dr. Ken Dunton and his lab at the University of Texas Marine Science Institute have chosen two sites, Northern Redfish Bay and Mud Island, and will be installing the transects and making the first measurements.

In the future, we also hope to begin monitoring mangroves within the Reserve. The Mission-Aransas Reserve has a substantial population of black mangroves and is near the northern limit of their range. Black mangroves appear to be expanding populations within the Reserve and may be displacing marsh grasses. Red mangroves have also been observed within the Reserve; this is the northernmost extent of this species in the Western Gulf and this range extension may be an indicator of climate change.

Larvae Recruitment

Many of the commercially and recreationally important fish and invertebrate species within the Mission-Aransas NERR have estuarine dependent life cycles. Adults release eggs into the Gulf of Mexico and larvae must recruit back to the estuaries to develop and grow. Examples of important species with this life history pattern include white and brown shrimp, blue crabs, red drum, and others. A nearly continuous barrier island system isolates the coastal bays and estuaries of south Texas from the Gulf of Mexico, with only a limited number of exchange passes between the two. The most direct pass between the Gulf of Mexico and the Mission-Aransas Reserve, the Cedar Bayou pass, has been closed by natural siltation processes for several years. Larvae recruiting from the Gulf of Mexico must enter the Reserve through the Aransas ship channel, on the southernmost boundary, or through Pass Cavallo, to the north of the next adjacent bay system, San Antonio Bay. Most of the studies of recruitment of invertebrate larvae to estuaries have taken place in east coast estuaries, with higher inputs of fresh water and larger tidal ranges than south Texas estuaries. It is thought that vertical stratification of the water column in these systems allows for selective tidal stream transport, where larvae vertically migrate in and out of layers with flows moving in or out of the estuary. South Texas estuaries are typically shallow and well mixed, with smaller freshwater inflows and microtidal exchanges with the Gulf. There is no paradigm to explain how larvae successfully recruit past the high energy passes to the interior of the estuaries. In the future, we would like to study the detailed hydrodynamics of water movement from the passes to the head of the estuaries, to understand how water moves within the estuary and how these currents are used to transport plankton, including larval fishes and invertebrates. More specifically, we would especially like to conduct an intensive study of circulation and larval recruitment within Mesquite Bay. Plans are underway to reopen Cedar Bayou in the near future, so it is an important opportunity to measure the change in circulation and larval recruitment after it is reopened.

Detecting Petroleum Hydrocarbons

The Deepwater Horizon oil spill in the Gulf of Mexico during the summer of 2010 has focused attention of the importance of being prepared to monitor oil spills and other pollution events within the Reserve. This is especially important since the Gulf Intracoastal Waterway is a marine transportation canal that is used by barges carrying large volumes of chemicals and refined petroleum products through the Reserve. In addition, tankers carrying crude and refined petroleum products enter the ship channel on a daily basis, and there are numerous active oil and natural gas production platforms located in the Bays. We are hoping to install and test sensors on the pier laboratory within the Aransas Ship Channel that will be capable of detecting petroleum hydrocarbons. If these prove useful, we may expand the placement of these sensors to other SWMP stations.

Establishment of Vertical Control

The Mission-Aransas NERR is in the process of establishing vertical control within the Reserve boundary (i.e., measuring water and land elevations at high resolution and tying these measurements to the National Spatial Reference System). The purpose of establishing vertical control is to provide a common vertical elevation framework for scientific data analysis, modeling, restoration, and conservation. Elevation is an important structural component of coastal ecosystems and determines such factors as: frequency/duration of inundation, sedimentation and erosion, species distribution, and shoreline exposure/protection from storm surge. As a result, accurate and precise measurements of elevation are needed to understand the impacts of sea level rise on sustainability of coastal ecosystems. The Mission-Aransas NERR, in coordination with the National Geodetic Survey will install vertical control infrastructure that will allow them to gather high-precision land and water elevation data. Surface Elevation Tables (SETs) will be installed to measure the elevation of the sediment surface in five Reserve habitats (mangroves, tidal mudflat, brackish marsh, high salt marsh, and low salt marsh) and will be monitored on a seasonal basis for comparison of elevation change between habitats. The data gathered from the SETs will be combined with local tidal datums (and additional data from future biotic monitoring and habitat mapping projects) to improve our understanding of local sea level rise impacts. Tidal data currently exists for the Reserve, but the five long-term water level monitoring stations of the NERR will be tied to upland benchmarks to improve assessments of local tidal hydrodynamics.

Habitat Mapping and Change Plan

A strategy is being developed to guide future mapping and vertical control efforts within priority areas/habitats of the Mission-Aransas NERR. This is part of a system-wide effort to track and evaluate short-term variability and long-term changes in the extent and type of habitats within Reserves and to examine how these changes are related to anthropogenic- and climate-related stressors. The Mission-Aransas NERR will develop a habitat mapping and change plan that: (1) identifies priority habitats and geographic locations for conducting habitat mapping and measuring elevation, (2) develops strategies for habitat mapping and vertical control in priority habitats and geographic areas (e.g., image and infrastructure requirements, ground-truthing requirements, identify partners), (3) describes potential data applications and dissemination strategies for habitat mapping and elevation products, (4) determines existing gaps in personnel, training, and/or hardware/software, and (5) estimates budget requirements for plan implementation. The products of this plan will provide an important context for the abiotic and biotic trends observed in the other components of the Reserve monitoring programs. By collecting information on habitat and elevation change, researchers and managers will be better able to relate environmental observations of water quality, nutrients, and estuarine habitats to anthropogenic and climate change impacts. High resolution imagery has already been acquired for freshwater wetlands (Fennessey Ranch), saltwater wetlands (ANWR), mangroves (Harbor Island), and seagrass beds (Redfish Bay), and will be used to produce baseline maps of current habitat extent. Future image acquisitions (along with elevation change information) will be used to monitor habitat change within these areas and will be important for understanding the abiotic and biotic changes that are observed in other reserve monitoring programs.

Bay/Basin Expert Science Teams

Freshwater quality and quantity are the biggest challenges that Texas resource managers face today. Freshwater is a critical component of Texas estuaries but as water demand increases the amount of freshwater that reaches the coast is projected to decrease. Determining flow regimes in the face of land use and climate change is proposed as part of a NERR Science Collaborative. Texas Legislature recognized the need to establish environmental flow standards and adopted Senate Bill 3. This law created a public process by which state authorities would solicit input from committees of scientists (referred to as BBEST) and stakeholders (referred to as BBASC) from each Texas bay/basin system. Recommendations from these groups would be used by the State to develop legal environmental flow standards for estuaries and rivers. The Guadalupe-San Antonio (GSA) bay/basin is located on the central Texas coast and includes the Guadalupe and Mission-Aransas estuaries and their watersheds. The GSA BBEST committee released a report that outlined their flow recommendations and highlighted several research gaps (social, climatic, physical, and biological). The Mission-Aransas NERR will use a collaborative approach to address the research gaps and incorporate the BBASC as the primary user group that will utilize the information to refine environmental flow recommendations. Specific goals include: (1) examine effects of land use and climate change on freshwater inflows to the

Guadalupe and Mission-Aransas estuaries, (2) improve inputs to the TxBLEND salinity model by measuring water exchange between adjacent bays, (3) collaborate with intended users to identify and conduct a priority research project, and (4) develop shared systems learning among the local stakeholders and scientists, and create a system dynamics model.

Coastal Texas 2020

Coastal Texas 2020 is a long-term statewide initiative to unite local, state, and federal efforts to promote the economic and environmental health of the Texas Coast. The document provides tools to identify challenges and find solutions to the coastal problems. In 2003, the Texas coast was divided into five regions for *Coastal Texas 2020*: (I) Jefferson and Orange counties, (II) Brazoria, Chambers, Galveston, and Harris counties, (III) Calhoun, Jackson, Matagorda, and Victoria counties, (IV) Aransas, Kleberg, Nueces, Refugio, and San Patricio counties, and (V) Cameron, Kenedy, and Willacy counties. Regional Advisory committees were established for each region and included representatives from state and local government, natural resource agencies, academia, and nonprofit organizations. The committees were responsible for developing a list of key coastal issues and projects to help stop coastal erosion.

The Mission-Aransas NERR is located in region IV. Region IV geomorphologic features include bay shorelines of Aransas, Corpus Christi, Oso, Nueces, and Baffin bays, and the Laguna Madre. Gulf shoreline features include the high-profile barrier islands of San Jose, Mustang, and the northern portion of Padre islands. Aransas Pass separates San Jose Island from Mustang Island and is a jettied navigation channel that alters the littoral flow of sediment from the northeast.

The Gulf shoreline in this region is experiencing an erosional trend with an exception to the Aransas Pass south jetty that is gaining sand because of impoundment. The erosion of the shoreline is mainly due to low sand supply and a muddy offshore substrate. Critical erosion areas include a stretch of the Corpus Christi Ship Channel in Port Aransas due to ship traffic in the channel. To help reduce the erosion the establishment of a ‘no wake’ zone and stabilizing the shoreline with bulkheads and vegetation was recommended (McKenna, 2004). Twenty-two erosion response projects have been implemented to help minimize shoreline retreat. These include a bulkhead extension at Cove Harbor in Rockport, beach nourishment of Rockport Beach, and revegetation of shorelines in Copano and Mission bays (McKenna, 2004).

Fennessey Ranch Management

The Mission-Aransas NERR benefits from the existence of short- and long-term research projects and monitoring programs that provide important information on the status and trends of palustrine habitats within the NERR boundary and the surrounding watershed. The acquisition of Fennessey Ranch, a 3,300-acre upland habitat that contains several freshwater wetland habitats, was crucial for research on the effects of freshwater inflow from rivers and adjacent freshwater wetlands on palustrine habitats. The exchange of water between freshwater wetlands, rivers, and groundwater has not been fully defined for the Reserve. However, Fennessey Ranch presents a great location to conduct the type of research that will help define these relationships due to its abundance of freshwater habitats, artesian aquifers, and adjacency to the Mission River. Initial analysis of river dynamics, such as CDOM and nutrient loading after storm events, have been completed, which provides good baseline information to conduct continued inquiry into the exchange between water flows. In turn, Fennessey Ranch has received great economic benefits from its palustrine habitats by offering ecotourism activities such as wildlife tours, photography, and hunting.

Blue Crab Research

When water inflows from rivers are high, blue crabs are abundant. However as more water is being taken up by growing cities and periods of drought extend, water inflows will decrease, which will cause a decrease in blue crab populations (Stehn, 2010). The GSA BBEST recognized the need for more research on the habitat condition versus salinity requirements of focal species like the blue crab. Scientists and stakeholders at the *Blue Crab Workshop*, hosted by the Mission-Aransas NERR, also identified a need to better understand the role of recruitment of blue crab larvae and newly settled juveniles as the recently observed population declines. A proposed project is in the works which would try to determine seasonal patterns of abundance and physical mechanisms regulating megalopal ingress through Aransas Pass inlet into the Estuary. This research would also assess (1) the relative abundance of megalopae outside the Aransas Pass inlet, in the Aransas pass channel, and in Aransas Bay, (2) the relative timing of settlement among different locations, and (3) determine seasonal and spatial trends in abundance of early juvenile blue crabs in the Mission-Aransas Estuary.

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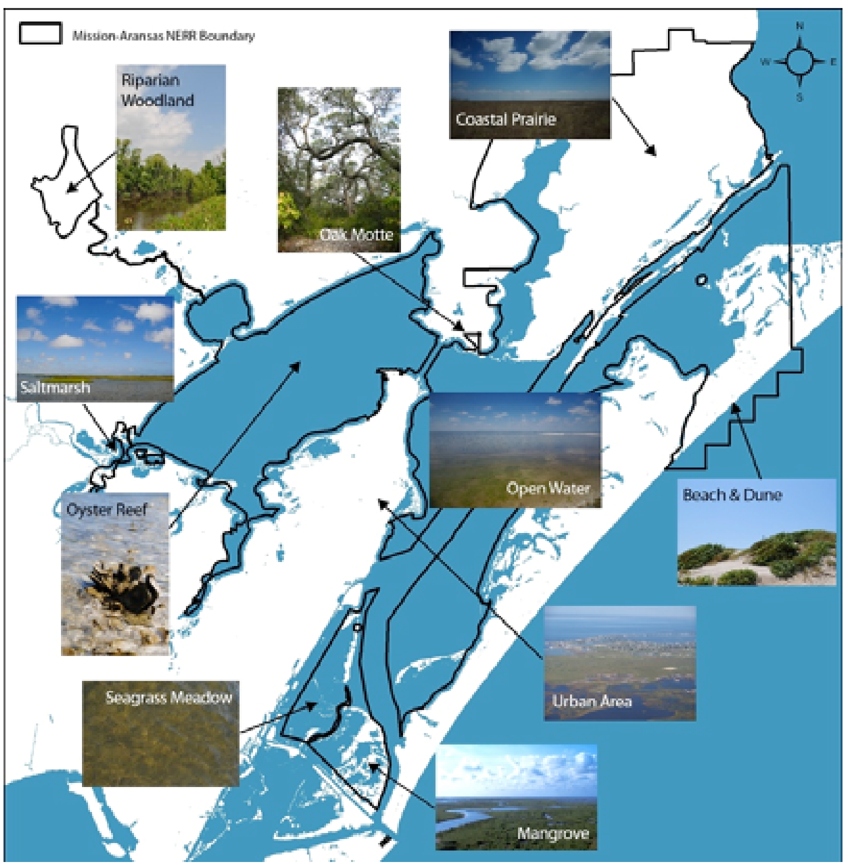

Habitats and uses within the Mission-Aransas NERR.

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