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ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT PADRE ISLAND NATIONAL SEASHORE, TEXAS

Kim Withers, Elizabeth Smith, Olivia Gomez, and John Wood

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Assessment of Coastal Water Resources and Watershed Conditions at Padre Island National Seashore, Texas

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure **Page**

Figure		Page

Figure		Page

LIST OF TABLES

Table		Page

EXECUTIVE SUMMARY

Padre Island National Seashore (PAIS) is located on Padre Island, a Texas barrier island in the western Gulf of Mexico and the longest barrier island in the world. The park is made up of over 52,000 hectares of rare coastal prairie and complex dynamic dunes. It is home to several species of endangered and threatened organisms including the wintering shorebird, the piping plover, and several sea turtle species, such as the Kemp's Ridley sea turtle, that lay eggs along the park's sandy beach. The park was established "in order to save and preserve for purposes of public recreation, benefit, and inspiration, a portion of the diminishing seashore of the United States that remains undeveloped".

Water resources are critical to the functioning of ecosystems, because they often determine the distribution of plants and animals as well as the suitability and quality of a habitat for its inhabitants. In addition, water resources are critical to the human users of the park, not just for consumption, but also for the aesthetics and recreational opportunities they provide. The objective of this report was to determine the current condition and possible impairments of PAIS water resources through a review of currently available information and data. This review will provide the National Park Service with an assessment of the condition of water resources within PAIS, and identify data and information gaps that impede that assessment and recommendations for future monitoring.

Padre Island National Seashore is part of the Laguna Madre Ecosystem, the largest hypersaline estuary in the world. Beginning on the Gulf side and going west to the Gulf Intracoastal Waterway (GIWW), the park includes the nearshore waters, the foreshore (swash zone) and backshore (from high tide line to dunes) on the beach, foredunes, vegetated flats behind the dunes with shallow fresh- or brackish water ponds and marshes, back-island dunes in some areas, wind-tidal flats and shallow, hypersaline seagrass beds in the lagoon. The interplay of climate, physiography and geomorphology results in a landscape that is largely shaped by wind.

Very little surface freshwater is available from terrestrial sources adjacent to the Laguna Madre or on Padre Island. On Padre Island, freshwater sources are limited and generally confined to ponds that form in swales and depressions in the vegetated flats. These ponds are an extremely important source of both drinking water and food for many terrestrial vertebrates and birds. However, most are ephemeral, and many become brackish or dry up, particularly during dry periods.

Padre Island is relatively undeveloped due to its remote location and the lack of permanent roads. The major populations centers in the vicinity of the park are Corpus Christi in the northernmost upper Laguna Madre; Port Mansfield along the south-central western shore in lower Laguna Madre; and Laguna Vista, Laguna Heights, Port Isabel, and South Padre Island along the southernmost lower Laguna Madre. The lack of development on the mainland adjacent to the Laguna Madre is largely a result of large landholdings in Laguna Atascosa National Wildlife Refuge, and privately owned ranches such as the King, Kenedy, and Yturria ranches.

Currently, recreation is the primary land use of the undeveloped areas of Padre Island including PAIS. Public use and recreational activities have a significant effect on natural resources of

barrier islands. The primary attraction of barrier islands is their natural settings, abundant wildlife, and their frequently remote location. The management of natural resources in conjunction with public use of these natural resources necessitates the understanding of potential impacts to human health and ecological impacts. The primary threats to water quality from recreational use of PAIS are human and animal wastes and trash accumulation.

The criteria used to assess the available water quality data for PAIS were drawn from current U.S. Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ) standards. For the purposes of both finding and assessing available water quality data, we considered the boundaries of the PAIS to include all Laguna Madre waters east of and including the GIWW and the nearshore waters within and just outside of Port Mansfield. The southern boundary of the park was set at the Mansfield Channel. We considered the "watershed" of PAIS to include the Laguna Madre west of the GIWW, Baffin Bay, and the tidal portions of the Arroyo Colorado and the ephemeral creeks flowing into Baffin Bay (e.g., Petronila Creek). We focused our efforts on two databases, the Legacy STORET maintained by EPA and the surface water quality database maintained by TCEQ.

The STORET Legacy database contains data submitted from a variety of sources through 1999. Several thousand observations, representing measurements of a single parameter at a unique station that was never visited again, to a few stations with suites of measurements that encompassed a few years to a decade or more, were obtained from this database. The data covered a total of 273 stations and three sample types: estuarine single, estuarine composite, and freshwater single. Most records contained the results of single sampling events or very short-term (within 1 year) studies, and very few stations with data that spanned more than 2 consecutive years. Only six stations have datasets spanning more than two consecutive years and that extend into the 1990s. We reviewed data from these stations starting with the earliest dates to 1993, when the record is picked up by the TCEQ database. This review represents historical or baseline conditions at the stations whereas the data from the TCEQ database represents recent, ongoing monitoring data. We focused our attention on nutrients for which screening criteria exist (ammonia nitrogen, nitrate+nitrite, total phosphorus, orthophosphate), chlorophyll *a* and dissolved metals.

TCEQ has collected data of various types at 134 stations within the Laguna Madre, Baffin Bay and the tidal segments of the streams that feed it, the tidal portion of Arroyo Colorado, and the Gulf of Mexico. However, like the STORET data, temporal coverage varies. We reviewed data on dissolved oxygen, fecal coliform, nutrients (ammonia nitrogen, nitrate+nitrite, total phosphorus, orthophosphate), chlorophyll *a* and dissolved metals and focused on stations that had at least five years of data.

Data from available sources is temporally and spatially patchy. Although there were a number of stations in the STORET legacy database that continued to be sampled through the 1990s by TCEQ, there was little continuity in the parameters that were sampled. For example, although nutrients were sampled with some frequency between 1972-1992, nutrient sampling occurred very infrequently after 1992, thus there is little to compare baseline (1972-1992) conditions with recent/current conditions (1993-present).

There are virtually no data with which to evaluate the water quality of freshwater ponds and marshes within PAIS. Based on the limited data that is available, nutrients may be of concern within some of the ponds. However, the ephemeral and closed nature of the ponds may cause them to become nitrogen sinks. There were also some indications that dissolved metals may be of concern, however, it may not be appropriate to evaluate 30 year old metals analyses using today's criteria due to changing methods and the possibility of contamination. Further investigation with wider spatial and temporal coverage is needed to determine the conditions of the fresh waters within PAIS.

Despite problems with the lack of long-term data, some general statements can be made. With the exception of the area around the Arroyo Colorado (Station 13447), which is well south of the boundary of PAIS, historical nutrient (including chlorophyll *a*) concentrations are not of concern based on today's TCEQ screening criteria.

Dissolved oxygen appears to be of concern for aquatic life in some areas of the Laguna Madre. However, the hypersalinity of the lagoon means that its waters have less capacity for holding dissolved oxygen than similar, less saline waters. Along with the extensive coverage of seagrasses, dissolved oxygen concentrations can be quite low depending on the time of day that readings are taken due to respiration of seagrasses and/or the temperature of the shallow water. Currently, TCEQ is investigating this issue through collection and analysis of 24-hour dissolved oxygen and *in situ* BOD at six stations spaced throughout the system between the JFK causeway and the Port Isabel causeway.

STORET data yielded few dissolved metal determinations. Some exceeded today's criteria, however, it is likely that these older values may not be strictly comparable to today's criteria due to changes in analytical methods as well as the very real possibility of contamination during sampling. In more recent data, although there were still only a few determinations of dissolved metal concentrations, none exceeded limits. Metal contamination of water does not appear to be of concern within the upper Laguna Madre. The status of metals in waters of the lower Laguna Madre is essentially unknown.

Very few data are available with which an assessment of nearshore Gulf water quality can be made. Chlorophyll *a* was monitored in the STORET data, but did not continue into the TCEQ data. Fecal coliform was monitored in TCEQ data. Neither exceeded criteria with enough frequency to warrant classification of concern or non-support of contact recreation. Like the fresh waters within PAIS, Gulf waters require additional water quality monitoring.

There are currently enough data to provide a general evaluation of the estuarine waters within PAIS boundaries, but very little data on either the fresh waters or marine waters. The condition of the estuarine waters appears to be good. There are some parameters, such as dissolved oxygen, that warrant investigation, but the most likely conclusion is that depressed dissolved oxygen concentrations are a result of the natural interactions of salinity, temperature and respiration. There are virtually no contaminants (e.g., pesticides, hydrocarbon) data from the Laguna Madre, and this represents a data gap of concern. The data collected and analyzed through the National Coastal Assessment (NCA) program and Regional Coastal Assessment Program (RCAP) are the most promising as far as establishing a solid baseline of conditions within the Laguna Madre. When these data become available they should serve as the benchmark to determine trends in the future.

Overall, the Laguna Madre, Baffin Bay and the tidal portion of the Arroyo Colorado were classified by TCEQ (2004) as "fully supporting" aquatic life, recreation, general use, and overall use. Our assessment of the historical and recent/current water quality data for the estuarine waters of PAIS agrees with TCEQ's classification of the Laguna Madre. The current state of knowledge of the water quality in the fresh waters of PAIS is very poor. There is no information concerning groundwater beyond general statements regarding its salinity so groundwater quality is unknown. There is also very little known about the quality of nearshore marine waters within the park. Fecal coliform and trash are the only parameters that have been sampled to any extent. Fecal coliform does not appear to be of concern. Trash, on the other hand, is of concern. Other water quality issues may exist, but there are no data with which overall water quality in the nearshore can be evaluated.

For the estuarine waters, TCEQ's monitoring program is already in place and seems to be working fairly well. The data are readily available from their website and updated on a regular basis. The primary failings of this monitoring program are 1) the lack of nutrient data overall, 2) the lack of metals and contaminants data, and 3) the decommissioning of several long-term stations that are of interest to PAIS. It appears that in the last two years there has been renewed interest in assessing nutrient concentrations in the Laguna Madre, so the lack of nutrient data may not continue to be an issue. For metals and contaminants, the large-scale surveys represented by EPA's National Coastal Assessment program and the Coastal Bend Bays and Estuary Program's Regional Coastal Assessment program will provide the needed data and recommendations for monitoring when completed. The decommissioning of stations represents a potential problem for PAIS.

For monitoring of estuarine waters we suggest:

- Communication of the needs of PAIS to TCEQ, particularly with regard to measured parameters and the decommissioning of stations. Parameters that need to be measured frequently (quarterly) are:
    - field parameters (pH, water temperature, salinity, turbidity, instantaneous and 24-hour dissolved oxygen);
    - nutrients (ammonia, nitrate+nitrite, total phosphorus, orthophosphorus) and chlorophyll *a*; and
    - fecal coliform and/or enterococci.
- At a minimum, Station 13448 needs to be brought back online, sampled for the parameters listed above, and paid for by PAIS, if necessary.
- Analyses of dissolved and sediment metals and contaminants are needed at set stations at a time interval that is currently unknown. This interval will depend on the findings of the NCA and RCAP studies. If contamination by metals or other compounds is not found, then the interval might be 2-5 years. However, if contamination is found, then at least annual analyses at stations of concern are warranted. It is likely that if contamination by metals or other compounds is found, TCEQ or some other state agency will investigate.

- Data from TCEQ stations in Laguna Madre available on the TCEQ website need to be downloaded and organized by PAIS personnel and updated at least quarterly. These data should be assessed at least yearly.
- Seagrass surveys within PAIS boundaries comparable to those conducted by USGS during 2004 should be repeated every 3-5 years. In addition, NPS and PAIS should encourage USGS to continue its decadal monitoring of the entire Laguna Madre system and contribute funding if necessary.

We also recommend that a cooperative effort be initiated among federal and state agencies, in conjunction with university researchers and modelers, to address circulation dynamics in the Laguna Madre

The condition of the freshwater ponds within PAIS is virtually unknown. Because they are critical to wildlife, this represents an important data gap the needs to be filled. Based on our review of the inland waters in PAIS, the majority of monitoring needs to occur within the park north of the Land-cut and in areas that serve as receiving waters for wastewater or stormwater. We recommend the following:

- Establishment of several permanent stations in freshwater bodies that are filled with water throughout most of the year and during most years. Parameters that need to be measured frequently (quarterly) are:
  - Field parameters (pH, water temperature, salinity, specific conductance and dissolved oxygen); and
  - nutrients (ammonia, nitrat+nitrite, total phosphorus, orthophosphorus), chlorophyll *a*, sulfate and chloride.
- The water quality of more ephemeral ponds (5-10) should be intensively studied from the time the ponds are filled to when they dry. This will provide information concerning changes in water quality and the potential for concentration of some components (such as salts and nutrients) that may alter an ephemeral pond's suitability for use by wildlife.

Other parameters that should be measured to provide a baseline include dissolved and sediment metals and contaminants. If there are no indications of contamination, and no events occur that would result in contamination, then there is no need for more intensive investigation. However, it would be prudent to assess both metals and other contaminants every five years.

In addition, we recommend a comprehensive inventory of wetlands within the park to determine types and extent of wetlands. This inventory will serve as a baseline for future monitoring and change detection analyses

Condition of groundwater within PAIS is unknown, probably because it is not used for drinking by park visitors. However, companies developing oil and gas reserves use it, thus its quality may affect plants and animals if it is brought to the surface and contained or if it is broadcast onto the surface. In addition, groundwater quality may be affected by development of oil and gas. A moderately intensive study that would characterize the condition of groundwater with regards to its chemical composition and contaminant load is warranted.

Current monitoring of marine waters is limited to determination of bacterial contamination in the waters adjacent to the developed beach at Malaquite. This type of monitoring should be continued, however, its spatial extent is limited and should probably be expanded somewhat since people swim all along the beach and not just at Malaquite. Additional monitoring of water quality is also warranted since no data exist. We recommend the following:

- Expansion of parameters measured at Station 13469 (Mansfield Pass; currently fecal coliform only) and establishment of a nearshore station near Malaquite Beach. The following parameters should be measured quarterly:
  - Field parameters (pH, water temperature, salinity, and dissolved oxygen);
  - nutrients (ammonia, nitrate+nitrite, total phosphorus, orthophosphorus) and chlorophyll *a*; and
- fecal coliform and/or enterococci should be determined weekly during months when swimming is a major activity of park visitors (March – October). An additional 4-5 stations outside of Malaquite Beach including the campground, and the areas between the northernmost park boundary and Malaquite Beach and between Malaquite Beach and the four-wheel drive area should also be sampled during the same time period.
- Monitoring abundances of red tide organisms during mid to late summer would allow the park to warn visitors before bloom conditions reach levels where respiratory irritation would be problematic.

Invasive or Exotic Species

Both Kleberg bluestem and guinea grass should be managed aggressively with herbicides to prevent their expansion into the native coastal prairies in the island interior. Although none of the islands within the park have any stands of the exotic Australian pine (*Casaurina equisetifolia*), regular monitoring (annual) of the parklands should be implemented to ensure seedlings do not become established. Because no exotic species have been documented within the inland ponds or wetlands, it would be prudent to monitor them to prevent invasion and establishment of both water lettuce (*Pistia stratiodes*) and water hyacinth (*Eichhornia crassipes*) in conjunction with water quality monitoring. Population status of brown mussels on the Mansfield Pass jetties should also be determined at least annually during the late spring or early summer when environmental conditions are optimal for their establishment and growth.

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INTRODUCTION

Padre Island National Seashore (PAIS) is located on Padre Island, a Texas barrier island in the western Gulf of Mexico and the longest barrier island in the world (Fig. 1). It is located within Kleberg, Kenedy, and Willacy counties and stretches approximately 113 km from just south of the Kleberg County line to just north of the community of South Padre Island. Interest in preserving Padre Island began in the 1930s (NPS 1974). In 1958, U.S. Senator Ralph Yarborough proposed the first bill to establish a national park on the island. The federal government purchased land on the island in 1962 and Padre Island National Seashore opened to the public in 1968 (Sheire 1971).

The park is made up of over 52,000 hectares of rare coastal prairie and complex dynamic dunes. It is home to several species of endangered and threatened organisms including the wintering shorebird, the piping plover, and several sea turtle species, such as the Kemp's Ridley sea turtle, that lay eggs along the park's sandy beach. At least 326 bird species utilize Gulf and bay shorelines, coastal marshes and tidal flats, and vegetated flats and freshwater marshes in the interior of the barrier island. The Park has been designated a globally important bird area by the American Bird Conservancy. PAIS borders the Laguna Madre, one of the few hypersaline lagoon environments in the world. The island is also located along the central flyway for shorebird migration and attracts over 350 migratory and residential shorebird species (NPS 2004).

The park was established "in order to save and preserve for purposes of public recreation, benefit, and inspiration, a portion of the diminishing seashore of the United States that remains undeveloped" (Weise and White 1980). The National Park Service outlined management objectives in its Master Plan for the Seashore (1974) which include the following:

- provide recreational opportunities and development in a manner compatible with the protection of the natural and cultural resources of the area;
- avoid short- and long-term impacts associated with occupancy and modification of the park's floodplains and the destruction or modification of wetlands;
- encourage continuing research needed to provide the staff with information for interpretation and management of the natural and cultural resources of the park;
- maintain close liason and cooperation with governmental and nongovernmental entities and individuals who have an interest in the park and its surroundings;
- provide visitors with a varied but balanced interpretive program; and
- ensure the ability to recover mineral resources with a minimal environmental impact (Bright & Company and Belaire Consulting, Inc. 1994).

Water resources are critical to the functioning of ecosystems, because they often determine the distribution of plants and animals as well as the suitability and quality of a habitat for its inhabitants. In addition, water resources are critical to the human users of the park, not just for consumption, but also for the aesthetics and recreational

Fig. 1. Map showing Padre Island National Seashore and surrounding areas.

opportunities they provide. The objective of this report was to determine the current condition and possible impairments of PAIS water resources through a review of currently available information and data. This review will provide the National Park Service with an assessment of the condition of water resources within PAIS, identify data and information gaps that impede assessment and make recommendations for future monitoring.

PARK DESCRIPTION

Physical Setting & Key Features

Padre Island is separated from Mustang Island to the north by Packery Channel and from Brazos Island to the south by Brazos Santiago Pass. It is bisected by an artificially maintained pass, Mansfield Pass, located about 32 km south of the terminus of the Land Cut, an extensive area of bayside sandflats near the middle of the island. The northern half of the island is slightly higher in elevation and has larger sand dunes and more extensive dune fields than the southern half; it is also generally wider (Smith 2002). South of Mansfield Pass, the island is narrower, and washover passes and wind-tidal flats prevail over well-established dune zones (Brown et al. 1980). The wide, gently sloping beaches in the north and south are composed of fine sand. In the central portion of the island (from 32-64 km north of Mansfield Pass), north and south flowing longshore currents converge. The resulting narrower beaches with steep berms, known as Little Shell and Big Shell, are composed of coarse sand and small to large broken shell. The interior of the island is covered with vegetated dunes and flats. Fairly extensive brackish and freshwater marshes and ponds, particularly north of Mansfield Pass, also may be found in the interior. For most of the island's length on the bay side, vast wind-tidal flats covered with blue-green algal mats are the dominant physical feature.

The seashore encompasses central Padre Island and is bounded on the east by the Gulf of Mexico (Fig. 2). The western boundary is located within the Laguna Madre and is less clear-cut; in some areas it extends westward as far as the eastern edge of the Gulf Intracoastal Waterway (GIWW), in others it ends at some point between the western edge of the barrier island and the GIWW. For the purposes of this report, we considered the GIWW the western boundary of the park. The northern boundary of the park is located about 16 km south of Packery Channel and just north of the Kleberg county line and the southern boundary extends south of Mansfield Pass along the narrow margin of the Gulf beach. For the purposes of this report, we considered Mansfield Pass the southern boundary of the park. North of the park boundary is a stretch of undeveloped beach approximately 13 km long that extends from Padre Balli County Park to the seashore. The Nature Conservancy owns and manages 506 ha adjoining the seashore to the south, which buffers the southern portion of the park from development in the town of South Padre Island. Beach driving is allowed for most of the length of the island, including all but ~3 km (Malaquite Beach) of PAIS.

Padre Island National Seashore is part of the Laguna Madre Ecosystem. The Laguna Madre extends from the mouth Corpus Christi Bay, Texas to the Rio Soto La Marina, Tamaulipas, Mexico, and is the largest hypersaline estuary in the world. It is one of the most unique and diverse ecosystems in the Western Hemisphere. Padre Island forms the eastern boundary of the Texas Laguna Madre, a system characterized by emergent wind-tidal flats rather than salt marshes with lush seagrass meadows (primarily shoalgrass, *Halodule* sp.) covering much of its shallow bottom. The Laguna Madre of Texas is physiographically subdivided into two systems by a land-bridge extending from Padre Island to the mainland. This area is known as the Salt Flats, Saltillo Flats, Kenedy Flats, Laguna Madre Flats, or, more commonly, the Land Cut. This latter name was probably coined when the GIWW was excavated through this area.

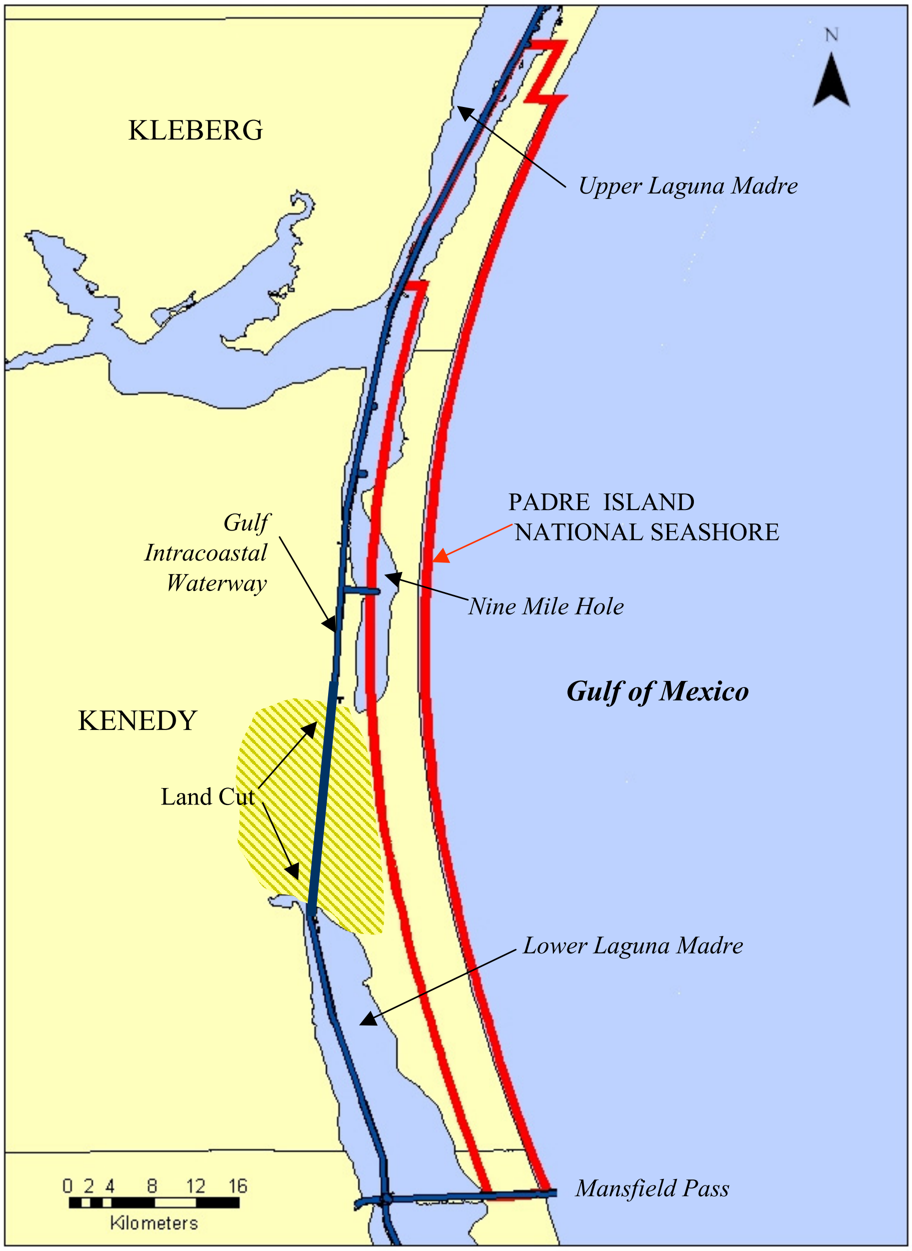

Fig. 2. Boundaries of Padre Island National Seashore and their relationship to the surrounding area.

The Land Cut was formed over several thousand years as a result of sediment transported from Padre Island to the mainland (Morton and McGowen 1980). The process that divided the Laguna Madre of Texas was most likely completed several hundred years ago (Watson 1989: Morton and Garner 1993). The GIWW, dredged in the late 1940s, altered the salinity and hydrology of the system. Although still hypersaline, mean salinities in the upper Laguna Madre have been reduced from an average of ≈50 ppt (Quammen and Onuf 1993). Salinity reduction has resulted in overall expansion of seagrass coverage, particularly in upper Laguna Madre, as well as changes in seagrass species composition, particularly in lower Laguna Madre.

Beginning on the Gulf side and going west to the GIWW, the park includes the nearshore waters, the foreshore (swash zone) and backshore (from high tide line to dunes) on the beach, foredunes, vegetated flats behind the dunes with shallow fresh- or brackish water ponds and marshes, back-island dunes in some areas, wind-tidal flats and shallow, hypersaline seagrass beds in the lagoon (Fig. 3). North and South Bird islands are within PAIS and are two of only a few natural islands in the Texas Laguna Madre. However, there are many dredged material islands along the eastern edge of the GIWW and within the boundaries of the seashore. Many of these islands support thousands of nesting colonial waterbirds including the largest coastal colony of American White Pelicans (Smith 2002).

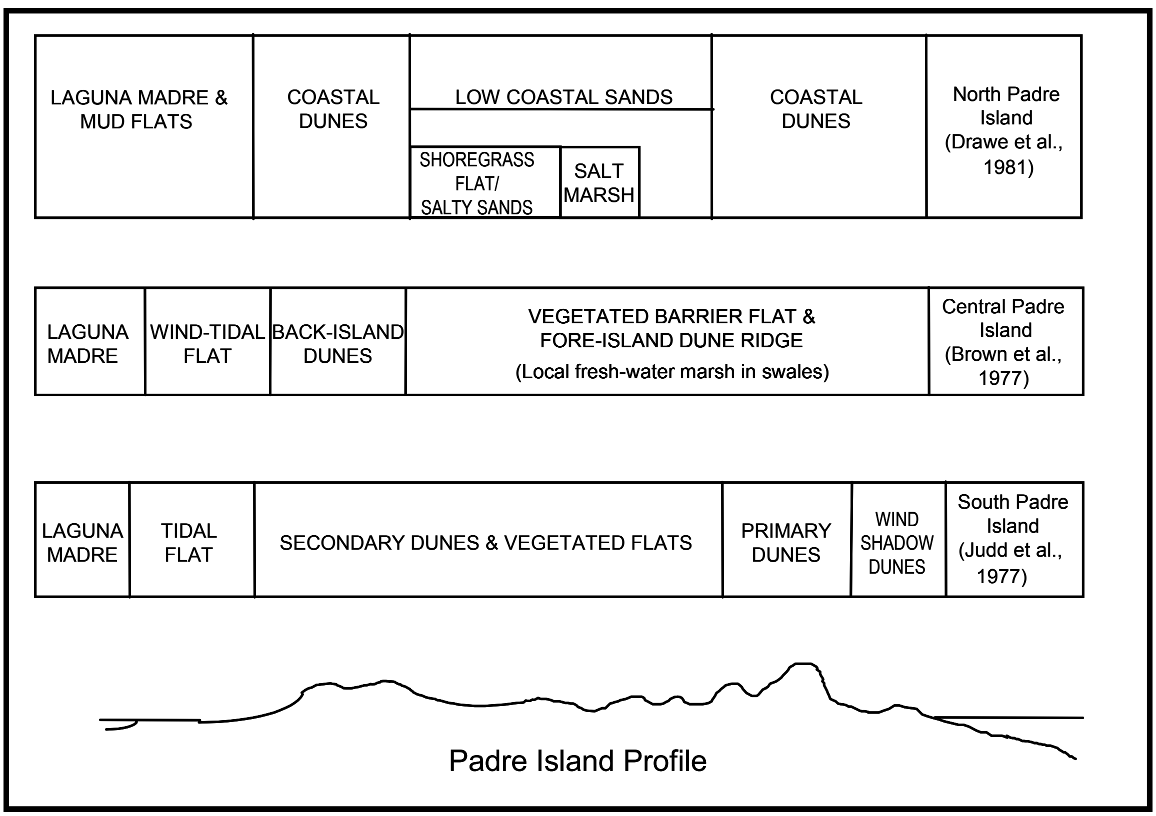

Fig. 3. Profile of Padre Island showing general topography and physiography (from Smith 2002).

The climate in the region of PAIS is semi-arid, subhumid and subtropical with temperatures that are generally warm, but precipitation that is highly variable in both amount and frequency. Drought conditions are not unusual and evaporation nearly always exceeds precipitation. The frequency and length of wet and dry periods greatly influence the type and extent of vegetation found on the island. No rivers run into the Laguna Madre, further decreasing freshwater inflow into the system. Most fresh water comes into the system during infrequent, but often massive, rainfall events when several inches to several feet of rain may fall within a few days. Although these events are often associated with summer tropical weather systems, they can occur at any time of the year. The low slope and low elevations of the Gulf coastal plain result in microtidal conditions on the Gulf beaches and isolation dampens the effects of tides on water levels in the Laguna Madre. Overall, the seasonal rise and fall of water levels combined with the effects of wind speed and direction have a greater impact on tidal range than do astronomical tidal cycles.

The interplay of climate, physiography and geomorphology results in a landscape that is largely shaped by wind. Winds can increase or decrease tide levels on the beach. Wind is largely responsible for water movements in Laguna Madre and the frequency, extent and length of flooding and exposure of tidal flats on the bayside of the island. Wind also moves sand. Depending on whether overall conditions are wet or dry, wind causes dune building and/or migration, tidal flat accretion or erosion and scouring and deflation of swales and depressions.

Land Use & Population

Coastal Development

Barrier islands have attracted the attention of humans since prehistoric times. Indigenous people with a subsistence lifestyle lived on the island until at least the end of the 17th century (Weise and White 1980; Ricklis 1996). Alonso de Pineda was the first European to explore the island (ca. 1519), naming it Isla Blanca (Weddle 1985; Thompson 1997). Numerous 16th century shipwrecks in the waters around Padre Island provide evidence of other explorations by man.

Development on the island began when the Balli family received a Spanish land grant in 1829. The family established a ranch that operated until 1840 but deserted the island in 1844 when the United States threatened to annex the land (Weise and White 1980). However, ranching continued on the island, through the Singer family, the Kings and Klebergs, and eventually the Dunns, who grazed cattle on the island until 1971.

Ranching has had a great deal of impact on the flora and fauna of Padre Island. When Mifflin Kenedy first saw Padre Island he stated that it was “as green as a garden” (Price and Gunter 1942). By 1870, it was denuded of vegetation and the fauna had also changed (Rabalais 1977). These conditions increased the amount of surface erosion and infilling of the Laguna Madre, in conjunction with hurricanes and droughts (Price and Gunter 1942).

Extensive changes have occurred on north Padre Island at the northern end of Laguna Madre. Early aerial imagery in 1956 shows Packery Channel extending in an east-west to northwest-southeast orientation across wind tidal flats and back-island marshes and circling around the upland/dune complex (Fig. 4a). The eastern end connected to the southernmost pass (Packery) of washover pass complex (Corpus Christi, Newport and Packery) that historically connected Corpus Christi Bay with Gulf of Mexico. The road connecting to Mustang Island to the north is visible bisecting Packery Channel and Corpus Christi Pass. The GIWW was constructed in 1945-46, and is located west of this view. One of the dredged material islands is situated on the upper left corner of this and other figures. By 1967, the causeway connecting the mainland at Flour Bluff (part of the City of Corpus Christi) had been constructed, connecting with the road to Mustang Island, and extending southward (Fig. 4b). This image shows the extensive back-island dune complex on northern Padre Island. In 1968, development of Padre Isles subdivision began excavating channels for a planned residential area (Fig. 4c). Construction of several residences had also been completed along Packery Channel by this time

The only established community on north Padre Island is Padre Isles, a recreation-oriented, bedroom community for Corpus Christi that was conceived and developed by the Padre Island Investment Corporation (Kier 1977). The entire development covers approximately 1620 ha from the Gulf beach to the Laguna Madre (Fig. 4d). The master plan shows 8,433 single-family lots, of which slightly more than half are directly adjacent to a network of finger canals. Apartments, duplexes, townhouses and condominiums, some of which would be located adjacent to the canals, are also part of the development. The development includes about 24 ha for commercial development and open space and an 18-hole golf course on 87 ha. Open space, consisting of the golf course, parks and canals (38.4 km of canals, all bulkheaded) comprises about one-third of the total development acreage. A seawall was constructed on the Gulf side. All streets in the development are paved, curbed, guttered. Stormwater is discharged into the canals.

In 1989, 900 single-family dwellings had been completed within the development (Ford 1998). This more than doubled by 1998 with 2,000 single-family residences. In addition, 1600 multi-family dwellings including duplexes, town homes and condos were present and about 200 additional permits for commercial development were permitted in 1998. Development of Padre Isles was largely completed by 1995, however, infilling has continued to occur to date. The back-island dune areas have been replaced by canal subdivisions, and a golf course occupies most of the vegetated flats area. Federal funding was approved for extending Packery Channel into the Gulf of Mexico, and excavation is underway at this date (2004).

Padre Island is relatively undeveloped due to its remote location and that lack of permanent roads. The major populations centers in the vicinity of the park are Corpus Christi in the northernmost upper Laguna Madre; Port Mansfield along the south-central western shore in lower Laguna Madre; and Laguna Vista, Laguna Heights, Port Isabel, and South Padre Island along the southernmost lower Laguna Madre (Table 1). Causeways connect Corpus Christi and Port Isabel to the island. The eventual residential population on north Padre Island expected by the developers of Padre Isles was estimated at 40,000-50,000 (Kier 1977). However, the establishment of PAIS in 1968 stopped any further development on the majority of Padre Island and the island's population as of 1998 (7300 permanent residents; Ford 1998) was still well short of the developer's estimate. The lack of development on the mainland adjacent to the Laguna Madre is largely a result of large landholdings in Laguna Atascosa National Wildlife Refuge, and privately owned ranches such as the King, Kenedy, and Yturria ranches (Tunnell 2002).

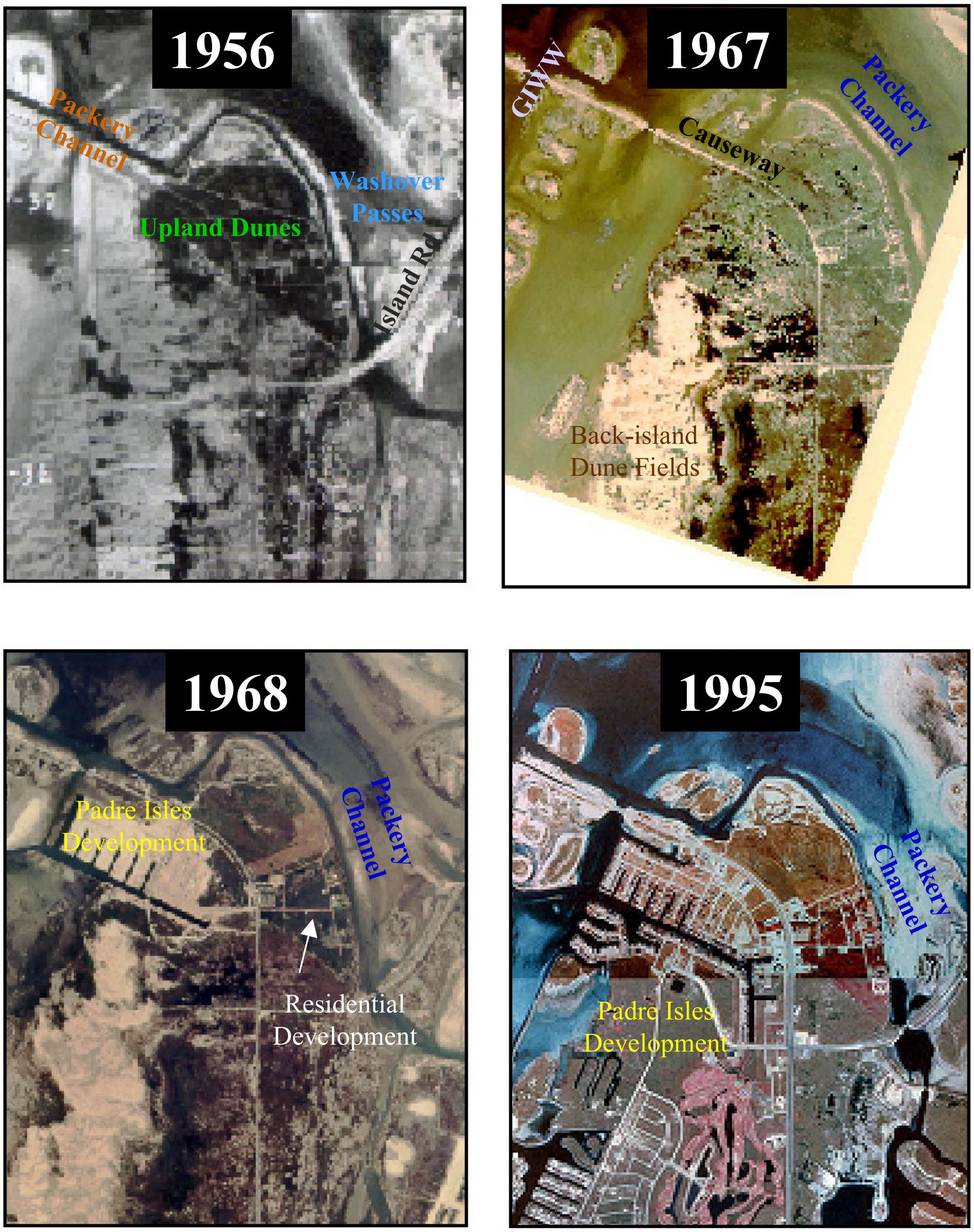

Fig. 4. Historical overview of development on North Padre Island adjacent to Packery Channel and Gulf Intracoastal Waterway (GIWW) from a) 1956, b) 1967, c) 1968, and d) 1995 (all images scanned from map files at Center for Coastal Studies, with the exception of 1995 Digital Orthophoto Quad file archived at Center for Coastal Studies).

Table 1. Current population (2000 census; http://factfinder/census.gov) of counties, cities, and towns along the shores of Laguna Madre of Texas with percent change since 1990 census.

County (North to South) City/Town	**Total County Population**	**City/Town Population**
Nueces County	313,645 (+3.69%)	
Corpus Christi		277,454 (+3.93%)
Kleberg County	31,549 (+1.21%)	
No Towns		
Kenedy County	414 (+1.22%)	
No Towns		
Willacy County	20,082 (+6.96%)	
Port Mansfield		415 (-43.23%)
Cameron County	335,227 (+17.88%)	
Laguna Vista		1,658 (+24.20%)
Laguna Heights		1,990 (+7.92%)
Port Isabel		4,865 (+1.33%)
South Padre Island		2,422 (+23.45%)
Total	700,917 (+10.00%)	288,804 (+4.02%)

Although these ranches are used for raising cattle and other livestock, and some row crops, large tracts are managed primarily for wildlife (deer, dove) and then leased to hunters. However, development continues in the north and south of the seashore as evidenced by the population increases in Corpus Christi and Willacy and Cameron counties between 1990 and 2000.

Currently, recreation is the primary land use of the undeveloped areas of Padre Island including PAIS. Public use and recreational activities have a significant effect on natural resources of barrier islands. The primary attraction of barrier islands is their natural settings, abundant wildlife, and their frequently remote location. The management of natural resources in conjunction with public use of these natural resources necessitates the understanding of potential impacts to human health and ecological impacts. The primary threats to water quality from recreational use of PAIS are human and animal wastes and trash accumulation.

The buffers that exist to the north and south of the park appear to be adequate. Development on the mainland adjacent to Laguna Madre is unlikely in the short-term due to the large amount of private land held in ranches. However, there are proposals for a wind farm on the Kenedy Ranch and it is likely that some development will occur within these ranches during the next few decades. In addition, increasing development north and south of the park will result in increased run-off, and wastewater and stormwater discharge. These impacts have the potential to impact seagrasses and other aquatic community types in Laguna Madre, as well as in the nearshore (i.e., beachfront hotel developments). Continued support for and expansion of areas such as the Nature Conservancy's South Padre Island Preserve, Laguna Atascosa National Wildlife Refuge, and the Nine Mile Hole State Scientific Area are needed.

Bird Island Basin (BIB) consisting of a boat ramp, campground, and picnic area is a popular destination for visitors and is located in the developed portion of PAIS (Bird Island Basin

Recreational Use Plan, 2001). In 1999 there were 51,600 visitors to BIB and visitation increased to 71,700 visitors in 2000. This increase in visitation has led to recreational use conflicts, off road parking from lack of parking places, and environmental impacts such as shoreline erosion associated with heavy visitor use. The park plans to ameliorate these problems by upgrading the BIB area through the modification and construction of additional roads and parking spaces, and through the reorganization of campgrounds and boating access.

The proposed alternative that was accepted by NPS includes the stabilization and widening of the existing BIB shoreline road and the reconstruction of a separate access road to the boat ramp. The portion of the shoreline road currently used to access the boat ramp will be closed and this area will be restored to natural conditions. Separating boat traffic from other visitor uses will reduce traffic congestion and minimize resource damage from lack of parking spaces. The existing BIB shoreline road will be widened to 30 feet and will include additional parking. The southern parking area will also be expanded to accommodate additional vehicles, including RVs. This will alleviate off road parking and subsequent shoreline erosion. Under this plan, vehicle access to the shoreline will cease. Although the plan entails the filling of approximately 200 square feet of wetland mudflats, it should ultimately reduce the impacts of vehicles on the Laguna shoreline and adjacent wetlands. Culverts will be installed to restore tidal flow to the southern mudflat, thus restoring wetland environments and possibly compensating for any wetlands lost during the construction of new roads and parking areas. The construction of a new boat access road and augmentation of the existing BIB access road will likely improve visitor access while protecting natural resources.

Camping locations will be reorganized and a day-use only area will be established in order to meet visitor needs and reduce environmental impact. A day-use only zone will be created with a "no camping" restriction where the boat ramp access road is currently located. Vehicles will be prohibited from accessing the shoreline and day-use parking for up to 15 cars will also be provided to lessen shoreline erosion. Additionally, camping will be allowed adjacent to the shoreline and along the access road, but not on the shoreline. The defining of camping spaces and adhering to the carrying capacity of this area is expected to greatly reduce the impact on resources and enhance environmental quality in this area.

Conservation Areas within PAIS Project Area

The Nature Conservancy of Texas has prioritized Padre Island as part of their Laguna Madre ecoregion initiative during the last several years. To date, more than 10,000 ha of high quality barrier island habitats has been conserved through their efforts and partnering with federal and other agencies. The conservation organization has assisted in acquiring lands for the Laguna Atascosa/Rio Grande Valley National Wildlife Refuge (NWR) system, as well as buy land under their preserve program. The South Padre Island Preserve encompasses 506 ha immediately south of the PAIS boundaries near Mansfield Pass (The Nature Conservancy of Texas, 2003) (Fig. 5). The Laguna Atascosa NWR is located on the western side of lower Laguna Madre, and covers over 18,000 ha of diverse habitat including temperate, subtropical, coastal, and desert communities. This refuge is surrounded by agriculture and encroaching development, and is the largest protected area of natural habitat left in the Lower Rio Grande Valley (http://southwest.fws.gov/refuges/texas/laguna.html).

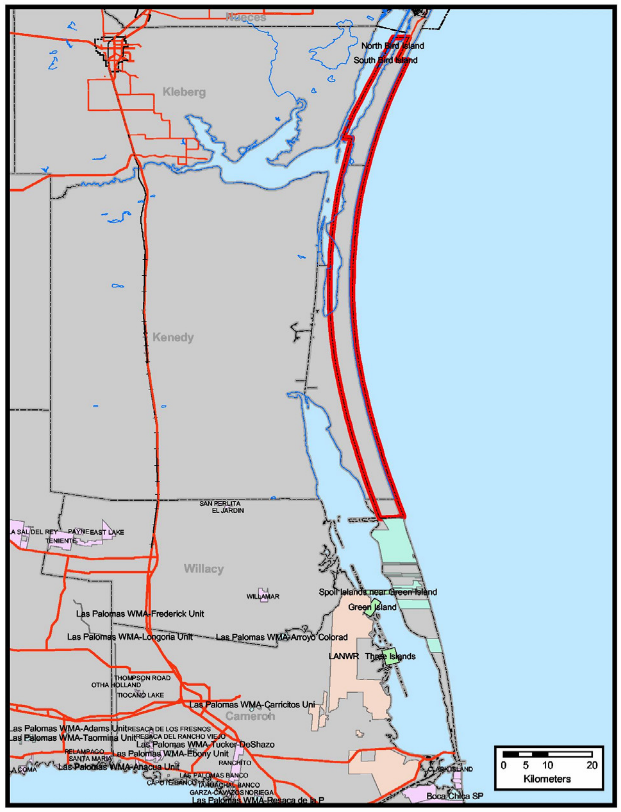

Fig. 5. Padre Island National Seashore boundaries (in red) and associated conservation lands owned by The Nature Conservancy and U.S. Fish and Wildlife Service (in green) and Laguna Atascosa/Lower Rio Grande Valley National Wildlife Refuges (in pink).

Wastewater Treatment Plants & Landfills

Wastewater treatment facilities and landfills were also identified within the PAIS project area as potential point-source contributors (Fig. 6). The wastewater facilities are mandated by TCEQ to maintain water quality standards of treated discharge waters and monitoring protocols. Two facilities are located on north Padre Island, with one facility located within PAIS near the headquarters.

Oil and Gas Activity within PAIS

Over time, there have been 77 oil and gas operations at PAIS, including 56 plugged and abandoned wells, 4 gas wells (2 active & 2 inactive), one water supply well, seven pipelines, and nine seismic operations (Arlene Wimer, National Park Service, Environmental Protection Specialist, pers com). Two sources were located that provided geographic coordinates, and one reference was used that was inclusive of all sites to develop a GIS data layer (Hunter Environmental Consulting 1996). Geographic locations were documented from records as well as in the field, and corrections were noted within the report. The GIS data layer includes site ID,

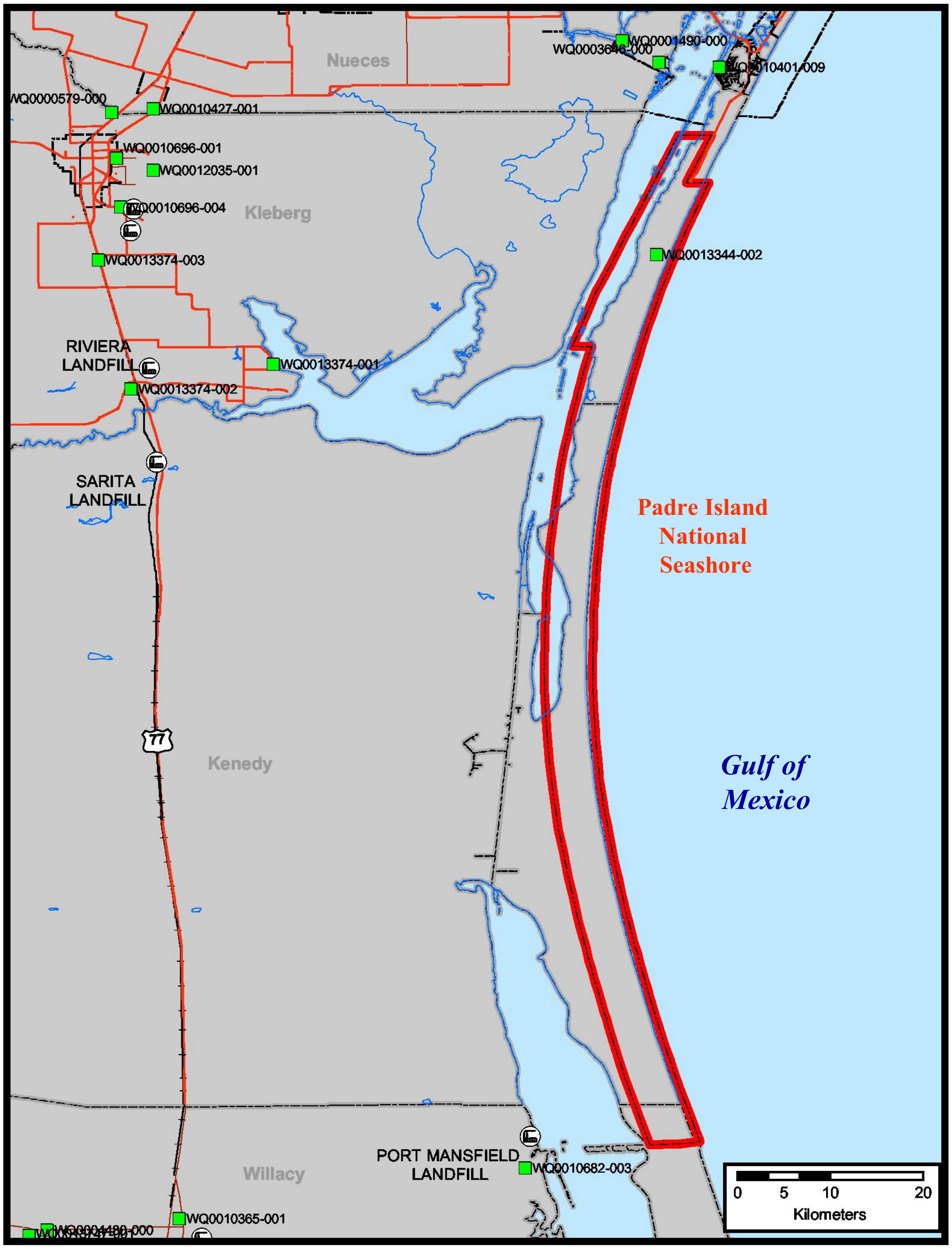

Fig. 6. Location of wastewater treatment facilities within Padre Island National Seashore project area.

site name, if site was located in the field, longitude, latitude, beginning and completion date (of activity), and status (as per report). The sites are distributed primarily in the northern portion of PAIS, with five sites located adjacent to Nine Mile Hole within the Land Cut (Fig. 7).

Overall, oil and gas operations at Padre Island have been conducted in an environmentally responsible manner (Lisa Norby, National Park Service Geologic Resources Divison, pers com). However, several accidental contaminant releases have occurred within park boundaries in the past. For example, meter runs at the Louis Dreyfus Yarborough Pass production facility contributed to mercury and hydrocarbon contamination of soils. The contaminated soil has been removed and the site is now considered remediated. At the Chevron shore-based production facility, condensate and oil was released, contaminating the soil in this area. The contaminated soil was washed and bioremediation techniques were utilized to remediate this site.

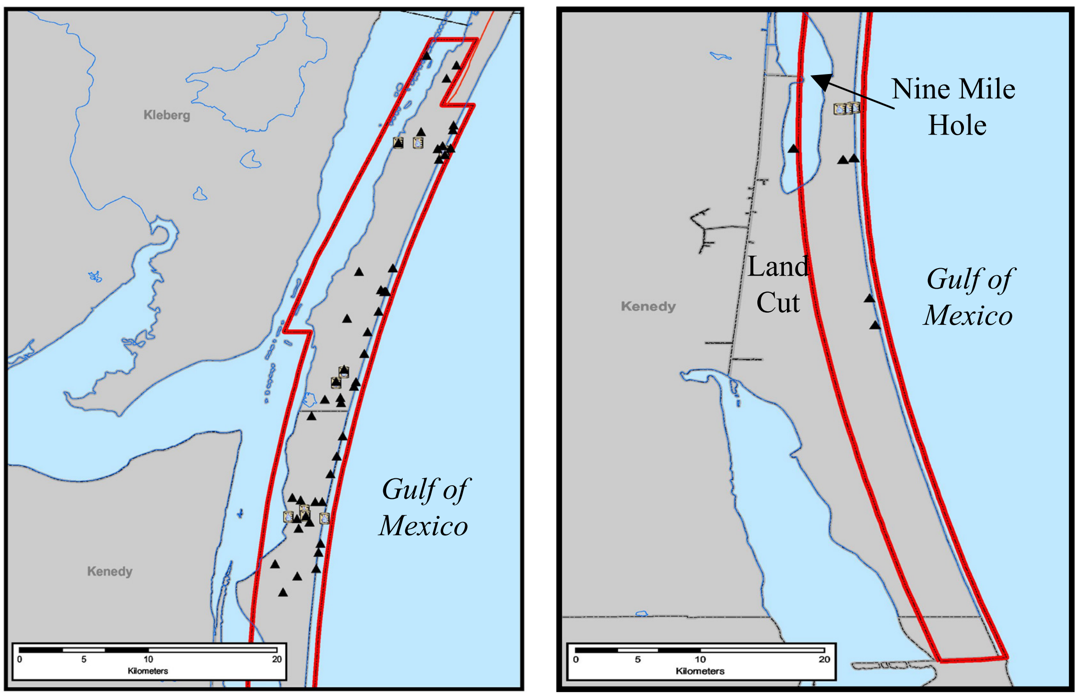

Fig. 7. Location of oil and gas exploration and productions sites within Padre Island National Seashore as reported up to 1996 (compiled from Hunter Environmental Consultants 1996).

Currently, there is existing contamination at two locations within park boundaries as well as the potential for contamination from future spills and accidental releases. Free phase hydrocarbons have been detected on a perched freshwater aquifer at the South Sprint Facility. Efforts are currently underway to remediate this site through the use of vacuum extraction technology. Contamination is also present at the Vector production site, where a faulty valve leaked hydrocarbons into the surrounding environment. This site is also being remediated at this time. The greatest threats to park resources from oil and gas operations are accidental leaks and spills of hydrocarbons from pipelines and producing wells. In addition to hydrocarbon contamination, there is the potential for contamination of groundwater from the injection of produced water into deep formations. However, proper well design greatly reduces this potential threat to groundwater quality. The NPS' oil and gas regulations at 36 CFR Part 9 subpart B require the use of least damaging methods which should greatly reduce the threat of damage to park resources and values.

Physical impacts associated with oil and gas development may also lead to habitat degradation and detrimental impacts to park resources. Infrastructure and activities associated with oil and gas operations such as road cuts through dunes and vehicles driving on the beach have the potential to increase erosion and disrupt shoreline processes. Wellpads and pipeline corridors could disturb wetlands and other resources within the park. For example, lights and noise from the well operations could disrupt the migration of sea turtle hatchlings.

Hydrology

Hydrologic Unit Areas (HUA) for PAIS Project Area

The U.S. Geological Survey developed a standardized system to delineate boundaries of river basins of the United States. The maps generated and their associated codes (HUC) provide a standard method for locating, storing, retrieving, and exchanging hydrologic data. At a watershed level (that includes coastal counties of Nueces, Kleberg, Kenedy and Willacy) three HUC areas were identified: northern Laguna Madre, Baffin Bay, and Central Laguna Madre (Fig. 8).

Hydrology & Sources of Fresh Water

Very little surface freshwater is available from terrestrial sources adjacent to the Laguna Madre or on Padre Island. In the upper Laguna Madre, fresh water flows into Baffin Bay via ephemeral creeks (e.g., San Fernando, Santa Gertrudis, Los Olmos, and others) that flow only when it rains (Tunnell 2002). The Arroyo Colorado, a northern distributary channel of the Rio Grande Delta, and a dredged channel, the North Floodway, drain the agricultural land adjacent to the lower Laguna Madre. Although the Rio Grande once flowed into South Bay, a small embayment at the very southern end of the Texas Laguna Madre, it now flows directly into the Gulf of Mexico, and no longer influences the Laguna Madre except during extreme flooding events. During these events, Rio Grande water is diverted into the North Floodway (Orlando et al. 1991). In the Land Cut, sheet-flow after precipitation events is the only source of freshwater (Brown et al 1977).

Evaporation exceeds precipitation in the Laguna Madre, and is the primary reason for the hypersalinity of the system. Precipitation is highly variable and pulsed, usually with peaks in April and September (Tunnell 1996), and averages about 74 cm/yr (TDWR 1983). Evaporation averages 158 cm/yr. Although average values must be considered with caution, due to the intermittent and variable nature of freshwater inflows into the system, annual freshwater inflow (excluding direct precipitation) from 1941-1976 averaged 851 million cubic meters. Of this amount, approximately half was contributed from gauged drainages (e.g., Arroyo Colorado).

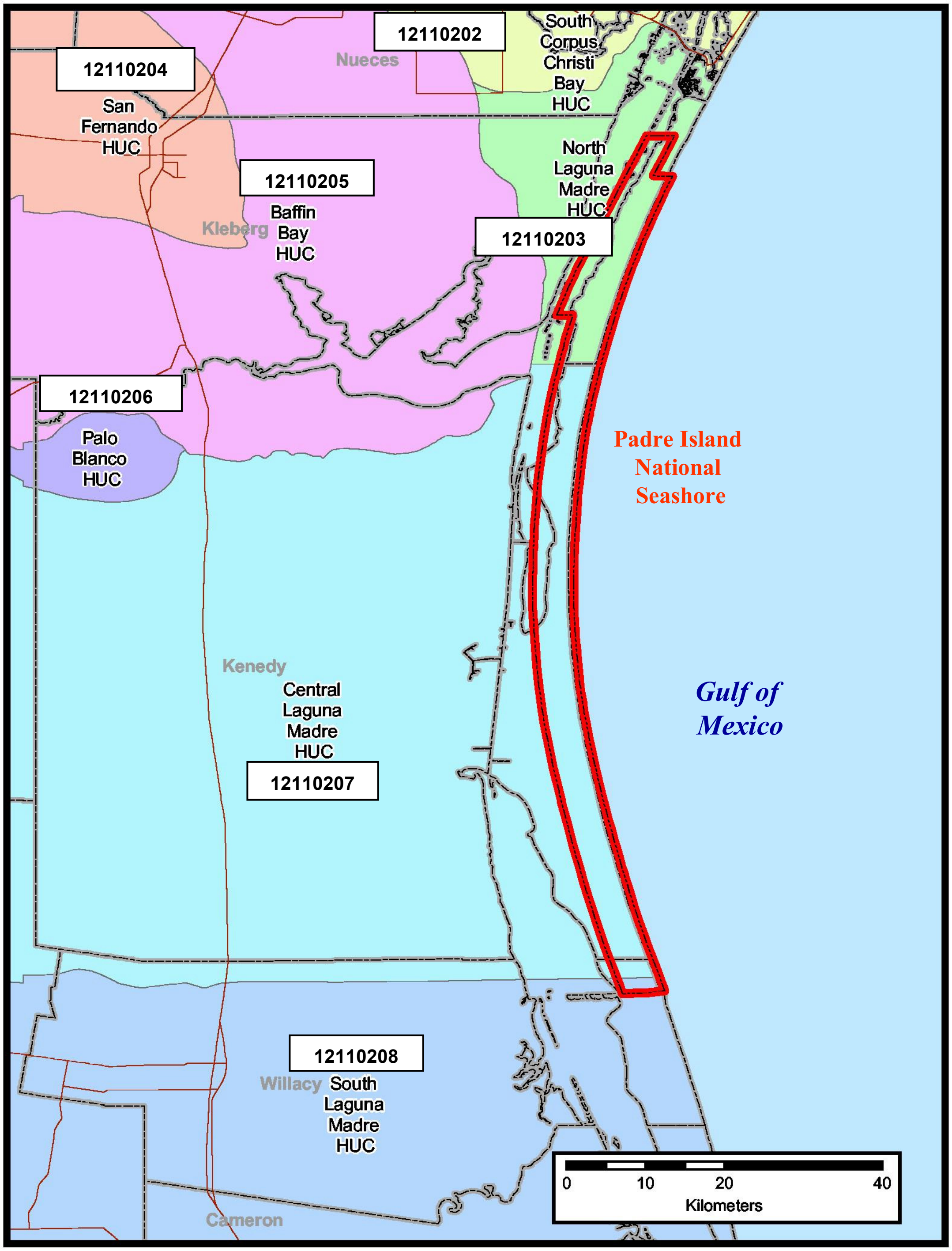

Fig. 8. Hydrologic unit codes (HUC) designated by U.S. Geological Survey for the South Texas coast including Padre Island National Seashore (modified from http://www.tnrcc.state.tx.us/gis/images/seg2000.pdf).

Although still a hypersaline system, average salinities in the Laguna Madre have declined since the late 1940s. Three factors working in concert appear to be responsible for this "freshening": 1) increased water exchange with the Gulf of Mexico resulting from channel and pass dredging, particularly dredging of the GIWW; 2) increased precipitation since 1965 compared to the previous 20 years; and, 3) increased freshwater inflow from the Arroyo Colorado and North Floodway (Quammen and Onuf 1993). Moderation of salinity has resulted in changes in both

the extent and species composition of seagrass communities throughout the system. In the upper Laguna Madre, seagrass, primarily shoalgrass, coverage expanded and by the 1990s, manatee grass (*Cymodocea filiformis*) was becoming more common. In the lower Laguna Madre, replacement of shoalgrass with manatee grass, and to a lesser extent, turtlegrass (*Thalassia testudinum*) has occurred.

On Padre Island, freshwater sources are limited and generally confined to ponds that form in swales and depressions in the vegetated flats. These ponds are an extremely important source of both drinking water and food for many terrestrial vertebrates and birds. However, most are ephemeral, and many become brackish or dry up, particularly during dry periods. Water levels are generally lowest in late summer and early fall (Sissom 1990). Rain is the primary source of water to these ponds, although those that are more permanent may also be fed from groundwater. At 2.4-3.0 m below the surface, a shallow, perched aquifer is situated above the saltwater table (Smith 2002). Like the ephemeral ponds, this aquifer is dependent on recharge from rain that percolates through the sand. A minor source of freshwater for both plants and animals is the dew that collects on plants most nights as a result of the onshore flow of moist Gulf air.

Hydrologic Dynamics & Effects of Alterations

The hydrology of beach and tidal flats are dominated by tidal action, regardless of how the tides are produced. Tidal regimes throughout the system are microtidal (Hill and Hunter 1976). Microtides have very small amplitudes, in this case, generally less than 0.5 m. On the beach, tides are primarily determined by astronomical factors although strong winds can increase tidal range. Gulf tides are generally diurnal, although they may be semidiurnal or mixed during some times of the year (Weise and White 1980)

Circulation patterns in the nearshore areas of the Gulf of Mexico and continental shelf adjacent to Padre Island exhibit seasonal variability due to annual cycles of heating and windstress (Smith 1975a). Tidal motions and longshore current strength decrease in winter and increase in summer; this is mostly attributed to the effects of water flowing into and out of Aransas Pass. Circulation patterns along the inner continental shelf along the Texas coast reflect the strong interdependence between circulation and wind, although astronomical tidal motions also have an effect. Net longshore flow is southwest during winter and northeast during summer. The microtides characteristic of the Texas coast are the result of poorly developed tidal motions that appear to exist primarily as a consequence of water moving into and out of bays.

In the Laguna Madre and the adjacent tidal flats, meterological tides or wind-tides are far more important than astronomical tides (Hedgepeth 1947; Collier and Hedgepeth 1950; Simmons

1957; Breuer 1957; Rusnak 1960). In the upper Laguna Madre, there are three components that affect water levels (Smith 1978):

1. A long-period, semi-annual rise and fall of water levels (≈50 cm) with high water during late May and late October and low water during late February and late July;
2. Water level variations (10-20 cm) that occur over variable time scales (~1-2 weeks) that are dependent on meteorological forcing (wind-tides); and
3. Diurnal or semi-diurnal astronomical tides (2-3 cm) that appear primarily as "noise" in the tidal signal.

Wind-tides in Laguna Madre are dependent on wind speed and fetch but commonly range from 0.3-1.2 m in amplitude (Rusnak 1960). Wind-tides may flood as much as 518 km^2 of exposed wind-tidal flats in Kenedy and Kleberg counties alone (Brown et al. 1977); wind-tidal flats occupy more than 900 km^2 within the system. In the central portion of the Laguna Madre winds from the south and southeast push water out of the northern portion of the lower Laguna Madre across the Land Cut, drive water out of The Hole and into the southern portion of the upper Laguna Madre, and cause water to flow from the upper Laguna Madre into Baffin Bay (Morton and McGowen 1980). North or northeasterly winds produce essentially the opposite effect.

Currents and circulation components in the upper Laguna Madre that have been identified are: 1) convergent flow into the Central Power and Light Company Barney Davis Power Plant; 2) predominantly diurnal tidal oscillations involving exchange of water with Corpus Christi Bay; and 3) a similar long-period oscillatory flow in response to meterological forces, including winter cold fronts (Smith 1975b). During the early years of operation, the Central Power and Light Company Barney Davis Power Plant pumped nearly 1 million cubic meters of water per day out of the lagoon and into the plant for power generation and this increased to about 5 million cubic meters at peak usage in the late 1980s. This pumping was a major component of circulation in the upper Laguna Madre until the late 1990s. However, less than 10% of the peak amount is being pumped currently due to pending shutdown of the plant (B. Hardegree, USFWS Ecological Services, pers. comm.). Although still a factor, it is unlikely that the power plant plays a large role in circulation or water levels in the upper Laguna Madre at this time.

Diurnal or semidiurnal tidal oscillations originating at Aransas Pass result in exchange of water between Corpus Christi Bay and upper Laguna Madre (Smith 1975b). Most of this exchange water flows in and out primarily through navigational channels that offer the path of least resistance. The majority of this movement is probably via the GIWW where it cuts through the JFK Causeway, although the other smaller channels that cut through the causeway also contribute. An estimated 0.77 cm/sec of water flowed in or out but this amount of exchange was not temporally or spatially uniform. During the early years of power plant operation, this constituted only about ½ - ¾ of the water needed to offset the effects (as seen in lowered water levels around Pita Island) of withdrawals by the power plant when water was flowing into the Laguna Madre from Corpus Christi Bay. By the time the power plant was running at peak capacity in the 1980s, it had virtually no ability to offset the affects of the plant. Since the power plant is running at only 10% capacity currently, and if the amount of water flowing through the channels has remained relatively stable since the 1970s, then when inflow from Corpus Christi Bay occurs, it is probably able to offset any water lowering effects of the power plant.

Currently, the JFK causeway is being raised onto pilings between the mainland and Humble Channel, the first small channel that cuts through the causeway. It is likely that circulation patterns will change when this project is completed. In the 1920s, prior to any channelization and more than 20 years before the causeway was constructed, all water that flowed into the upper Laguna Madre from Corpus Christi Bay moved along a narrow, natural channel adjacent to the mainland (Pearson 1929). At that time, the upper Laguna Madre was separated from Corpus Christi Bay by a large sand flat that extended nearly to Pita Island and that was covered with a maximum of only a few centimeters of water. Currently, net water movement from Corpus Christi Bay toward the Laguna Madre along the mainland is southerly, but it hits the earthen causeway and is deflected back toward Corpus Christi Bay (http://hyper20.twdb.state.tx.us/data/bays_estuaries/ccbnep.html). The restoration of flow along the mainland may increase exchange with Corpus Christi Bay or redistribute it more evenly between the GIWW and the area along the mainland.

The third component that produces currents in the upper Laguna Madre are meterological and produce long period net flushing and local internal circulation (Smith 1975b). Variations in surface pressure gradients and windstress affect net loss of water from upper Laguna Madre as well as Corpus Christi Bay and the entire Texas Gulf Coast. These exchanges occur over a period of at least several days and merge with other tide and circulation components such as seasonal water level variations. Although slow, particularly in the isolated upper Laguna Madre, this mechanism is effective in flushing water out of the bays, which is then swept up in the longshore currents of the Gulf and eventually returned to the bays as nearshore shelf water. Although this mechanism, in concert with the other components of tidal movement and water circulation described above, was estimated by Smith (1975b) to be able to flush the system north of Pita Island in as little as 10 days to 2 weeks, turnover in the entire system has been estimated to be at least one year (Buskey 1996)

Trends in Surface & Groundwater Withdrawals

With the exception of the Nueces River, Arroyo Colorado and Rio Grande River, the lack of rivers and impoundments in areas adjacent to and within PAIS means that much of the water that is potentially available for use must come from groundwater. Most of the water supplies within Nueces County come from the Nueces River. On northern Padre Island and the mainland adjacent to the Laguna Madre, a shallow perched aquifer is found within Recent and Pleistocene beach and dune sands with an estimated thickness of 40 ft, to perhaps a maximum of 100 ft (Shafer 1968). This stratigraphic unit yields small quantities of slightly to moderately saline water. However, this source does not appear to be used to any great extent because all water used by Corpus Christi, its suburb adjacent to the Laguna Madre, Flour Bluff, the Padre Isles development on north Padre Island and PAIS comes from surface supplies. There is little potential for groundwater development in Nueces County (Shafer 1968).

In Kleberg and Kenedy counties, Tertiary, Quaternary and Recent formations contain water-bearing strata (Shafer and Baker 1973). Within PAIS and in areas adjacent to the Laguna Madre, a small, shallow supply of fresh to moderately saline water is found just below or within barrier island and beach deposits. These deposits are tapped with wells in numerous places. Although this water bearing strata is fairly limited in distribution, its occurrence is important locally because the principal aquifer, the Goliad Sand, contains only highly mineralized water. On Padre Island, the permeability of the sands allows rainfall to accumulate in thin lenses of freshwater over the more saline water in the aquifer. However, this source of groundwater is somewhat ephemeral and shallow, consisting of only a few feet of freshwater sand. Although shallow sand-point wells have been driven into this stratum in the sand dunes, this source is capable of producing only a few gallons of freshwater per minute. Oil and gas developers working within PAIS boundaries use some groundwater from the deeper Goliad formation in the drilling process (D. Echols, PAIS, pers. comm.). The eolian deposits of the South Texas Sand Plain can also yield small quantities of slightly saline water that is suitable for stock watering, but much of this formation contains only brine (Shafer and Baker 1973).

Groundwater supplies 95-100% of the water needs in Kleberg and Kenedy counties (Shafer and Baker 1973). Generally, the groundwater is of good quality, although contamination with more saline water has occurred and will continue to occur, particularly in areas where pumping has lowered aquifer water levels (e.g., Kingsville area). Much of the suitable groundwater in these counties has already been developed, particularly in areas adjacent to the Laguna Madre and PAIS. Land subsidence due to groundwater pumping has not been noted.

In Cameron and Willacy counties, Quaternary and Pliocene age formations contain the Evangeline and Chicot aquifers (McCoy 1990). These aquifers yield moderate to large quantities of fresh to slightly saline water, but water quality is generally poor except in southernmost Cameron County. Although the majority of water used in these counties comes from the Rio Grande, some groundwater is used for irrigation and it is also mixed with better quality surface water to augment drinking water supplies, particularly in smaller communities. Although of low quality, and potentially with adverse health effects, many people living outside of incorporated areas rely on groundwater for drinking water. Subsidence due to groundwater pumping has not been encountered, even during periods of heavy pumping. Due to declines in irrigation, surface water is adequate to meet the demands for water in these counties, and further development of groundwater resources is not expected to be necessary, particularly since their quality is marginal.

Alterations of PAIS Hydrology or Hydrodynamics Attributable to Water Use

PAIS is relatively remote and freshwater inflows into the Laguna Madre are already limited due to the lack of rivers on the adjacent mainland. Groundwater resources on the mainland are used, but subsidence has not been noted. Because of these characteristics, increases or decreases in water use on the mainland probably have little potential to affect the overall hydrology or hydrodynamics of the Laguna Madre or PAIS. However, as water use and the presence of impermeable surfaces (e.g., sidewalks, hardscaping) increase within the Padre Isles development, greater amounts of stormwater and wastewater effluent from the Whitecap Treatment Plant (0.8 mgd) flows into the Laguna Madre. Despite plans to increase plant capacity to 2.5 mgd (http://www.ci.corpus-christi.tx.us), beyond the addition of fresh water, outflow from the Whitecap Treatment Plant has little potential to alter circulation patterns except locally, and tide patterns not at all.

Biological Resources: Overview of Habitats & Associated Flora & Fauna

Barrier islands have similar structure and dynamics along the Atlantic and Gulf states, and several generalizations can be made at a regional scale. Texas barrier islands are briefly described in this report to identify the various components and their interrelationships in barrier island systems. Barrier islands can be divided into four physical zones (moving from Gulf to bay): 1) beach, including surf zone; 2) dunes; 3) vegetated flats, including freshwater marshes; and, 4) tidal flats and marshes. The forces that control the topography of beach and dune field are distinctive. The beach/surf zone is a marine, wave-driven ecosystem, whereas dune fields are terrestrial, wind-driven systems (Brown and McLachlan 1990). The topography of barrier islands on the Texas Gulf Coast is characterized by distinctive features formed primarily by the constant redistribution of sand by prevailing southeasterly winds. Aeolian erosion and accretion, particularly during droughts, results in active dune migration across islands, and high winds and tides associated with storms result in topographic changes in the beach/surf zone. Along the interior and baysides of islands, features often become stabilized, either by vegetation (vegetated flats), or algae (wind-tidal flats) or both (salt marshes). Currently, Padre Island is prograding landward in the Bird Island Basin area due to the accumulation of wind-borne sand (Prouty and Prouty 1989). However, historical shoreline monitoring of Padre and Mustang Island beaches indicates that the result of reduced riverine sediment supplies and natural and human-induced alterations has been net erosion over the past 115 years (Brown et al. 1974; Morton and Pieper 1976; 1977).

North of Little Shell Beach to the Sabine River, beaches are composed of fine to very-fine, well-sorted sands (Britton and Morton 1989). North and south longshore currents converge between Little Shell and Big Shell resulting in a beach composed of coarser-grained and poorly sorted sand mixed with abraded shells. Dunes and tidal flats are also composed of fine sands whereas vegetated areas are underlain by sand and shell deposits. Accumulations of organic matter and fine sediments are limited to ponds and marshes (Weise and White, 1980). With the exception of pond deposits, permeability of barrier island sediments is high to very high with low water-holding capacity (McGowen et al. 1976). Highly porous soils do not retain nutrients, especially in the dunes, resulting in overall low levels of nitrogen and organic matter (Drawe et al. 1981).

Beach

The beach is characterized by relatively few vascular plants. It is generally divided into an unvegetated foreshore (intertidal) zone with a backshore zone characterized by a belt of sea purslane (*Sesuvium protulacastrum*) nearest the Gulf, and a landward zone dominated by seaoats (*Uniola paniculata*) (Judd et al. 1977). Plants in the foreshore zone are limited to interstitial diatoms and phytoplankton in the overlying water.

A unique aspect of the plant community of the beach is stranded pelagic algae, primarily *Sargassum* spp. (Phaeophyta). Seasonally, beaches in PAIS receive large quantities of *Sargassum* spp. This species and its associated fauna often form a drift or wrack line in the upper reaches of the intertidal zone. In 1950, a band of *Sargassum* approximately 14 m wide and 0.3 m deep was reported lining the Texas coast for over 483 km (Gunter 1979) and the depth of the band can be much deeper (~ 1m) on south Texas beaches during peak deposition in late spring or early summer (K. Withers, pers. obs.). Wrack provides the major organic input on many beaches (McGwynne et al. 1988). Due to the almost complete lack of *in situ* primary production (McLachlan et al 1981), production in the intertidal zone is based on offshore inputs of detritus and phytoplankton held in motion by breaking waves (Britton and Morton, 1989) and on carrion and stranded macrophytic algae deposited as beach wrack (Griffiths et al. 1983). It is not known whether *Sargassum* continues to photosynthesize after stranding. Species such as *Laurentia natalensis*, that forms similar wrack lines on sandy beaches in South Africa, continues to actively photosynthesize after stranding, thus breaking down very slowly (van der Merwe and McLachlan 1987). Amphipods and dipteran larvae consumed 60-80% of the stranded kelp on sandy beaches on the west coast of Africa (Griffiths and Stenton-Dozey 1981), while a portion of the high concentrations of organic leachates found beneath the decomposing kelp are available for direct absorption of interstitial meiofauna (Koop et al. 1982). Shorebirds, particularly Ruddy Turnstones (*Arenaria interpres*), and plovers, often forage along the wrack line of south Texas beaches (K. Withers, pers. obs.). Recommendations for managing *Sargassum* wrack on PAIS during periods of peak deposition to provide an aesthetically pleasing recreational area for visitors while maintaining ecosystem health have been provided in Engelhard and Withers (1997) and Engelhard (1998).

The invertebrate community of the beach generally exhibits low species diversity and is organized into three major zones, backshore, intertidal foreshore, and the subtial bar-trough system. Zones of distribution usually coincide with changes in the physical environment such as sediment composition or surf action and are dominated by unique assemblages of organisms. Numerous studies have described the community composition and zonation of intertebrates on Texas barrier island including Hill and Hunter (1976), Shelton and Robertson (1981), Kindinger (1991), Tunnell et al. (1981), and Vega (1988). The backshore is dominated by ghost crabs (*Ocypode quadrata*), and the foreshore by haustoriid amphipods, coquinas (*Donax* spp.), mole crabs (*Emerita* spp.), and a spionid polychate (*Scolelepsis squamata*). Species diversity generally increases in the subtidal bar-trough system. The polychate *Lumbrineris impatiens*, moon snails (*Polinices duplicatus*), and sand dollars (*Mellita quienquiesperforata*) are common.

Vertebrates on the beach are dominated by birds in the foreshore and fish in the surf zone and subtidal troughs. Terrestrial mammals on the beach are generally transients from the dunes and vegetated flats such as coyote (*Canis latrans*) and raccoon (*Procyon lotor*). Keeled earless lizards (*Holbrookia propinqua*) and whip-tailed lizards (*Cnemidophorus gularis*) are occasionally found in the backshore (Selander et al. 1962). The most conspicuous vertebrates on the beach are the birds, primarily shorebirds (Charadriiformes). The bird community is characterized by both resident and migratory species and individuals, and Gulf beaches serve as a staging area for migratory movements north and south (Chaney et al. 1993). Gulls and terns (Laridae), the most common and abundant species, use the beach primarily as a loafing habitat. Shorebirds feed in the intertidal foreshore on the abundant invertebrates inhabiting the substrate. They use the backshore and wrack line for feeding, roosting, and loafing habitat. Sanderlings (*Calidris alba*) are the most abundant shorebird on the beach and are found throughout the year but do not breed in the area. Other birds that are common throughout most of the year are Willet (*Catoptrophorus semipalmatus*), Red Knot (*Calidris canutus*), Piping Plover (*Charadrius melodus*), and Black-bellied Plover (*Pluvialis squatorola*) (Chapman 1984; Chaney et al. 1993).

Of the preceding, only Willet breed in the area. Peak abundances generally coincide with fall and spring migratory periods, and lowest numbers occur during the late spring and summer months (Chapman 1984). In addition to the Piping Plover, several other federal or state endangered or threatened species frequent the beach, particularly during fall and spring migratory periods and winter: Snowy Plover (*Charadrius alexandrinus*); Least Tern (*Sterna antillarium*); Reddish Egret (*Egretta rufescens*); Peregrine Falcon (*Falco peregrinus*); and, Brown Pelican (*Pelecanus occidentalis*).

Ninety-percent of the fish collected from the surf-zone on Padre Island were larvae and small juveniles of a few species (Shaver 1984). The most abundant species were (in order of abundance): sardine (*Harengula jaguana*); Atlantic croaker (*Micropogonias undulatus*); and, anchovy (*Anchoa nasuta*). Most fish in the surf zone were planktonivores and their relative abundances were correlated with plankton abundance. Seasonally, fish were most abundant during summer and fall, and diel abundances were greatest during the day. Differences in the abundances of age classes were correlated with environmental parameters. Large fish were most abundant during outgoing and high tides, whereas small fish were most abundant during incoming tides.

Sea Turtles

All five species of sea turtles have been reported in the nearshore waters of the western Gulf of Mexico (Owens et al. 1983; Renaud and Carpenter 1994). Loggerhead turtles (*Caretta caretta*) are the most common, as indicated by both nesting and swimming sightings (Renaud and Carpenter 1994). Kemp's ridley turtle (*Lepidochelys kempi*) has been reported to nest sporadically on Padre Island beaches. In mid- July 2004, 22 Kemp's ridley, one loggerhead and one green (*Chelonia mydas*) sea turtle nests had been found nesting on the beaches of PAIS (http://www.nps.gov/pais/pphtml/newsdetail13677.html). Fewer than 2,000 adult Kemp's ridley turtles comprised the world population in the early 1900s, and it the most endangered sea turtle species (Shaver 1992). The population has increased since then, but many factors threaten its recovery including capture and drowning in shrimp nets, poaching of eggs from nests, and collection for food. The entire nesting population of Kemp's ridley sea turtles (adult females) was estimated to be fewer than 700 in 1990s. Efforts to protect a natural nesting area in Mexico at Rancho Nuevo, as well as remove eggs and incubated for hatching and eventual release will hopefully increase the population (D. Shaver, pers. comm.).

The Gulf of Mexico shoreline of PAIS provides essential habitat for nesting sea turtles, particularly the federally endangered Kemp's ridley sea turtle. Efforts to protect this section of this species' nesting habitat has been a primary focus of the National Park Service and U.S. Geological Survey, Biological Resources Division. Dr. Donna Shaver, Chief of the Division of Sea Turtle Science and Recovery at PAIS, has spearheaded this program for more than 20 years. Beginning in late 1970s, PAIS worked to establish a second nesting colony of Kemp's ridley sea turtles by collecting eggs from the primary colony site at Rancho Nuevo, Tamaulipas, incubating the eggs at PAIS, and releasing the hatchings on PAIS gulf beach to imprint them to the PAIS site. The individuals were then recaptured and reared in captivity for nine to eleven months (termed "head starting"), tagged, and released. This portion of the project extended from 1978-1988 (Shaver 2001).

Currently the program works on detecting nesting along the PAIS shoreline as well as other Texas beaches, by patrolling the PAIS beaches and educating the public to report nesting sightings immediately. Tagged females returning to south Texas have been documented, and data collections are continuing to evaluate the "headstarting" efforts. The increases in sea turtle nesting in Texas are promising, and could have major implications in the conservation of this species. However, a majority of the sea turtles continue to be documented in Mexico, where protection efforts are much lower. Other data on their movements throughout the year are underway using satellite tracking methods. Early results have shown that many of the turtles left the Texas coast following nesting and traveled northward paralleling the shoreline to other Gulf states (Shaver 2001).

Many human-related activities impact Kemp's ridley sea turtles, as well as other sea turtle species. Incidental capture in shrimp trawls accounts for most of the sea turtle deaths (National Research Council 1990). Mandatory use of Turtle Excluder Devices (TEDs) is required on U.S. Gulf shrimp vessels since 1990. Positive correlations have been established between shrimp seasons and sea turtle strandings along the south Texas Gulf coast (Caillouet et al. 1996; Shaver 1998). Collaborative efforts to protect the sea turtles in their natural Gulf environment includes revisions to Texas Parks and Wildlife regulations including shrimp-trawling closures from December 1 to May 15. This effort will potentially protect sea turtles in this nearshore area while they are migrating to and from the nesting area. Partnerships between Mexico and United States continue to strengthen, and the program at PAIS has been instrumental in these initiatives. Other research areas currently underway include nest number trend analyses, age to sexual maturity, and nest site fidelity (Shaver 2001).

Red Tide

Blooms of toxic dinoflagellates cause red tides. These organisms are attracted to light and actively swim to the surface where they may be concentrated by wind, currents and tides (Tester and Fowler 1990). The compounds these organisms produce can cause mass mortalities of marine organisms and respiratory irritation in humans when toxic aerosols produced by cell destruction are inhaled (Buskey et al. 1996). *Gymnodinium breve* and *Alexandrium monilata* are the two species that have been identified from red tides in Texas, although *G. breve* has been implicated most frequently. Red tides in Texas offshore waters occur primarily during late summer, with major fish kills recorded in 1935, 1955, 1974 and 1986. Average frequency of major blooms in Texas is 17 ±3-4 years with durations of up to 60 days.

Salinity and temperature are significant factors in initiation of red tide blooms. Optimal salinity for *G. breve* is 27-37 ppt (Aldrich and Wilson 1960), and optimal temperature is 16º-28º C (Rounsefell and Nelson 1966). Sufficient light and carbon dioxide are also required because these organisms are not heterotrophic (Aldrich 1962). There is no evidence that pollution catalyzes blooms (Steidinger and Ingle 1972). Dinoflagellate blooms most likely initiate from seed populations located offshore. The same factors that concentrate organisms and bring them close to shore (wind, currents, tides) are also largely responsible for dispersing organisms and terminating blooms, although other factors such as cell death, grazing or parasitism may also contribute (Steidinger 1983).

Dunes and Vegetated Flats

Vascular plant species richness increases in the dunes and vegetated flats. The primary dune ridge is dominated by morning glories (*Ipomoea pes caprae*, *I. imperati*), gulfdune paspalum (*Paspalum monostachyum*), and seaoats on the windward side and dense stands of windward grass species and forbs such as croton (*Croton punctatus*). Secondary dunes and vegetated flats form a mosaic in most interior island environments. Secondary dunes are dominated by gulfdune paspalum, seacoast bluestem (*Schizachyrium scoparium*), and wooly stemodia (*Stemodia tomentosa*) and are one of the few areas where plant litter accumulates. Although climax vegetation on barrier islands may not be exhibited, it is characterized as a mid-or tallgrass prairie sere dominated by seacoast bluestem, bushy bluestem (*Andropogon glomeratus*), and bitter panicum (*Panicum amarum*) (Judd et al. 1977; Drawe et al. 1981).

Invertebrate communities in the dunes and vegetated flats are dominated by insects, primarily herbivorous species or life stages such as grasshoppers, plant hoppers, katydids, and butterfly or moth caterpillars, but all consumer types are represented. Spiders are also common. Vertical zonation is typically related to wind speed and directions, and distribution is affected by offshore winds, blowing sand, and vegetation density (Ortiz 1976; McAlister and McAlister 1993).

A fairly diverse assemblage of reptiles occurs in the dunes, vegetated flats and associated ponds. Prairie-lined racerunners (*Cnemidophorus sexlineatus*) and keeled earless lizards are common in the dunes and flats, along with numerous poisonous [e.g., cottonmouths (*Agkistrodon piscivorus*) and western diamondback rattlesnakes (*Crotalus atrox*)] and nonpoisonous snakes [e.g., kingsnakes (*Lampropeltis* spp.)]. Turtles and frogs may be found in freshwater ponds in island interiors. Texas tortoise (*Gopherus berlandieri*) and Texas diamondback terrapin (*Malaclemys terrapin littoralis*) are rare or protected reptiles which are found in this habitat (PAIS 1984; McAlister and McAlister 1993).

Heteromyid and cricetid rodents dominate mammal communities in the dunes and vegetated flats. Species richness increases from the dunes to the vegetated flats. Gulf Coast kangaroo rat (*Dipodomys compactus compactus*) and spotted ground squirrel (*Spermophilus spilosoma*) are found in the dunes. A more diverse fauna including rabbits (*Lepus californicus* and *Sylvalagus floridanus*), coyotes, whitetail deer (*Odocoileus virginianus*), a variety of cricetid rodents (e.g., *Oryzomys palustris*, *Reithrodontomys fulvescens*), raccoons, bats (e.g., *Tadarida brasiliensis*), and skunks (*Mephitis mephitis*) are found in the vegetated flats and around interior ponds (Thomas 1972; Baker and Rabalais 1975; Segers and Chapman 1984; Zehner 1985; Harris 1988; Chapman and Chapman 1990; McAlister and McAlister 1993). Matagorda Island supports a large population of feral hogs (*Sus scrofa*) (McAlister and McAlister 1993), but their impacts have not been assessed on PAIS.

Little is known about bird communities in dune and grassland areas. Barrier island grasslands can be important stopovers for neotropical migrant landbirds, since they are the first land encountered after their trans-gulf migration. In addition, birds that migrate along the western Gulf shoreline also use these habitats. Resident and migrant seed-eating birds are likely to be common in both dunes and vegetated flats. Vegetated flats are the principal habitat used by wintering Loggerhead Shrikes (*Lanius ludovicianus*) (Rappole and Blacklock 1985; Root 1988; Chavez-Ramirez and Gawlik 1993). Ducks, grebes, egrets, herons, rails, and cranes feed on aquatic vegetation and insects found in ponds and marshes of barrier island interiors (McAlister and McAlister 1993).

Inland Waters

Wetlands within the barrier island interior are generally ephemeral, filling following rainfall and gradually drying out from evaporation and plant transpiration processes. The wetlands provide freshwater, plant seeds, and invertebrates for waterfowl, wading birds, and passerines. Changes in amount and aerial extent of wetlands on barrier islands have not been studied comprehensively; however, a comparison of north Padre Island from 1950s-1992 using National Wetland Inventory (NWI) data has been done (White et al. 1998). They reported an increase in Palustrine Emergent Marshes (PEM) from 1950s-1979 (+213 ha) and from 1979-1992 (+450 ha). An evaluation of dataset interpretation found that areal coverage of PEM wetlands in the 1992 was overstated with only 40% classified as PEM when ground-truthed, and the remainder more appropriately classified as wetland/upland transitional areas. Interestingly, coverage of PEMIC wetlands (wetter than PEM1A) remained similar, although they were not located in the same areas in all years. In addition, ~80% of PEM1A wetlands were classified as Upland in the 1950s survey. These variations in interpretation make comparisons difficult among years. However, White and his colleagues postulated that the rising relative sea level might have resulted in the expansion of PEM wetlands on the barrier islands. This process raises the freshwater lens above the sea water table, providing more groundwater availability for plant establishment and stabilization of dune fields that can fill in low swales. The decrease in active dune fields also has been attributed to the removal of cattle and recovery from drought conditions and stabilizing the island's interior habitats (Prouty and Prouty 1989).

We utilized the inland water designation in a GIS landuse/landcover dataset developed by National Wetlands Research Center (NWRC) for PAIS (Laine and Ramsey 1998) to determine the distribution and abundance of wetlands/ponds within the park. The NWRC data also included other habitat features of the island, allowing a more holistic comparison of wetlands/ponds within the landscape structure. Inland waters form a linear chain within a wide mosaic of emergent wetlands and patches of grasslands in the northern end of the Park (Fig. 9). Bodies of inland waters are fairly large in size in the lower portion of the map, forming a near continuous water corridor along the island axis that continues in the northern portion of the next section (Fig. 10). Although the island continues to be quite wide, the inland waters decrease substantially, and are replaced by grasslands in the island interior. A line of active foredunes are located at the southern extent of the wide vegetated section of the island, replaced by a more continuous line of grassland (vegetated dunes) on the Gulf side and increasing wind tidal flats on the upper Laguna Madre side of the island. Wind tidal flat habitat increases in Figure 11, and almost half of the island is comprised of this productive habitat type even as the island width continues to decrease. Very little inland water habitat is present adjacent to Nine Mile Hole (Fig. 12), but inland waters increase in conjunction with minor washover passes (Figs. 13, 14). Wind tidal flats and back-island dunes increase southward, and no inland water was identified in the southern portion of the Park adjacent to Mansfield Pass (Figs. 15, 16). A comparison of landcover transects constructed from each map view (Fig. 17) shows the relationship between inland waters, the relative width of the vegetated portion of the island, and decreases in wetlands progressing southward. Inland water associated with washover passes is present only in the southern portion of the island.

Tidal Flats and Salt Marshes

Salt marsh vegetation on barrier island baysides decreases from Freeport, Texas southward and is often restricted to narrow fringes bordering tidal flats. Irregular tidal inundation, coupled with lack of freshwater inflows generally precludes establishment of typical salt marsh vegetation (Pulich et al. 1982). Salt marsh grasses such as smooth cordgrass (*Spartina alterniflora*) may be present, but more often the zone is characterized by halophytic vegetation including saltwort (*Salicornia* spp.), dropseed (*Sporobolus virginicus*), sea ox-eye daisy (*Borrichia frutescens*), and shore grass (*Monanthochloe littoralis*) (Judd et al. 1977). Algae, particulary blue-green algae, dominate tidal flat plant communities forming feltlike or leathery mats at and above mean sea level (Fisk 1959; Sorenson and Conover 1962; Armstrong and Odum 1964; Zupan 1971; Herber 1981; Pulich et al. 1982; Pulich and Rabalais 1986). Because salt marsh development is limited on barrier islands of the central and southern coast, the rest of the discussion will center around tidal flats.

Tidal flat invertebrate communities are dominated by primarily marine organisms such as polychaetes and tanaids in areas of frequent inundation where sediments remain wet or saturated and by semi-terrestrial insect larvae (primarily dipterans) in areas where sediments remain damp (Withers, 1994). Although the community is structured similarly to the beach, zones are not clearly delimited and form more of a mosaic because of microtopography within the flat, and the greater importance of wind in tidal inundation period and pattern.

Hypersalinity and harsh conditions limit the diversity of non-bird vertebrate populations in tidal flat ecosystems. Reptiles and amphibians have not been noted on flats and occurrence of mammals such as white-tailed deer and coyotes is incidental. Sheepshead minnows (*Cyprinodon variegatus*) dominate the fish community found in the shallow water adjacent to tidal flats and move into deeper water as water levels recede (Pulich et al. 1982).

Tidal flats are extremely important foraging habitats for wintering and migrating shorebirds. Peeps (*Calidris* spp.), and Piping and Snowy plovers were common and often abundant on tidal flats on Padre and Mustang islands, particularly between October and March or April (Withers 1994). Shorebirds feed on the invertebrates found on or in the substrates, while wading birds such as Great Blue Herons (*Ardea herodias*) and Reddish Egrets feed on the fish in the nearshore waters. Numbers of wading birds were generally highest during the summer and early fall. Gulls and terns can be abundant and use flats as loafing areas. Tidal flats are also important foraging habitats for wintering Peregrine Falcons, which feed on shorebirds and other avian prey.

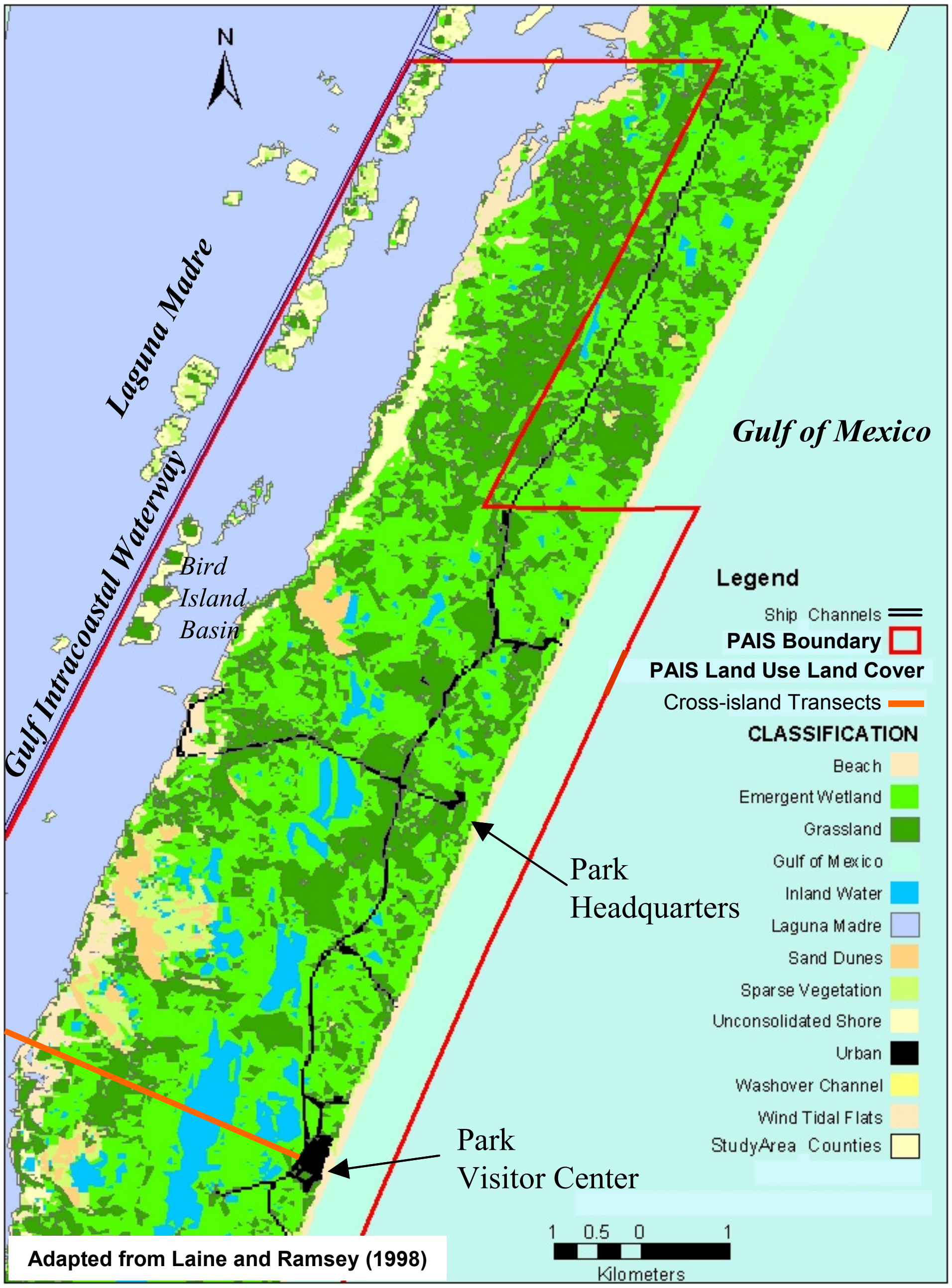

Fig. 9. Northern portion of Padre Island National Seashore depicting land use/land cover types. Note abundance and size of interior ponds to west of park roads and bisected by road leading to Bird Island Basin in Laguna Madre.

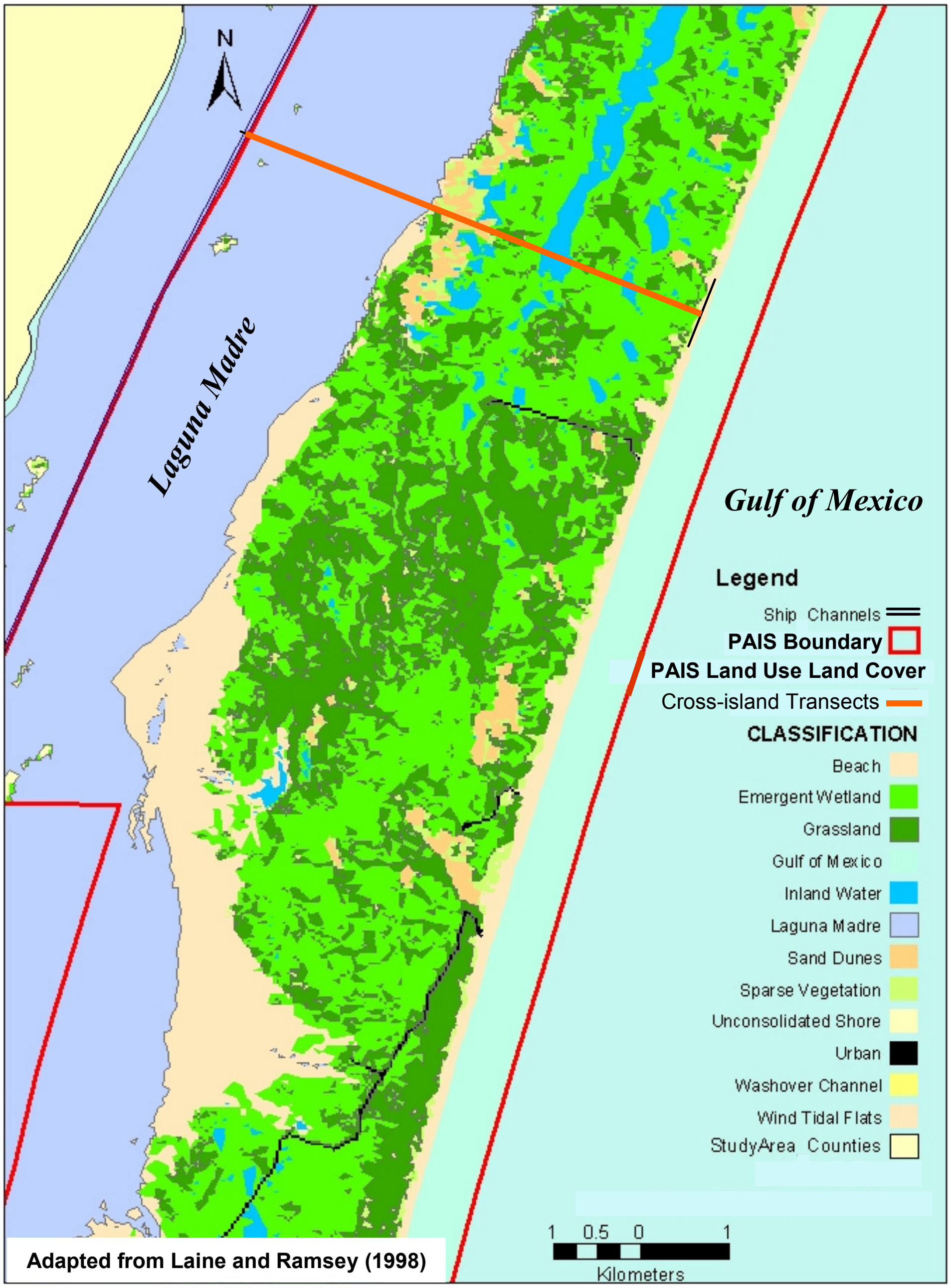

Fig. 10. Portion of Padre Island National Seashore immediately south of park visitor center. Note the decrease of interior ponds, widening of vegetated flats as well as wind tidal flats.

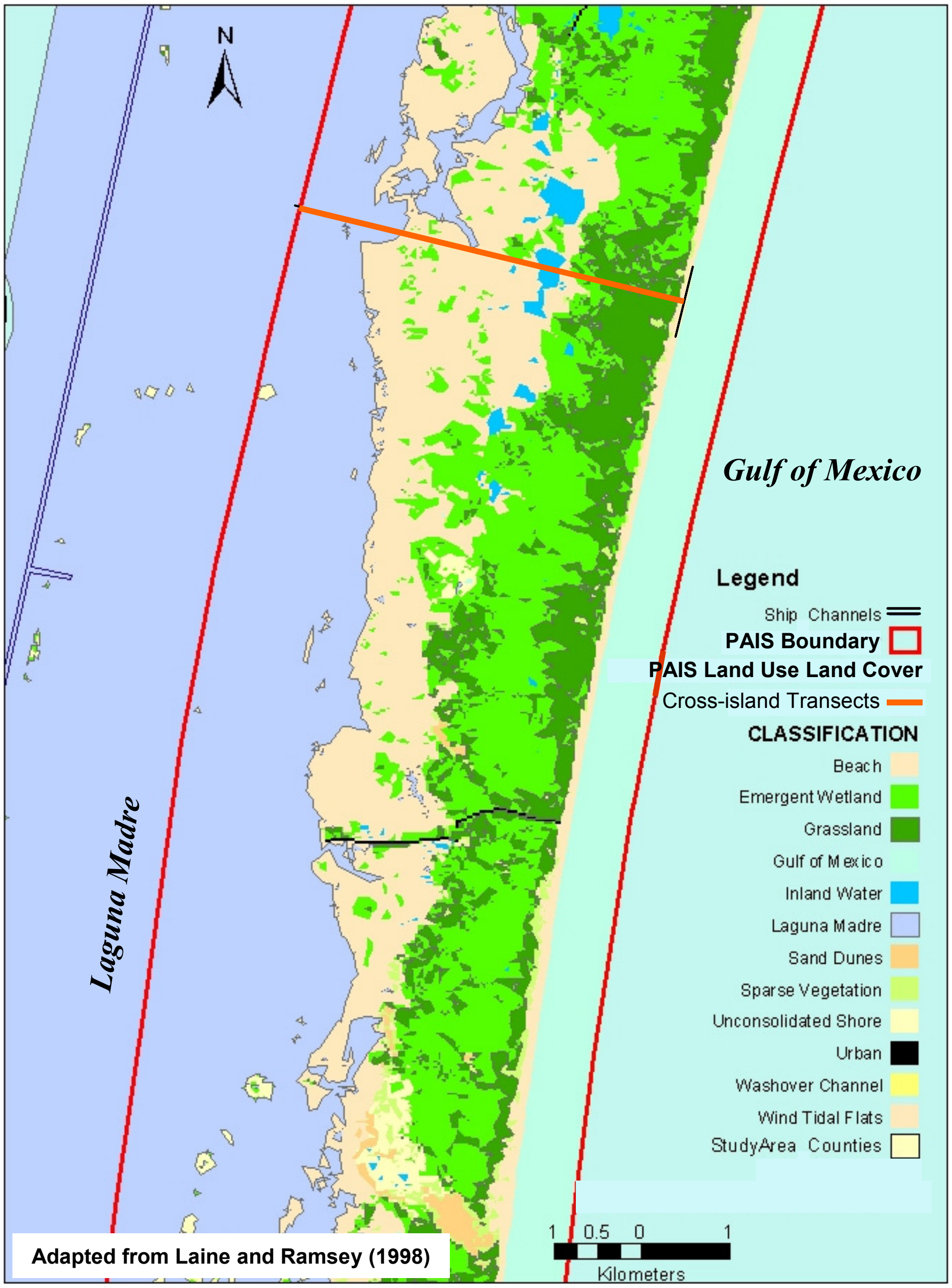

Fig. 11. Central portion of Padre Island National Seashore depicting increases in wind tidal flats along Laguna Madre and decreases of vegetated and pond habitats.

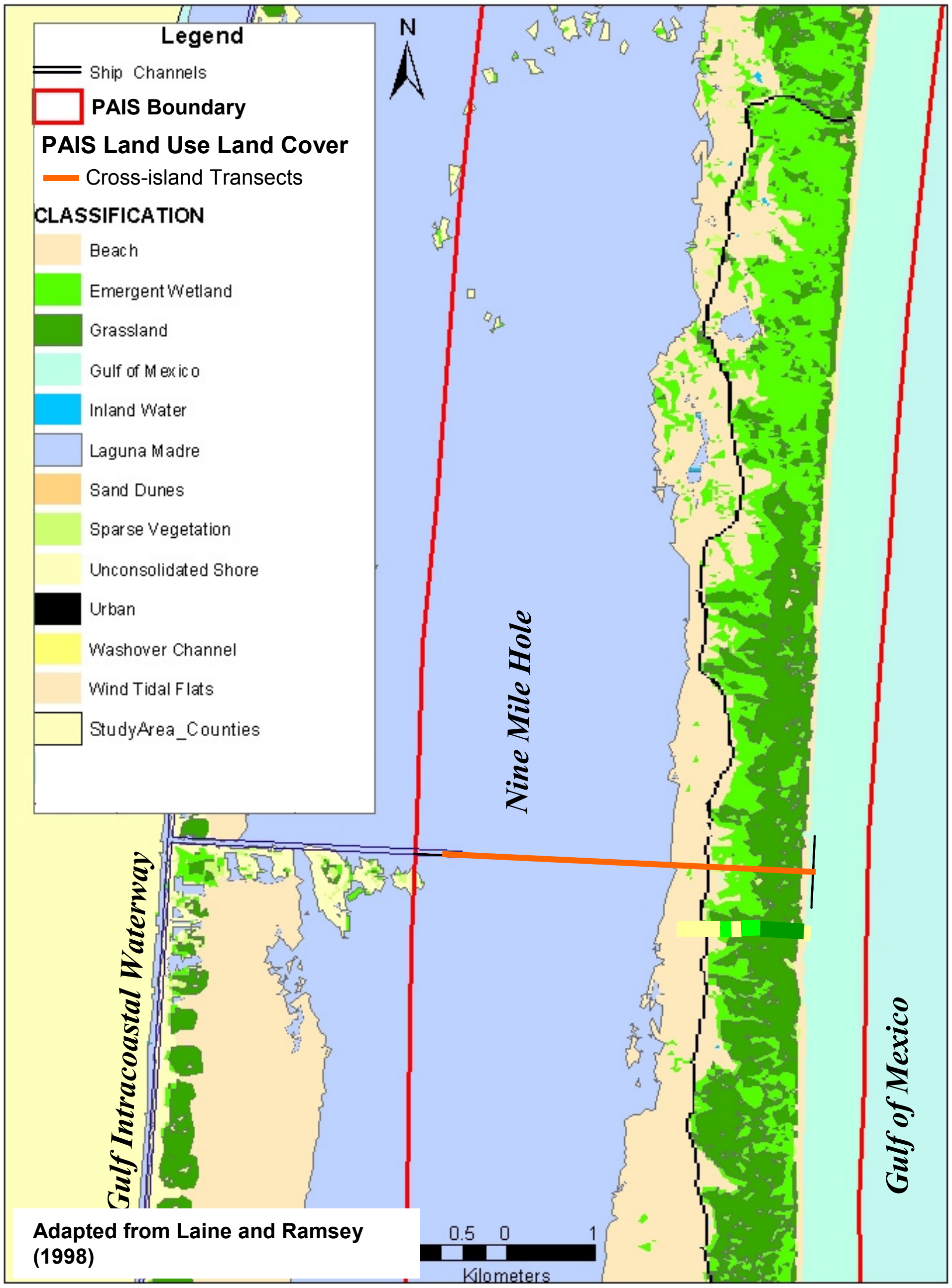

Fig. 12. Portion of Padre Island National Seashore that includes the eastern section of Nine Mile Hole within the Land Cut. Note narrow width of the barrier island and continuation of wind tidal flats along the western shoreline, as well as few interior ponds.

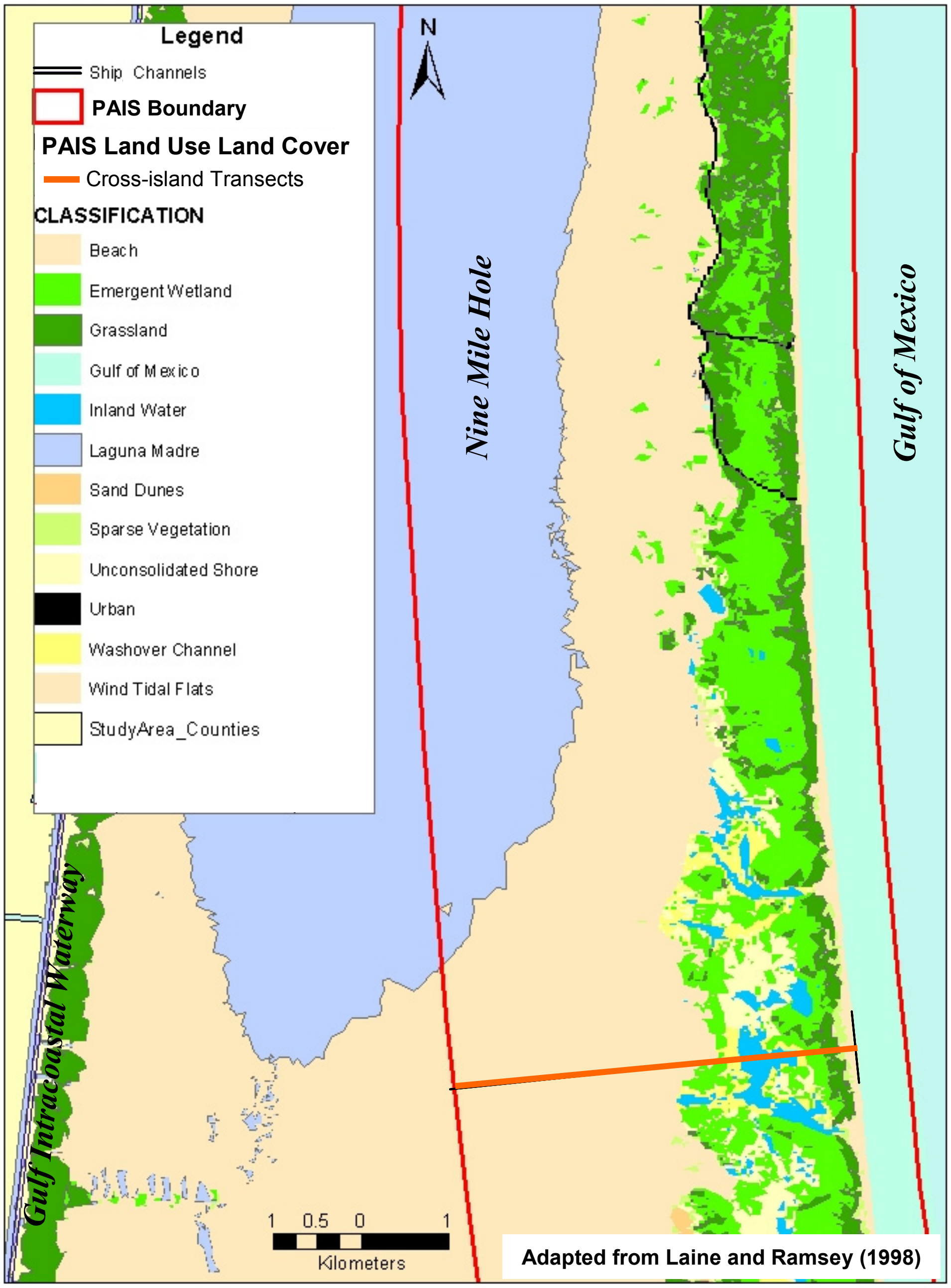

Fig. 13. Portion of the Padre Island National Seashore that include the southern portion of the Nine Mile Hole within the Land Cut. Note increased coverage of wind tidal flats and decreasing vegetation along the barrier island. Several inland ponds are delineated within the vegetation patches.

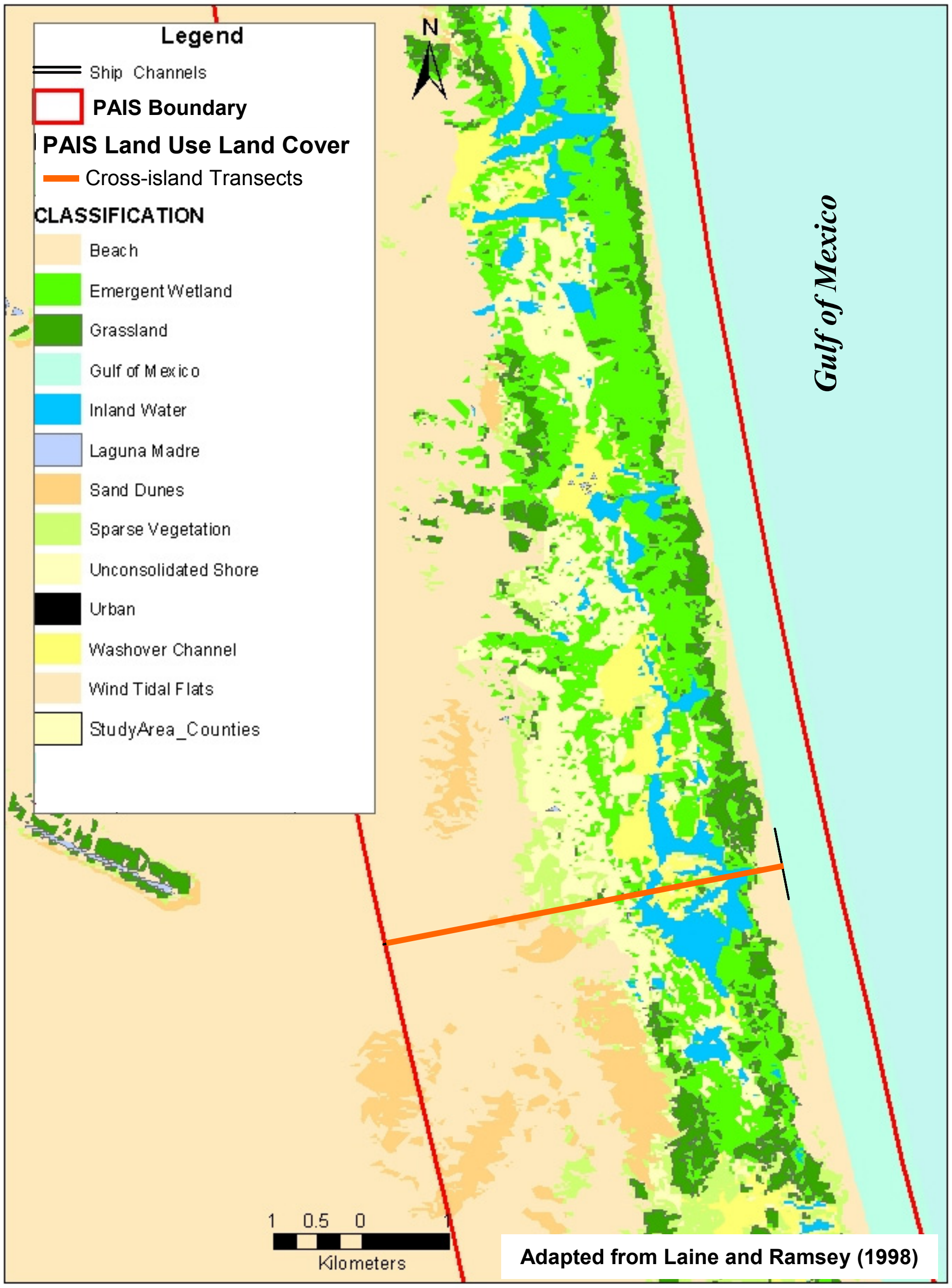

Fig. 14. Portion of Padre Island National Seashore immediately north of the Lower Laguna Madre (see minor portion in lower left corner). Note predominance of wind tidal flat habitat, and presence of inland ponds delineated among vegetated and washover channel patches.

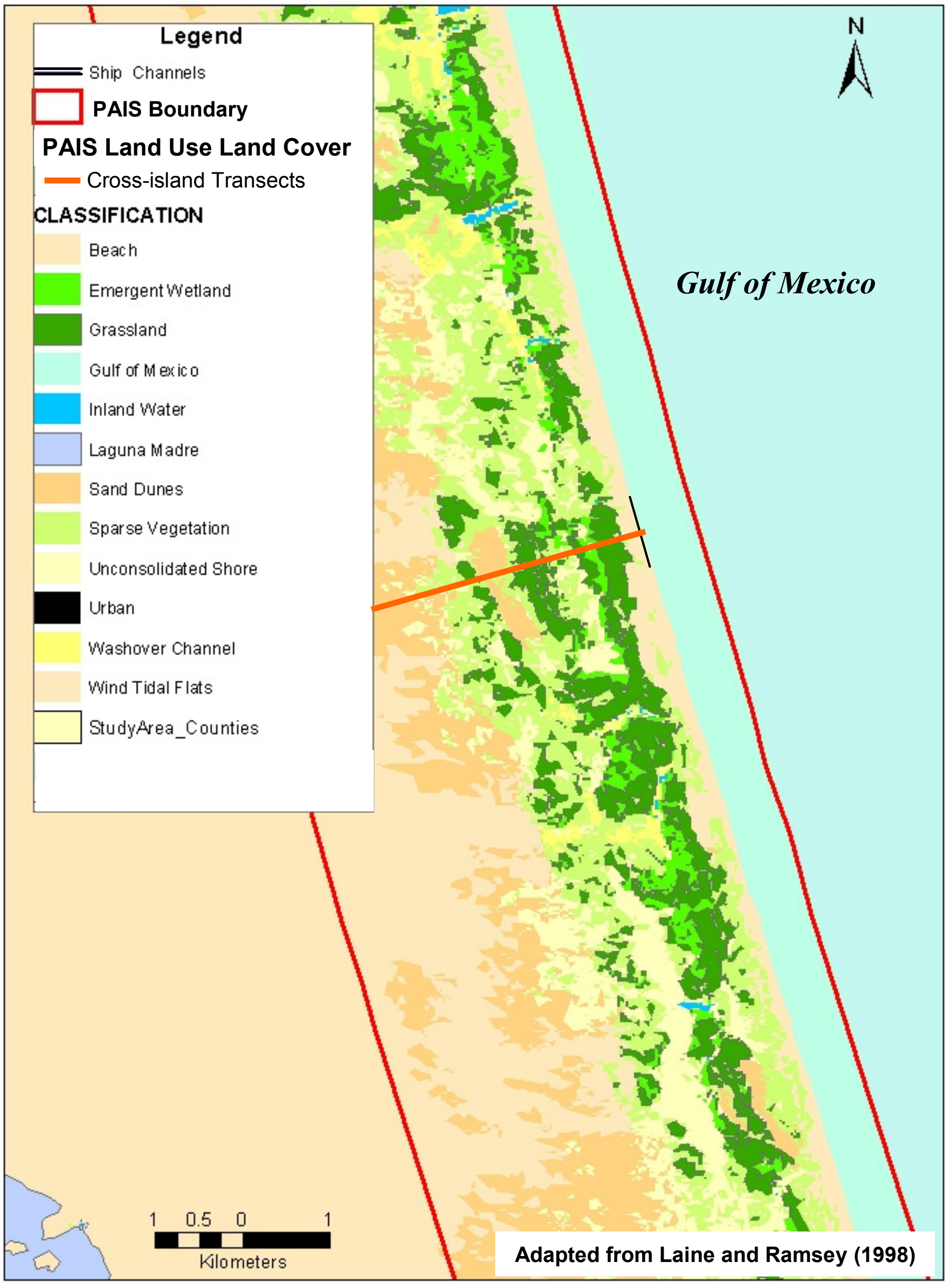

Fig. 15. Portion of Padre Island National Seashore adjacent to Lower Laguna Madre, depicting patching vegetation and an increase in back island dunes interspersed on wind tidal flats.

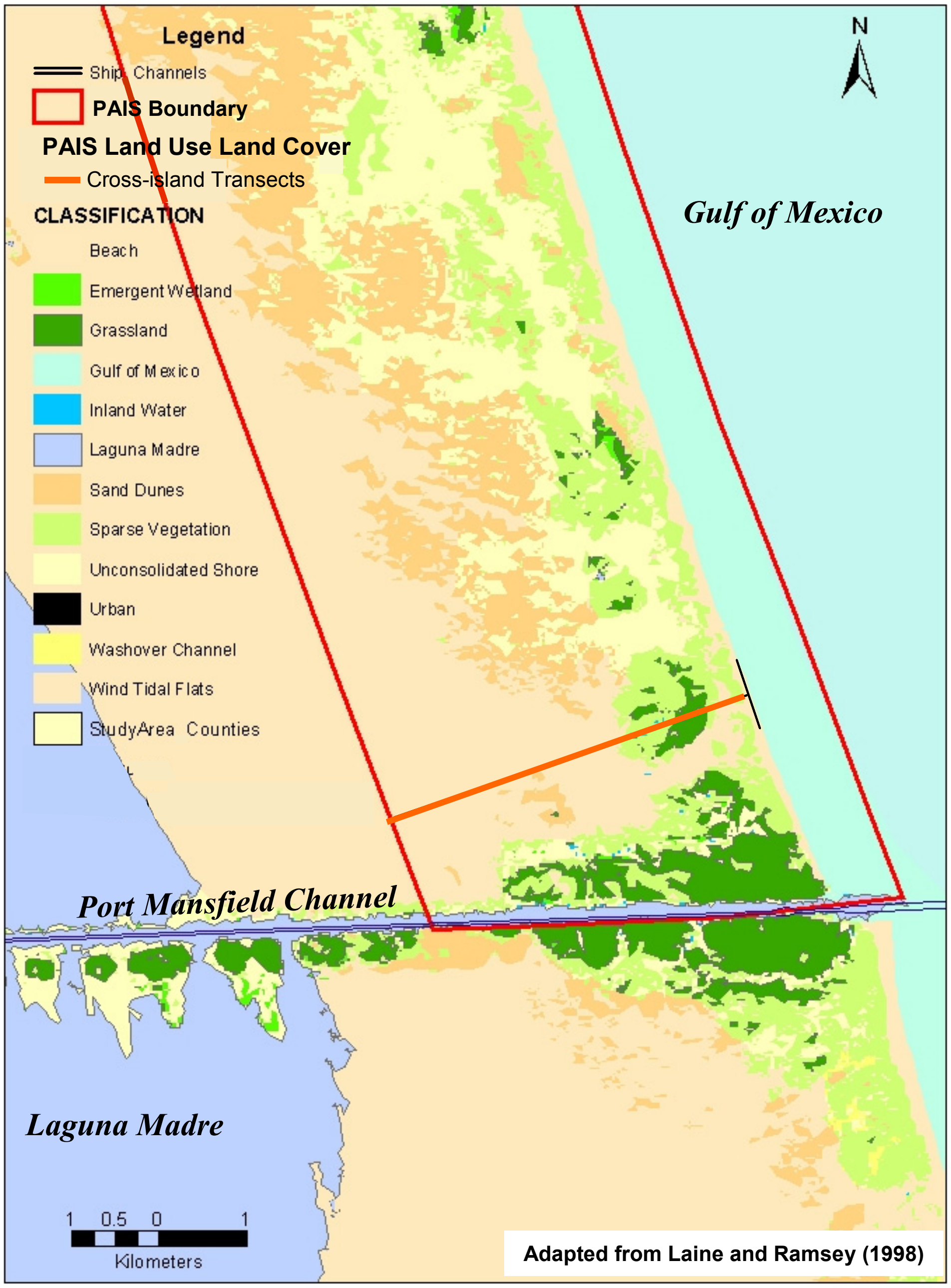

Fig. 16. Portion of Padre Island National Seashore at the southern boundary of the park along Port Mansfield Channel. Note grassland vegetation established on dredged material adjacent to the channel.

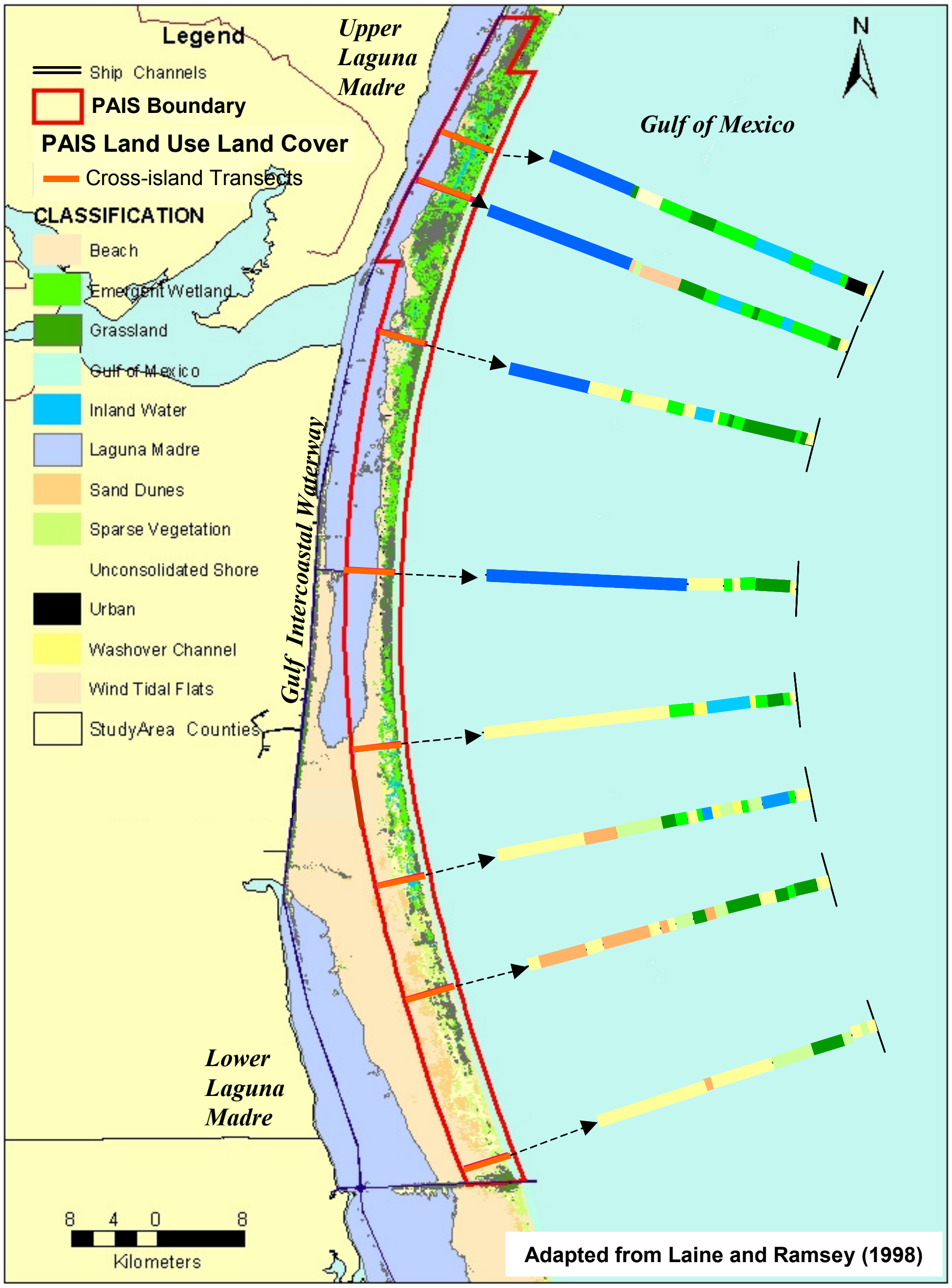

Fig. 17. Land cover of Padre Island National Seashore and transects constructed to show inland water habitats and their relative position in the island profile from north to south.

Seagrass

Seagrass communities are common estuarine components and are extremely productive for fish and wildlife. About 80% of seagrasses on the Texas Coast are found in Laguna Madre (Pulich 1998). Five seagrass species are documented within the Laguna Madre ecosystem: shoalgrass, manatee grass, turtlegrass, wigeon grass (*Ruppia maritima*), and clover grass (*Halophila engelmannii*). In upper Laguna Madre, seagrasses covered 243 km^2 in the early 1990s (Quammen and Onuf 1993), whereas they covered 480 km^2 in the lower Laguna Madre (Pulich et al. 1997). The structure of seagrass meadows provides baffling effects from waves, reduces erosion, and promotes water clarity by removing suspended sediments. Biologically, seagrasses provide nursery areas, refuge, and rich foraging grounds for a variety of estuarine fish and invertebrates, including a number of commercially and recreationally important species. The majority (>70%) of the population of Redheads (*Aythya americana*), a migratory waterfowl species, winters in the Laguna Madre system (Weller 1964) where they forage primarily on shoalgrass (Adair 1990; Woodin 1996). Seagrass wrack plays a major role in nutrient cycling and is a primary source of organic material to adjacent coastal and nearshore ecosystems (Withers 2002).

The invertebrate community of seagrass meadows is diverse and consists of epibenthic, benthic, epiphytic, and nektonic organisms. Polychaetes predominate in both upper and lower Laguna Madre. Gastropods typically outnumber bivalves, and include ceriths (Family Cerithidae), slippershells (*Crepidula* spp.), and caecums (Family Caecidae). The bivalves Atlantic papermussel (*Amygdalum papyrium*) and Morton eggcockle (*Laevicarium mortoni*) have been described indicator species in seagrass meadows of Laguna Madre. Shrimp and crabs are the predominant epibenthic and/or nektonic crustaceans, and are also important commercial species (Withers 2002).

Both seasonal and permanent fish residents can be found in Laguna Madre seagrasses. Seasonal species are typically juvenile or subadult stages or spawning adults and include commercially and recreationally important species (e.g., drums, mojarras, grunts, and porgies) (Kikuchi 1980). Permanent fish species are typically small, cryptic, less mobile species spending their entire life cycle within the seagrass meadow (e.g., pipefishes, gobies, blennies, and eels). Many fish species are carnivorous, preying on other fish and crustaceans. Several fishes forage on seagrass as well, including sheepshead (*Archosargus probatocephalus*), black drum (*Pogonia chromis*), cownose ray (*Rhinoptera quadriloba*) (Carangelo et al. 1975); pinfish (*Lagodon rhomboides*) (Darnell 1958; Carr and Adams 1973); Atlantic needlefish (*Strongylura marina*) (Darnell 1958); and striped mullet (*Mugil cephalus*) (Pullen 1960).

Sea turtles historically utilized seagrass meadows of the Laguna Madre, as evidenced by records of cannery production in late 1900s (Shaver 1990; USFWS and NMFS 1992). Many of these turtles came from lower Laguna Madre, where green turtles comprised the leading marine product by weight (Hildebrand 1981; Doughty 1984). Recently, several sea turtles have been captured in gill nets in the lower Laguna Madre during TPWD fishery surveys (R. Blankenship, Texas Parks and Wildlife Department, pers. comm.). Leaves of seagrass comprise up to 100% of juvenile green turtles and hawksbill turtles (*Eretochelys imbricata*) diets (Bustard 1972; Hirth et al. 1973; Rebel 1974). Radio and sonic telemetry studies conducted on one loggerhead turtle and four green turtles in South Bay resulted in habitat preference for seagrasses as 50% and 60%, respectively.

Changes in Seagrass Community Composition

Seagrass cover and community composition in the Laguna Madre have been changing since the early 1900s. There is no data concerning seagrass community composition or distribution prior to the late 1950s. A vague description of the bottom as grassy or muddy is found in Pearson (1929). Prior to completion of the GIWW (1948), seagrass populations probably waxed and waned in response to changing salinities caused by drought and tropical storms and hurricanes (Withers 2002), similar to the "boom-bust" dynamics of Laguna Madre de Tamaulipas where the system has remained relatively unchanged. Shoalgrass and widgeon grass were probably present in upper Laguna Madre, and in the lower Laguna Madre, these species probably dominated, although manatee grass and turtlegrass may have been present near Brazos Santiago Pass where salinities would have been tolerable.

In 1965, shoalgrass dominated both upper and lower Laguna Madre, although its distribution in the upper lagoon was limited to the area north of Baffin Bay (McMahan 1966, 1967). Some manatee grass was present in the lower lagoon near Brazos Santiago Pass. By the mid-1970s, manatee grass coverage had expanded in lower Laguna Madre, displacing shoalgrass, and shoalgrass cover in the upper lagoon had increased to both north and south of Baffin Bay (Merkord 1978). In 1988, manatee grass was found at intermediate depths throughout lower Laguna Madre, but had been replaced by turtlegrass near Brazos Santiago Pass (Quammen and Onuf 1993). Clover grass was found along the southerly end of the GIWW. In upper Laguna Madre, shoalgrass cover had also increased, with clover grass found where meadows transitioned to bare bottom. Manatee grass was not found in samples taken from upper Laguna Madre in 1998, but patches were observed in transit between stations (Quammen and Onuf 1993), and cover has increased dramatically since 1988 (C. Onuf, USGS, pers. comm.).

Salinity declines following dredging of the GIWW has been proposed as driving factor in changes in seagrass community composition in Laguna Madre. The shift in species dominance is advancing at a faster rate in the lower Laguna Madre, primarily as a result of the more direct connection to the Gulf of Mexico through Brazos Santiago Pass (Quammen and Onuf 1993). Succession appears to be proceeding toward a turtlegrass climax in lower Laguna Madre, although the rate of change suggests that it will take at least 50 years for it to be achieved. The expansion of manatee grass in upper Laguna Madre also suggests movement toward a turtlegrass climax, but at a slower pace. It is likely that seagrass community composition in upper Laguna Madre will more resemble current community composition in lower Laguna Madre in the next few decades.

In the winters of 1993-95, losses of 9.4 km^2 of shoalgrass were documented in upper Laguna Madre as a result of a brown tide bloom (*Aureomonas lagunensis*; Onuf 1996). As light attenuation due to the bloom persisted, reductions in seagrass biomass also increased. Although this long-term algal bloom (~8 years from initiation to termination) was likely caused by the synergism of a unique set of natural conditions (Onuf 2000) watershed contributions of nutrients were not ruled out (Onuf 1996). Despite the fact that bloom conditions have not occurred in the system since 1997, seagrasses have exhibited little recovery (C. Onuf, USGS, pers. comm.). The reason for the lack of recovery is not known at this time.

The upper Laguna Madre has not been considered particularly vulnerable to stressors such as pollutant loadings because there is relatively little development in its watershed (EPA 1999). However, limited exchange with the Gulf of Mexico and low volumes of freshwater inflow may cause the Laguna Madre to be more susceptible to pollutant inputs and inhibit its ability to remove or dilute dissolved or suspended pollutants (Touchette and Burkholder, 2000; Morin and Morse, 1999; Cotner et al., 2004). Agricultural runoff and industrial and municipal wastewater inflows have the potential to introduce nitrogen and phosphorus into natural ecosystems, with possibly amplified effects in a region with very low amounts of natural freshwater inflow (Onuf, 1995). There is some evidence that freshwater and/or nutrient inputs from wastewater discharges and other sources (e.g., leaky septic tanks) may be affecting seagrass species composition in the upper Laguna Madre near the mainland (Thurlkill 2003). In addition, the effluent from the Whitecap Treatment Plant appears to be causing increases in epiphytic algal growth on seagrasses along the edge of the channel where effluent is discharged (K. Withers, pers. obs.).

Seagrass Scarring

Seagrass meadows that are located in shallower areas of the Laguna Madre are vulnerable to shallow-draft motorboats that can maneuver in very shallow waters (<1 m). Although boats are capable of traversing very shallow waters, once the boat has reduced speed more water depth is needed to resume speed. The boat propellers bury into the soft sediments of the bay, causing direct damage to the seagrass leaves aboveground and roots and rhizomes belowground. The boat operator will often employ a tight, circular route within the shallow area and thus increase the linear and areal extent of the damage. The areas most impacted by shallow-draft boats are also favored by anglers as premier fishing destinations, or as areas located between fishing spots.

Wave action and water currents provide the physical forces to erode the soils within the prop channel, resulting in scouring and deepening within the impacted area. These “prop scars” can persist for years, and localized impacts have been documented in areas where prop scars are collectively fragmenting and degrading seagrass meadows. Causes of seagrass scarring in the local area (including Laguna Madre) have been attributed to 1) access to shallow grassbeds from blind channels built for gas well or pipeline access; 2) shortcut routes at channel junctions, around shallow areas adjacent to islands, or between islands; and 3) illegal use of PVC poles as navigational aids to mark an access channel (Dunton et al. 1998).

In upper Laguna Madre (south of JFK Causeway) 3% of seagrass areas were lightly scarred; 12% moderately scarred, and 1.4% severely scarred (Dunton et al. 1998). In the area north of the JFK Causeway, the percentage of light, moderate and severely scarred seagrass area was similar to that seen in upper Laguna Madre. These levels of scarring, especially severe scarring, are much lower than in many areas of Corpus Christi and Redfish bays, where as much as 75% of seagrasses area is severely scarred (i.e., Estes Flats).

Few data exist on impacts of prop scarring on seagrass faunal communities in the Texas Coastal Bend. Two thesis projects designed to determine if fauna were affected by scarring in local bays found no evidence of differences between scarred and unscarred areas (Davidson 2002; Burfeind 2004). No studies have been conducted with the PAIS boundaries.

The Nine Mile Hole was identified as an area of concern by local anglers, conservation groups, and state and federal agencies. The depth of this area is consistently < 1m, and seagrass occurs throughout a large portion of the Hole. Texas Parks & Wildlife is the state agency with the authority to designate state scientific areas for preservation of unique flora and fauna in public. The northwest portion of Nine Mile Hole was specifically designated as providing a quality fishing experience, and signage/boundary stakes were located around the mandatory no motor zone area. The Texas Parks & Wildlife Commission adopted the rule in 2000 (31 Texas Administrative Code, Section 57.920) effective 31 August 2000. The area of Nine Mile Hole within PAIS boundaries (primarily in the eastern portion) was also designated as a voluntary no motor zone. No scientific data are available to assess the impact actions have had on seagrass protection and recovery.

Commercial and Recreational Fisheries

Of the total commercial bay finfish catch on the Texas Coast, Laguna Madre contributed 62% (upper = 43%, lower 19%) between 1997-2001 (Culbertson et al. 2004). The only commercial fisheries still in existence in Laguna Madre are those for the fish and shellfish species listed in Table 2. Atlantic croaker, Atlantic cutlassfish (ribbonfish), herring, killifish and mullet are used primarily for bait. The other species are sold as food fish. Black drum, flounder, Florida pompano, gafftopsail catfish and sheepshead may only be taken with trotlines, pole and line (including rod and reel), spear gun and spear, lawful archery equipment or gig (TPWD 2004). Bait fish can be taken with cast net, minnow seine, and perch trap; menhaden only can also be taken with a purse seine.

Black drum is the most important commercial bay fishery on the Texas Coast. Since 1989, black drum constituted 98-99% of finfish catch in upper Laguna Madre and 77-95% of finfish catch in lower Laguna Madre. Flounder is more important in lower Laguna Madre than in upper Laguna Madre (Table 2). Black drum and flounder were the most important species both by weight and dollar value in 2001, the most recent data that are available. Overall, finfish catch has generally been greater in upper than in lower Laguna Madre except in 1981 and between 1989-1995 (Fig. 18). Modeling of fishery-independent data suggest that black drum populations have been increasing in upper Laguna Madre since 1988 (Lacson and Lee 1997).

The offshore commercial finfish fishery in Grid Zones 20 (middle of San Jose Island to Land Cut) and 21 (Land Cut to Port Isabel) is concentrated on grouper (Family Serranidae), and snapper (Family Lutjanidae) although other fish such as black drum, flounder, sheepshead, mullet, cobia (*Rachycentron canadum*), tunas and mackerels (Family Scombridae) and jacks (Family Carangidae) may also be landed. Fish are taken with hook and line. During the mid-1980s and early 1990s, more fish were landed from Grid Zone 20 than Grid Zone 21; the reverse was true from 1992-2000 (Fig. 19). These grid zones together constituted an average of 41% of Texas offshore landings between 1981-2001, from a high of 65% in 1991, to a low of 22% in 1997.

Table 2. Catch (kg) of commercial species and ex-vessel value ($) landed in Laguna Madre during 2001.

Species	Scientific Name	ULM		LLM	
		Weight (kg)	Value ($)	Weight	Value
Atlantic croaker	*Micropogonias undulatus*			430	7,061
Atlantic cutlassfish	*Trichiurus lepturus*			1,209	2,480
Black drum	*Pogonias cromis*	626,724	1,032,530	191,026	334,783
Flounder (unclassified)	*Paralichthys* spp.	360	1,419	6,547	28,402
Florida pompano	*Trachinotus carolinus*			21	107
Gafftopsail catfish	*Bagre marinus*	0.9	2		484
Herring (unclassified)	Family Clupeidae			85	618
Killifish (unclassified)	Family Cyprinodontidae			22	618
Mullet (unclassified)	*Mugil* spp.	113	404	5,408	17,777
Sheepshead	*Archosargus probatocephalus*	1,262	1,364	1,450	1,817
Finfish Total		**628,459**	**1,035720**	**206,303**	**393,733**
Blue crab	*Callinectes sapidus*			5,752	14,017
Shrimp	Family Penaeidae	934	7,789		
Mantis shrimp	*Squilla empusa*			177	713
Squid (unclassified)	Family Loliginidae			3,533	3,585
Shellfish Total		**934**	**7,789**	**215,764**	**18,315**

Penaeid shrimp (primarily brown shrimp, *Farfantepenaeus aztecus*; pink shrimp, *F. duorarum*; white shrimp, *Litopenaeus setiferus*) are the most important commercial fishery species overall on the Texas Coast (Culbertson et al. 2004). Brown shrimp are more abundant on the central and lower coast than white shrimp. Shrimp are caught for both food and bait in Texas; Laguna Madre is considered a "bait bay" and only bait shrimp can be taken. Shrimp are currently only harvested commercially in upper Laguna Madre; lower coast shrimpers concentrate their efforts in the offshore waters of the Gulf of Mexico. Historically (1942-1970), shrimp represented the largest proportion of the commercial catch of all species from Rockport to Brownsville (Withers and Dilworth 2002). Brown shrimp were the primary commercial species from the central coast south between 1956-1959 (Gunter 1962). Although shrimp continue to be significant commercial species on the central and southern Texas coast (Lacson and Lee 1997), overall, catch in upper Laguna Madre has declined since 1981 (Fig. 20). The majority of the Texas bay shrimp fishery is currently concentrated on the upper and middle coast (e.g., Galveston, Matagorda, Aransas bays; Culbertson et al. 2004). Upper Laguna Madre contributed less than 2% to bay shrimp landings on the central coast (Withers et al. 2003) so its current contribution to the total catch from Texas is negligible. Data from offshore shrimp catch in Grid Zones 20 and 21 are not reported separately; offshore shrimp data are only reported by Texas Parks and Wildlife Department for the entire Texas coast by year.

Analysis of fisheries-independent data on small shrip (bag seine collections) from upper Laguna Madre suggeste that populations of pink shrip declined from 1992-1996 and brown shrimp increased frp, 1977-1996 (Withers et al. 2003). Populations of small white shrimp have remained stable since the mid-1970's. Sizes of pink and white shrimp decreased, with brown shrimp

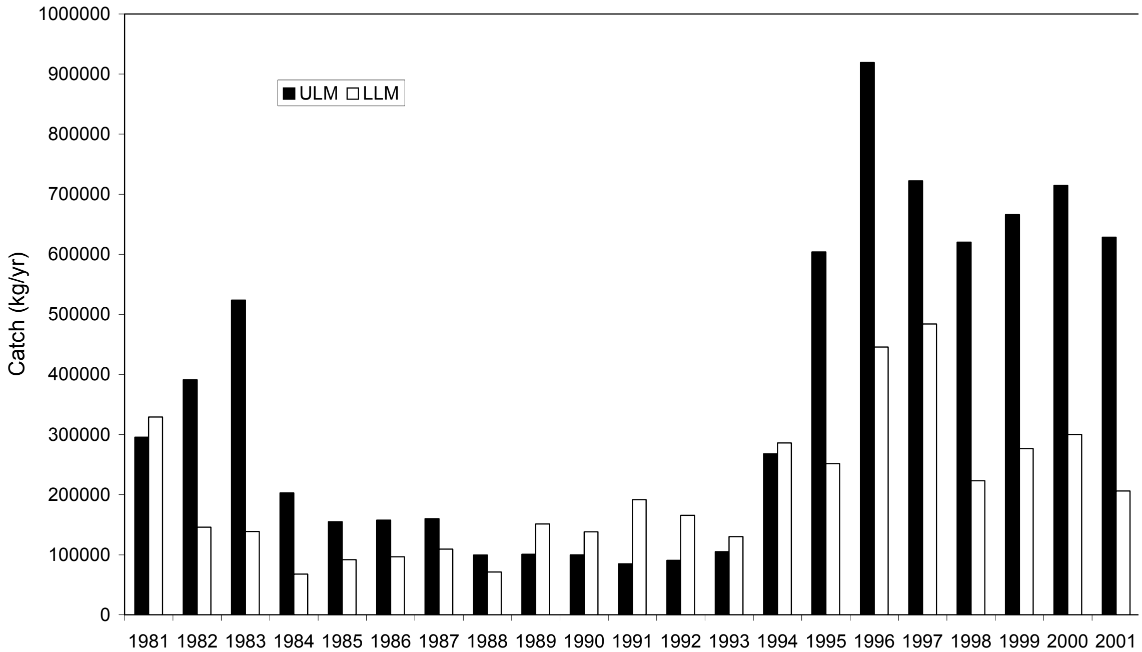

Fig. 18. Commercial finfish catch (kg/yr) in Laguna Madre 1981-2001 (data from Culbertson et al. 2004).

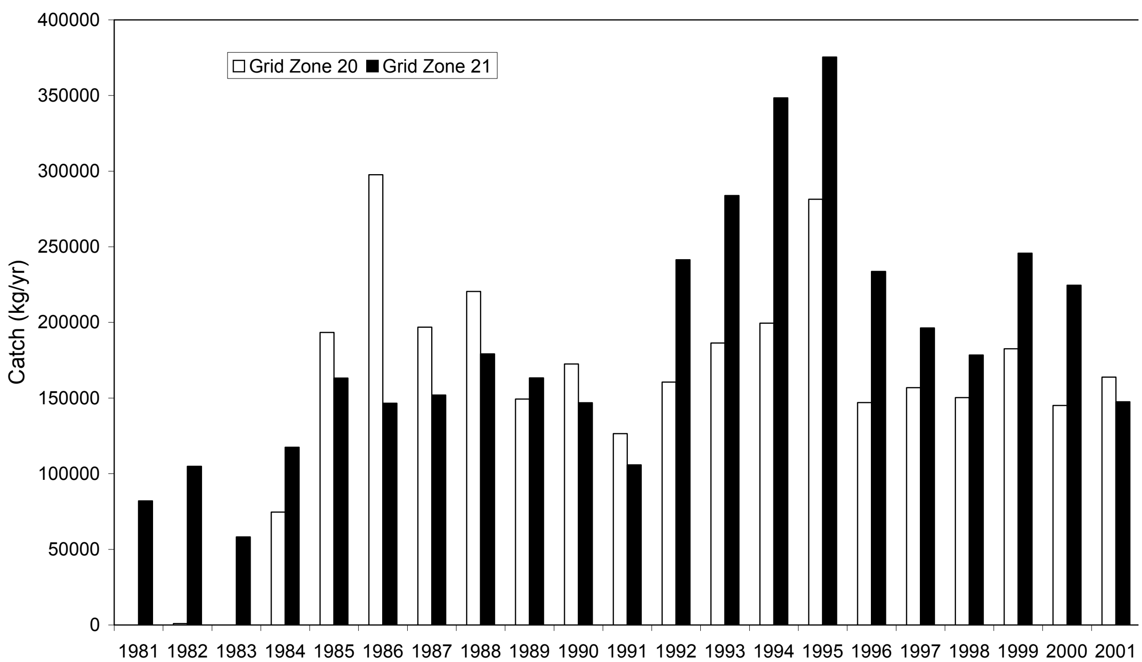

Fig. 19. Commercial finfish catch (kg/yr) in Gulf of Mexico Grid Zones 20 and 21, 1981-2001 (data from Culbertson et al. 2004).

lengths remaining relatively stable. For larger shrimp (trawl collections), no significant trends were detected for either abundance or size. No comparable analyses are available for lower Laguna Madre or offshore.

Blue crab landings in Texas are concentrated on the upper coast (Culbertson et al. 2004). In Laguna Madre, blue crab landings were greatest in lower Laguna Madre, but have generally declined since 1981 (Fig. 21). Peak landings occurred in 1981, the year after Hurricane Allen came ashore near Port Mansfield in lower Laguna Madre. The 3.7 m storm surge cut numerous passes through Padre Island allowing exchange between Laguna Madre and the Gulf, and up to 51 cm of rain fell. It is likely that freshening due to the storm increased blue crab production between 1981-1987. Currently, no "picker" plants exist south of Rockport, Texas (M. Ordner, Texas Department of Health, personal communication) and this is probably at least partly responsible for the relative lack of production in either upper or lower Laguna Madre over the last decade. No analysis of fishery independent blue crab data is available.

The recreational fishery in Laguna Madre is concentrated on red drum (*Scieanops ocellatus*), spotted seatrout (*Cynoscion nebulosus*) and black drum. Upper and lower Laguna Madre together constitute less than 20% of coastwide private boat pressure and landings but about 40% of coastwide party boat pressure and landings between 1988-1998 (Green et al. 2002). Approximately 25% of black and red drum, 30% of spotted seatrout, and less than 10% of sand seatrout, sheepshead, southern flounder landed by private boats came from Laguna Madre during the same 10 year period. Breakdowns by fish species were not available for party boat landings.

Landings of fish caught by recreational anglers offshore were only recorded for lower Laguna Madre (Green et al. 2002), since there is no direct connection to the Gulf from upper Laguna Madre. These landings were further divided into those from the Texas Territorial Sea (TTS; i.e., Gulf of Mexico waters from the surf line to 16.7 km offshore excluding the 1.6 km area around the gulfward end of passes) and those from the United States Exclusive Economic Zone (EEZ; Gulf of Mexico waters beyond 16.7 km offshore). About 8% of coastwide pressure and 12% of coastwide offshore private boat landings in lower Laguna Madre came from the TTS between 1988-1998. Less than 10% of offshore private boat pressure and landings in lower Laguna Madre came from the EEZ during the same period. No party boat statistics were available for either the TTS or EEZ. Breakdowns by fish species and landing area were not available, however, coastwide, the species most commonly taken from the TTS between 1988-1998 were spotted seatrout, red snapper (*Lutjanus campechanus*), king mackerel (*Scomberomorus cavalla*), and sand seatrout (*Cynoscion arenarius*), although the category of "other species" constituted nearly 40% of landings. In the EEZ, the most common species coastwide (~50%) was red snapper; king mackerel, dolphin (*Coryphaena hippurus*), and sand seatrout were also common, and approximately 20% of landings were fish in the "other" category.

Exotic or Invasive Species

The edible brown mussel (*Perna perna*) successfully invaded hard substrates along the Texas coast, including the Mansfield Pass jetties, during the early 1990s (Hicks and Tunnell 1993). By 1993, brown mussels were found from the mouth of the Colorado River in Texas and southward

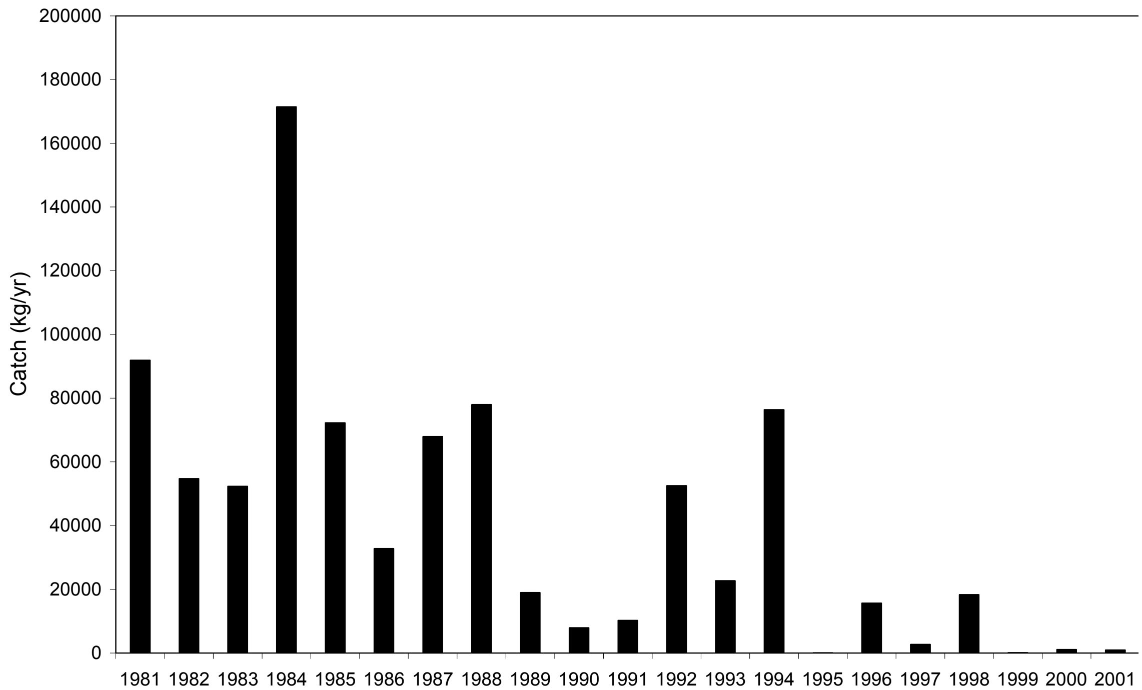

Fig. 20. Penaeid shrimp catch (kg/yr) in upper Laguna Madre, 1981-2001 (data from Culbertson et al. 2001).

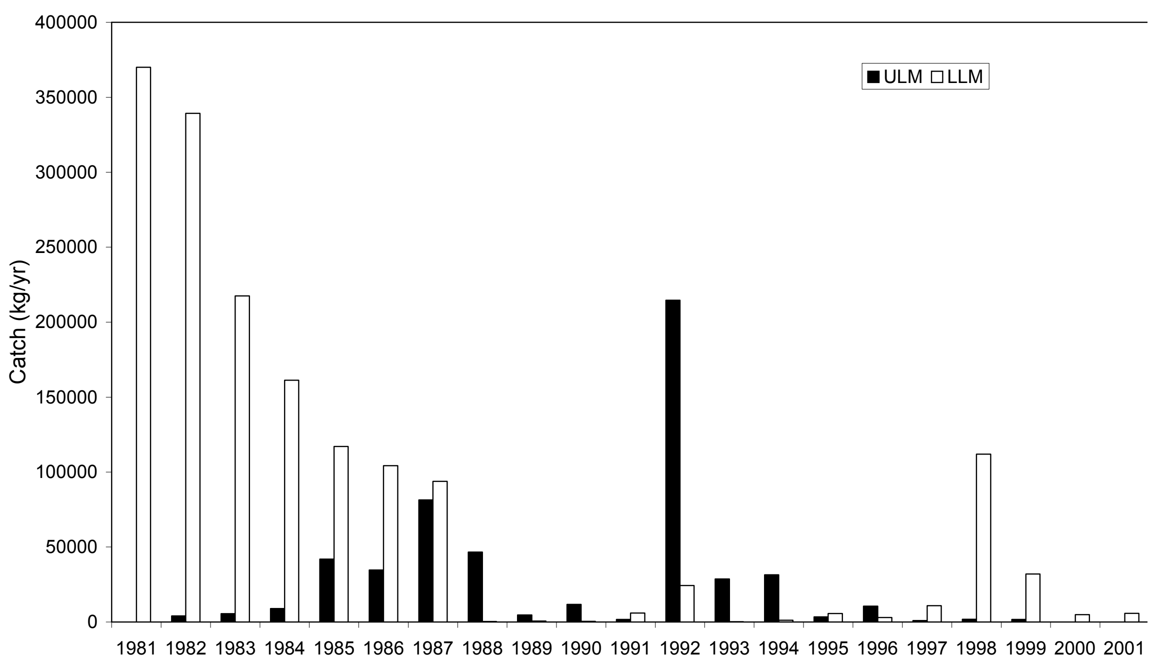

Figure 21. Blue crab landings (kg/yr) in Laguna Madre, 1981-2001 (data from Culbertson et al. 2004)

to Playa Escondido, Mexico, in the Bay of Campeche (Hicks and Tunnell 1995). Densities in the thousands and the appearance of a distinct "mussel belt" on shoreline and offshore hard structures indicated that this aggressive new member of the fouling community had successfully invaded both man-made and natural hard substrates throughout the western Gulf of Mexico. In addition, by the mid-1990's, this normally "open water" species was also found in Texas estuaries Davenport 1995; McGrath et al. 1998). This invasion was probably caused by the release of ballast water from Venezuelan ships entering the Corpus Christi Ship Channel through the Aransas Pass jetties (Hicks et al. 2001) and was of interest because of the potential economic affect of its fouling of navigational buoys and power plant intake screens (Hicks and Tunnell 1995).

Subsequent research suggested that brown mussels had the potential to colonize many marine and estuarine coastal habitats in the Gulf of Mexico. Population dynamics of the species in the Gulf of Mexico were similar to those of endemic populations on other continents (Hicks et al. 2001). Its salinity tolerance was wide (15-50 ppt; Hicks et al. 2000). However, its thermal limits suggested a limited capacity to colonize more northern areas of the Gulf (Hicks and McMahon 2002a) and its inability to regulate oxygen uptake above 25º C indicated it would not be able to become permanently established in most bays (Hicks and McMahon 2002b). Declines in populations along the Texas coast were noted between 1995-1997 suggesting that populations had reached equilibrium (McGrath et al. 1998). However, densities of the species appear to have continued to decline up to the present.

Exotic and invasive species that may have negative impacts on the terrestrial portion and dredged material islands of PAIS have been observed (G. Blacklock, Coastal Bend Bays and Estuaries Program, pers. comm.). Kleberg bluestem (*Andropogon annulatus*) is an introduced pasture grass that has become established along the main roadways in the park where regular roadside mowing occurs. Another exotic species, guinea grass (*Urochloa maxima*), has been observed recently as well. On the dredged material islands in the Laguna Madre and with in the PAIS boundary, these two species, as well as several other exotic grasses have become established and replaced the native flora to varying extents. King Ranch bluestem is the predominant grass on several of the active nesting islands for colonial waterbirds. In addition, smaller amounts of Johnson grass (*Sorghum halpense*) and exotic shrubs [Brazilian pepper (*Schinus terebinthifolius*), leadtree (*Leucaena leucocephala*)] have invaded the dredged material islands. No exotic species have been reported in the inland waters.

WATER QUALITY ASSESSMENT

Water Quality Standards

The criteria used to assess the available water quality data for PAIS are summarized in Table 3. These data were drawn from current national EPA (EPA 2002) and TCEQ (TCEQ 2002) standards. The criteria for metals and most other contaminants are identical in both documents. Criteria for other parameters such as dissolved oxygen are state standards that are segment dependant. TCEQ provides a method by which a quantitative evaluation of a water body with regards to its support of various uses (e.g., drinking, contact recreation, support of aquatic life) can be made (TCEQ 2002). Briefly, this method involves determining the number of analyses of a parameter and the number of times the parameter exceeded criteria concentrations. These numbers are then looked up in the appropriate tables within the guidance document (TCEQ 2002) and a determination can be made of support, partial support or non-support of activities such as contact recreation, or of concern or no concern with regards to other parameters, such as dissolved oxygen or nutrients.

EPA has relegated nutrient criteria to the states and/or ecoregions (EPA 2002). Numerical nutrient criteria in Texas are under development and currently exist as "screening" criteria that do not represent adopted state criteria (TCEQ 2002). Nutrient and chlorophyll *a* concentrations fall under the category of "secondary concerns" in the state of Texas (TCEQ 2002). Screening levels were developed to identify areas where elevated nutrient concentrations cause secondary concerns. Classification of concern or no concern depends on the number of samples and is based on a sliding scale of given sample sizes. When a water body is identified as having secondary concerns it is identified in the state 305(b) report, but not placed on the 303(d) list. The identification of secondary concerns results in increased monitoring of the water body and measurement of additional parameters.

Available Water Quality Data

For the purposes of both finding and assessing available water quality data, we considered the boundaries of the PAIS to include all Laguna Madre waters east of and including the GIWW and the nearshore waters within and just outside of Port Mansfield. The southern boundary of the park was set at the Mansfield Channel. We considered the "watershed" of PAIS to include the Laguna Madre west of the GIWW, Baffin Bay, and the tidal portions of the Arroyo Colorado and the ephemeral creeks flowing into Baffin Bay (e.g., Petronila Creek). We focused our efforts on two databases, the Legacy STORET maintained by EPA and the surface water quality database maintained by TCEQ.

Legacy STORET

The STORET Legacy database (http://www.epa.gov/STORET/dbtop.html), contains data submitted from a variety of sources through 1999. This "legacy" database is "complete" in that no additional data will ever be added to it; any more recent data that is submitted will be input into the modernized STORET. No data from Texas had been submitted to the modernized STORET as of the date of this report.

Table 3. Water quality criteria used for assessment of water quality in PAIS.

Parameter	Freshwater	Saltwater	Source
Nutrients			
Nitrate Nitrogen (mg/L)	10 (domestic water supply criteria)	n/a	EPA 1986
Ammonia Nitrogen (mg/L)[1]	0.17 (freshwater streams)	0.1 (estuaries) 0.58 (tidal streams	TCEQ 2002
Nitrate+Nitrite (mg/L)[1]	2.76 (freshwater streams	0.26 (estuaries) 1.83 (tidal streams)	TCEQ 2002
Total Phosphorus (mg/L)[1]	0.8 (freshwater streams)	0.22 (estuaries) 0.71 (tidal streams)	TCEQ 2002
Orthophosphate (mg/L)[1]	0.5 (freshwater streams)	0.16 (estuaries) 0.55 (tidal streams)	TCEQ 2002
Total Nitrogen[2] (mg/L)	0.76	n/a	EPA 2002
Chlorophyll *a* (μg/L)[1]	11.6 (freshwater streams)	11.5 (estuaries) 19.2 (tidal streams)	TCEQ 2002
Other Parameters			
Dissolved Oxygen[3]	5.0 mg/L	5.0 mg/L	TCEQ 2002
Chloride[3]	250 mg/L	n/a	TCEQ 2002
Sulfate[3]	250 mg/L	n/a	TCEQ 2002
Fecal Coliform (primary contact)	400 col/100 ml (single sample); 200 col/100 ml (geometric mean 10+ samples)	400 col/100 ml (single sample); 200 col/100 ml (geometric mean 10+ samples)	TCEQ 2002
Metals[4]			
Arsenic (μg/L)	150	36	EPA 2002
Cadmium (μg/L)	2.2	9.3	EPA 2002
Copper (μg/L)	9	3.1	EPA 2002
Lead (μg/L)	2.5	8.1	EPA 2002
Mercury (μg/L)	0.77	0.94	EPA 2002
Nickel (μg/L)	52	8.2	EPA 2002
Selenium (μg/L)	5.0	71	EPA 2002
Silver (μg/L)	3.4	1.9	EPA 2002
Zinc (μg/L)	120	81	EPA 2002

[1] TCEQ screening levels
[2] Total Nitrogen can be calculated by adding TKN to Nitrate+Nitrite values (EPA 2001)
[3] Regional criteria from TCEQ; freshwater from TCEQ segment 2102 – Nueces River below Lake Corpus Christi, salt water from TCEQ segment 2491 – Laguna Madre
[4] All concentration values represent criteria chronic concentrations

Several thousand observations, representing measurements of a single parameter at a unique station that was never visited again, to a few stations with suites of measurements that encompassed a few years to a decade or more, were obtained from this database. The data covered a total of 273 stations and three sample types: estuarine single, estuarine composite, and freshwater single (Figs. 22, 23, 24; Table 4). Most records contained the results of single sampling events or very short-term (within 1 year) studies, and very few stations with data that spanned more than 2 consecutive years.

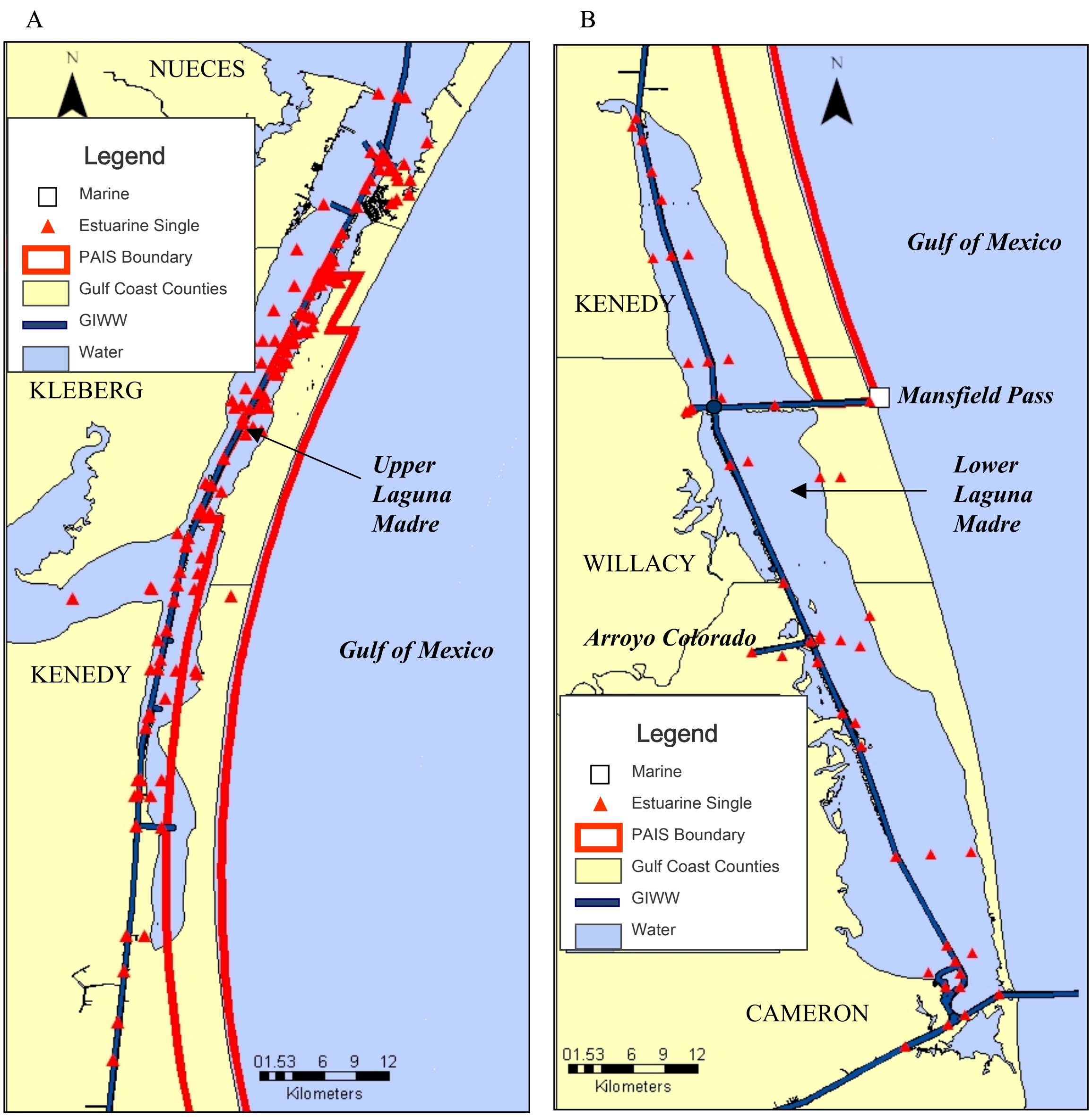

Fig. 22. Location of estuarine single stations, STORET Legacy database.

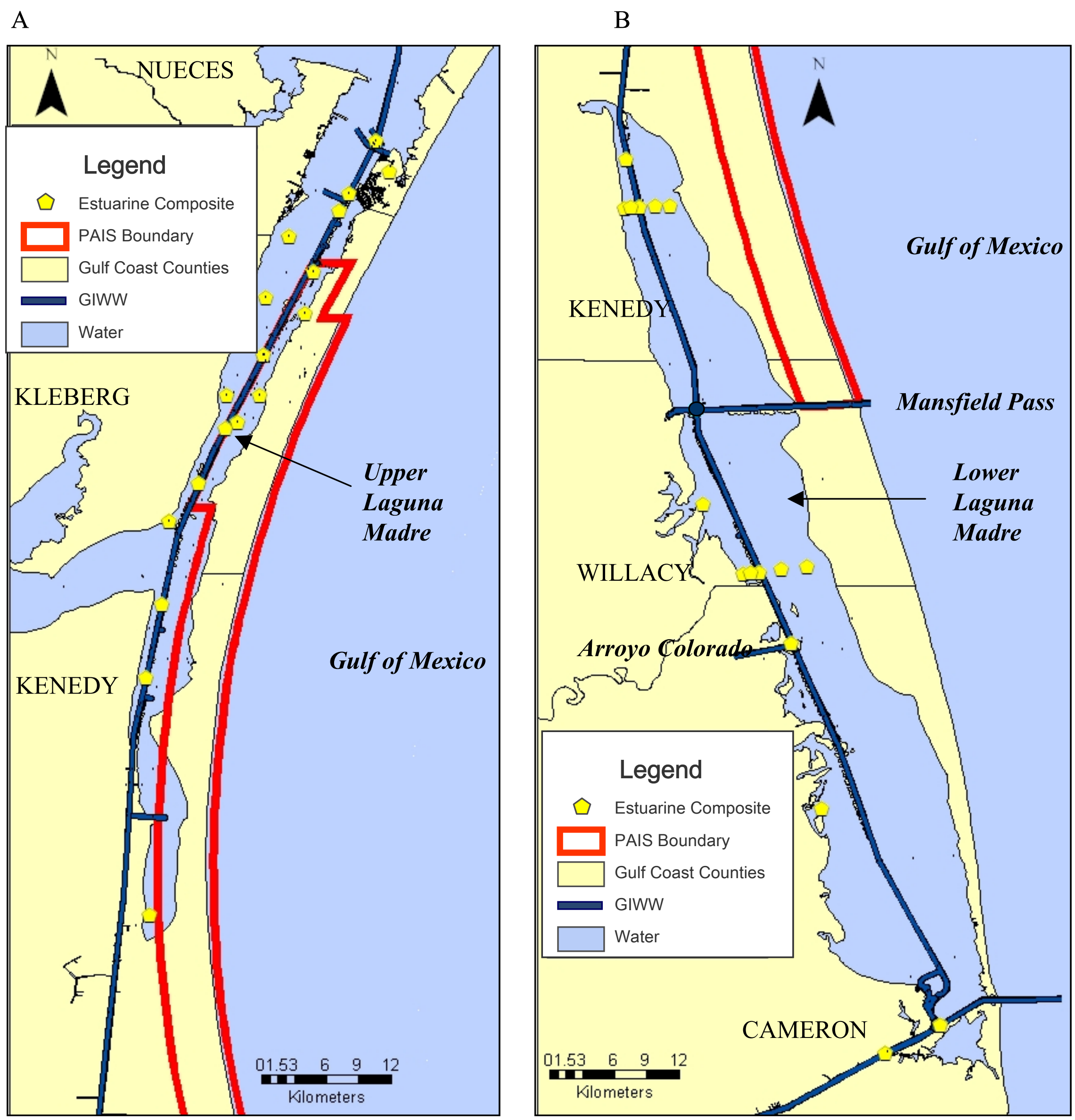

Fig. 23. Location of estuarine composite stations, STORET Legacy database.

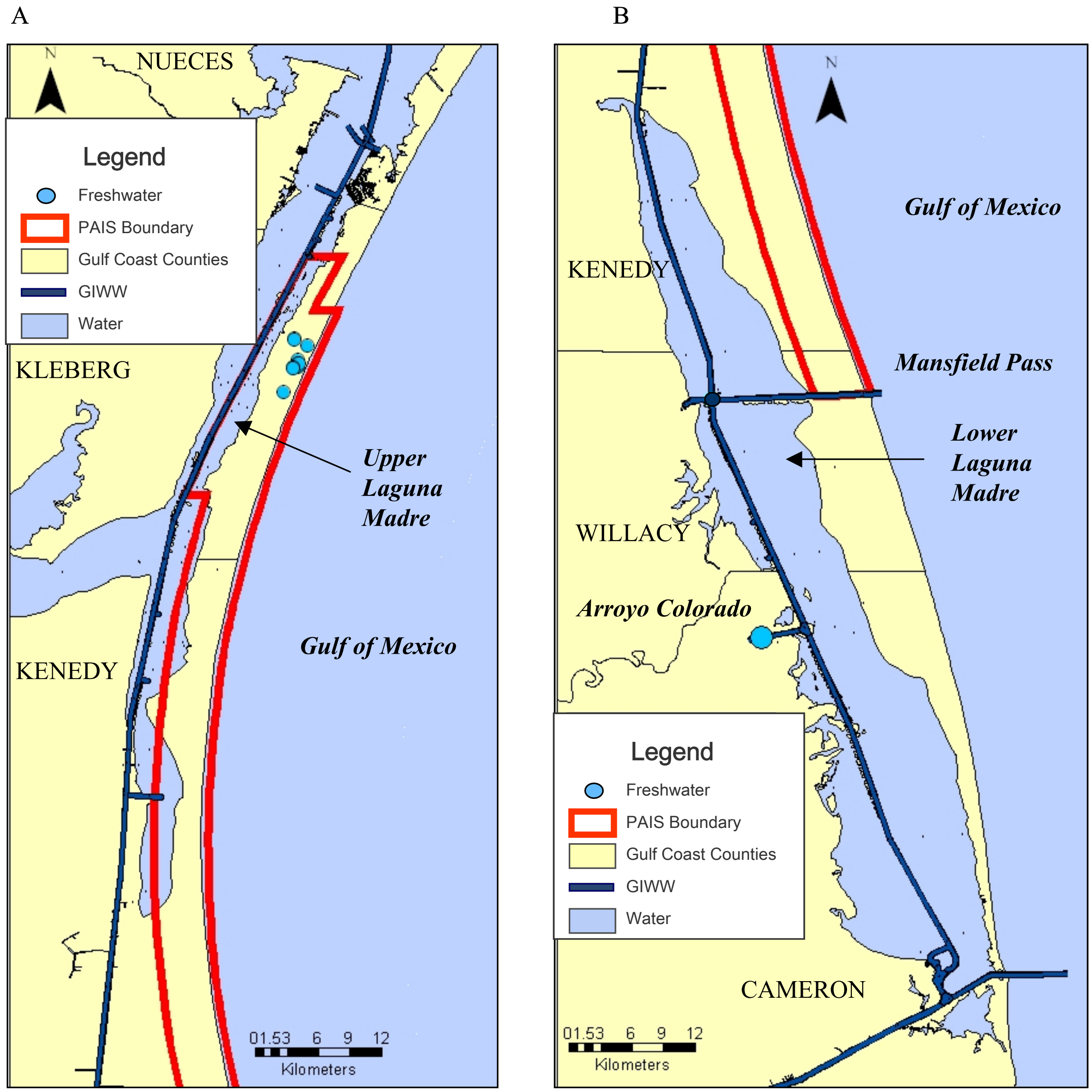

Fig. 24. Location of freshwater stations, STORET Legacy database.

Table 4. Summary of STORET Legacy database station water sampling within PAIS and the Laguna Madre and its watershed. Field parameters include dissolved oxygen, pH, salinity, conductivity, water temperature; nutrients includes various nitrogen and phosphorus species and chlorophyll *a*; contaminants includes pesticides and other organic compounds; bacteria is fecal coliform only.

Station Type	Total number	Number sampled more than once	Number sampled more than once and over at least 2 yrs	Number sampled in 1990 or later	Analyses by station type				
					Field	Nutrients	Metals	Contaminants	Bacteria
Freshwater	15	5	4	2	13	12	3	0	0
Estuarine Composite	37	31	28	0	34	1	1	0	0
Estuarine Single	221	56	28	6	184	59	41	5	8
Gulf of Mexico	1	1	1	1	0	1	0	0	1

Database Development & Management

Data from the Legacy STORET were input into Microsoft Access to provide PAIS with a usable database containing the data and to facilitate our assessment of the data. The database was queried by selecting the state of interest (Texas), county (Nueces, Kleberg, Kenedy, Willacy, and Cameron, respectively), stations within that county, additional search criteria (parameters). On the confirmation page, “detailed data report” was selected under Select Report Type, and “TXT: Comma separated report” under Choose the Output Format for Your Report. The database was created with Microsoft Access software program, importing TXT files from the website and creating a table with the following field headings: Organization Code, Primary Station ID, County, Latitude, Longitude, Hydrologic Unit Code, Legacy STORET Station Type Code, Start Date, Sample Depth, Primary Activity Category, Parameter Code, Parameter Long Name, and Result Value. The data was formatted where the data information was duplicated for every parameter that was measured within the same sample and/or station information may have duplicate entries within the database. Therefore, imported data tables were queried to identify duplication and duplicated information was removed. A detailed description of data capture provided upon request. Data were then entered into each appropriate table by matching up each data set to the standardized field headings, as each data report was often uniquely tabulated. Data structure was organized by Estuarine Single, Estuarine Composite, and Freshwater by county with 18 parameter group categories. The data tables were then organized in Access, and all “NULL” data of unused parameter codes were eliminated. This process was time consuming, however, standardization of all data was necessary to link tables efficiently. The database was in correct format for us in a geographic information system program, such as ArcGIS program

(Environmental System Research, Inc. 2002). Due to the large size of the metadatabase, it is advisable to use the data separated by county and data type.

The objective of developing the GIS project file with links to Access tables was to provide a spatial program of the STORET Legacy database, and develop a method that allows visual spatial interpretation of the STORET Legacy database coverage for monitoring and event-driven queries. Several layers were downloaded and clipped to the project boundary area for use in spatially evaluating the water quality database and developing water quality monitoring recommendations. Detailed step-by-step instructions provided upon request. The following methodology summarizes the general approach used to generate a GIS project file in ArcGIS 8.3 software. The Texas County map was used as the base map, clipping the following counties to the project area: Nueces, Kleberg, Kenedy, Willacy, and Cameron. The hydrology data provided the aquatic base layer, and major roads and ship channels (depicting Gulf Intracoastal Waterway in project area) were added to provide locations of towns and show transportation corridors. Two databases were available to identify natural features within PAIS boundaries. The Land Use/Land Cover data provided by U.S. Geological Survey (Laine and Ramsey 1998) was added, and a legend was developed using the unique value "Classification" to show the following classes: beach, emergent wetland, grassland, Gulf of Mexico, inland water, Laguna Madre, sand dunes, sparse vegetation, unconsolidated shore, urban, washover channel, and wind tidal flats. The PAIS boundary was added to delineate the park perimeter. An additional database layer is available that identifies palustrine (freshwater) wetlands from the 1992 National Wetlands Inventory; however, we used the inland water classification developed by USGS for our freshwater marsh evaluations.

An X,Y Coordinate layer was created for the stations (total of 284) that were identified in the STORET Legacy Data Center website. Water quality data availability was summarized within this layer to facilitate identification of appropriate stations that measured parameters of interest. The following process was developed to link the stations to the water quality database. All water quality data were stored in the PAIS.mdb database (see above). Selected data were added by selecting X_YSTATIONs table in Access, as well as a water quality data table of interest. Data were grouped by county, location (estuarine or freshwater) as well as type of sample (single or composite), and parameter group. The two tables were then joined in ArcGIS by the common field Station_ID.

A basic advantage of using GIS is creating maps of water quality stations for STORET data. However, summary information included in the attribute table will also provide the user to organize the data according to single or multiple year data collection. The user may also want to identify which parameters were collected (e.g., nutrients; metals in sediment, water, tissure; contaminants in water, tissure; inorganics; routine; BOD). The utility of using the GIS project file will also allow the user to identify pertinent stations in relation to a geographic area of interest, depending on project objectives.

Freshwater Stations

Although freshwater is limited within park boundaries as well as within the designated PAIS watershed, it is an important resource, particularly for wildlife. Very little water quality data is available on the freshwater sources within the park and its temporal coverage is extremely limited (Table 5). With the exception of two stations, data were collected in 1990 or before.

Table 5. Freshwater stations (STORET station codes), years sampled and associated nutrient and/or metals assessments. No organic contaminant or bacterial assessments were made at any freshwater stations through the most recent data year (1999).

Station Code (date range)	Nutrients	Metals
PAISHANNEP1 (1978)	TKN	
PAISHANNEP2 (1978)	TKN	
PAISHANNEP3 (1978)	TKN	
PAISHANNEP5 (1978)	TKN	
PAISHANNPP1 (1978)	TKN, Chlorophyll *a*	
PAISHANNPP3 (1978)	TKN, Chlorophyll *a*	
PAISHANNPP7 (1978)	TKN, Chlorophyll *a*	
PAISCEM01 (1973-1974)	Nitrate+Nitrite, Orthophosphate	Cu, Zn
PAISSISSPA (1989-1990)	Nitrate, TKN, Phosphorus	As, Cu, Pb, Zn
PAISSISSPB (1989-1990)	Nitrate, TKN, Phosphorus	As, Cu, Hg, Pb, Zn
PAISSISSPC (1989-1990)	Nitrate, TKN, Phosphorus	As, Cu, Hg, Pb, Zn
PAISTNRCCP1 (1998)	Ammonia, TKN, Phosphorus, TOC, Chlorophyll *a*	
PAISTNRCCP2 (1998)	Ammonia, TKN, Phosphorus, TOC, Chlorophyll *a*	

Several ponds were analyzed for various nutrients either during 1978 or during 1989-1990 (Table 6). When compared with the nutrient criteria recommendations or screening levels (Table 3), TKN exceeded the criteria (0.76 mg/L) for Total Nitrogen (which can be calculated by adding TKN to Nitrate+Nitrite, thus TKN represents a minimum total nitrogen) in every instance, often by several orders of magnitude. Ammonia concentrations in PAISHANNEP1 and PAISHANNEP5 exceeded the screening level of 0.17 mg/L in freshwater streams. Mean nitrate nitrogen was slightly elevated (criterion = 10 mg/L as N) only in PAISSISSPC, but the variability associated with this value is high ranging from 18 mg/L in September 1989 to only 3 mg/L in February 1990. However, if nitrate is considered as a component of nitrate+nitrite (thus representing a minimum value), then all ponds except PAISISSPB exceed TCEQ screening levels for freshwater streams (2.76 mg/L). Because salinity in PAISSISSPC was brackish, use of the tidal stream or estuary screening level (1.83 mg/L and 0.26 mg/L, respectively) is more appropriate. Nitrate concentrations in PAISISSPC exceeded screening levels overall or if concentrations of each sample are considered.

Dissolved metals were analyzed in three ponds: PAISSISSPA, PAISSISSPB and PAISSISSPC. These values were assessed taking salinities into account. Arsenic, chromium, lead and mercury were below criteria in all ponds where concentrations were determined. Cadmium was elevated in PAISSISSPA, PAISSISSPB and copper was elevated in all three; zinc was elevated only in PAISSISSPC.

The most recent data (1998) are from two ponds located near the Ranger Station (PAISTNRCCP1) and near the Bird Island Basin Road (PAISTNRCCP2). Both data sets consist of single assessments of various nitrogen species (e.g., ammonia, total Kjedlhal nitrogen, nitrate+nitrite nitrogen), phosphorus (total and dissolved orthophosphate), solids TSS, TDS, VSS), sulfate, chloride, total organic carbon, chlorophyll *a*, phaeophytin, alkalinity, 5-day BOD, COD and field parameters (pH, dissolved oxygen, conductivity) (Table 7). At PAISTNRCCP1, field parameters only were sampled a second time within the same month the other parameters were sampled (April). Comparing these results to TCEQ freshwater standards for the Nueces River Basin (Table 3), dissolved oxygen was slightly below the standard of 5.0 mg/L in PAISTNRCCP1, and pH was slightly elevated (range 6.5-9.0) in PAISTNRCCP2. The calculated total nitrogen was elevated slightly above criteria concentrations in PAISTNRCCP1 but was about 10 times greater than the criteria in PAISTNRCCP2. Criteria for other parameters were not exceeded. Nutrient analyses, including chlorophyll *a*, were uniformly low. The phaeophytin result for PAISTNRCCP2 may indicate that a large amount of detritus had accumulated in the pond at the time of sampling. No criteria are available for phaeophytin.

The use of freshwater criteria for nutrients in the ponds within PAIS may not always be appropriate. These ponds may become brackish depending on rainfall, since the shallow groundwater beneath the ponds in slightly to moderately saline. Results of a single sampling events, or even multiple sampling events over two years, the maximum amount of sampling of any freshwater ponds in PAIS, are not a firm basis for making an overall determination of water quality of the freshwater resources sources throughout the seashore. Although there are indications that the water quality of these ponds may be of concern (nitrogen, metals), the limited temporal and spatial sampling of fresh waters within the park, combined with the age of most data means that the condition of the freshwater resources are essentially unknown. The use of TKN, often the only nitrogen assessed, is problematic due to a lack of criteria for comparison. In addition, since the accuracy of dissolved metals analysis is dependent on proper sampling procedures, the reported concentrations may be high due to contamination during sampling. The age of the metal determinations is also a factor to be considered. The methods used for dissolved metals assessments have changed over the years, and older values may not be strictly comparable to current criteria. Further investigation of these findings was warranted at the time they were made, and continue to be warranted today.

Estuarine Composite Stations

Estuarine composite data (37 stations, Fig. 23) contained only salinity data with the exception of five stations (PAIS_KAH_2494, PAIS_STOK_4CT, PAIS_STOK_6ST, PAISKAH2491, PAISKAH2491 and PAISCONO91). At those stations where salinity was not measured or was

Table 6. Results of nutrient and metal analyses in water from freshwater ponds within PAIS. Means with standard deviations are given when more than one sample was analyzed. Bold indicates that the parameter exceeded criteria.

Station	Salinity (ppt)	Total Kjeldahl Nitrogen (mg/L)	Dissolved Ammonia Nitrogen (mg/L)	Total Nitrate Nitrogen (mg/L)	Total Phosphate (mg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)	Mercury (µg/L)
PAISHANNEP1		**1.3**	**2.0**									
PAISHANNEP2		**2.2**	0.1									
PAISHANNEP3		**1.3**	0.1									
PAISHANNEP4			0.1									
PAISHANNEP5		**6.0**	**1.0**									
PAISHANNPP1		**9.0**	0.1									
PAISHANNPP3		**2.3**	0.1									
PAISSISSPA	0.2	**7.0**		4.0	0.0	10	**10**	10	**20**	2	30	
PAISSISSPB	0.4	**13.0**		2.5 (0.7)	0.0	10	**20**	20	**20**	8	100	0.07
PAISSISSPC	14.8	**13.0**		**10.5 (10.6)**	0.025 (0.035)	10	10	10	**20**	2	**320**	

Table 7. Results of water quality analysis of a single sampling event at two freshwater ponds within PAIS during 1998. Bold indicates that the parameter exceeded criteria.

Parameter	PAISTNRCCP1	PAISTNRCCP2
Specific Conductance (μmhos)	423.5	551
Salinity (ppt, calculated)	<2	<2
Dissolved Oxygen (mg/L)	4.32	8.6
pH	7.5	**10**
Alkalinity (mg/L as $CaCO_3$)	310.1	50
Total Nonfiltrable Residue (TSS; mg/L)	4	42
Volatile Nonfiltrable Residue (mg/L)	3	38
Total Filtrable Residue (mg/L)	246	356
Total Ammonia Nitrogen (mg/L as N)	0.025	0.025
Total Kjeldhal Nitrogen (mg/L as N)	**0.83**	**7.48**
Nitrate + Nitrite Nitrogen (mg/L as N)	0.05	0.5
Total Nitrogen (mg/L, calculated)	0.88	7.53
Total Phosphorus (mg/L as PO_4)	0.05	0.03
Dissolved Orthophosphate (mg/L as P)	0.03	0.03
Total Organic Carbon (mg/L as C)	24	84
Total Chloride (mg/L)	81.9	110
Total Sulfate (mg/L as SO_4)	6.22	10
Chlorophyll *a* (μg/L)	2.47	0.5
Phaeophytin (μg/L)	0.05	141

not the only parameter measured other parameters such as sulfate, solids and chloride were measured and typically consisted only single measurements. The stations with the most recent data records are PAIS_KAH_2494 (single chloride measurement, 1985) and PAISKAH2491 (single measurements of several parameters other than salinity, 1985). Most other stations have salinity records spanning 1-3 years, with the majority from either the 1950s or 1970s.

The three estuarine composite stations with the longest data coverage (1946-48 and 1951-55) and with multiple measurements each year were PAISBBB25, PAISBBB28 and PAISBBB32. All three of these stations were located in the upper Laguna Madre. A single salinity reading was taken at each of these stations once monthly, usually between May and December, but with occasional omissions of months, particularly May and the occasional addition of January. Single salinity readings were taken at all three stations in 1941 and 1944. The record of salinity between 1946-48 encompasses the years prior to dredging of the GIWW and the record between 1951-1955 encompasses salinities after dredging of the GIWW. Interestingly, there were no significant differences (t-test) between mean salinities at these stations just before and just after the GIWW was dredged (Table 8). Although observations of long-term salinity reductions (50+ years), particularly in upper Laguna Madre, have been made (Quammen and Onuf 1993), it does not appear that the GIWW impacted salinities in the first few years after dredging. However, factors such as rainfall and flushing events both before and after dredging were not taken into consideration here and may have affected salinities.

Table 8. Salinities at three stations in the upper Laguna Madre with results of comparison of years prior to dredging of GIWW (1946-48) and after dredging (1951-55).

Station	Mean Salinity 1946-1948	Mean Salinity 1951-1955	df	t	p
PAISBB25	42.6	47.3	38	-1.267	0.106
PAISBB28	45.7	48.2	41	-0.657	0.257
PAISBB32	55.3	51.8	35	-0.857	0.199

Estuarine Single Stations

Data from 221 estuarine single stations were found in the STORET legacy database (Table 4). One station that is included under this category is located in the very nearshore waters of the Gulf of Mexico just outside of Mansfield Pass (13469). Twenty-eight estuarine single stations have observations on one or more parameters over at least two consecutive years, but most data from these stations were collected between 1968-1974 (Table 9). Data from these stations will only be reviewed if the observations represent parameters (e.g., metals) that are not found in stations with more long-term data coverage. Only six stations have datasets spanning more than two consecutive years and that extend into the 1990s: 13446, 13447, 13448, 13449, 13469, and TWC13090. These stations represent long-term monitoring stations used by TCEQ and data has continued to be collected from some of them until at least 2003.

In this section, we will review data from these stations starting with the earliest dates to 1993, when the record is picked up by the TCEQ database that will be reviewed in the next section. This review will represent the historical or baseline conditions at the stations whereas the data from the TCEQ database will represent recent, ongoing monitoring data. For this assessment, we will focus our attention on nutrients for which screening criteria exist (ammonia nitrogen, nitrate+nitrite, total phosphorus, orthophosphate), chlorophyll *a* and dissolved metals. Although some of these stations have dissolved oxygen data, temporal coverage is spotty and many of the determinations appear to be in percent saturation rather than mg/L, despite the fact that they are coded as mg/L. Thus, dissolved oxygen will not be assessed. Nitrogen indicates any nitrogen species or combinations of nitrogen species, phosphorus indicates either total phosphorus and/or orthophosphate.

TWC13090 – This station is located in the tidal portion of Petronila Creek, a relatively permanent stream that flows into Baffin Bay. Petronila Creek above tidal is on the Texas 303(d) list for chloride, sulfate and total dissolved solids from non-point sources (TCEQ 2002). Nutrients were analyzed annually in August of 1989, 1990 and in October 1992; summer (July) and fall (November) samples were taken in 1991. Overall, nutrient levels for the tidal segment of Petronila Creek between 1989-1992 were below screening criteria (Fig. 25). The only exception was chlorophyll *a* during August 1990.

Table 9. Estuarine and marine stations that were sampled more than once over at least 2 years, associated nutrient and/metals assessments, and range of dates assessed through the most recent year (1999).

Station Code (date range)	Field Parameters &/or Nutrients	Metals
13446 (1969-96)	DO, Nitrogen, Phosphorus, Sulfate, Chlorophyll *a*, Fecal Coliform	
13447 (1972-96)	Chlorophyll *a*	
13448 (1969-96)	Chlorophyll *a*	
13449 (1969-94)	DO, Nitrogen, Chlorophyll *a*, Fecal Coliform	
13469 (1971-94)	Chlorophyll *a*, Fecal Coliform	
PAIS_2491_300 (1971-74)	DO, Nitrogen, Chlorophyll *a*	
PAIS_2491_400 (1971-74)	DO, Nitrogen, Chlorophyll *a*	
PAIS_TWDB_21-2 (1968-71)	DO, Nitrogen	Zn
PAIS2491050 (1972-74)	DO, Nitrogen, Chlorophyll *a*	
PAIS2491100 (1972-74)	Nitrogen	
PAIS2491500 (1971-74)	DO, Nitrogen, Chlorophyll *a*	
PAIS2491600 (1972-74)	DO, Nitrogen, Chlorophyll *a*	
PAISCEM03 (1973-75)	DO, Nitrogen	
PAISTWDB01-3 (1968-70)	DO, Nitrogen	
PAISTWDB02-3 (1968-70)	DO, Nitrogen	Zn
PAISTWDB03-1 (1968-70)	DO, Nitrogen, Phosphorus	Ni
PAISTWDB13-2 (1968-70)	DO, Nitrogen	Zn
PAISTWDB15-2 (1968-70)	DO, Nitrogen, Phosphorus	Ba, Cd, Cr, Cu, Pb, Zn
PAISTWDB16-2 (1968-70)	DO, Nitrogen	Zn
PAISTWDB17-1 (1968-70)	DO, Nitrogen	
PAISTWDB17-2 (1968-70)	DO, Nitrogen	
PAISTWDB17-3 (1968-70)	DO, Nitrogen	
PAISTWDB18-2 (1968-70)	DO, Nitrogen	Zn
PAISTWDB19-1 (1968-70)	DO, Nitrogen, Phosphorus	Cd, Cu, Pb, Zn
PAISTWDB19-2 (1968-70)	DO, Nitrogen, Phosphorus	Zn
PAISTWDB19-3 (1968-70)	DO, Nitrogen	
PAISTWDB19-4 (1968-70)	DO, Nitrogen, Phosphorus	
TWC13090 (1989-97)	DO, Nitrogen, Phosphorus, Chlorophyll *a*, Fecal Coliform	As, Cd, Cu, Ni, Pb, Zn, Hg

Station 13446 – This station is located in the Laguna Madre near GIWW channel marker 129, south of Bird Island Basin. Nutrients were analyzed at least once during most years from 1969-1992; no values appear in the STORET legacy database for 1970-1971, or 1981. Ammonia levels were greater than current screening criteria four times (n=53) from 1969-1992 and values frequently approached screening criteria concentrations (Fig. 26). Screening criteria from nitrate+nitrite were exceeded only once and neither total phosphorus nor orthophosphate exceeded screening levels. Nutrients are not of concern at this station.

Station 13447 – This station is located at the intersection of the Arroyo Colorado (on state 303(d) list) and GIWW in the lower Laguna Madre with data from 1972-76, 1978-84, and 1986-1992. This dataset does not contain any nutrient analyses other than chlorophyll *a* (49 determinations). Chlorophyll *a* concentrations exceeded criteria 20 times in 20 years, or about 41% of the time (Fig. 27). Using TCEQ's method for assessing secondary concerns, this number of exceedances results in classification of "concern" at this station during historical or baseline sampling prior to 1993.

Station 13448 – This station is located at the intersection of the GIWW and the Port Mansfield Channel in the lower Laguna Madre with data from 1970-76, 1978-84, and 1986-1992. This dataset does not contain any nutrient analyses other than chlorophyll *a* (46 determinations). Chlorophyll *a* concentrations exceeded screening criteria 9 times or~20% of the time (Fig. 28). Based on these data, chlorophyll *a* was not of concern at this station during the baseline time period.

Station 13449 – This station is located in the GIWW in lower Laguna Madre at channel marker 225A north of Mansfield channel with data from 1972-1992 (some missing years depending on parameter). This dataset contains nutrient (except orthophosphate) and chlorophyll *a* determinations. Ammonia concentrations exceeded screening criteria in six of 63 determinations (14%), and total phosphorus concentrations exceeded screening criteria twice (64 determinations); nitrate+nitite concentrations not exceed screening criteria (Fig 29). Chlorophyll *a* concentrations (58 determinations) exceeded screening criteria 12 times or about 21% of the time. These data indicate that nutrients and chlorophyll *a* were not of concern at this station during the baseline time period.

Station 13469 – This station is located just outside Mansfield Pass in the nearshore waters of the Gulf of Mexico with data from 1972-76, 1977-84, 1986, 1988-1992. This dataset does not contain any nutrient analyses other than chlorophyll *a* (45 determinations). Chlorophyll *a* concentrations exceeded screening criteria 2 times or ~4% of the time (Fig. 30). Based on these data, chlorophyll *a* was not of concern at this station during the baseline time period.

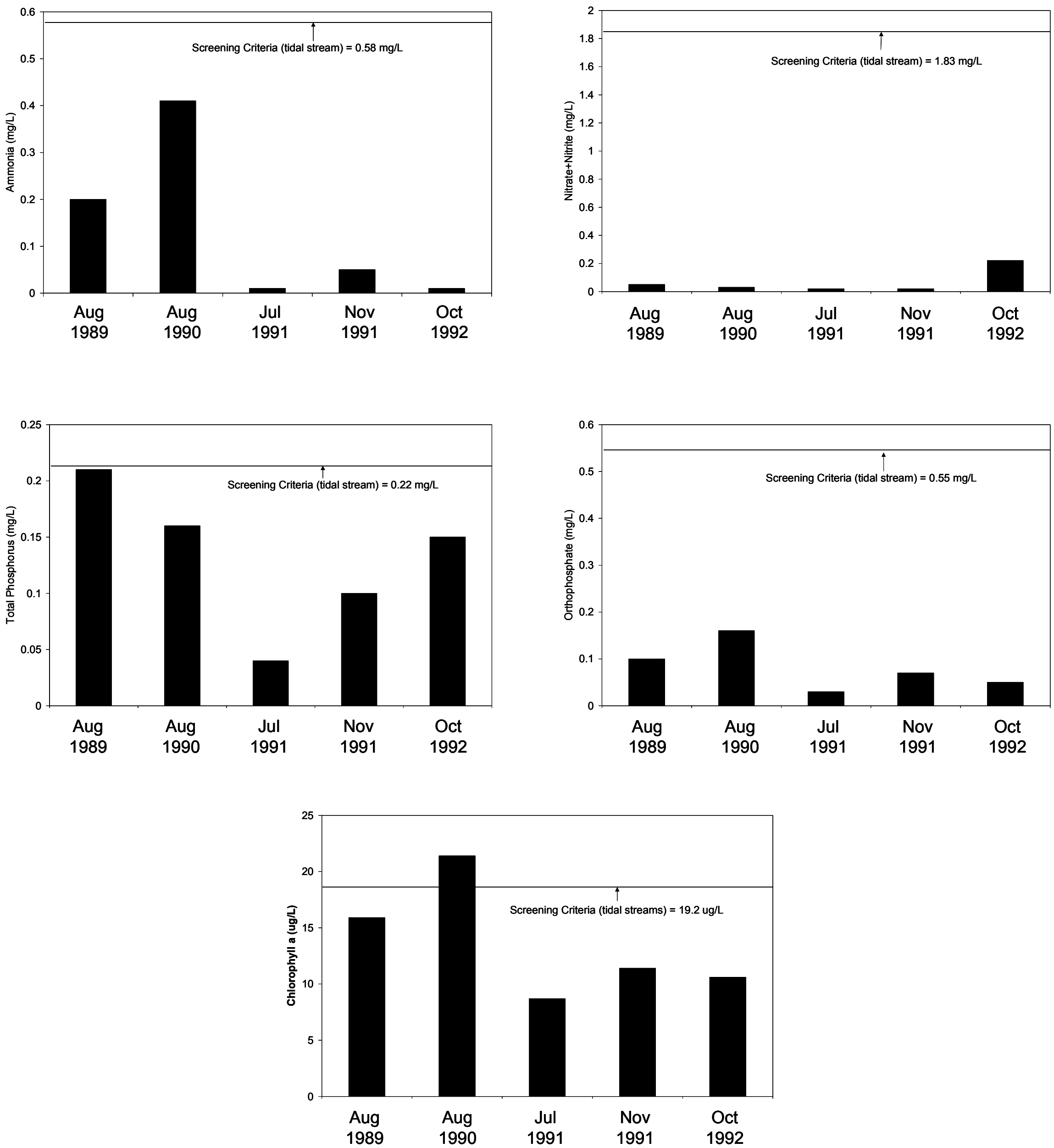

Fig. 25. Nutrient concentrations at station TWC13090, Petronila Creek – tidal. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

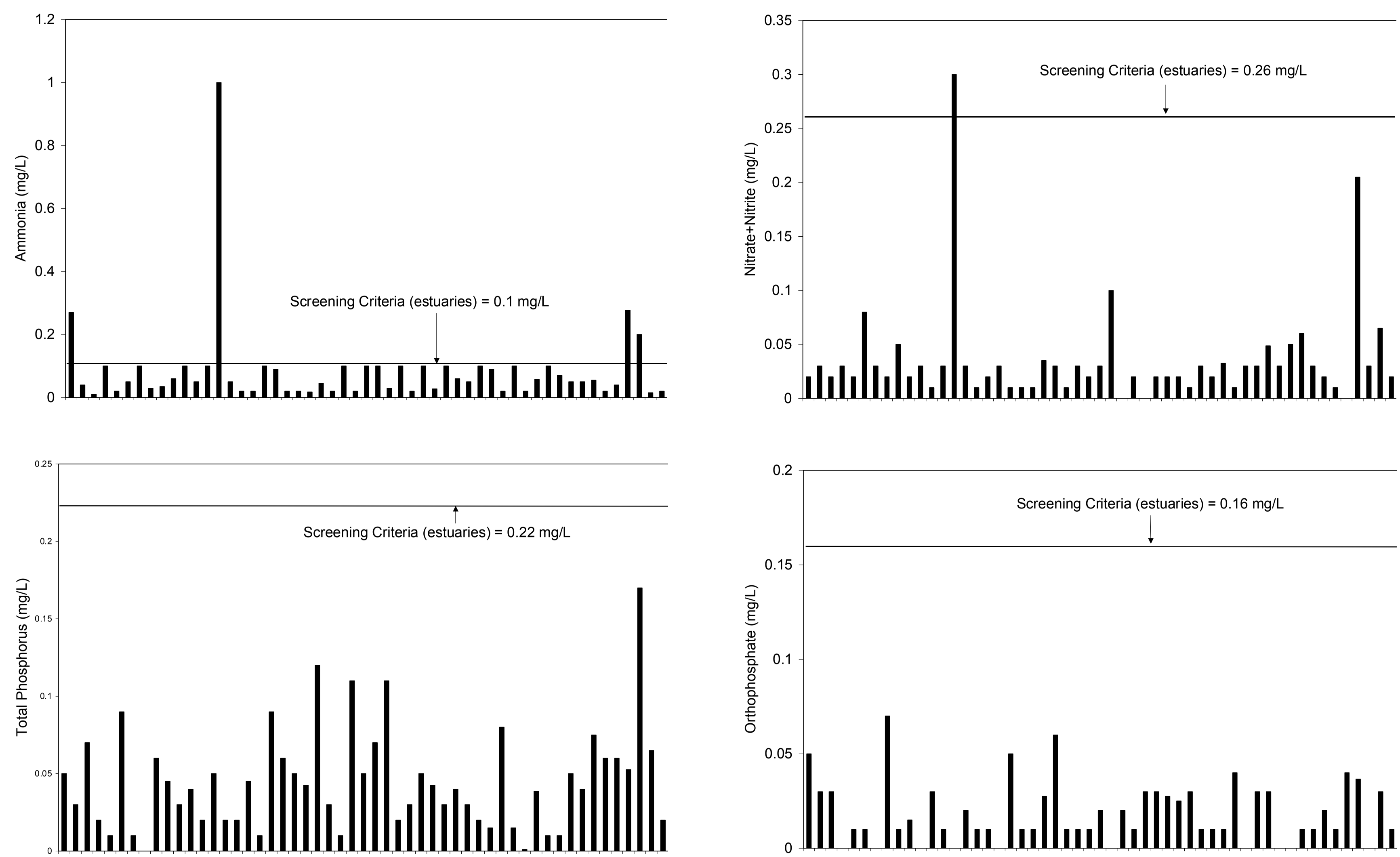

Fig. 26. Nutrient (ammonia, top left; nitrate+nitrite, top right; total phosphorus, lower left; orthophosphate, lower right) concentrations at Station 13446, 1969-1992. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

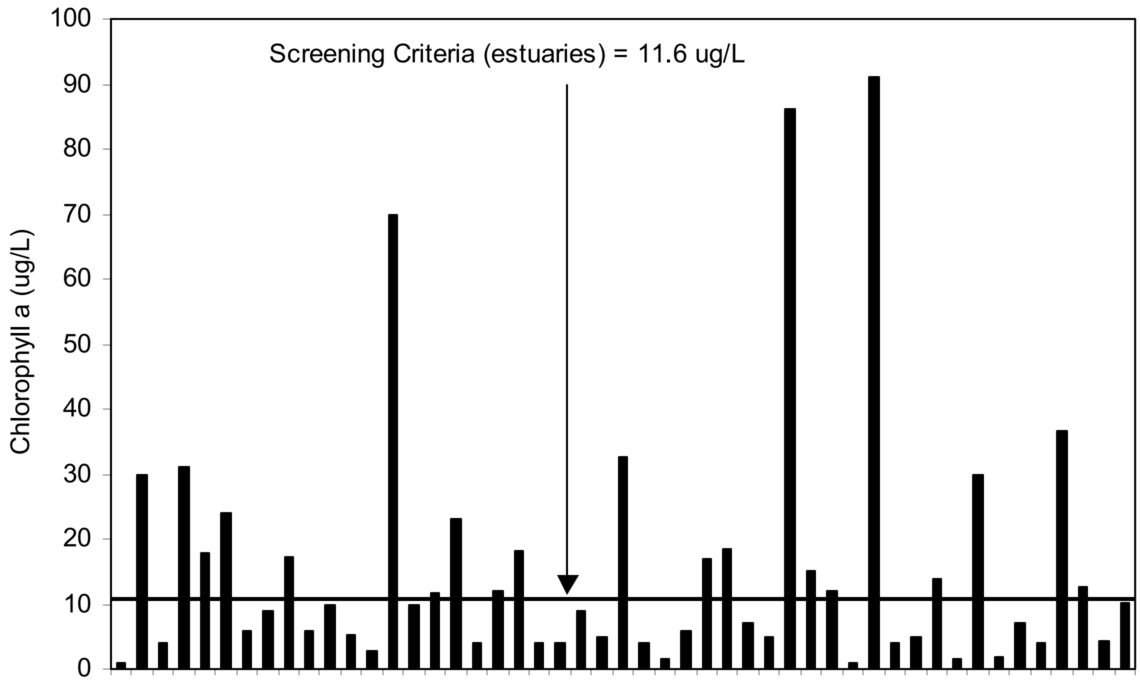

Fig. 27. Chlorophyll *a* concentrations at Station 13447, 1972-1992. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

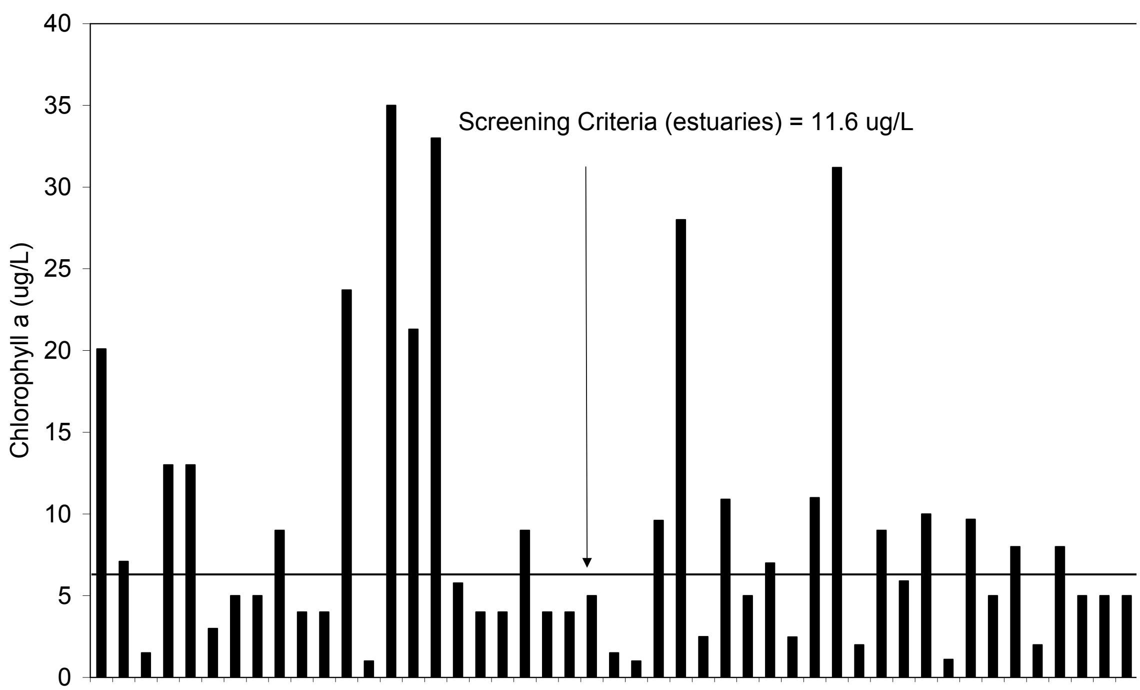

Fig. 28. Chlorophyll *a* concentrations at Station 13448, 1972-1992. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002)..

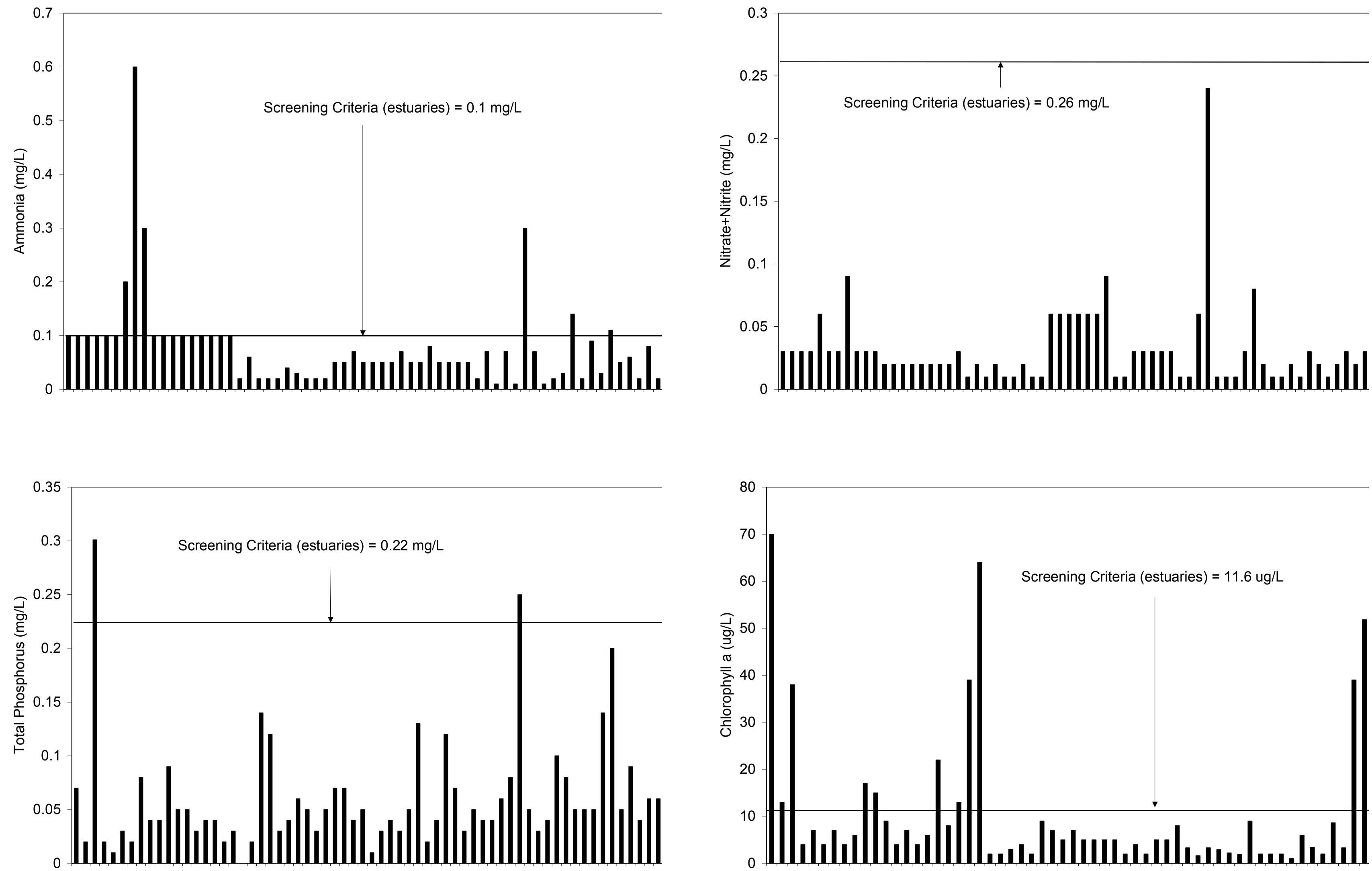

Fig. 29. Nutrient (ammonia, top left; nitrate+nitrite, top right; total phosphorus, lower left) and chlorophyll *a* (lower right) concentrations at Station 13449, 1969-1992. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

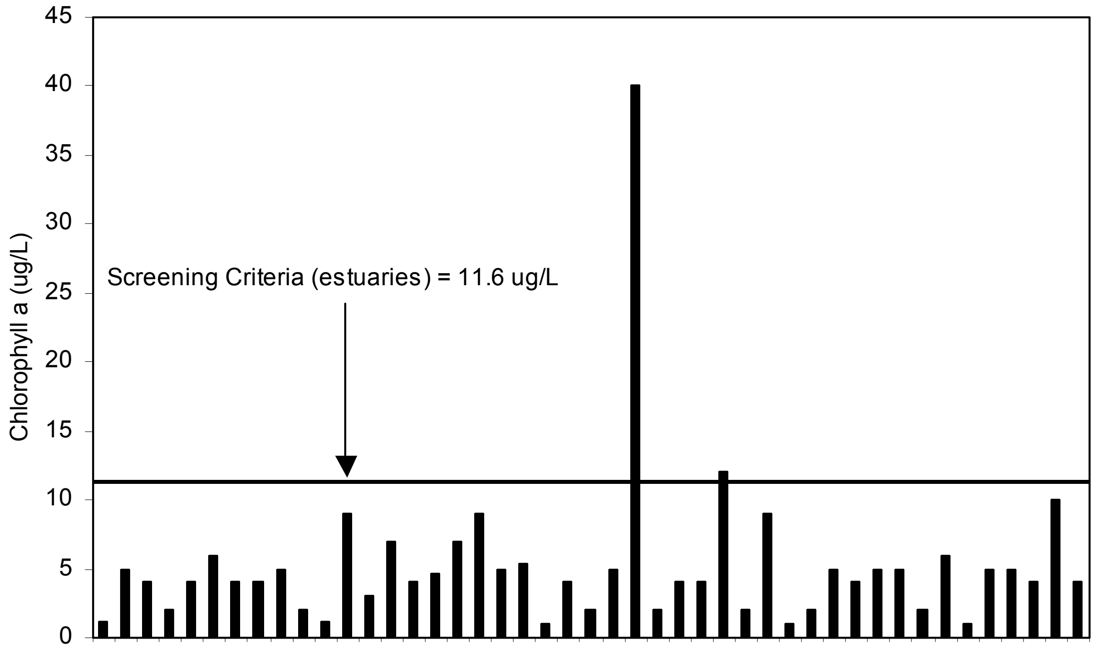

Fig. 30. Chlorophyll *a* concentrations at Station 13469, 1972-1992. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

Metals – Very few stations were sampled for dissolved metals from 1968-1992 and all determinations were made prior to 1973 (Table 10). Using today's criteria there were a number of exceedances, particularly at TWC13090. These exceedances must be interpreted with caution. The accuracy of dissolved metals analysis is dependent on proper sampling procedures so the reported exceedances may be due to contamination during sampling. The age of the determinations is also a factor to be considered, since the methods used for dissolved metals assessments have changed over the years, and older values may not be strictly comparable to current criteria. These data suggest the need for additional sampling using "clean" collection methods and field filtering procedures.

Texas Commission on Environmental Quality (TCEQ) Data

Geographic Area Designations for Assessing & Monitoring Water Quality

The Texas Commission on Environmental Quality (TCEQ), formerly known as Texas Natural Resource Conservation Commission (TNRCC), established a process to manage water resources using a watershed approach. River basins have been designated throughout the state of Texas to coordinate water management regionally. PAIS is located within the Nueces-Rio Grande Coastal Basin that encompasses the coastal region from Corpus Christi to Brownsville and inland (Fig. 31). Geographic areas are further subdivided into stream segments for monitoring and management purposes. These stream segments exhibit common natural, physical, chemical, hydrological, and biological characteristics and processes as well as respond similarly to external stressors (e.g. discharge, pollutants; Office of Water Resources Management (OWRM) and Cadmus Group, Inc. 1997). The stream segments are classified in the water identification system utilized by the TCEQ OWRM. They are the designated management units to which water quality standards and regulations are applied. Several stream segments lie within the PAIS watershed area (Fig. 32). These stream segments are evaluated by TCEQ, and may become listed on the 303(d) list for Segments of Impaired Waters. Several stream segments were designated as impaired (2204, 2202, 2202A, 2201) by TCEQ in 2001 within the PAIS project area (Fig. 32). Each segment is then further evaluated to determine if the listing is appropriate and what actions are necessary to delist them in the future.

Table 10. Dissolved metals (μg/L, standard deviation in parenthesis when more than one value available) in estuarine single stations. Bold indicates concentrations that exceed current criteria

Station	As	Cd	Cu	Pb	Ni	Zn	Hg
PAIS_TWDB_21-2						**100**	
PAISICW103	2						
PAISICW115	0						
PAISICW121	2						
PAISICW33	10						
PAISICW39	12						
PAISICW45	8						
PAISICW51	8						
PAISICW57	2						
PAISICW63	0						
PAISICW69	0						
PAISICW75	2						
PAISICW83	0						
PAISICW95	2						
PAISTWDB01-4		0	0	0		40	
PAISTWDB02-3						**100**	
PAISTWDB03-1					**7400 (2007.5)**	0.24	
PAISTWDB05-2					**6930**	8.8 (17.4)	
PAISTWDB07-2			0	0	**9400**	0.25	
PAISTWDB08-2						**100**	
PAISTWDB11-3		0	**7**	0		40	
PAISTWDB13-2						**100**	
PAISTWDB15-2		0	**10.5 (0)**	4 (1.4)		15 (7.1)	
PAISTWDB16-2						**100**	
PAISTWDB18-2						**100**	
PAISTWDB19-1		0	**39 (5.7)**	6 (1.4)		45 (7.1)	
PAISTWDB19-2						100	
TWC13090	22.3	**11.6 (16.4)**	**15.4 (15.3)**	**13.4 (17.0)**	**26 (36.9)**	8.8 (17.4)	0.14 (0.76)

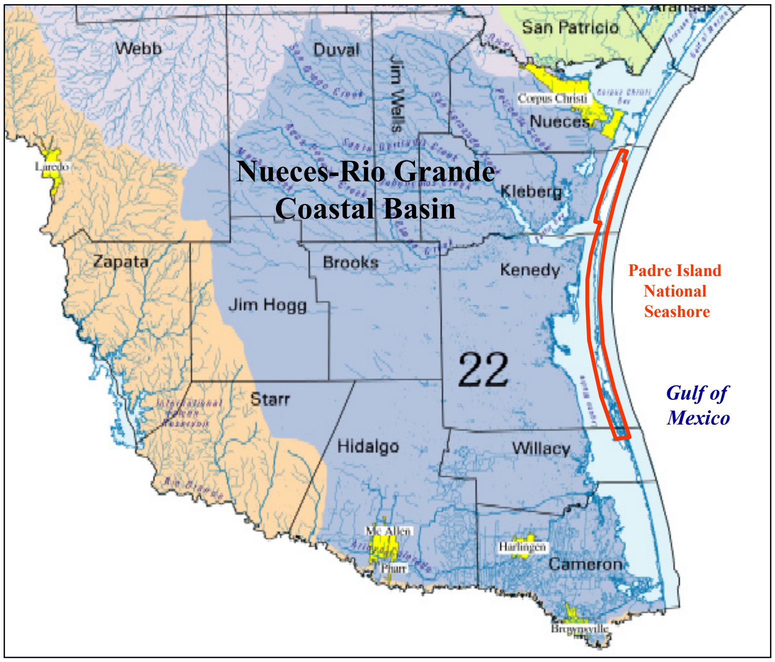

Fig. 31. The Texas Commission on Environmental Quality basin designation for the geographic area including Padre Island National Seashore, Nueces-Rio Grande Coastal Basin (22) (modified from http://www.tnrcc.state.tx.us/gis/images/basins.pdf).

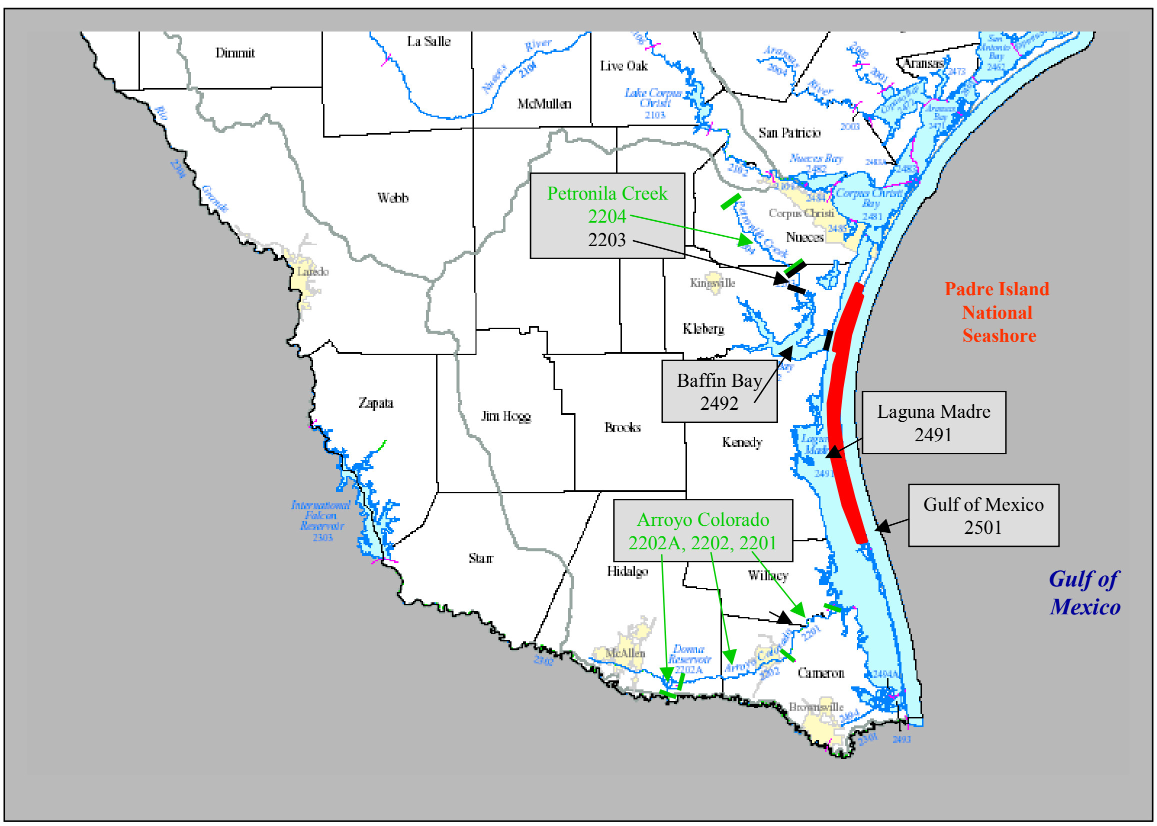

Fig. 32. Stream segment units designated within south Texas coast within PAIS project area. Segments identified on 303(d) list are highlighted in green (modified from http://www.tnrcc.state.tx.us/gis/images/seg2000.pdf).

Data Description & Summary

TCEQ has collected data of various types at 134 stations within the Laguna Madre, Baffin Bay and the tidal segments of the streams that feed it, the tidal portion of Arroyo Colorado, and the Gulf of Mexico (Fig. 33). However, like the STORET data, temporal coverage varies.

In this section, we review data on dissolved oxygen, fecal coliform, nutrients (ammonia nitrogen, nitrate+nitrite, total phosphorus, orthophosphate), chlorophyll *a* and dissolved metals. We will focus on stations that have at least five years of data except in the case of dissolved metals where we will review all pertinent determinations. We will also limit spatial coverage primarily to the Laguna Madre and Gulf of Mexico from Mansfield Pass to the northern PAIS boundary, but will include Station 13447, at the intersection of the GIWW and Arroyo Colorado, which is a long-term station that was included in the review of STORET data above. For dissolved oxygen, nutrients, and chlorophyll *a*, we will review the data on a station-by-station basis. For fecal coliform and dissolved metals, we will overview all stations under a single heading.

Station 13443 – This station is located south of the intersection of the GIWW and the JFK Causeway. Other than fecal coliform (reviewed below), the only parameter of interest measured at this station was dissolved oxygen. Dissolved oxygen was below criteria (5.0 mg/L) six times between January 1993 and March 2004 or ~ 16% of all observations (n=38; Fig. 34). At this level of exceedances, dissolved oxygen appears to be of concern at this station.

Station 13444 – This station is located at the intersection of the GIWW and the Baffin Bay channel. Other than fecal coliform, the only parameter of interest measured at this station was dissolved oxygen. Dissolved oxygen fell below criteria (5.0 mg/L) three times between January 1993 and February 2004 or ~10% of all observations (n=31; Fig 35). Dissolved oxygen does not appear to be of concern at this station.

Station 13445 – This station is located at the intersection of the GIWW and the Bird Island Basin channel. Ammonia, nitrate+nitrite, total phosphorus, orthophosphorus and chlorophyll *a* were measured at this station, but fewer than 10 determinations were made between 1992-2004, the minimum needed for adequate assessment. However, none of the parameters exceeded TCEQ's screening criteria except chlorophyll *a*. Additional monitoring of chlorophyll *a* concentrations is needed. Other than fecal coliform, the only other parameter of interest available for assessment at this station is dissolved oxygen. Dissolved oxygen fell below criteria (5.0 mg/L) seven times between January 1993 and April 2004 or ~12% of all observations (n=57, Fig. 36). At this level of exceedances, dissolved oxygen appears to be of concern at this station.

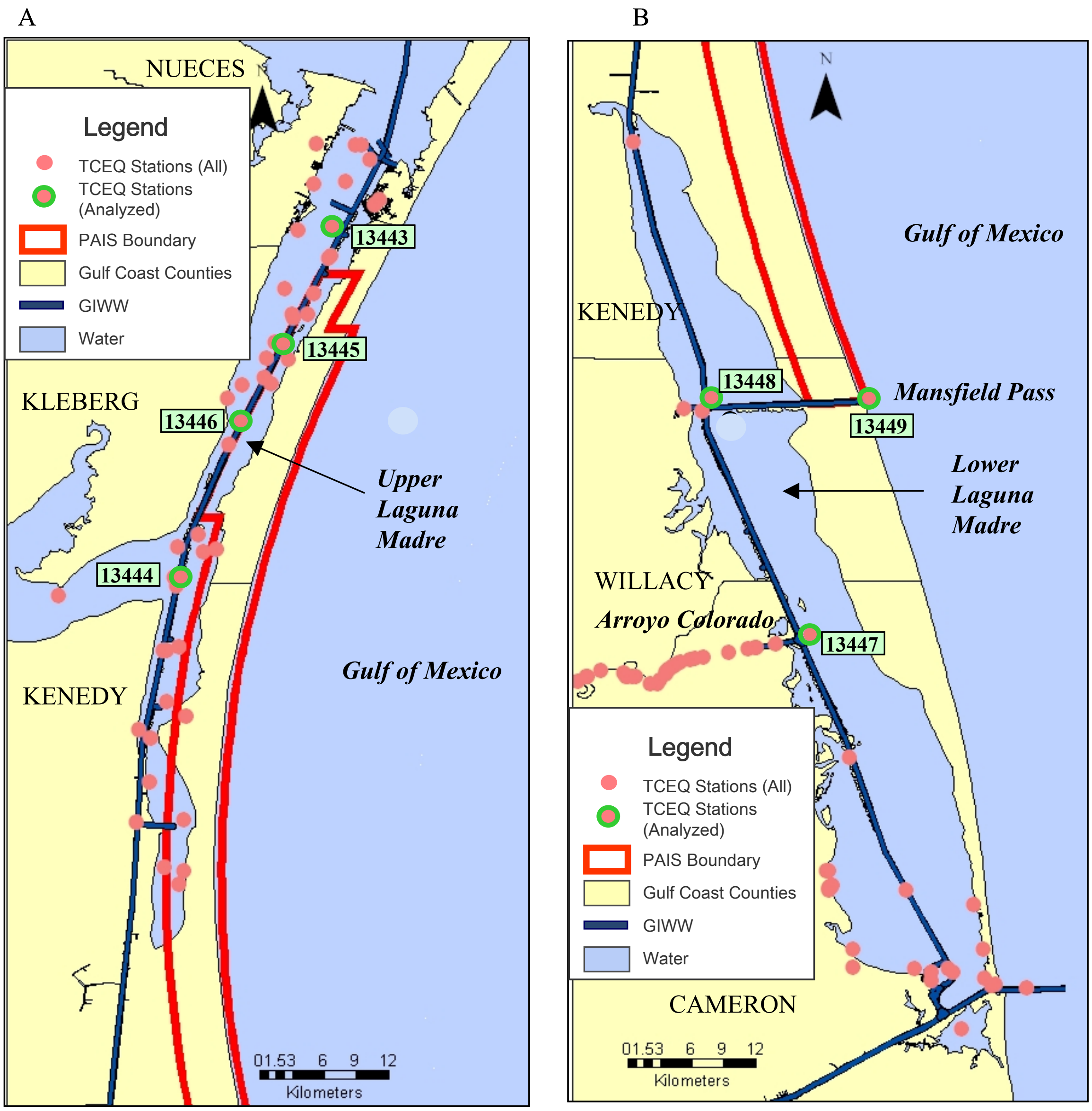

Fig. 33. Locations of TCEQ stations.

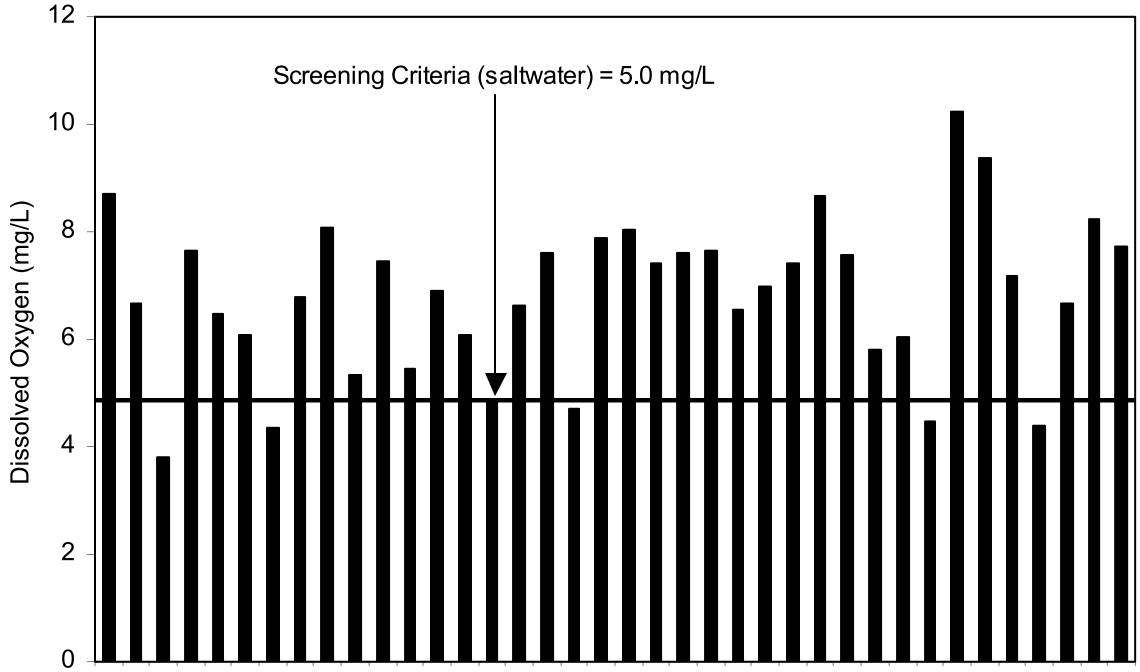

Fig. 34. Dissolved oxygen concentrations (mg/L) at Station 13443, 1993-2004. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

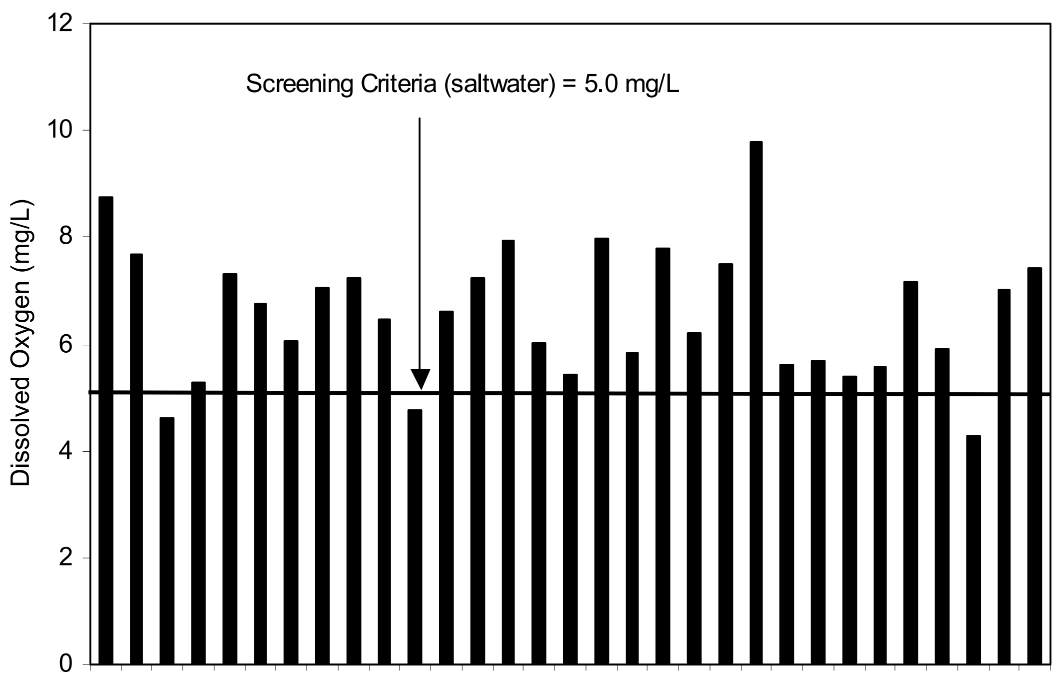

Fig. 35. Dissolved oxygen concentrations (mg/L) at Station 13444, 1993-2004. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

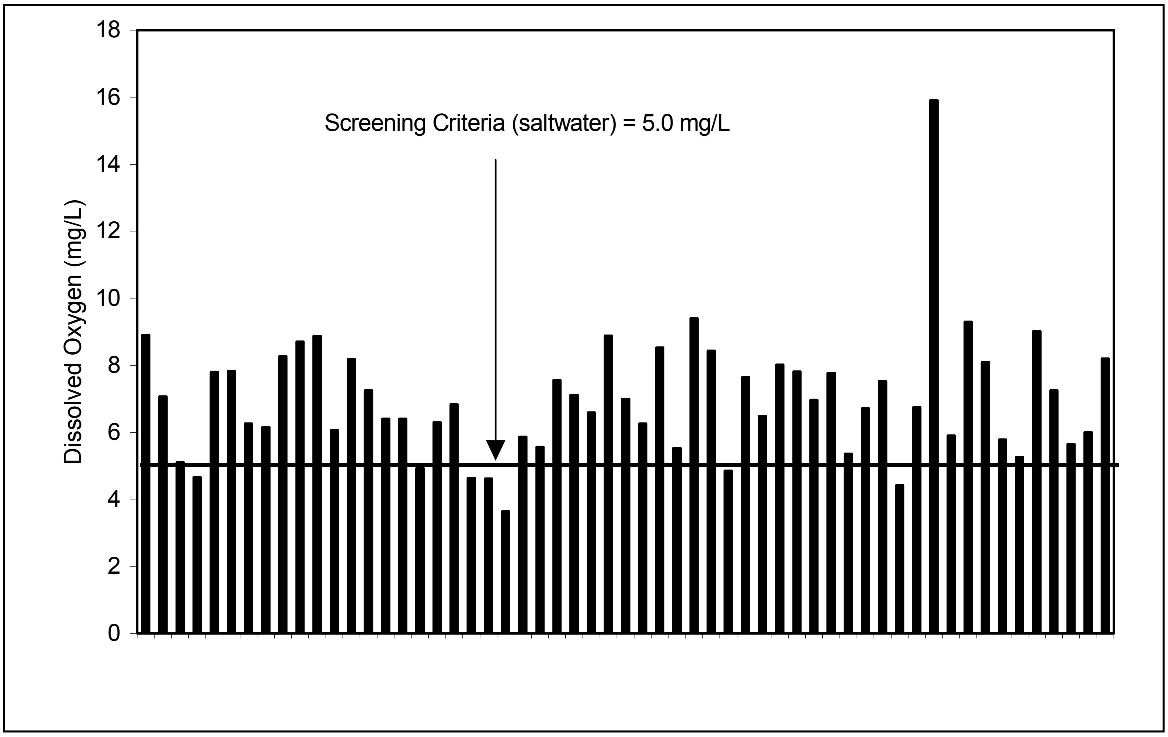

Fig. 36. Dissolved oxygen concentrations (mg/l) at Station 13445, 1993-2004. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

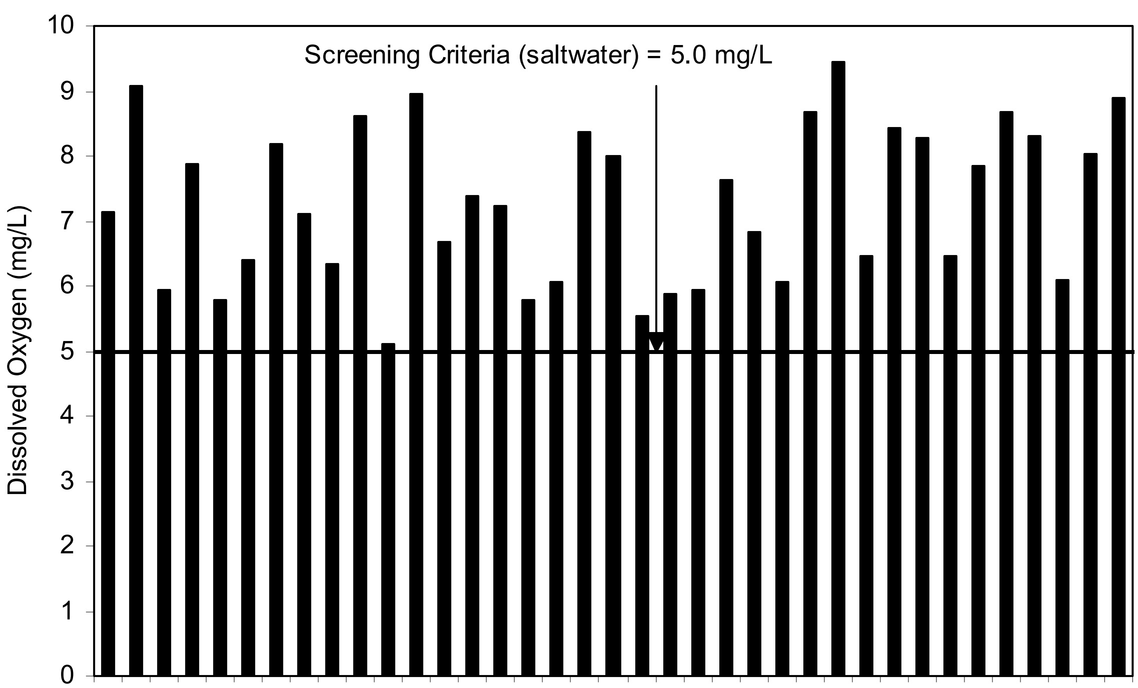

Fig. 37. Dissolved oxygen concentrations (mg/L) at Station 13446, 1993-2004. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

Station 13446 – This station is one of the STORET legacy stations and is located near GIWW channel marker 129, south of Bird Island Basin. Ammonia, nitrate+nitrite, total phosphorus, orthophosphorus and chlorophyll *a* were measured at this station, but fewer than 10 determinations were made between 1992-2004, the minimum needed for adequate assessment. However, none of the nutrient parameters exceeded TCEQ screening criteria in the limited sampling. Other than fecal coliform, the only other parameter of interest available for assessment at this station is dissolved oxygen. Dissolved oxygen did not fall below criteria between May 1993 and April 2004 (Fig. 37). Dissolved oxygen is not currently of concern at this station.

Station 13447 – This station is one of the STORET legacy stations and is located at the intersection of the Arroyo Colorado and GIWW. Ammonia, nitrate+nitrite, total phosphorus, orthophosphorus and chlorophyll *a* were measured at this station, but fewer than 10 determinations were made between 1993-2004, the minimum needed for adequate assessment. However, all nutrient parameters exceeded screening criteria at least once in five samples. These exceedances indicate the need for additional nutrient monitoring at this station to determine if nutrients are of concern. Nutrient exceedances in the STORET data indicated "concern" at this station for nutrients and it appears that they may still be of concern today. Other than fecal coliform, the only other parameter of interest available for assessment at this station is dissolved oxygen. Dissolved oxygen fell below criteria 9 times between January 1993 and April 2004 or ~19% of all observations (n=47; Fig. 38). At this level of exceedances, dissolved oxygen is of concern at this station.

Station 13448 – This station is one of the STORET legacy stations and is located at the intersection of the GIWW and the Port Mansfield Channel in the lower Laguna Madre. Other than fecal coliform, the only parameter of interest measured at this station was dissolved oxygen. Dissolved oxygen fell below criteria only once between May 1993 and December 2003 or 2.5% of all observations (n=40; Fig. 39). Dissolved oxygen is not of concern at this station.

Station 13449 – This station is one of the STORET legacy stations and is located in the GIWW in lower Laguna Madre at channel marker 225A north of Mansfield channel. Other than fecal coliform, the only parameter of interest measured at this station was dissolved oxygen. Dissolved oxygen fell below criteria twice between May 1993 and December 2003 or ~15% of all observations (n=13; Fig. 40). At this level of exceedances, dissolved oxygen is of concern at this station.

Fecal Coliform – Geometric means of the number of fecal coliform colonies per 100 mL were calculated from data from 20 TCEQ stations and six stations inside PAIS that were monitored approximately weekly during the summers of 2000-2003 (Table 11). The highest geometric mean was 8.61 colonies/100 mL at Station 14863. No station even approached the screening criteria of 200 colonies/100 mL (geometric mean of 10+ samples). Fecal coliform is not of concern either within PAIS or in the surrounding waters.

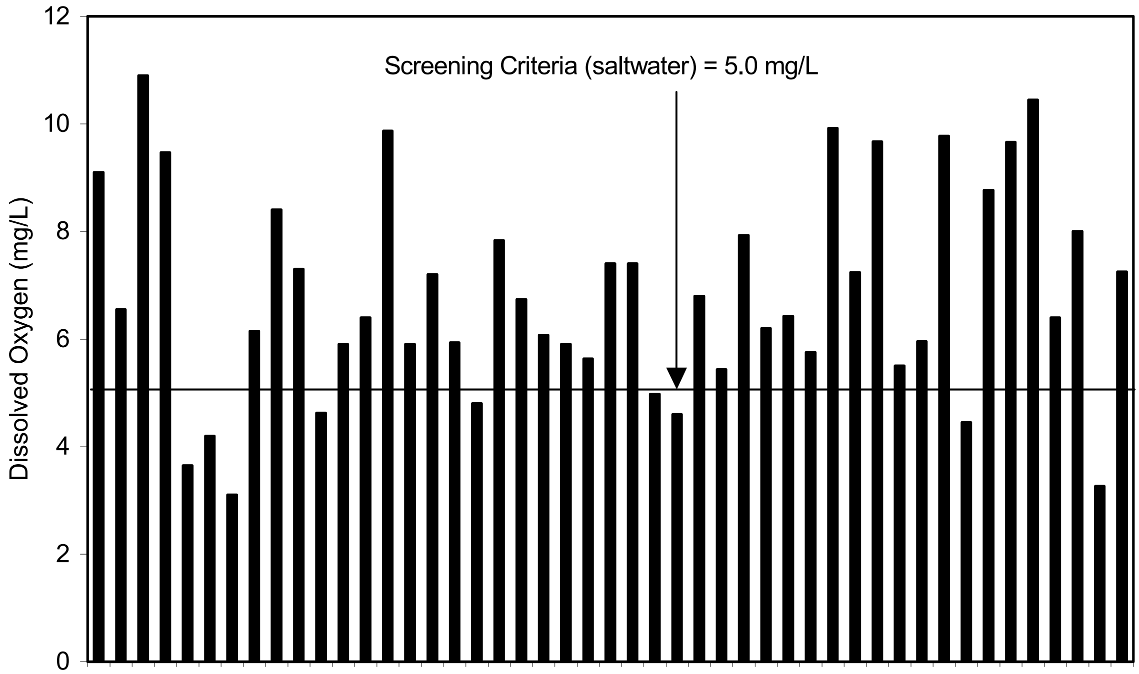

Fig. 38. Dissolved oxygen concentrations (mg/L) at Station 13447, 1993-2004. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

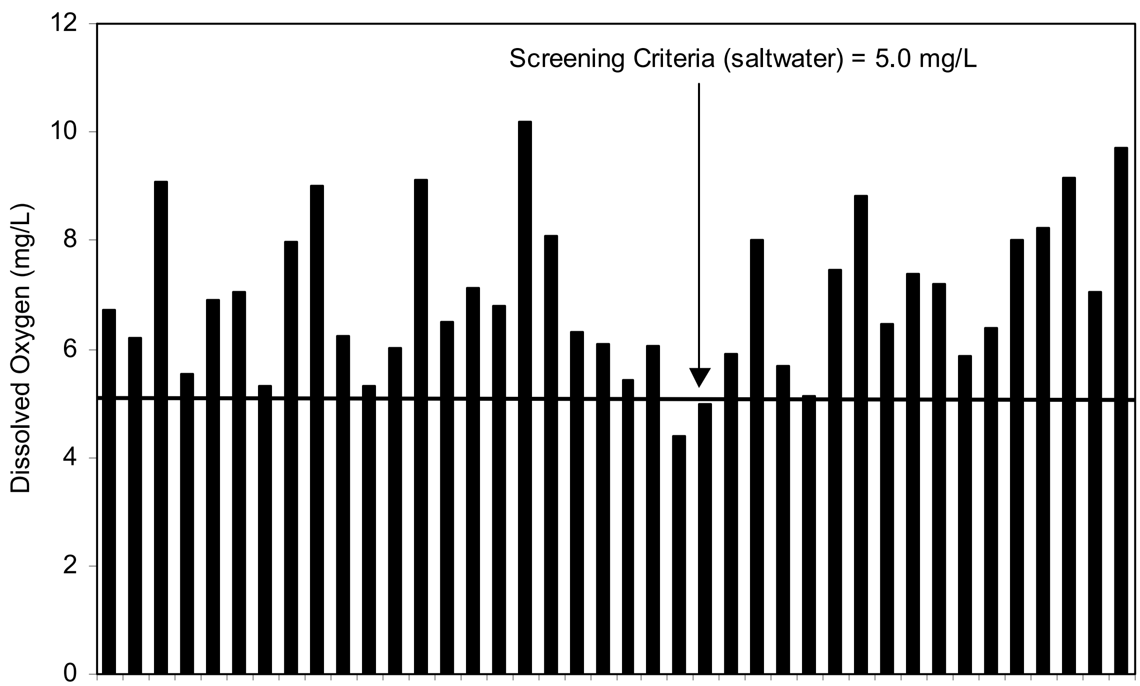

Fig. 39. Dissolved oxygen concentrations (mg/L) at Station 13448, 1993-2003. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

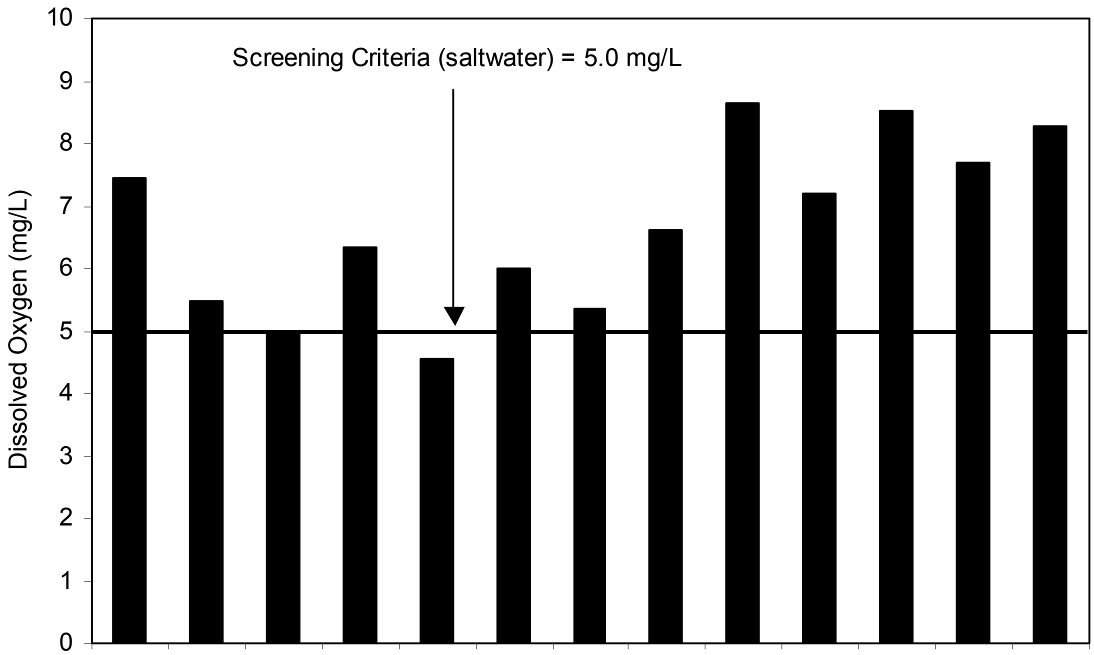

Fig. 40. Dissolved oxygen concentrations (mg/L) at Station 13449, 1993-2003. The solid line within the graph represents TCEQ screening criteria (TCEQ 2002).

Dissolved Metals – Dissolved metals (arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc) were analyzed at 31 stations in the upper Laguna Madre including several in the Yarborough Pass area (18170-18175) and in Nine-Mile Hole (18177-18182). All metals were analyzed just once at each station during either 2001 or 2002; this sampling effort was part of the Regional Coastal Assessment Program (RCAP) that will be reviewed below. No metals were found to exceed maximum allowable concentrations (Table 12).

National Coastal Assessment Program (NCA)

The U.S. EPA's National Coastal Assessment (NCA) is a five-year effort led by EPA's Office of Research and Development (ORD) to evaluate assessment methods it has developed to advance the science of ecosystem condition monitoring. This program has been surveying the condition of the Nation's coastal resources (estuaries and offshore waters) by creating an integrated, comprehensive coastal monitoring program among states to assess coastal ecological condition. The strategy for the NCA focuses on strategic partnerships with all 24 coastal states and Puerto Rico. Using a probabilistic design and a common set of survey indicators, each state conducted the survey and assessed condition of their coastal resources independently, yet these estimates can be aggregated to assess conditions at regional, biogeographical, and national levels.

Table 11. Fecal coliform geometric means (colonies/100 mL) for stations within PAIS boundaries. Data from TCEQ database (1993-present) and Joanna Mott, Texas A&M University-Corpus Christi, May or June through August or September, 2000-2003 (unpublished). See Appendix Y for more complete descriptions of TCEQ stations including date ranges.

Station	n	Geometric mean
Upper Laguna Madre		
TCEQ 13443	32	3.31
TCEQ 13444	26	2.64
TCEQ 13445 (Bird Island)	54	3.73
TCEQ 15006	20	3.02
Bird Island Station 1	67	1.87
Bird Island Station 2	68	2.37
Bird Island Station 3	68	2.31
Lower Laguna Madre		
TCEQ 13446	29	4.39
TCEQ 13447 (Arroyo Colorado)	48	3.08
TCEQ 13448	14	2.38
TCEQ 14843	42	5.36
TCEQ 14844	47	3.23
TCEQ 14845	47	2.16
TCEQ 14861	55	2.33
TCEQ 14862	55	2.44
TCEQ 14863	55	8.61
TCEQ 14868	55	2.47
TCEQ 14869	55	2.74
TCEQ 14870	55	2.45
TCEQ 14876	55	2.22
TCEQ 17100	34	2.49
TCEQ 17117	30	2.19
Gulf of Mexico		
TCEQ 13469	30	2.28
Malaquite Station 1	68	5.00
Malaquite Station 2	71	5.00
Malaquite Station 3	69	5.42

Table 12. Dissolved metals concentrations (µg/L) at stations in upper Laguna Madre. Analyses were performed in 2001-2002.

Station	As	Cd	Cu	Pb	Hg	Ni	Se	Zn
18066	1.08	0.02	0.37	0.07	0.002	0.69	0.25	0.20
18067	3.06	0.02	0.31	0.07	0.001	0.42	0.16	0.27
18069	1.38	0.02	0.46	0.04	0.005	0.70	0.26	0.30
18074	1.13	0.03	0.56	0.11	0.001	0.77	0.17	0.20
18076	1.01	0.02	0.36	0.07	0.005	0.64	0.18	0.20
18078	1.77	0.02	0.27	0.04	0.002	0.62	0.15	0.20
18079	2.50	0.02	0.43	0.11	0.001	0.72	0.24	0.95
18083	2.16	0.02	0.24	0.08	0.003	0.60	0.13	0.20
18084	1.60	0.02	0.47	0.06	0.003	0.70	0.15	0.20
18086	2.16	0.02	0.45	0.10	0.001	0.45	0.12	0.26
18087	1.50	0.02	0.42	0.08	0.001	0.46	0.14	0.21
18089	0.93	0.02	0.42	0.11	0.001	0.68	0.15	0.20
18091	2.31	0.02	0.44	0.08	0.001	0.46	0.17	0.20
18094	2.43	0.02	0.45	0.12	0.001	0.51	0.11	0.21
18095	1.55	0.02	0.32	0.13	0.001	0.64	0.14	0.28
18096	2.22	0.02	0.42	0.06	0.001	0.50	0.24	0.20
18099	1.60	0.02	0.31	0.06	0.001	0.70	0.11	0.26
18101	1.40	0.02	0.45	0.05	0.001	0.71	0.14	0.20
18103	2.12	0.02	0.30	0.10	0.001	0.45	0.10	0.20
18162	2.57	0.02	0.37	0.07	0.001	0.41	0.22	0.20
18163	2.24	0.02	0.4	0.03	0.001	0.68	0.13	0.20
18164	0.73	0.02	0.34	0.05	0.001	0.66	0.12	0.20
18166	3.27	0.02	0.33	0.08	0.001	0.42	0.10	0.20
18170	1.98	0.02	0.28	0.07	0.002	0.37	0.26	0.28
18171	0.70	0.03	0.52	0.41	0.001	0.76	0.11	0.20
18174	2.93	0.02	0.21	0.04	0.001	0.38	0.17	0.20
18175	1.29	0.02	0.68	0.06	0.001	0.8	0.14	0.20
18177	2.56	0.02	0.28	0.03	0.001	0.38	0.15	0.30
18180	1.31	0.02	0.43	0.10	0.001	0.78	0.05	0.20
18181	1.10	0.02	0.40	0.08	0.002	0.29	0.18	0.25
18182	0.99	0.02	0.42	0.07	0.001	0.69	0.05	0.20

In Texas, Texas Parks and Wildlife Department (TPWD) is the lead agency for the NCA via a cooperative agreement with EPA. Data have been collected under this program since 2000; 2004 is currently slated as the final year for data collection. Parameters that are measured include water column data, sediment contaminants and toxicity data, and benthic macroinvertebrate and demersal fish community and contaminant data. The Laguna Madre has been sampled, but currently, no data from Texas are available. These data will provide an excellent measure of the overall condition of the Laguna Madre, especially when combined with the more intensive Regional Coastal Assessment Program described below. When Texas data become available they will be located at http://www.epa.gov/emap/nca/html/data/index.html.

Regional Coastal Assessment Program (RCAP)

The Regional Coastal Assessment Program (RCAP) is a baseline water, sediment and biological monitoring program funded by the Coastal Bend Bays and Estuaries Program. It was initiated in 2001 to expand monitoring efforts within the bays and estuaries of the central Texas coast including upper Laguna Madre (Nicolau and Nuñez. 2004). The bays and estuaries of the central Texas coast have been undersampled historically, but sampling continued to decline from the 1970s through the late 1990s. The lack of water, sediment and biological data was the impetus for initiation of RCAP. The sampling design of RCAP mirrors that of the NCA in that it is an intensive, probabalistic design. In the upper Laguna Madre and Baffin Bay, a total of 30 hexagonal sampling areas were designated, from which quarterly samples were taken. The first two years of the effort were considered baseline monitoring and involved intensive sampling. Subsequently, sampling was reduced to annually during the summer. Sampled parameters include field measurements (e.g., dissolved oxygen, pH), dissolved metals, sediment metals, sediment organics (e.g., pesticides), and water and sediment bacteria. Dissolved metals data (2001-2002) were reviewed above and are currently available on the TCEQ website (http://www.tnrcc.state.tx.us/water/quality/data/wmt/samplequery.html).

This report currently exists in draft form only and is not complete. Because data have not been completely explored or analyzed, conclusions cannot be made at this time. Preliminary analyses indicate that throughout most of the upper Laguna Madre, nutrients and metals are not of concern. There are some areas where dissolved oxygen and chlorophyll *a* may be of concern. However, in the hypersaline Laguna Madre, these conditions may be natural, particularly depressed dissolved oxygen, due to both the reduced ability of hypersaline water to hold oxygen, as well as increased respiration due to the vast amounts of seagrasses found in the system. Due to the unique conditions that characterize the Laguna Madre, particularly the upper lagoon, more site-specific criteria may be needed to adequately assess water quality conditions.

Trash

Trash has been identified as one of the major water quality issues for areas that are used primarily for recreation. Following a study conducted by the National Park Marine Debris Monitoring Program, PAIS was identified as receiving more beach trash than any other park in the national park system (Cole et al. 1995; Cole and Kliwinski 1998). From 1980-1993, PAIS was one of 10 national park units that participated in a national shoreline monitoring program. PAIS staff implemented a longer term research and monitoring program from 1989-1998 to determine appropriate methods for quantifying trash components, sources of trash, and seasonality of trash accumulation (Miller and Jones 2003). A variety of data collection methods and sampling frequencies were employed, including a daily survey (n=957 days) along a 25.7 km stretch of gulf beach (total length=20,112 km) during 1994-1996 and 1997-1998. Nearly 400,000 trash items were recorded.

The purpose of the study was to document the extent, source, and potential impact of shoreline trash within PAIS, as well as develop guidelines for monitoring trash along coastal beaches. Shoreline trash has aesthetic, ecological, safety, and economic implications. Non-hazardous waste includes commercial and household trash that can harm or kill marine and terrestrial animals by entanglement or accidental ingestion. Other trash can be hazardous to both marine life and humans, including toxic chemicals and medical waste.

Within the more comprehensive study, several statistical analyses were conducted to determine the types of waste that were collected, their spatial and temporal distribution, and importance or "weighting" of each waste type. By utilizing principal components analyses, the authors evaluated if the waste items could be grouped into categories and perhaps elucidate their source (Table 13). The first principal component explained 23.1% of the total variation, with principal components 2-5 explaining a combined 19.8% of the variation, and a combined 43% of the total variability in the data. When waste items are ranked by their respective coefficients, the larger values reflect more of an impact on the variance (e.g., glass condiment bottles, plastic condiment bottles, 1-gallon oil containers, incandescent lights, and plastic 1-gallon milk containers). When data were analyzed to assess seasonal variation, the results showed large variation among months with two peaks in April-May and during the fall. Deposition of more trash items appears to correspond to spring tides. In December-February and June-July the least amount of trash was documented.

Determining the origin of the trash is problematic; several other studies identified commercial vessels and offshore marine industry as contributing 75-90% (Center for Marine Conservation 1987) with most trash traceable to offshore sources (American Management Systems, Inc. 1991), and commercial fisherman as a major source of trash in the Gulf of Mexico (Center for Marine Conservation 1990). Alternatively, other studies suggest that as much as 80% of ocean trash originates from onshore sources (Faris and Hart 1995, NOAA 1996). Other studies maintain that source tracking is difficult at best (Reggio 1985, Ribic et al. 1997).

During the NPS survey, a large quantity of freshly discarded trash was documented in late July 1992 (Miller and Jones 2003). Several shrimp trawlers were observed offshore, and most of the items were related to galley wastes, as well as items used during shrimp trawling. The authors postulated that most of this trash was discarded by shrimpers. They initiated another survey period prior to and during shrimp season in 1993, where they grouped identifiable trash items into two categories: probable and suspected as being discarded by shrimpers. Although the data were not analyzed statistically, they proposed that a high probability existed that both categories were discarded by Gulf shrimpers. In a following survey, they identified specific items as definitively connected to shrimpers (Table 14), as well as additional items suspected as being

Table 13. Identified waste items collected during PAIS survey and associated eigenvalues from statistical analyses (Principal Components Analysis). Those items that were identified as contributing to the variance of each component are designated in bold type (adapted from Miller and Jones 2003).

Item Category	1st Principal Component	2nd Principal Component	3rd Principal Component	4th Principal Component	5th Prinipal Component
Glass condiment bottle	**0.798**	-0.155	-0.113	-0.244	-0.236
Plastic condiment bottle	**0.785**	0.096	-0.116	0.117	-0.286
1-gallon oil container	**0.765**	-0.234	0.219	0.111	0.004
Incandescent light	**0.698**	-0.112	-0.316	-0.306	-0.102
Plastic 1-gallon milk container	**0.683**	-0.317	0.030	-0.034	0.177
Florescent light	**0.676**	-0.297	-0.267	-0.232	-0.090
1-gallon white bleach container	**0.648**	-0.179	-0.005	0.178	0.137
Egg carton	**0.635**	0.162	-0.373	-0.176	-0.117
1-quart white bleach container	**0.609**	0.055	0.079	0.294	-0.163
5-gallon container	**0.583**	-0.223	0.240	-0.102	0.286
Hard hat	**0.580**	-0.293	0.162	-0.084	0.055
Plastic 1/2--gallon milk container	**0.560**	-0.184	0.172	-0.035	-0.010
1-quart oil container	**0.556**	-0.339	-0.103	0.145	0.203
Strip lumber piece	**0.555**	0.120	-0.270	0.090	0.282
1-quart green bleach container	**0.530**	-0.213	**0.502**	0.213	-0.223
Pipe thread protector	**0.505**	-0.055	0.003	0.154	-0.310
Paper milk container	**0.497**	0.128	-0.109	-0.127	-0.290
Scoop	**0.485**	0.304	0.334	-0.195	0.300
Brush or broom	**0.468**	**0.418**	-0.082	0.046	-0.224
Onion sack	**0.455**	0.513	0.245	-0.213	0.049
Rubber glove	**0.444**	**0.614**	0.111	-0.374	0.009
1-quart blue bleach container	**0.430**	-0.152	**0.466**	0.315	-0.238
1-litter oil container	**0.430**	0.090	**0.533**	-0.059	0.139
Salt bag	**0.414**	0.329	0.072	-0.101	0.388
Wooden pallet	**0.407**	-0.055	-0.351	0.069	0.263
Life jacket	0.386	-0.229	-0.266	-0.001	-0.049
Clear plastic sheeting	0.351	**0.433**	-0.207	**0.595**	0.048
Oil or fuel filter	0.343	0.278	-0.165	0.051	-0.132
Styrofoam buoy	0.328	-0.207	-0.233	-0.032	0.232
Fish basket	0.242	0.062	0.199	0.051	0.136
Propane or freon container	0.221	0.012	-0.262	0.147	-0.014
Black plastic sheeting	0.220	**0.404**	-0.143	**0.597**	0.109
Wooden disk	0.217	0.331	-0.099	-0.217	-0.193
Wooden spool	0.204	0.205	-0.057	-0.014	0.046
Tire	0.200	0.021	-0.068	-0.025	0.295
Write enable ring	0.168	0.031	0.088	-0.009	-0.031
Muriatic acid container	0.149	0.273	0.291	-0.089	-0.045
55-gallon container	0.149	0.037	-0.159	0.075	**0.444**
6-gallon sodium metabisulfate cont.	0.054	0.040	0.180	0.067	0.052
50 gal sodium meta-bisufate container	0.020	0.009	0.094	-0.028	0.140

associated with Gulf shrimping (Table 15). After combining similar trash items, they concluded that 81% of the trash collected was significantly correlated to Gulf shrimpers.

Additional efforts to identify point sources of trash items documented on PAIS beach shorelines utilized a previous study (by ARCO Oil and Gas Company) that listed several items associated with the offshore petroleum industry (Table 16). In the NPS study, 10% of all trash collected could be related to industry activities (Table 17). They concluded that during their extensive survey period, 80.8% of trash was attributed to Gulf shrimping industry. In addition, contrary to popular belief that most trash on Texas beaches originates in Mexico, only a small percentage (11%) of labeled trash had non-English labels and an even smaller percentage in Spanish.

Although this comprehensive study did not evaluate effects of marine trash and debris on water quality within PAIS boundaries, it is interesting that most items were related to galley wastes and not items of concern (i.e., chemical-based containers or medicinal waste). Several items were documented that could be potential sources of contamination, such as 50-gallon and 5-gallon containers; 50-gallon and 6-gallon sodium metabisulfate containers; 1-gallon, 1-liter, and 1-quart oil containers; muriatic acid containers; propane or freon containers, and 1-gallon and 1-quart bleach containers. However, no distinction was reported regarding amount of product remaining in intact items. Therefore, it is difficult to propose a relationship between marine debris and water quality at this time.

Potential sources of trash also originate in upland, terrestrial areas of the Gulf coast. The trash that flows into the Gulf during storm events can be voluminous, particularly in areas that receive stormwater from large urban areas. While no comprehensive studies have evaluated the extent of trash derived from upstream flooding, rivers that empty directly into the Gulf probably contribute a higher percentage than those that flow into an estuary. Several rivers meet this criteria along the western Gulf of Mexico (Fig. 41). A recent assessment of population growth patterns highlights areas along the Gulf of Mexico that have increased in the past decade (Fig. 42) (Dokken and Bates 2004). Note that the geographic locations of the large river systems emptying into the Gulf and the areas exhibiting high population growth changes are very similar. The relationship of population centers and rivers in relation to trash issues should be further evaluated gulfwide to develop strategies and management practices aimed at reducing trash discharges into the Gulf. The National Park Service holds a particular interest in this issue, as most of the trash that does strand on Gulf beaches is concentrated within PAIS boundaries as a result of Gulf current patterns.

Table 14. Number of point-source items identified by PAIS during a survey from 1994-1998 (Miller and Jone 2003).

Point Source Item	1994-95	1995-96	1997-98	TOTAL
Rubber gloves	6,517	5,132	7,575	19,224
Onion sacks	1,922	1,479	1,901	5,302
Salt bags	796	860	826	2,455
Wooden disks	45	24	97	166
Egg cartons	1,407	786	2,154	4,347
Incandescent lights	2,506	2,578	2,571	7,655
Condiment containers	4,617	2,647	6,402	13,666
1-gallon milk containers	4,938	5,296	3,636	13,870
White bleach bottles	744	830	1,426	3,000
Oil filters	66	58	156	280
Total	23,531	19,690	26,834	69,965

Table 15. Number of trash items designated by PAIS as new or suspected point-source items during survey from 1994-1998 (Miller and Jones 2003).

Trash Items	1994-95	1995-96	1997-98	TOTAL
New Items				
Fish basket	26	27	34	87
Shrimp scoop	1,971	582	1,015	3,568
Sodium metabisulfate	7	8	4	19
1/2-gallon milk jug	256	235	206	697
Paper milk container	214	222	405	841
Florescent light bulb	978	942	708	2,628
Quart oil container	1,610	1,096	1,135	3,841
1-liter oil container	850	906	391	2,147
1-gallon oil container	284	242	208	,734
Total	6,196	4,260	4,106	14,562
Suspected Items				
Green bleach bottle	3,299	1,927	1,452	6,678
Blue bleach bottle	295	177	191	663
Total	3,594	2,104	1,643	7,341

Table 16. Items reported to be associated with offshore petroleum industry collected during PAIS survey from1994-1998 (Miller and Jones 2003).

Item	Offshore Petroleum Industry Use
Strip lumber	Stripping over pipe or equipment
Plastic sheeting	Weatherproofing material used during transportation and storage
Wooden pallet	Transporting chemicals and equipment
Wooden spool	Transporting wire, rope and electrical wire
Hard hat	Personal protective equipment for platform personnel
Write enable ring	Storing platform information
Pipe thread protector	Protection of drilling pipes
Styrofoam buoy	Marking undergroud pipelines and equipment

Table 17. Number of trash items collected by season reported to be associated with offshore petroleum industry during PAIS survey from1994-1998 (Miller and Jones 2003).

Item	1994-95	1995-96	1997-98	Total
Hard hat	240	243	169	652
Pipe thread protector	152	63	329	544
Write enable ring	3	13	21	37
Wooden spool	13	7	29	49
Styrofoam buoy	124	142	109	375
Strip lumber	2,875	1,026	3,771	7,672
Wooden pallet	112	106	114	332
Plastic sheeting	148	37	719	904
Total	3,667	1,637	5,261	10,565

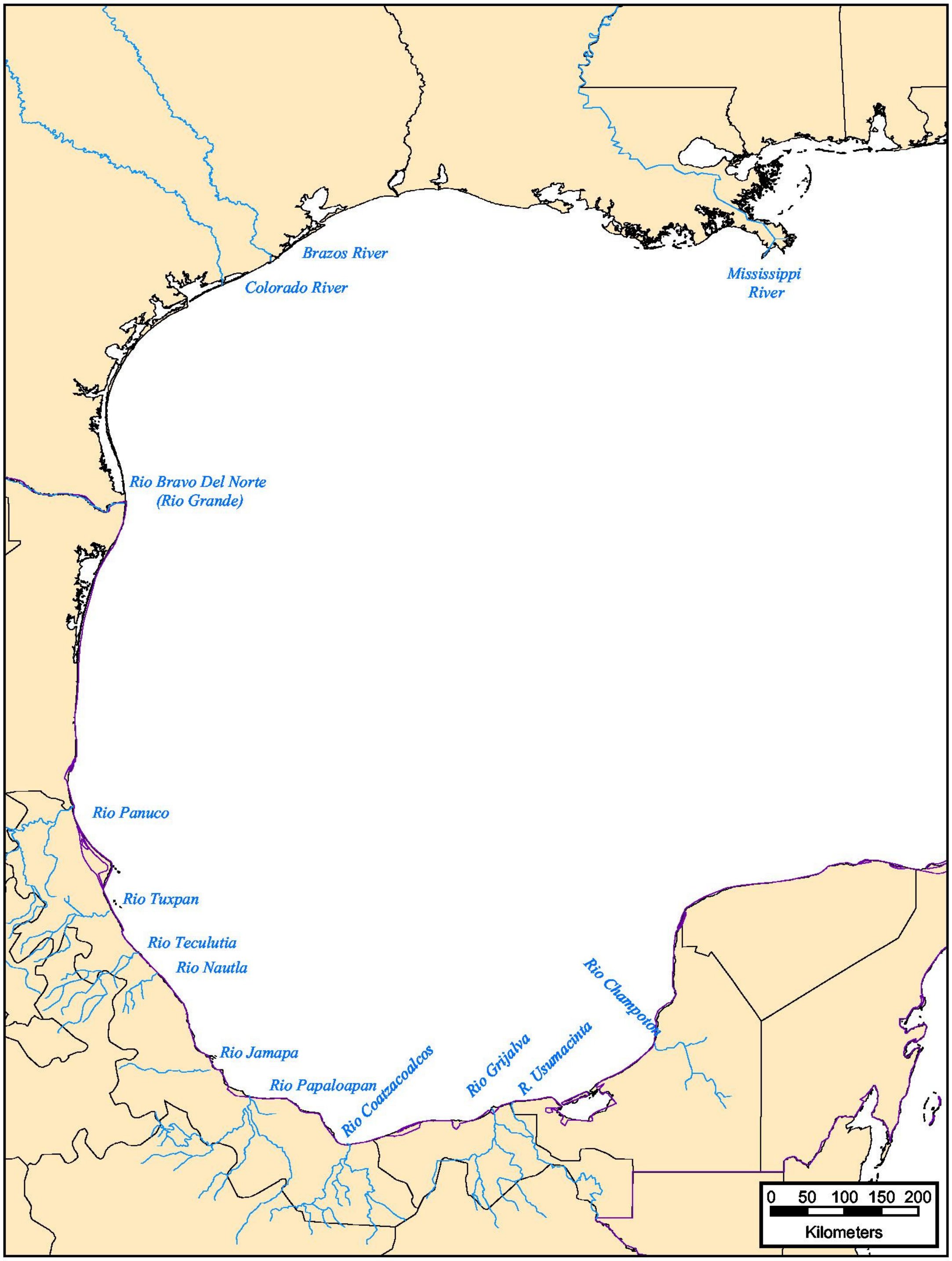

Fig. 41. Rivers in the western Gulf of Mexico that flow directly into the Gulf without entering an estuary system first.

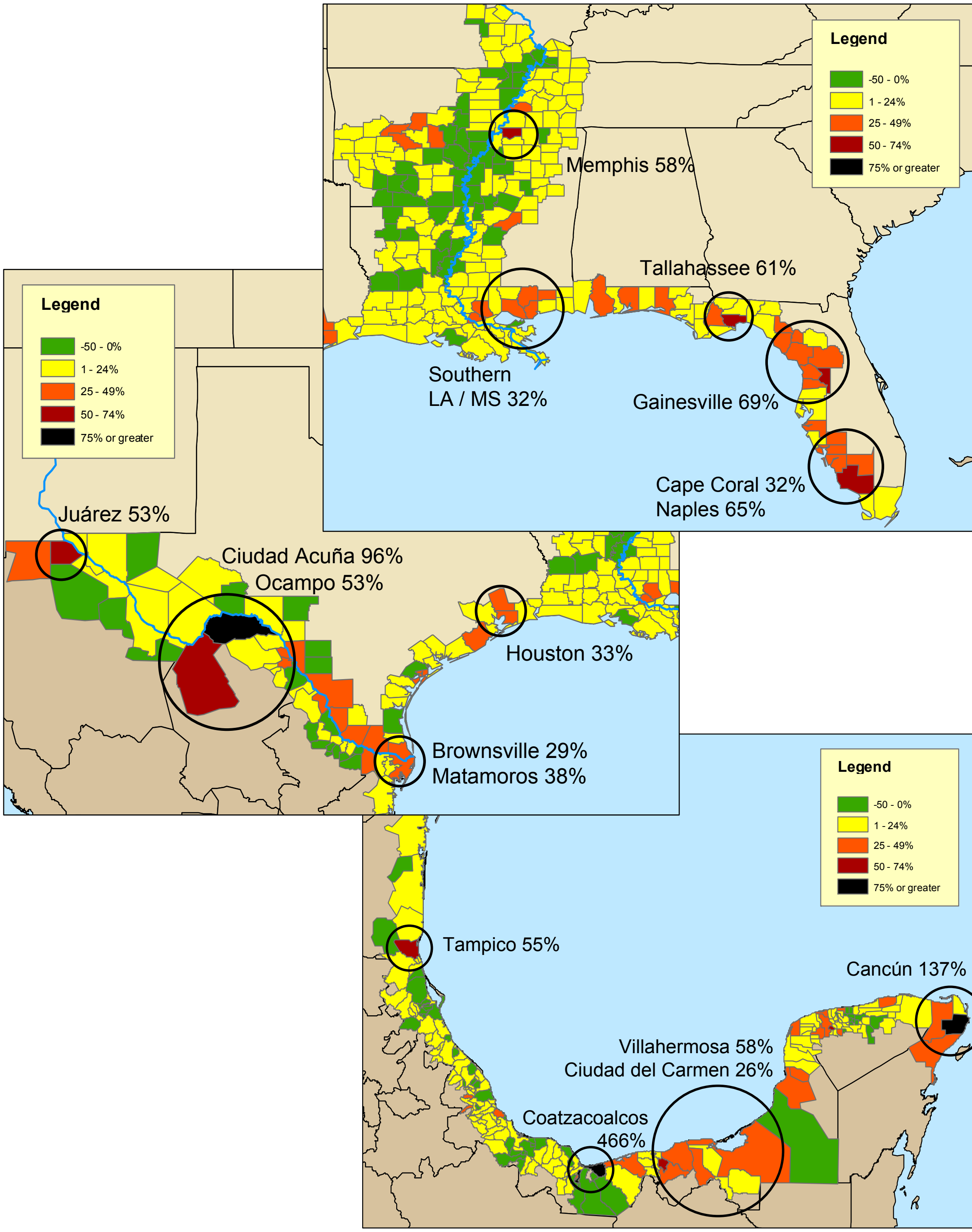

Fig. 42. Composite of percent population changes in eastern, western, and southern Gulf of Mexico (adapted from Dokken and Bates 2004).

Assessment Summary and Identification of Data Gaps

Data from available sources is temporally and spatially patchy. Although there were a number of stations in the STORET legacy database that continued to be sampled through the 1990s by TCEQ, there was little continuity in the parameters that were sampled. For example, although nutrients were sampled with some frequency between 1972-1992, nutrient sampling occurred very infrequently after 1992, thus there is little to compare baseline (1972-1992) conditions with recent/current conditions (1993-present).

Fresh Waters

There are virtually no data with which to evaluate the water quality of freshwater ponds and marshes within PAIS. Based on the limited data that is available, nutrients may be of concern within some of the ponds (Table 18). However, the ephemeral and closed nature of the ponds may cause them to become nitrogen sinks (Dudley 1987), thus, the use of TCEQ screening criteria may not be appropriate. There were also some indications that dissolved metals may be of concern, however, it may not be appropriate to evaluate 30 year old metals analyses using today's criteria due to changing methods and the possibility of contamination. Further investigation with wider spatial and temporal coverage is needed to determine the conditions of the fresh waters within PAIS.

Estuarine Waters

Despite problems with the lack of long-term data, some general statements can be made. With the exception of the area around the Arroyo Colorado (Station 13447), which is well south of the boundary of PAIS, historical nutrient (including chlorophyll *a*) concentrations are not of concern based on today's TCEQ screening criteria (Table 18). Chlorophyll *a* concentrations at Station 13447 exceeded screening criteria often enough to warrant classification of the station as of "concern". Although few chlorophyll *a* data exist after 1993, it appears that this classification may continue to be appropriate, with at least one exceedance of both chlorophyll *a* concentrations as well as nutrient concentrations at that station between 2003-04. The Arroyo Colorado serves as the receiving waters of 39 sources of municipal and industrial wastewater and is listed on the state's 303(d) list as impaired. There is a great deal of interest in water quality in the Arroyo Colorado and this has spawned a number of efforts focused on managing and improving water quality including consolidation of data (http://www.arroyo.tamu.edu). However, because of the distance of the Arroyo Colorado from the southern boundary of PAIS (>32 km south), it is unlikely that the Arroyo Colorado has or will affect water quality within PAIS. Station 13448, which is north of the mouth of the Arroyo Colorado at the intersection of the Mansfield Channel and GIWW at what is essentially the southern boundary of PAIS, has not shown any indication of concern for any measured parameter either in historical or more recent sampling. This indicates that the impact of the Arroyo Colorado remains somewhat localized.

Dissolved oxygen appears to be of concern for aquatic life in some areas of the Laguna Madre (Table 18). However, the hypersalinity of the lagoon means that its waters have less capacity for holding dissolved oxygen than similar, less saline waters. Along with the extensive coverage of

Table 18. Current and potential stressors that are affecting or may affect Padre Island National Seashore environemnts.

Padre Island National Seashore Stressors

Stressor	Gulf	Upper Laguna Madre	Lower Laguna Madre	Freshwater Ponds	Wetlands
Algal blooms	PP[1]	PP[1]	LP-PP	LP	LP
Nutrient loading	ND	LP-PP	LP-PP	MP[2]	LP
Hypoxia	ND	LP-PP	MP[3]	PP	LP
Excessive fecal bacteria	LP	LP	LP	ND	LP
Metals contamination	ND	LP	PP[4]	PP[4]	ND-LP
Toxic compounds	ND	ND	ND	ND	ND-LP
Invasive species	ND	PP[5]	PP[5]	PP[6]	PP[6]
Habitat disruption[7]	PP	MP[8]	MP[8]	LP	PP
Trash	HP	ND	ND	ND	LP
Oil and Gas Development[9]	LP-MP	LP-MP	LP	LP	LP

Definitions: HP – high problem, MP – moderate problem, LP – low or no problem, PP – potential problem, ND – insufficient data to make judgment

1-Based on regional Red/Brown Tide events
2 -Nutrient standards were exceeded in ponds
3 -Based on the level of exceedances of DO criteria
4 –Exceedances of criteria should be interpreted with caution due to the potential for sampling contamination
5-Brown Mussel, *Perna perna*
6-Not currently a problem, but there is potential for the invasion of water lettuce (*Pistia stratiodes)* and water hyacinth (*Eichhornia crassipes*)
7-Includes salinity alteration, coastal development, dredging, etc.
8-Based on declining salinity and prop scarring of seagrass beds
9- Includes impacts from roads, spills, noise/lights, pipelines, offshore operations. Only applies to the northern part of PAIS.

seagrasses, dissolved oxygen concentrations can be quite low depending on the time of day that readings are taken due to respiration of seagrasses and/or the temperature of the shallow water. Currently, TCEQ is investigating this issue through collection and analysis of 24-hour dissolved oxygen and *in situ* BOD at six stations spaced throughout the system between the JFK causeway and the Port Isabel causeway. These data will become available by 2006.

STORET data yielded few dissolved metal determinations. Some exceeded today's criteria, however, it is likely that these older values may not be strictly comparable to today's criteria due to changes in analytical methods as well as the very real possibility of contamination during sampling. In more recent data, although there were still only a few determinations of dissolved metal concentrations, none exceeded limits. Metal contamination of water does not appear to be of concern within the upper Laguna Madre (Table 18). The status of metals in waters of the lower Laguna Madre is essentially unknown.

The data collected and analyzed through the NCA and RCAP programs are the most promising as far as establishing a solid baseline of conditions within the Laguna Madre. When these data become available they should serve as the benchmark to determine trends in the future.

Gulf of Mexico

Very few data are available with which an assessment of nearshore Gulf water quality can be made. Chlorophyll *a* was monitored in the STORET data, but did not continue into the TCEQ data. Fecal coliform was monitored in TCEQ data (Table 18). Neither exceeded criteria with enough frequency to warrant classification of concern or non-support of contact recreation. Like the fresh waters within PAIS, Gulf waters require additional water quality monitoring.

CONCLUSIONS & RECOMMENDATIONS

Evaluation of the Current State of Knowledge

There are currently enough data to provide a general evaluation of the estuarine waters within PAIS boundaries, but very little data on either the fresh waters or marine waters. The condition of the estuarine waters appears to be good. There are some parameters, such as dissolved oxygen, that warrant investigation, but the most likely conclusion is that depressed dissolved oxygen concentrations are a result of the natural interactions of salinity, temperature and respiration. TCEQ is currently investigating dissolved oxygen in the Laguna Madre. There are virtually no contaminants (e.g., pesticides, hydrocarbon) data from the Laguna Madre, and this represents a data gap of concern.

Overall, the Laguna Madre, Baffin Bay and the tidal portion of the Arroyo Colorado were classified by TCEQ (2004) as "fully supporting" aquatic life, recreation, general use, and overall use although there were some sub-segments with concerns regarding dissolved oxygen or other parameters; these are under investigation by TCEQ. Most concerns are located in either the Arroyo Colorado well south of PAIS boundaries or in the non-tidal portions of Petronila Creek, which flows into Baffin Bay, and is also very far from PAIS boundaries. The primary reasons for concerns within these segments are inflows from both municipal and industrial wastewater treatment plants and runoff from agriculture. However, neither of these segments seem to exert any major influence on the water quality of the Laguna Madre as a whole. Our assessment of the historical and recent/current water quality data for the estuarine waters of PAIS agrees with TCEQ's classification of the Laguna Madre.

Although seagrass communities are changing in Laguna Madre, the cause of change is most likely due to salinity amelioration that accompanied dredging of the GIWW. In some ways, this change is positive because it probably increased shoalgrass cover in upper Laguna Madre as well as making seagrass cover more permanent. The changes in community composition are most likely due to natural successional forces that were set in motion by salinity declines, however, it would be prudent to more thoroughly assess other factors, such as nutrient and freshwater inputs from wastewater and stormwater drainage, that may be having some effect. Although there have been recent declines in cover and biomass in upper Laguna Madre due to the brown tide of the late 1990s, the cause of slow recovery is unknown. Studies are needed to determine if recovery is just slow or if declines are permanent. When compared with other bay systems in the surrounding area, propeller scarring in upper Laguna Madre has not destroyed or fragmented large areas of seagrass. Overall, Laguna Madre seagrasses appear to be in good condition.

Seagrass cover, biomass, and community composition were determined within the entire Laguna Madre during 1988 and 1998; the 1998 report is currently still in review at the Gulf of Mexico Status and Trends Program and should be available sometime early in 2005 (C. Onuf, USGS, pers. comm.). Additional monitoring with regards to the brown tide also occurred during the

1990s, and most of these results are available in the primary literature (e.g., Onuf 1996). It is unknown at this time if a seagrass survey will be done during 2008. In addition, baseline monitoring by USGS personnel was conducted within PAIS boundaries during 2002-2003. In connection with seagrass losses due to brown tide, seagrass cover, biomass and community composition between JFK Causeway and Baffin Bay was determined during 2004. These data are currently being compiled and analyzed.

The bay shrimp fishery is fully exploited on the Central Texas coast (Withers et al. 2003). However, shrimp in the Laguna Madre are not harvested to any great extent and the resource appears to be stable. There is no information concerning the level of exploitation of the other bay or offshore commercial fisheries with which to assess their condition. In the recreational fishery, the Laguna Madre is generally under less pressure than other bays on the Texas Coast. Stocking of both red drum and spotted seatrout are ongoing. Texas Parks and Wildlife Department currently collects both fishery-dependent and fishery-independent data and appears to be monitoring the resource fairly well.

Circulation patterns within the Laguna Madre system have been variously addressed in terms of transport of dredged material in the water column during dredging of GIWW. However, a comprehensive model of circulation in the system is not available. The tidal flats and nearshore seagrass beds located between the leeward side of Padre Island and dredged material islands adjacent to GIWW is of particular concern. This area has effectively been isolated from the central body of the lagoons as a result of dredged material island placement.

Use of dredge material islands by colonial waterbirds is fairly well known due to the efforts of the Texas Colonial Waterbird Society that coordinates counts of nesting birds on estuarine islands each year during early summer. This effort has been going on for 30+ years. Effects of invasive plant species on nesting success of colonial waterbirds is unknown. In addition, coalescence of islands due to continued dredge material disposal provides predators with easy access to many islands.

The current state of knowledge of the water quality in the fresh waters of PAIS is very poor. Although some data exist, they are generally nearly 30 years old, and very few ponds within the park have ever been sampled. What data do exist suggest that there are potential nutrient and/or metals concerns. These concerns are in need of investigation. In addition, since these ponds are at least partially fed by groundwater, and since there is no information concerning groundwater beyond general statements regarding its salinity, groundwater quality is unknown.

There is also very little known about the quality of nearshore marine waters within the park. Fecal coliform and trash are the only parameters that have been sampled to any extent. Fecal coliform does not appear to be of concern. Trash, on the other hand, is of concern. However, identification of the shrimping industry as the primary contributors to trash accumulation on the beach may not be accurate due to a lack of statistical analysis. Other water quality issues may exist, but there are no data with which overall water quality in the nearshore can be evaluated.

Red tides are natural phenomena that occur during summer when water temperatures become warm enough for the causative organisms to bloom. Although blooms may cause respiratory irritation to beach visitors, there is little or nothing that can be done to control them, and attempts at control may actually exacerbate toxin release (Buskey et al. 1996). Early determination of bloom conditions would provide park managers with the ability to warn visitors. Currently, the first signs that blooms have reached levels to cause irritation are usually visitor complaints.

Recommendations for Monitoring

Estuarine Waters

For the estuarine waters, TCEQ's monitoring program is already in place and seems to be working fairly well. The data are readily available from their website and updated on a regular basis. The primary failings of this monitoring program are 1) the lack of nutrient data overall, 2) the lack of metals and contaminants data, and 3) the decommissioning of several long-term stations that are of interest to PAIS. It appears that in the last two years there has been renewed interest in assessing nutrient concentrations in the Laguna Madre, so the lack of nutrient data may not continue to be an issue. For metals and contaminants, the large scale surveys represented by EPA's National Coastal Assessment program and the Coastal Bend Bays and Estuary Program's Regional Coastal Assessment program will provide the needed data and recommendations for monitoring when completed. The decommissioning of stations represents a potential problem for PAIS. Two that have been decommissioned (13448, 13449) are the only estuarine stations in the lower Laguna Madre adjacent to PAIS. Station 13448 at the intersection of the GIWW and Mansfield Channel is a station that can serve as a "bellweather" for impacts that may come from offshore or from the Arroyo Colorado.

For monitoring of estuarine waters we suggest:

- Communication of the needs of PAIS to TCEQ, particularly with regard to measured parameters and the decommissioning of stations. Parameters that need to be measured frequently (quarterly) are:
    - field parameters (pH, water temperature, salinity, turbidity, instantaneous and 24-hour dissolved oxygen);
    - nutrients (ammonia, nitrate+nitrite, total phosphorus, orthophosphorus) and chlorophyll *a*; and
    - fecal coliform and/or enterococci.
- At a minimum, Station 13448 needs to be brought back online, sampled for the parameters listed above, and paid for by PAIS, if necessary.
- Analyses of dissolved and sediment metals and contaminants are needed at set stations at a time interval that is currently unknown. This interval will depend on the findings of the NCA and RCAP studies. If contamination by metals or other compounds is not found, then the interval might be 2-5 years. However, if contamination is found, then at least annual analyses at stations of concern are warranted. It is likely that if contamination by metals or other compounds is found, TCEQ or some other state agency will investigate.

- Data from TCEQ stations in Laguna Madre available on the TCEQ website need to be downloaded and organized by PAIS personnel and updated at least quarterly. These data should be assessed at least yearly.

Seagrasses

Seagrass surveys within PAIS boundaries comparable to those conducted by USGS during 2004 should be repeated every 3-5 years. In addition, NPS and PAIS should encourage USGS to continue its decadal monitoring of the entire Laguna Madre system and contribute funding if necessary.

Some prop scars are able to revegetate in the absence of continued disturbance or in areas where the elevation of the scar channel has not been significantly altered. However, most prop scars are still evident several years following the impact. Revegetation techniques may include refilling the prop scar channel with appropriate sediment prior to replanting seagrass plugs. Innovative techniques are being developed in Florida seagrass restoration projects, and could be used as an information source.

Monitoring extent of prop scar coverage and degree of fragmentation necessitates a remote-sensing approach. Seagrass prop scars often cover large areas, yet the scar itself may extend < 0.5 m in width. Aerial photography flown at different elevation will produce imagery at different scales and resolution. An appropriate scale to delineate individual scars was defined as 1:2,400 in an assessment in Florida and in Texas (Sargent et al. 1995; Dunton et al. 1998). This method would be appropriate for the seagrass areas within PAIS, and would need to be repeated at least every five years, preferably following winter cold fronts. These conditions provide clear atmospheric conditions and minimal surface winds. The aerial photographs should be georectified and mosaiced prior to assessment using a GIS program. Several levels of scarring intensity would be identified and digitized to determine location and areal extent of scarring. These data would be instrumental in tracking seagrass recovery, defining new areas of impact, and identifying areas requiring protection and restoration.

Circulation & Dredge Material Placement

We recommend that a cooperative effort be initiated among federal and state agencies, in conjunction with university researchers and modelers, to address circulation dynamics in the Laguna Madre. Following a thorough assessment of circulation patterns, enhancement of water flows to this area may be facilitated by the excavation of passes between dredged material islands. In addition, excavation of passes may help alleviate predator problems on waterbird nesting islands. Continued support of the efforts of the Texas Colonial Waterbird Society is needed as are studies of the effects of invasive plant species on waterbird nesting success.

Fresh (Inland) Waters

The condition of the freshwater ponds within PAIS is virtually unknown. Because they are critical to wildlife, this represents an important data gap the needs to be filled. Based on our review of the inland waters in PAIS, the majority of monitoring needs to occur within the park north of the Land-cut and in areas that serve as receiving waters for wastewater or stormwater. We recommend the following:

- Establishment of several permanent stations in freshwater bodies that are filled with water throughout most of the year and during most years. Parameters that need to be measured frequently (quarterly) are:
  - Field parameters (pH, water temperature, salinity, specific conductance and dissolved oxygen); and
  - nutrients (ammonia, nitrat+nitrite, total phosphorus, orthophosphorus), chlorophyll *a*, sulfate and chloride.
- The water quality of more ephemeral ponds (5-10) should be intensively studied from the time the ponds are filled to when they dry. This will provide information concerning changes in water quality and the potential for concentration of some components (such as salts and nutrients) that may alter an ephemeral pond's suitability for use by wildlife.

Other parameters that should be measured to provide a baseline include dissolved and sediment metals and contaminants. If there are no indications of contamination, and no events occur that would result in contamination, then there is no need for more intensive investigation. However, it would be prudent to assess both metals and other contaminants every five years.

These ponds are used only by wildlife and are not used for either drinking water or contact recreation. It is unlikely that assessment of bacteria (e.g., fecal coliform or *E. coli*.) would provide any useful information and is not warranted.

Wetlands

The increase of PEM wetlands within the barrier island interior has been potentially attributed to relative sea level rise. The increase in surface water retention within barrier island wetlands may have a direct effect on vegetation dominance, in most cases, cattail expansion. The placement of the main road accessing the park has effectively bisected the island and reduced surface water exchange across the island. However, it is unknown to what extent this structure has had on wetland vegetation dynamics. We recommend a comprehensive inventory of wetlands within the park to determine types and extent of wetlands. This inventory will serve as a baseline for future monitoring and change detection analyses. Several wetlands could be identified as reference sites to monitor seasonal and interannual hydrology in relation to local rainfall patterns, tidal conditions in the Gulf and water level conditions in the Laguna Madre. In addition, groundwater wells positioned within the wetland complex would provide the data necessary to understand the belowground connectivity of wetlands on the island. An experimental approach should be developed to investigate management strategies for cattail control in key wetland areas. Active management may only be feasible in some wetland complexes; however, the increase in vegetation diversity and open water habitat would be beneficial to both resident and migratory wildlife.

Groundwater

Condition of groundwater within PAIS is unknown, probably because it is not used for drinking by park visitors. However, companies developing oil and gas reserves use it, thus its quality may affect plants and animals if it is brought to the surface and contained or if it is broadcast onto the surface. In addition, groundwater quality may be affected by development of oil and gas. A moderately intensive study that would characterize the condition of groundwater with regards to its chemical composition and contaminant load is warranted.

Nearshore Marine Waters

Current monitoring of marine waters is limited to determination of bacterial contamination in the waters adjacent to the developed beach at Malaquite. This type of monitoring should be continued, however, its spatial extent is limited and should probably be expanded somewhat since people swim all along the beach and not just at Malaquite. Additional monitoring of water quality is also warranted since no data exist. We recommend the following:

- Expansion of parameters measured at Station 13469 (Mansfield Pass; currently fecal coliform only) and establishment of a nearshore station near Malaquite Beach. The following parameters should be measured quarterly:
  - Field parameters (pH, water temperature, salinity, and dissolved oxygen);
  - nutrients (ammonia, nitrate+nitrite, total phosphorus, orthophosphorus) and chlorophyll *a*; and
- fecal coliform and/or enterococci should be determined weekly during months when swimming is a major activity of park visitors (March – October). An additional 4-5 stations outside of Malaquite Beach including the campground, and the areas between the northernmost park boundary and Malaquite Beach and between Malaquite Beach and the four-wheel drive area.
- Monitoring abundances of red tide organisms during mid to late summer would allow the park to warn visitors before bloom conditions reach levels where respiratory irritation would be problematic.

Invasive or Exotic Species

Both Kleberg bluestem and guinea grass should be managed aggressively with herbicides to prevent their expansion into the native coastal prairies in the island interior. Although none of the islands within the park have any stands of the exotic Australian pine (*Casaurina equisetifolia*), regular monitoring (annual) of the parklands should be implemented to ensure seedlings do not become established. Because no exotic species have been documented within the inland ponds or wetlands, it would be prudent to monitor them to prevent invasion and establishment of both water lettuce (*Pistia stratiodes*) and water hyacinth (*Eichhornia crassipes*) in conjunction with water quality monitoring. Population status of brown mussels on the Mansfield Pass jetties should also be determined at least annually during the late spring or early summer when environmental conditions are optimal for their establishment and growth.

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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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